# Brack's Hardwall Cactus
# Distribution, Habitat, and Status Survey 2015

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# Brack's Hardwall Cactus
# Distribution, Habitat, and Status Survey 2015[1]

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## Summary

Brack's hardwall cactus (*Sclerocactus cloverae* subsp. *brackii*) is a rare plant that occurs on the Nacimiento Formation of northwestern New Mexico. It is listed as a BLM sensitive species and is included on the State of New Mexico list of endangered plant species. Most of the known populations of Brack's are on lands under Bureau of Land Management (BLM) jurisdiction (about 80%), but it is also present on the Navajo Nation, State of New Mexico Trust Lands, and private property. Portions of the Nacimiento Formation have actively developing oil and gas fields that include the construction of well pads, roads and pipelines that have the potential to significantly negatively impact this species. Yet, the full extent of the species regionally, its habitat requirements, and abundance have not been systematically addressed to support the management of the species. Accordingly, Natural Heritage New Mexico (NHNM) conducted field study in 2015 with two primary objectives: **1) provide a regional assessment of the overall distribution of *Sclerocactus cloverae* ssp. *brackii* on the Nacimiento Formation in the context of other closely related *Sclerocactus* species; and 2 ) describe the potential habitats and relative degree of occupancy by the species within those habitats focusing on the Lybrook area, a major population center for the species and an area of ongoing intensive oil and gas exploration.** Based on these surveys, in combination with legacy data, we provide a provisional assessment of the status of Brack's hardwall cactus in the context of land use, particularly energy development, along with ecological factors.

The regional assessment sets the range limits of potential habitat for Brack's hardwall cactus to the northern portion of the Nacimiento Formation (from the Aztec/Bloomfield region southward to just southwest of Lybrook ), but it also uncovered a range of variability in the size and other characteristics of the taxon. Within this range, we identified 56 local populations that were ascribed either to Brack's hardwall cactus, or Clover's hardwall cactus (*Sclerocactus cloverae* subsp. *cloverae*), or as intermediate "Indeterminate" forms. The Brack's and Indeterminate occurrences were then grouped into six larger population centers (metapopulations), two of which are core for the species: the Kutz-Angel Peak area associated with the type locality of the subspecies, and the Lybrook region at the southern end of the range (and a zone of intensive oil and gas development).

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[2] E. Muldavin, Ph.D., Director of Natural Heritage New Mexico, was the lead ecologist on the project; M. East is the NHNM Asst. Data Manager; M. Horner is the NHNM GIS Analysist ; Y. Chauvin is the NHNM senior botany technician.
[3] R. Sivinski, M.S., of RCS Southwest, Santa Fe, was the lead botanist on the project.

To support management of the species in the Lybrook region where development pressures are currently high, we conducted a habitat assessment to identify suitable habits at the local scale and evaluate the degree of occupancy by the species in those habitats. This was based on detailed ground measurements anchored at known locations along with aerial photo interpretation. Relative densities of plants varied among habitats. The highest densities were found on eroding soils within grasslands, open sagebrush/sparse grasslands, and pinyon-juniper woodland savannas of valley bottoms within shale barrens (badlands) or on sandstone hill slopes adjacent to the badlands (these were also habitats where there is significant oil and gas development). Plants were scarce or absent in dense sagebrush shrublands or on the barren gray and white shales of the badlands. In addition, individuals were shown to be highly clustered within habitats. That is, on average of only 10% of suitable habitat was occupied by the cactus. This provides both a concern and an opportunity. Highly clustered populations can be inordinately impacted when disturbance occurs, but because they are clustered, with careful planning impacts can be avoided at the local scale.

*Brack's hardwall cactus remains a species at risk*. Based on the 2015 survey data and legacy observation data, and analysis of trends and threats, NHNM updated the conservation state status rank to S2, or Imperiled. The limited number of high-quality local populations and metapopulations coupled with high incidence of damage from beetles and other animals, trampling, increased drought, as well as habitat fragmentation by development drove this ranking. While an S2 rank is high, it provides the context for future monitoring of population trends of the subspecies across its range in support of adaptive management. In the meantime, there are opportunities for conservation and resource planning that have potential for alleviating conflict and avoiding further impacts on the species. As a first step , we identified ten Conservation Opportunity Areas (COAs) in the Lybrook region where the Brack's hardwall cactus is present but extensive development has not yet taken place—potential non-conflict safe sites where the species can be sustained. Beyond this, additional COAs should be identified throughout the range of the species to avoid a concentration of conservation activities in one particular place, particularly with respect to issues beyond oil and gas development.

The 2015 NHNM survey of the distribution and habitat of Brack's hardwall cactus (*Sclerocactus cloverae* subsp. *brackii*) represents the most comprehensive analysis to date, but much remains to be understood about the species. We recommend the following:

1. A genetic and plant morphology study to further clarify the differences among the subspecies and their taxonomic status.
2. A validation study of the suitable habitats and their density ranks using randomized sampling to alleviate bias, and then expanding the habitat modeling across the range of the species to support environmental review and conservation planning.
3. Refine the provisional Conservation Opportunity Areas (COAs) provided here and develop additional COAs throughout the range of the subspecies in the context of expected future oil and gas development.
4. Establish a long-term, range-wide monitoring grid to support adaptive management of the species using the survey plots provided here as a foundation.
5. Develop an overall conservation strategy to ensure the long-term sustainability of the species.

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Cover: Brack's hardwall cactus (*Sclerocactus cloverae* subsp. *brackii*); photo R. Sivinski and all other cactus photos in the report.

# INTRODUCTION

Brack's hardwall cactus (*Sclerocactus cloverae* Heil & Porter subsp. *brackii* Heil & Porter) is a rare plant that occurs on the Nacimiento Formation of northwestern New Mexico (Figure 1). It is listed as a BLM sensitive species and is included on the State of New Mexico list of endangered plant species. Most of the known populations of Brack's hardwall cactus are on lands under Bureau of Land Management (BLM) jurisdiction (about 80%), but it is also present on the Navajo Nation, State of New Mexico Trust Lands, and private property. Portions of the Nacimiento Formation have actively developing oil and gas fields that include the construction of well pads, roads and pipelines that have the potential to significantly negatively impact this species. Plant surveys conducted as part of environmental assessments of these activities have been finding *Sclerocactus* plants in oil and gas project areas, most of which appear to be Brack's hardwall cactus. Yet, the full extent of the species regionally, its habitat requirements, and abundance have not been systematically addressed to support the management of the species. As a first step towards gaining a better understanding of the species distribution and ecology, Natural Heritage New Mexico (NHNM) conducted field study in 2015 with two primary objectives: **1) provide a regional assessment of the overall distribution of *Sclerocactus cloverae* ssp. *brackii* on the Nacimiento Formation in the context of other closely related *Sclerocactus* species; and 2) describe the potential habitats and relative degree of occupancy by the species within those habitats focusing on the Lybrook area, a major population center for the species and an area of ongoing intensive oil and gas exploration.** Based on these surveys, in combination with legacy data, we provide a provisional assessment of status of Brack's hardwall cactus in the context of land use, particularly energy development, along with ecological factors. This assessment lays the foundation for future work on the taxonomic and genetic relationship to closely related species, estimating true population numbers, habitat mapping, and monitoring population trends to support adaptive management of the species to avoid future land use conflicts.

# BACKGROUND

## Plant Description

*Sclerocactus cloverae* is a flowering stem succulent in the cactus family (Cactaceae) (Figure 2). Morphological characteristics from the original description (Heil and Porter 1994), Flora of North America (Heil and Porter 2003), and the Four Corners Flora (Heil and Porter 2013) are slightly different, but summarized as follows: **Stem** usually solitary, occasionally with one or few additional stems sprouting from the base, ovoid or elongate-cylindric, usually with 13 ribs. **Central spines** 4-9, 1.5-4.6 cm long, the lower one hooked or absent, the upper one flattened on the outer (abaxial) face and often ribbon-like**. Lateral spines** 3-8, usually not hooked and a bit shorter than the centrals. **Radial spines** 2-8, somewhat thinner than the laterals. **Flower buds** rounded at the apex. **Flowers** pink-purple, 2.3-4 cm long. **Fruit** green, tan or pink, 7-15 mm long, 5-12 mm wide, opening along an irregular line of dehiscence just below the middle. **Seeds** black or brown, 1.5-3 mm long, 2-4 mm wide. Flowers from mid-April to early June.

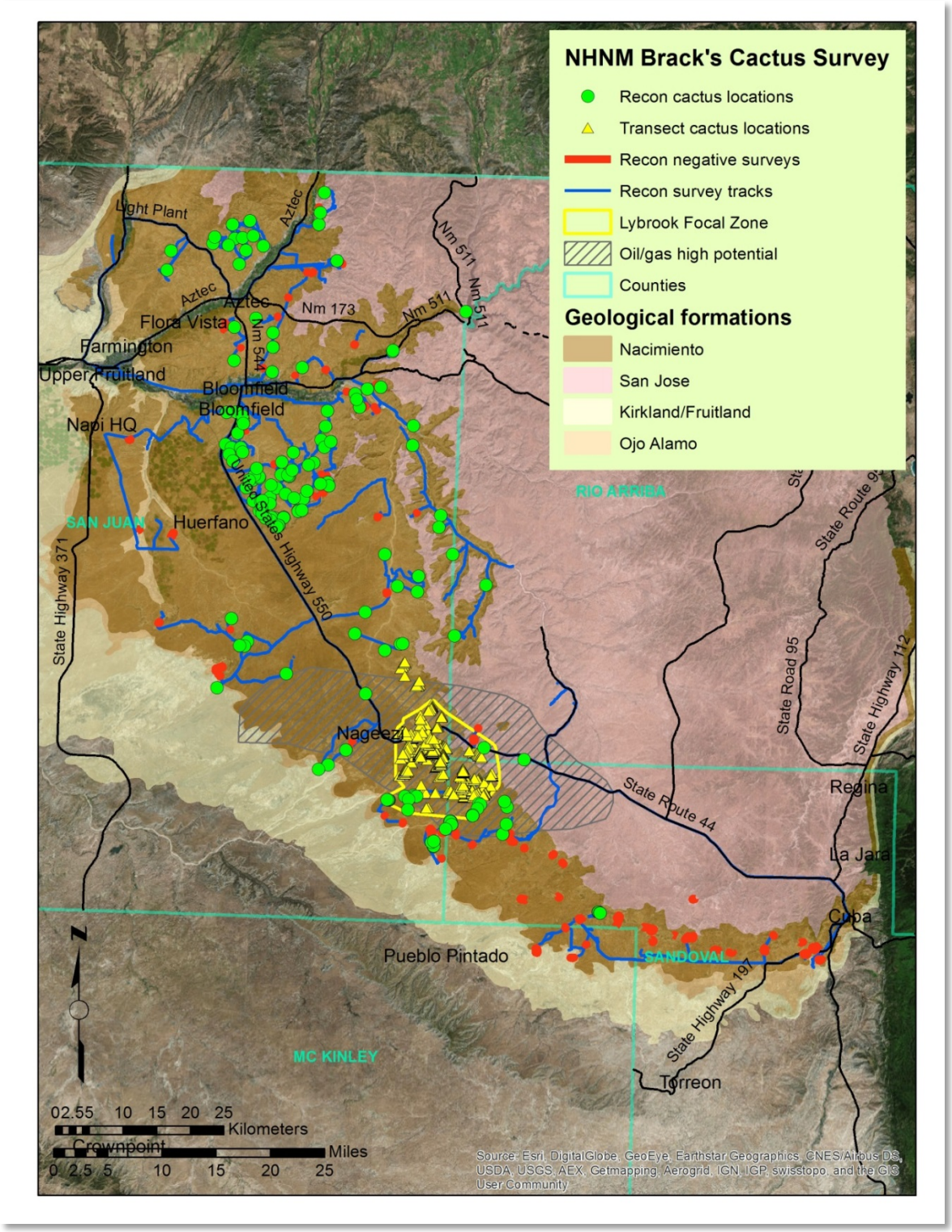


**Figure 1. The NHNM 2015 Brack's hardwall cactus survey focused on the Nacimiento geologic formation and had two components: a wide-area reconnaissance to help determine the extent of the subspecies, and an intensive focal-zone survey in the Lybrook region to describe potential habitats and estimate plant numbers in a core population that is also in a region of active oil-and gas exploration. Geology based on the Geologic Map of New Mexico (New Mexico Bureau of Geology and Mineral Resources (2003)).**

There are two subspecies that are distinguished by the characteristics outlined in Table 1. The size difference between the two subspecies is not only the generally smaller stem size within a subsp. *brackii* population, but rather the small size and juvenile spine arrangement of individual cacti when they first attain reproductive maturity. Subspecies *brackii* plants are often in the 2-3 cm diameter range when flowers are first produced (Heil and Porter 1994). These small flowering cacti still have their immature spine arrangements with areoles of short-spine radials that are usually missing the hooked lower central spine. This juvenile spine arrangement is often retained in subsequent years and the development of full areoles with adult spines may not occur until after a few years of reproductive maturity. Subspecies *cloverae* cacti begin blooming at a larger size when at least some of the upper areoles are producing hooked central spines. As subsp. *brackii* ages, however, the morphologies of the two subspecies tend to become more convergent (Porter and Prince 2011).

**Table 1. Morphological distinctions of *Sclerocactus cloverae* subsp. *cloverae* and subsp. *brackii*, summarized from Porter and Prince (2011), Heil (2013) and Heil and Porter (2013).**

| Plant character | subsp. *cloverae* | subsp. *brackii* |
|---|---|---|
| Stem length | Mostly 5-25 cm | Mostly 3-7 cm |
| Stem width | 5-15 cm | 2-6 cm |
| Number of central spines | 5-9, mostly 8 | Mostly 4 |
| Lower hooked central | Present | Often absent |
| Number of lateral spines | 5-8 | 3 |
| Number of radial spines | 2-6 | 5-8 |
| Spine prominence | Very dense, obscuring the stem | Spines very sparse and not obscuring the stem, in age becoming more dense and ± obscuring the stem |

**Figure 2. Brack's hardwall cactus with 2 x 3 cm stem and 3-4 central spines per areole at lower Kutz Canyon south of Bloomfield (left). Clover's hardwall cactus with 12 x 17 cm stem and 4 central spines per areole at Navajo Lake (right).**

For survey purposes, our standard methodology for counting central spines is illustrated in Figure 3. It is based upon the arrangement of the upper central spine being flattened or ribbon-like at the 12:00 position on the areole and the lower central spine being the erect hooked spine in the center of the areole. Heil and Porter (1994); Porter and Prince (2011), and Heil and Porter (2013) all call the hooked spine the lower central. The other two central spines found in our survey are laterals at the 11:00 and 1:00 positions. These are usually not hooked. The remaining spines in the areole are radial spines, but some of these can be different in color and size from the others. The two lower, lateral radials at the 4:00 and 8:00 positions are often well developed and similar to the lateral centrals at the top of the areole. The lowest radial at the 6:00 position can occasionally be a different color and size than the other radials.


**Figure 3. Spine arrangement in a new, developing areole of Brack's hardwall cactus west of Lybrook (left) and mature areole on Brack's hardwall cactus at Kutz Canyon, south of Bloomfield (right). 1 = upper flattened central; 2 and 3 = lateral centrals; 4 = lower hooked central; R = radial; L = lower lateral radial.**

## Distribution and General Habitat

*Sclerocactus cloverae*, including both subspecies, is almost entirely endemic to New Mexico, but extends a short distance into La Plata and Archuleta Counties in southern Colorado. The total range of this species is about 150 miles north to south and about 60 miles wide. Heil and Porter (2013) describe its range as scattered locations from south of Albuquerque, northward up the Rio Puerco, San Pedro and San Juan River valleys to near Waterflow, then northward into southern Colorado along the Animas, La Plata and Los Pinos Rivers. The New Mexico counties cited, however, include only Rio Arriba, Sandoval and San Juan, which exclude any other county locations south of Albuquerque. Herbarium specimen records of New Mexico collections are from only those three counties with the southernmost collections being from south and west of San Ysidro in Sandoval County and just east of Laguna in Cibola County (SEINet 2015).

Subspecies *cloverae* occurs throughout the range of the species in a variety of habitats from sandy shale badlands to deeper soils with big sagebrush (*Artemisia tridentata*) and shallower sandy soils on or near sandstone outcrops in pinyon-juniper woodland up to ponderosa pine (*Pinus ponderosa*), both on and off the Nacimiento Formation. Elevations range from 1,500 – 2,200 m (4,920 – 7,220 ft) (Porter and Prince 2011).

Subspecies *brackii* occurs on the Nacimiento Formation in Rio Arriba, Sandoval and San Juan Counties, New Mexico. When initially described (Heil and Porter 1994), this subspecies was known from a few San Juan County locations near Bloomfield and Aztec and south to near Huerfano Mountain. Subsequent field surveys extended the southern range of Brack's hardwall cactus into the extensive badlands of the Nacimiento Formation between Nageezi and Lybrook, including the southwest corner of Rio Arriba County and northwest corner of Sandoval County. The elevation range for this subspecies is 1,680 – 2,200 m (5,510 – 7,220 ft). For further details on the range see "Range limits" under "Results."

In general, Brack's hardwall cactus usually occurs on eroding sandy clay soils derived from shales and sandstones in badlands regions of the Nacimiento. The Nacimiento Formation is well known for its Paleocene mammal fossils (Williamson and Lucas 1992), but very little is published about the surface outcrops of its geologic strata. It is not a marine deposit, but the Lybrook badlands are extensive, barren depositional shales and mudstones. Barite nodules are common on the dark mudstones and occasional selenite crystals are found in the shale and silty sandstone. Terrains are variable and include low ridges, slopes, pockets of soil at or near the base of steep sandy shale or sandstone slopes, and eroding alluvial fans and valley fill sediments on the edges of dry washes. On occasion it can also occur in gypseous soils, especially north of the San Juan River, but is not classified as a gypsophile (a small portion of these badlands are classified as gypsum soils in the San Juan County soil survey (USDA-SCS 1980)). Habitat has commonly been used to allocate plants to subspecies. Brack's hardwall cactus is usually relegated to open desert scrub habitats on gypseous soils or badlands, while Clover's hardwall cactus occurs in pinyon-juniper woodland or big sagebrush shrubland and often in loamy soils with deposits of river gravel and cobble (Heil and Porter 1994, Porter and Prince 2011). Below we provide a detailed habitat analysis for the Lybrook area.

Brack's hardwall cactus occurs within a variety of vegetation communities including sparse grasslands dominated by blue grama (*Bouteloua gracilis*), Galleta (*Pleuraphis jamesii*), Indian ricegrass (*Achnatherum hymenoides*), and needle and thread grass (*Hesperostipa comata*); open to dense shrublands dominated big sagebrush and rabbitbrush (*Ericameria nauseosa*), and woodlands dominated by pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) (see Tables 2 and 3 for additional details). It is also associated with sparsely vegetated badland habitats with species that indicate saline and clayey substrates such as shadscale (*Atriplex confertifolia*), stalked orach (*Atriplex saccaria*), bud sagebrush (*Picrothamnus desertorum*), oblongleaf basin daisy (*Platyschkuhria integifolia*), alkali sacaton (*Sporobolus airoides*), and greasewood (*Sarcobatus vermiculatus*). Some areas in these badlands have high concentrations of selenium, which was obvious by its odor and by the presence of seleniphytic plants such as yellow milkvetch (*Astragalus flavus*) and Aztec milkvetch (*Astragalus proximus*). Common gypsophilic plant species (e.g., *Sporobolus nealleyi*) that indicate gypseous soils on the Todilto Formation of southern Sandoval County, New Mexico and other gypsum strata in southwestern Colorado are

absent from Brack's hardwall cactus habitats on the Nacimiento Formation. A list of species encountered during the 2015 NHNM surveys is provided in Appendix A.

## Taxon History

Heil and Porter (1994) published *Sclerocactus cloveriae* and both subspecies as a reassessment and revised circumscription of existing *Sclerocactus* taxa. Their revision confined *S. whipplei* to northeastern Arizona, but acknowledged the close relationship between *S. whipplei, S. parviflorus* and the newly named *S. cloverae*. Unpublished molecular phylogenetic analyses of trnL–F DNA sequences also support a close relationship between *S. cloverae, S. whipplei* and *S. parviflorus* (Porter and Prince 2011). The New Cactus Lexicon (Hunt et al. 2006) continues to place *S. cloverae* populations into synonymy with *S. whipplei*. Some floristic databases such as a BONAP (Kartesz 2015) and PLANTS (USDA-NRCS 2015) treat *S. cloverae* as a synonym of *S. parviflorus,* and, whether overlooked or ignored, *S. cloverae* is not mentioned in the recently published Flora of Colorado (Ackerfield 2015).

*Sclerocactus parviflorus* is the most widespread and variable species in the genus. It occurs in northwestern New Mexico, but is generally allopatric in its distribution to the west of *S. cloverae*. The only area where both species occur together is on the north side of the San Juan River at the east base of the Hogback (Ferguson 1998b). The two species are similar and can easily be confused with one another except that *S. cloverae* has smaller, narrower flowers and blooms two to three weeks earlier than *S. parviflorus* (Ferguson 1998b). Very little laboratory research has been published to quantify the genetic distinctions between these three closely related species. One DNA analysis from this Hogback population of *S. cloverae* has been published for comparison with *S. parviflorus* DNA and the results were mixed. The chloroplast analysis indicated they are not diverged enough to be separate species. Microsatellite diversity statistics, however, showed (for this one population) that based on genetic differentiation, *S. cloverae* is a distinct species (Schwabe 2012).

*Sclerocactus cloverae* subsp. *brackii* is named for Steven Brack (owner of Mesa Gardens, Belen, NM). The type locality population at Kutz Canyon, south of Bloomfield, had been known since 1982 as *Sclerocactus gradyi* – a nomen nudum that was never validly published (Ferguson 1998a). When Heil and Porter (1994) finally did make a valid publication, they chose a different epithet at subspecific rank. The Flora of North America treatment of *Sclerocactus* (Heil and Porter 2003) only briefly mentions subsp. *brackii* in the *S. cloverae* discussion stating "Populations with all reproductive individuals maintaining juvenile morphology have been segregated as *S. cloverae* subsp*. brackii*." This is an inaccurate characterization since there are no subsp. *brackii* populations with only juvenile morphology because most older plants begin to acquire the adult morphology as they age (Heil and Porter 1994, Ferguson 1998a, Porter and Prince 2011).

DNA samples of *S. cloverae* subsp. *cloverae* and *S. cloverae* subsp. *brackii* possess identical sequences in portions of the genome (Porter unpubl. data), confirming their close relationship (Porter and Prince 2011), however, no comprehensive genetic studies have been conducted to compare populations of these subspecies.

## Conservation Status

The only current federal policy or law protecting Brack's hardwall cactus is its listing as a BLM Sensitive Species, which has management requirements prescribed in BLM Manual 6840 – Special Status Species Management (BLM 2008). This formal policy directs BLM to initiate proactive conservation measures that reduce or eliminate threats to Bureau sensitive species to minimize the likelihood of and need for listing of these species under the Endangered Species Act. The State of New Mexico lists Brack's hardwall cactus as a New Mexico Endangered Plant Species (NMAC 19.21.2). This state law only prohibits unauthorized collection and transport of species on the state endangered plant list and does not protect them from destruction within their natural habitats. Navajo Nation (2008) includes Brack's hardwall cactus in Group 4 of its endangered species list. Group 4 is a candidate list of species or subspecies for which the Navajo Nation Department of Fish and Wildlife does not have sufficient information to support their being listed as endangered, but has reason to consider them and is actively seeking additional information.

NatureServe (2015) ranks Brack's hardwall cactus with a global status of G3T1 and S1 for both Navajo Nation and New Mexico in 1995. These ranks indicate a subspecies that is critically imperiled (this rank is reviewed in detail below). The New Mexico Rare Plant Technical Council (NMRPTC 1999) includes Brack's hardwall cactus on the list of New Mexico rare plants because the length of its range is less than 100 miles. Its NMRPTC R-E-D Code is 2-1-3 (2 = occurrence confined to several populations, 1 = not endangered, 3 = endemic to New Mexico).

## Legacy data

We compiled all known locations and associated data for both Brack's and Clover's from museum records and observations in the NHNM NMBiotics database along with data obtained from clearance surveys provided to us by the BLM (many of these surveys were conducted by consultants as part of biological assessments for proposed well pads, pipelines and roads--these are referred to as the "Consultant" observations). All of the data was entered into a Microsoft Access relational database and an ArcMap 10.2 geodatabase. NHNM data collected in 2015 was also added to this dataset and the databases are provided in Digital Addendum to this report.

# METHODS

Two types of surveys were used to meet the study objectives: a Regional Reconnaissance Survey to evaluate the overall distribution of Brack's hardwall cactus on the Nacimiento Formation (Objective 1) and a Focal Zone Habitat Survey to address the cactus habitat and occupancy (Objective 2), and the spatial distribution of the species at a local to landscape scale. We describe each method below beginning with the Focal Zone Habitat Survey, which chronologically came first and provided the foundation for the Regional Reconnaissance Survey that followed.

## Lybrook Focal Zone Habitat Survey

As a first step towards understanding the status of this species, we conducted a Focal Zone Habitat Survey within a major population area centered in the Lybrook region (Figure 4). The aim was to describe suitable habitats for species, percent occupancy among those habitats, and the relative importance of the habitats and their extent in the zone. Coupled with determining occupancy, we conducted an initial analysis of the ranges of patch sizes of local occurrences of cacti. This region was also chosen because it is an area intensive oil and gas development with ongoing road, well pad, and pipeline construction occurring through known Brack's populations. Hence, understanding suitable habitats and its distribution in the area is vital to effective management at the local site level to avoid or mitigate impacts on the species.

### Sampling design and field methods

The focal zone was delineated using the Minimum Bounding Geometry tool within ArcGIS 10.2 (ESRI 2013) based on known Brack's hardwall cactus locations (consultant observations and herbarium collections) in the Lybrook area. The GIS tool produces a convex bounding polygon wrapped around the input observations extending out 500 m from the perimeter of the observations (See Figure 4). To be included in the input data set, a cactus observation had to be within a 3 km radius of another location.

We used a belt-transect approach with opportunity-based quadrat sampling within the transect to gather field data on habitat and occupancy. Using the known locations from our database, we created field maps and GPS files to guide survey teams of two to three people to initial starting points for the belt transects. Given that most of the starting points were from previous clearance surveys along roads and pipelines they were inherently positively biased, but to help minimize bias, the belt transects were established at right angles to the road and extended outward into the adjacent landscape for 90 m to 2,750 m. To further minimize bias, transects followed a straight line along a compass bearing except when avoiding topographic obstacles (in which case they were offset and resumed in the same direction). Transects were terminated at significant topographic obstacles such as steep shale barren slopes, when they entered extensive unsuitable habitat for Brack's, or when surveyors ran out of time. At the terminus of a transect, the team moved 150–200 m at a right angle to begin a second belt transect in an opposite and parallel line to the first transect for a return trip. Upon completion of a two-transect set, the team would either move to the other side of the road if there was space for transects or travel to a new starting point at least 1 km distant (but usually more), and begin the process again.

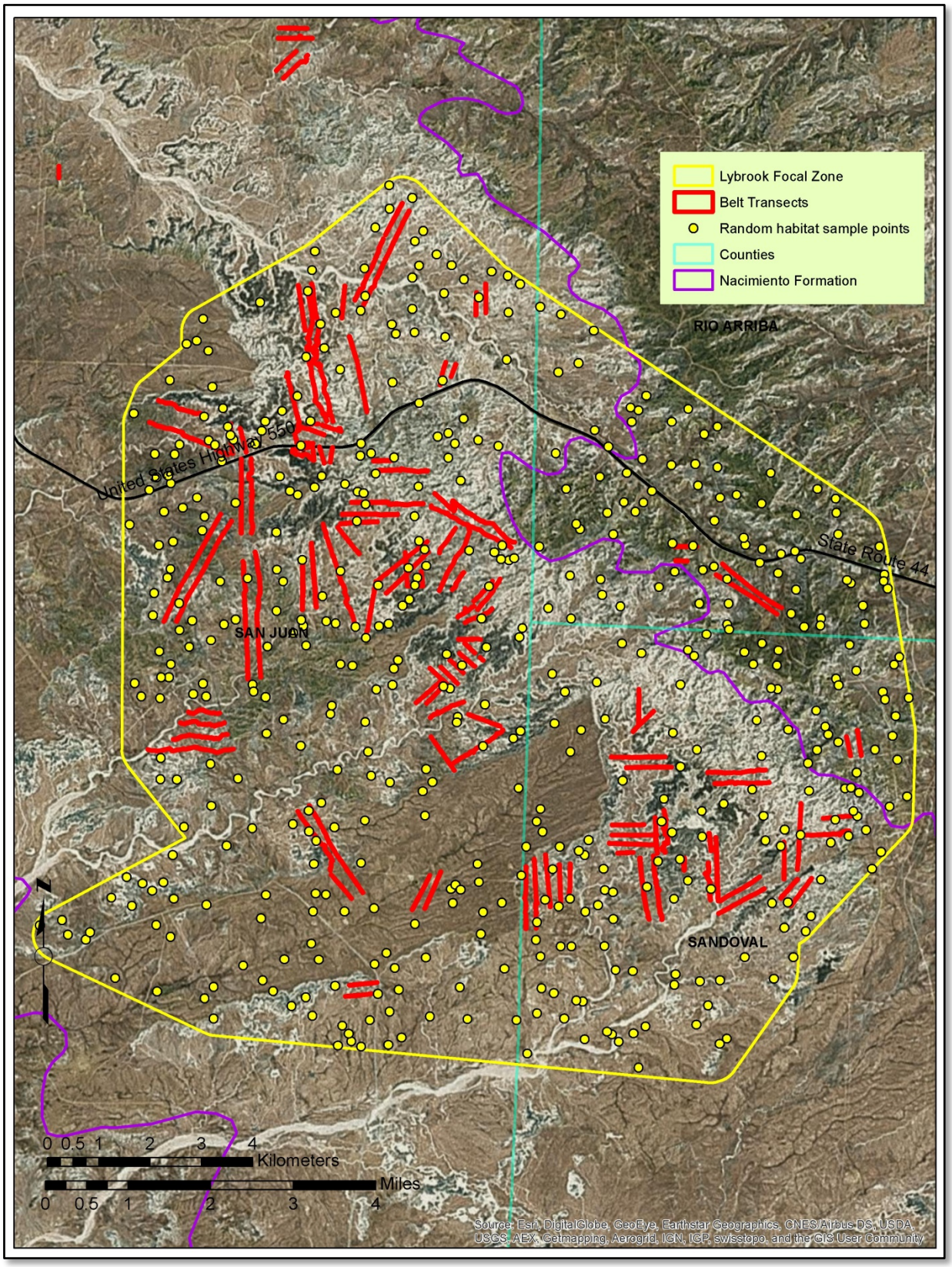


**Figure 4. The distribution of the Lybrook Focal Zone belt transects and the distribution of random aerial-photo interpreted samples for estimating habitat extent.**

On each of the transects, each person visually searched a 5-m wide area of the line (2.5 m left and 2.5 m right) at a pace suitable for a thorough scan for cacti. Distance between the surveyors was kept at 5 m so the belt transect was 10 m wide (or 15 m wide when three team members worked the transect). Whenever a Brack's hardwall cactus was encountered within a transect, the next 20 m of transect became a quadrat plot of 10 x 20 m for a count of all cacti (living and dead) within the quadrat and estimated abundance of dominant vegetation species (Figure 5). Dominant plant species within each plot were visually scored for canopy cover using the broad classes of Braun-Blanquet cover scale: + < 1%, 1 = 1-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5= 75-100% (Braun-Blanquet 1932). Evidence of ungulate herbivores (domestic or wild) was noted, as was any habitat damage or damage to the cacti by insects or vertebrate herbivores. Each quadrat was located by GPS (+/- 2 m) at the transect center position lined up laterally with the first sighting of a plant. All data were recorded on paper data sheets; scanned versions are provided in the digital addendum. Photos of plants and habitat conditions are also provided in the digital addendum

A total of 131 transects were established and 100 km of transect length surveyed in 2015, representing a total area of 123 ha. All sampling was conducted at the height of flowering season during the month of May to maximize visibility of the population. All three survey team leads were professional botanists with extensive experience in rare cactus surveys in New Mexico. All transect survey data was entered in a Microsoft Access relational database and quality controlled for errors of transcription. Locational information was entered into an ArcMap 10.2 geodatabase (plot locations and survey tracks). All data and photos are provided in the digital addendum.

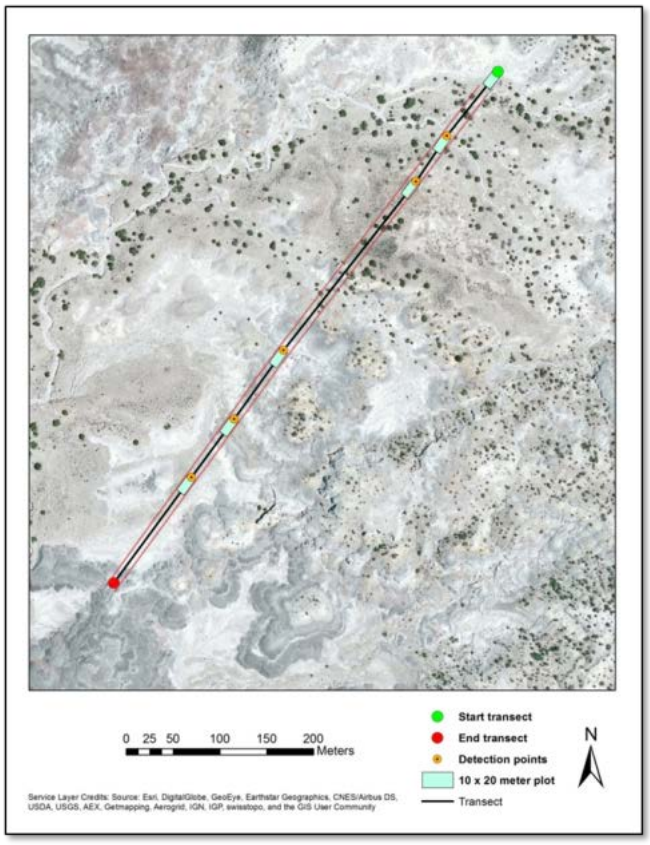


**Figure 5. An example of a belt transect with 10 x 20 m quadrat plots at Brack's detection points. In each quad, all cacti were counted and the cover of the dominant plant species recorded. At a minimum, a photograph was taken from each end down the transect. Each quadrat was assigned a habitat based on species cover and aerial-photo interpretation and the entire belt transect was mapped by the habitats in Tables 2 and 3.**

## Analysis

To evaluate cactus occupancy by habitat, we developed a habitat classification based the transect data and aerial imagery. Habitats in the focal zone were defined in terms of vegetation composition and cover, geology, and landform. We developed a two-tiered classification where the upper level 1 was represented by broad landscape elements such as hills, mesa tops and valleys (Table 2), and the lower level 2 by generalized vegetation types e.g., woodlands, sparse shrublands, etc.(Table 3). Using recent aerial imagery (2014 NAIP and high-resolution ortho-photography and imagery provided by ESRI in ArcMap) along with the transects' quadrat data as ground control, we then mapped the entire length of transects by habitat and assigned each occupied quadrat along the transect to a type (the minimum mapped-segment length in the transects was 20 m, equivalent to a single quadrat). The ratio of occupied area within a habitat type to the total habitat area along a transect is a measure of percentage occupancy stratified by type. Percentage occupancy also reflects the degree of clustering of individuals—greater occupancy leads to more continuous populations.

To estimate the amount of each habitat type that occurred within the focal zone as a whole, we used the GIS to establish 500 random points across the zone and assigned them to habitats based on aerial photo interpretation (see Figure 4). The aerial extent of each habitat was computed by multiplying the total zone area (20,793 ha) by the percentage. These sample points also represent a set that can subsequently be used for unbiased sampling and estimation of cactus numbers in the focal zone (numbers derived from the known locations of the belt transects are inherently positively biased to an unknown degree).

### *Conservation Opportunity Areas (COAs)*

To support integrated conservation and oil and gas development planning within the focal zone, we identified a set of draft Conservation Opportunity Areas (COAs) for Brack's hardwall cactus where the cactus might be present but the oil and gas development limited, i.e., areas of potentially low conflict between the species and other resource uses. We used the observations associated with clearance surveys, belt transect observations, and habitat type data to delineate areas within the focal zone that are not currently developed but might have potential cactus occupancy based on habitat and offer refuge for the species. Lack of development was based on an impact layer of roads, well pads, and other structures developed by us from 2014 NAIP aerial imagery. Potential habitat was identified by aerial photo interpretation in a similar way to the belt transect mapping. These provisionally defined areas will need to be validated with field reconnaissance for both cacti and impacts, but they may offer opportunities to efficiently ease pressure on the species while still facilitating development.

**Table 2. Level 1 Brack's hardwall cactus habitats focused on landscape features of soils and**

| 1. Mesa Top | 4. Yellow Hills |
|---|---|
|  |  |
| Summits of table lands interspersed among badlands, canyons and valleys. | Hills and associated alluvial fans composed of yellow to tan sandstones (sometimes orange) and some shale. |
| **2. Gray/White Hills** | **5. Valley** |
|  |  |
| Badlands dominated by gray (blue) and white shales. Includes barren alluvial fans extending out from the hill slopes. | Valleys, including dissected alluvial fan piedmonts and valley bottom fills. May also include remnant pediments of hills. |
| **3. Red hills** | **6. Dry Wash** |
|  |  |
| Hills and associated alluvial fans composed of red-colored baked sandstone and ancient unconsolidated river gravels. | Ephemeral desert washes; includes adjacent alluvial terraces deposited by intermittent high flows. |

**Table 3. Level 2 habitats are focused on vegetation and are nested within Level 1 habitats in Table 2.**

| **Level 2** | |
|---|---|
| a. Woodlands | d. Grassland |
|  |  |
| Open to moderately closed woodlands (10-60% canopy cover) dominated by pinyon pine and Utah juniper with grassy to sparse understories. | Grasslands with low to moderate cover dominated by blue grama with galleta and alkali sacaton as common associates. |
| b. Dense Shrubland | e. Barren/Sparse Grassland |
|  |  |
| Dense canopied shrublands (>33% cover) dominated by big sage with rabbitbrush a common associate. Grass cover is generally low or absent. | Sparsely vegetated or with scattered grasses (seldom greater than 5% cover). |
| c. Open Shrubland | f. Barren (channel) |
|  |  |
| Open shrublands (10-33% canopy cover) dominated by big sage; inter-shrub spaces can be grassy or sparse but are often grassy. | Open, active, sparsely vegetated desert washes. |

## Regional Reconnaissance Survey

The objectives of the Regional Reconnaissance Survey were to evaluate the range-wide distribution of Brack's hardwall cactus across entire Nacimiento Formation (over 1,500 sq. miles) and to differentiate Brack's versus Clover's distributions at transition zones between the two subspecies (but this survey was not intended to determine the entire range of the species).

### Sampling design and field methods

For the reconnaissance survey, we developed a two-step sampling strategy that would allow us to cover the large survey area within the available time while still collecting sufficient quantitative plant data to meet the objectives. First, we sampled all the known locations across the current range to confirm cactus presence and identity. If cacti were located at these locations, teams established 20 m- diameter circular plots, counted all living and dead cacti, and assigned them to subspecies (Brack's, Clover's or Indeterminate). Vegetation cover and herbivore use were assessed in the same way as on the belt transects (see above). Then, new locations that had not been searched previously by consultants or botanists were identified based on habitat indicators of geology, soils, and vegetation from aerial imagery or opportunistically during the reconnaissance itself. The new areas were deliberately searched for cacti in walking surveys across what the surveyors felt was the best habitat at a particular location. When *Sclerocactus* plants were located, 20 m-diameter circular plots were established, with the first cactus at the center. Whenever one or two positive plot locations were established, the crew discontinued the search and moved to a new location. Overall survey tracks are illustrated in Figure 1. A total of 155 positive-location plots were established and geo-located. The plot design was also adopted with an eye to the future, where the network of plots can serve to monitor the status of the species across its range with consistent, repeatable plant counts. The two-step process was begun in June 2015 after the completion of the Lybrook Focal Survey. While the species had mostly bloomed by then, the search experience gained by the teams in the focal survey lent a high confidence to locating the cacti in a vegetative and fruiting state along with a good understanding of potential habitats for detecting the species elsewhere in its range.

### Analysis

We used the 2015 NHNM survey data (both transects and recon plots), legacy data (consultant and herbarium records) and negative survey information to: 1) evaluate the overall distribution of Brack's hardwall cactus; 2) define local populations (element occurrences) and meta-populations (sub-regional groups of local populations); and 3) evaluate the overall status of the species. The overall range of the species was evaluated by the inspection of the Brack's, Clover's or Indeterminate observations in combination with the negative surveys. Discrete local populations were delineated using the NatureServe (2002) element-occurrence methodology and the guidance of Ladyman (1999) for *S. cloverae* at the species level. Element occurrences (EOs) are operational surrogates for local populations in lieu of data on individual plant interactions, genetic isolation and population dynamics. A key rule is that when an individual or group of individuals are separated by more than 3 km with suitable intervening habitat, they are considered separate EOs. This is reduced to 1 km when there is significant non-habitat between individuals. The condition of each element occurrence was provisionally ranked based on the plant counts from the observations (EO ranks).

Metapopulations as defined by Hanski and Simberloff (1997) are 'sets of local populations within some larger area, where typical migration from one local population to at least some other patches is possible.' Delineating definitive metapopulations can be complex, requiring observations through time and an understanding of habitats and their distribution. Yet, even roughly outlined they can provide a framework for addressing species status and conservation at broader landscape scales. Accordingly, we used the EO distribution coupled with a regional predictive density surface based on the observations to delineate a set or working metapopulations for Brack's. The surface was interpolated using the Inverse Distance Weighted (IDW) algorithm in ArcGIS 10.2 (ESRI 2013). All interpolation methods estimate the value at a given, unsampled location as the weighted sum of the values in the local neighborhood. IDW is an exact interpolator. That is, it preserves the values at sampled points, which is often an important aspect to continuous surface creation and use but can create a more heterogeneous surface. For Brack's, we wished to preserve the values at the sampled locations as well as identify and visualize a reasonable delineation of the Brack's hardwall cactus population center(s). To smooth the surface somewhat, we chose to aggregate point counts by 1-km$^2$ grids and create a surface at that resolution which would be sufficient for a region-wide analysis. The resulting interpolated surface was then visualized in ArcGIS 10.2 (ESRI 2013) using Jenks Natural Breaks, which seeks to minimize variation within groups while maximizing variation among groups. Class intervals were rounded to the nearest integer value. Given the interpolated surface and the sample points, we broadly delineated the provisional metapopulations using heads-up digitizing in the GIS.

To address the overall status of the Brack's hardwall cactus we followed the NatureServe status ranking approach and standard (Faber-Langendoen et al. 2009; Master et al. 2009) using a standardized spreadsheet rank calculator (the rank calculator is provided in the digital addendum). The calculator uses the number of EOs, their condition (EO rank based on plant numbers), along with an overall assessment of trends and threats, to derive state status (S-rank) as shown in Table 4.

**Table 4. State conservation status rank definitions based on the NatureServe standard of Faber-Langendoen et al. (2009) and Master et al. (2009).**

| |
|---|
| **S1 = Critically Imperiled** |
| Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation. Typically 5 or fewer high-quality occurrences or very few remaining individuals (<1,000). |
| **S2 = Imperiled** |
| Imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation. Typically 6 to 20 high-quality occurrences or few remaining individuals (1,000 to 3,000). |
| **S3 = Vulnerable** |
| Vulnerable in the state either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 high-quality occurrences or between 3,000 and 10,000 individuals |
| **S4 = Apparently Secure** |
| Uncommon but not rare, and usually widespread. Possible cause for long-term concern. Typically more than 100 occurrences in the state or more than 10,000 individuals. |
| **S5 = Secure** |
| Common, typically widespread and abundant. |
| **SH = Possibly Extirpated** |
| Known only from historical occurrences. Still some hope of rediscovery. |
| **SX = Presumed Extirpated** |
| Believed to be extirpated. Not located despite intensive searches and virtually no likelihood that it will be rediscovered. |

# RESULTS

## Suitable habitats and occupancy

As part of the 2015 Lybrook Focal Zone Survey, we identified 22 provisional habitat types in the zone, of which 19 were occupied by Brack's hardwall cactus (Table 5). We detected 2,571 live cactus plants in 483 quadrats along the 100 km of belt transects, but plants were not equally distributed among or within habitats. The highest densities were found in sparse grama-galleta grasslands (types 5d, 6d) and open sagebrush shrublands (type 5d) with scattered grass understories that occurred in valleys and along dry washes (Figure 6). Cacti tended to prefer eroding sandy-loam to sandy-clay substrates within the valleys. This includes eroding alluvial terraces along washes and channel edges, but not the active channels themselves (type 6f). Other valley occurrences tended to be on eroded alluvial fans and remnant hill slope pediments, that is, patches of eroded yellow/tan sandstone hills within the valleys. These latter sites often had scattered open woodlands (4a, 5a) with fewer cacti (woodland inset Figure 6). Grasslands without significant shrubs while ranked high for cactus density (1 and 2), were relatively uncommon across the focal zone (Zone Habitat Area ranks of 16 and 17 among 22). Hence, their contribution of grasslands to overall cactus numbers is likely relatively low. In contrast, valley open shrubland (5c) with some grass cover have a modest density rank but was the most common habitat across the focal zone and is therefore potentially the most important habitat for the cactus.

The next highest densities were on red hills where plants tended to occur directly on eroding hills of the baked red sandstone and ancient alluvial cobble, or on colluvial/alluvial rubble veneers deposited over other rock types like gray shales (Figure 7). These sites were sparsely vegetated but usually had scattered grasses (type 3e) and occasional cacti and were moderately prevalent across the focal zone (Zone Habitat Area rank 7). Red hill woodlands and open shrubland had modest density ranks but were less prevalent across the zone (Zone Habitat Area ranks of 17 and 21, respectively). There were modest densities of cacti in the woodlands and open shrublands at higher elevations of the hill country (yellow/tan hills) that flank the eastern edge of the Nacimiento Formation (type 4a; Figure 8). The open shrublands dominated by big sage and rabbit brush were limited in extent (Zone Habitat Area rank 17) and tended to lie between the woodlands on the slopes and the valley fill areas dominated by dense shrubs. Cacti could also occupy woodland, open shrub and grassland habitats and along edges and interior drainages of the mesas (types 1a, c & d; Figure 9) but these habitats are scattered and limited in area. The common denominator throughout was that plants preferred erosional sites at the local scale. In contrast, plants were scarce or absent in valley fill areas (type 5b) dominated by dense sagebrush or on the dense sagebrush areas on mesa tops (type 1b) with deep soils (inset Figure 9). They also had relatively low abundance in conspicuous barren badlands dominated by gray and white shales and silty sandstones (types 2a, c, & e; see #2 Table 2) or gypsum outcrops.

**Table 5. Brack's hardwall cactus transect occupancy and density summary by habitat and habitat distribution across the Lybrook Focal Zone .**

| Habitat | Transect % Occu-pancy. | Transect Density (plants/ha) | Relative Density Rank | Zone Habitat Area (ha) | Zone Habitat % | Zone Habitat Area Rank |
|---|---|---|---|---|---|---|
| 1. Mesa Top | | | | | | |
| a. Woodlands | 6 | 15.7 | 11 | 374 | 1.8 | 15 |
| b. Dense Shrubland | 0 | 0 | 20 | 1456 | 7 | 5 |
| c. Open Shrubland | 8.9 | 5.9 | 17 | 665 | 3.2 | 12 |
| d. Grassland | 14.9 | 9.9 | 14 | 208 | 1 | 16 |
| 2. Gray/White hills | | | | | | |
| a. Woodlands | 6.7 | 7.5 | 15 | 832 | 4 | 9 |
| c. Open Shrubland | 7 | 20.4 | 10 | 42 | 0.2 | 22 |
| e. Barren/Sparse Grassland | 1.2 | 3.4 | 18 | 2620 | 12.6 | 2 |
| 3. Red Hills | | | | | | |
| a. Woodlands | 5.4 | 15.3 | 12 | 125 | 0.6 | 17 |
| c. Open Shrubland | 7.5 | 26.2 | 6 | 83 | 0.4 | 21 |
| e. Barren/Sparse Grassland | 11 | 42.4 | 4 | 956 | 4.6 | 7 |
| 4. Yellow/Tan Hills | | | | | | |
| a. Woodlands | 9 | 22.6 | 9 | 2537 | 12.2 | 3 |
| c. Open Shrubland | 12.4 | 24.8 | 8 | 125 | 0.6 | 17 |
| d. Grassland | 40.1 | 62.6 | 1 | 125 | 0.6 | 17 |
| 5. Valley | | | | | | |
| a. Woodlands | 9 | 12.4 | 13 | 1331 | 6.4 | 6 |
| b. Dense Shrubland | 1.6 | 2.2 | 19 | 1913 | 9.2 | 4 |
| c. Open Shrubland | 14.4 | 35.5 | 5 | 3660 | 17.6 | 1 |
| d. Grassland | 22.5 | 52.9 | 2 | 125 | 0.6 | 17 |
| 6. Dry Wash | | | | | | |
| a. Woodlands | 5.1 | 25 | 7 | 790 | 3.8 | 10 |
| c. Open Shrubland | 6.6 | 6.6 | 16 | 790 | 3.8 | 10 |
| d. Grassland | 18.4 | 47.3 | 3 | 665 | 3.2 | 12 |
| f. Barren (channel) | 0 | 0 | 20 | 457 | 2.2 | 14 |
| 7. Disturbed | | | | | | |
| g. Barren | 0 | 0 | 20 | 915 | 4.4 | 8 |
| Summary | 9.8 | 20.8 | -- | 20794 | 100 | -- |

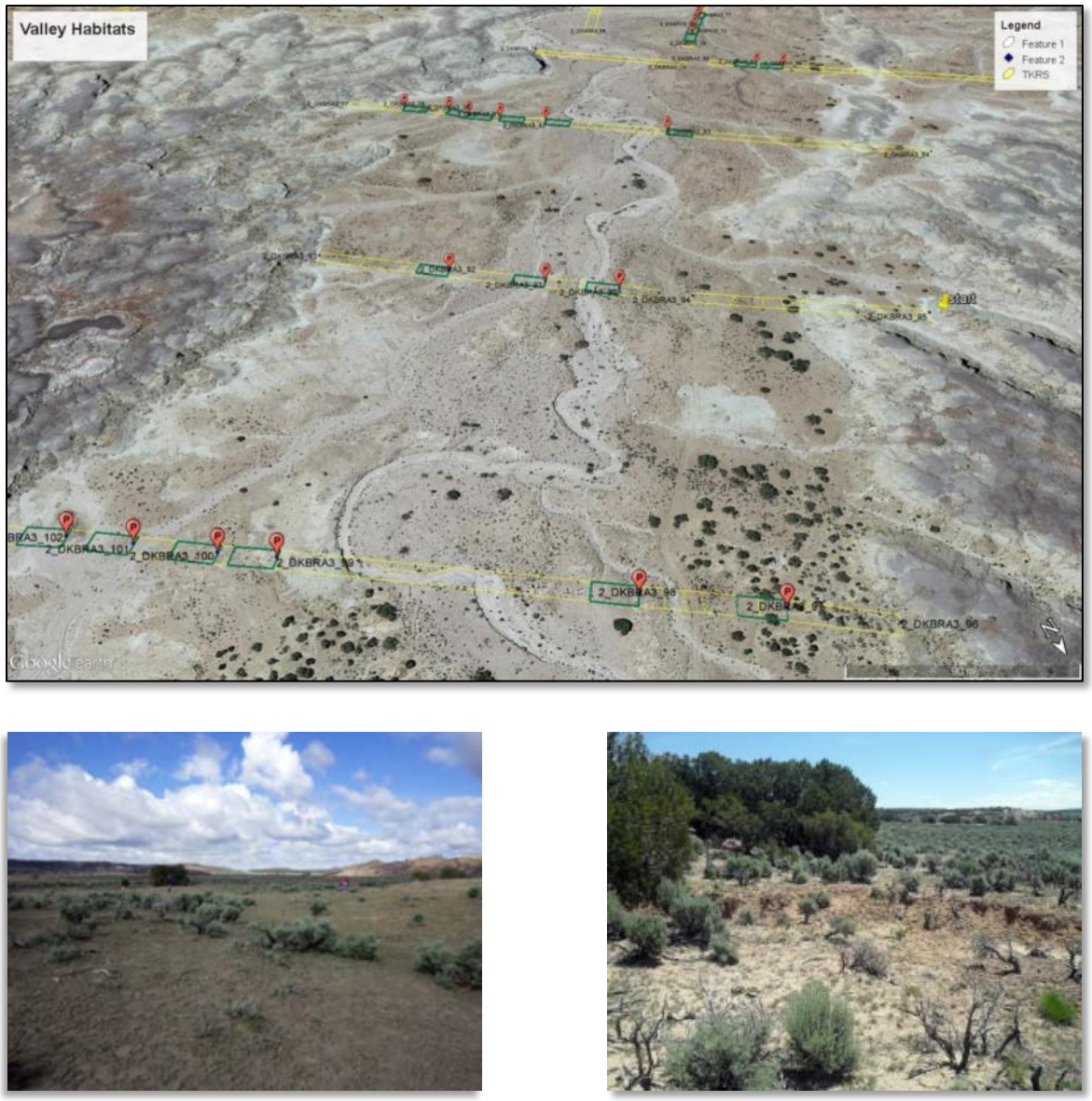


**Figure 6. Brack's often occurred on eroding alluvial fans and alluvial terraces adjacent to active dry washes. These sites were characterized by scattered grasses and shrubs. Cacti were also present amongst valley woodlands that occur on remnant hillslope pediments (e.g., lower right woodlands on yellow to tan substrates). Green squares are occupied transect quadrats.**

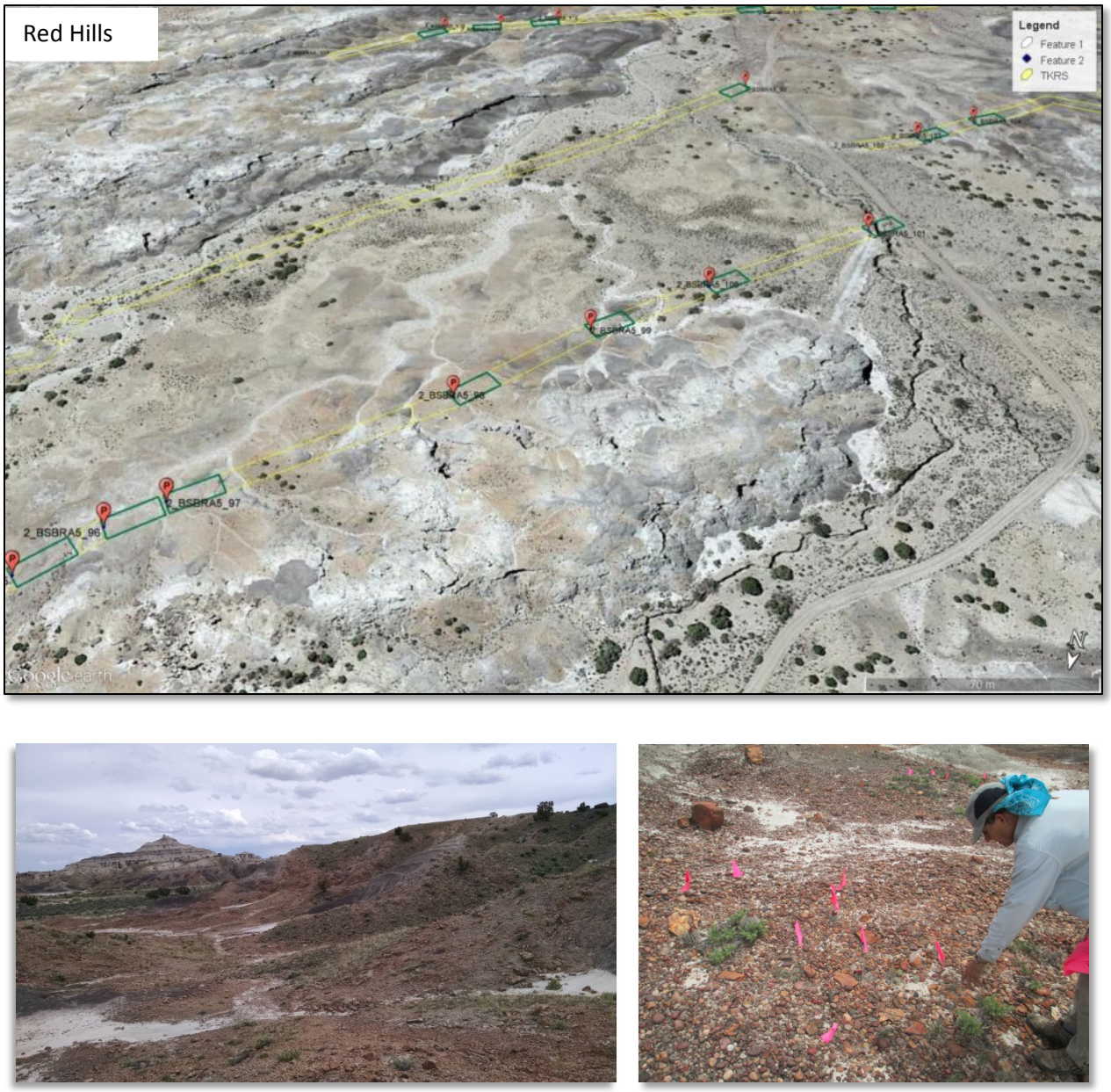


**Figure 7. In the badlands, Brack's is most common on baked red sandstone hills and alluvial fans. Green squares are occupied transect quadrats.**

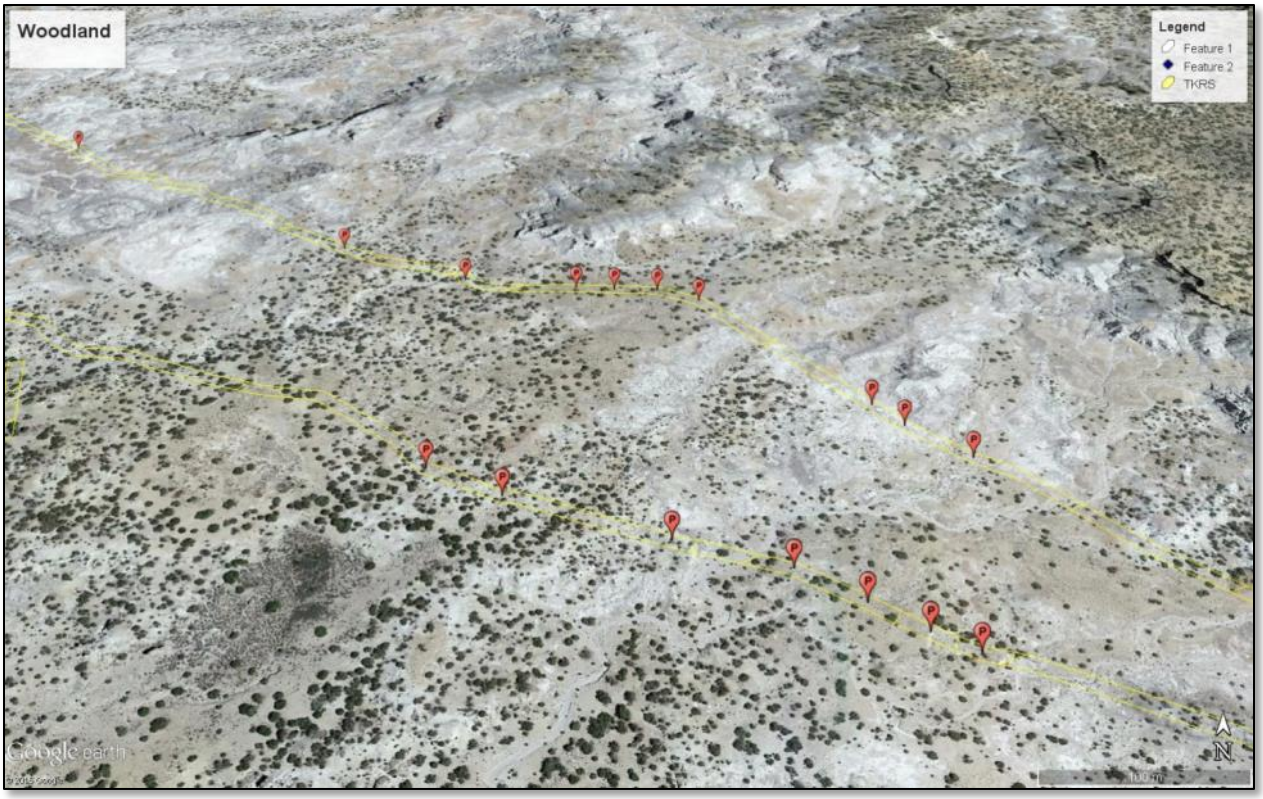


**Figure 8. Brack's hardwall cactus could also be moderately common in pinyon-juniper woodlands on eroding hillslopes of sandstones and shales.**

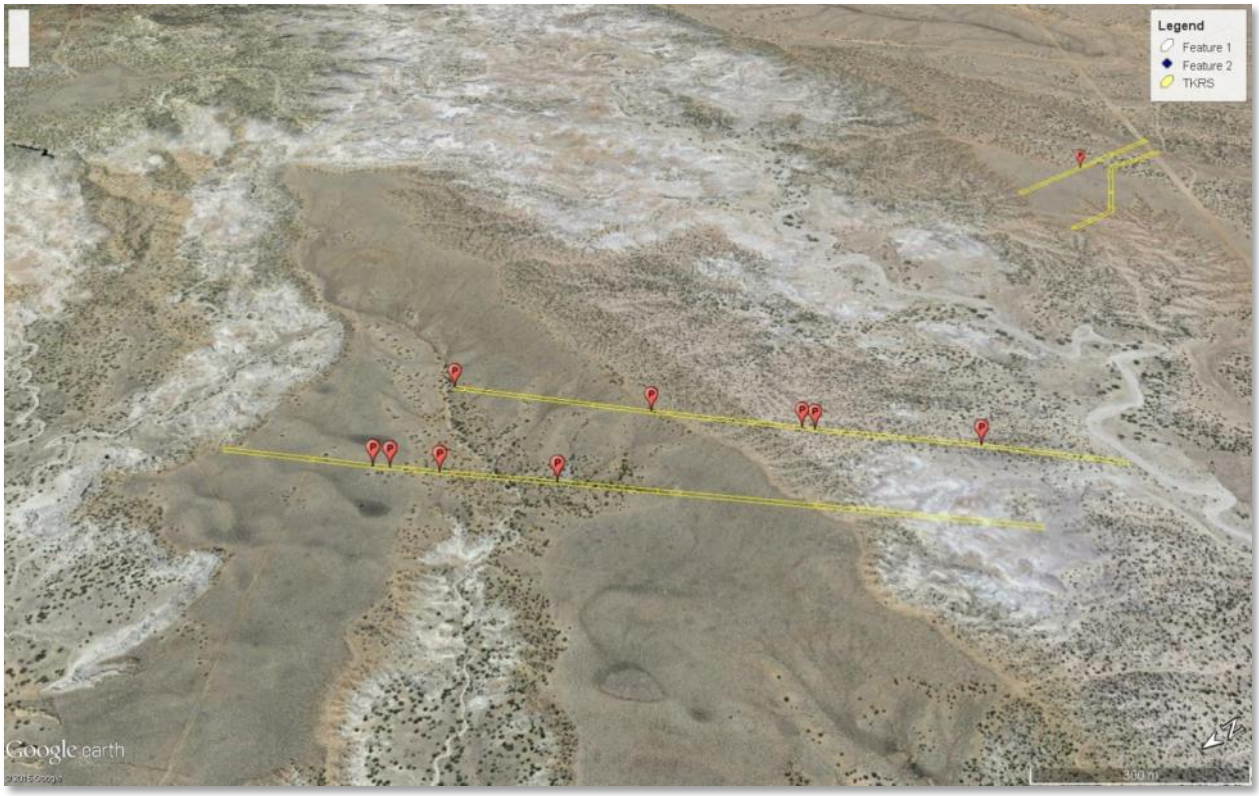


**Figure 9. Brack's also occurred on mesa tops, but was mostly associated with the eroding mesa edges, while the heart of the mesas was dominated by dense big sagebrush shrublands.**

Plants are not uniformly distributed within habitats as well. Percent occupancy in suitable habitat in the focal zone varied from 1% to 40% and averaged 9.8% (see Table 5). Even among the key habitats such as valley grasslands and open shrublands or dry wash terraces, occupancy was less than 25%. Based on their distribution along our belt transects, plants tended to form small patches with the majority of occurrences limited to single quadrats (minimum length 20 m by 10 m wide) (Figure 10). These small 10 x 20 m patches ranged from 1 plant (50/ha) to 27 plants (1,350/ha). The largest continuous patch (with no breaks greater than 50 m) was 278 m, but cacti densities were relatively low across this cluster. This suggests that plants are very clumped in their distribution—forming local "family" clusters of low to high density driven by local dispersal of seeds and micro-habitat conditions (Figure 11). In addition, several transects had little or no detections despite the availability of habitat. That is, there were relatively large places in the Lybrook zone with suitable habitat where we expected to find plants but did not. This may be an indication of landscape-scale processes and habitat differences at work that need to be further investigated. *Additional validation field studies are needed to correct for the known sampling bias and to confirm the spatial extent of the habitats derived from aerial imagery interpretation.*

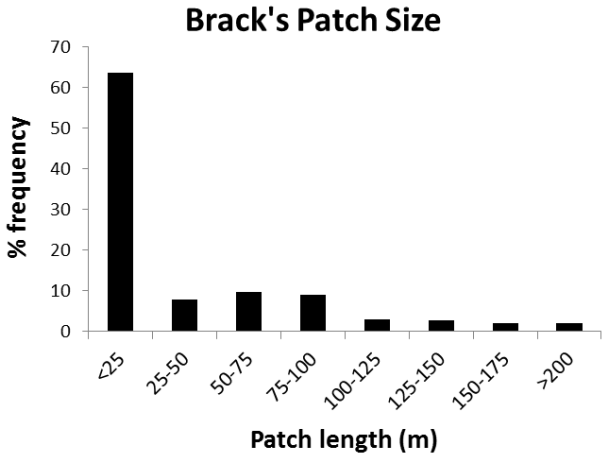


**Figure 10. Frequency of Brack's hardwall cactus patch sizes based on the length of occupied continuous habitat along the belt transects. Habitat was considered continuous if contiguous occupied transect quadrats were separated by less than 50 m.**

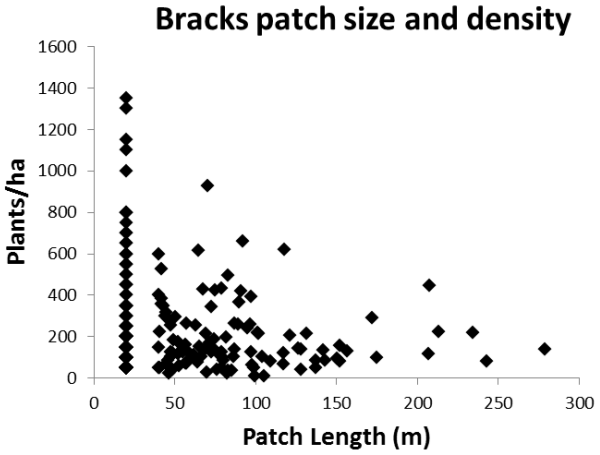


**Figure 11. Quadrat densities and patch size measured by length of continuous occupied habitat showing that plants could be highly clustered and have high densities in small areas.**

Suitable habitats tended to be associated with specific soils as mapped by NRCS (Figure 12). The high-density ranked suitable habitats tended to occur on soils mapped as Badlands, which account for about 35% of the zone area (Group 1, Table 6). Relatively high ranking Habitat Valley Open Shrublands (5c), Yellow/Tan Hills Woodlands (4a), and Dry Wash Grassland could be found across various soil types, but it is likely that the majority of suitable habitat still lies within Badlands. Gray/White Hills Open Shrubland (2c), Red Hills Barren/Sparse Grassland (3e), Yellow/Tan Hills Grasslands (4d), and Valley Grasslands (5d) were restricted to Badlands. In contrast, habitats with low density ranks tended to be more prevalent on other soils besides Badlands (e.g., 1b, 1c, 5b, 8e). *Accordingly, mapped soils can provide a rough but not definitive guide to suitable Brack's hardwall cactus habitat.*

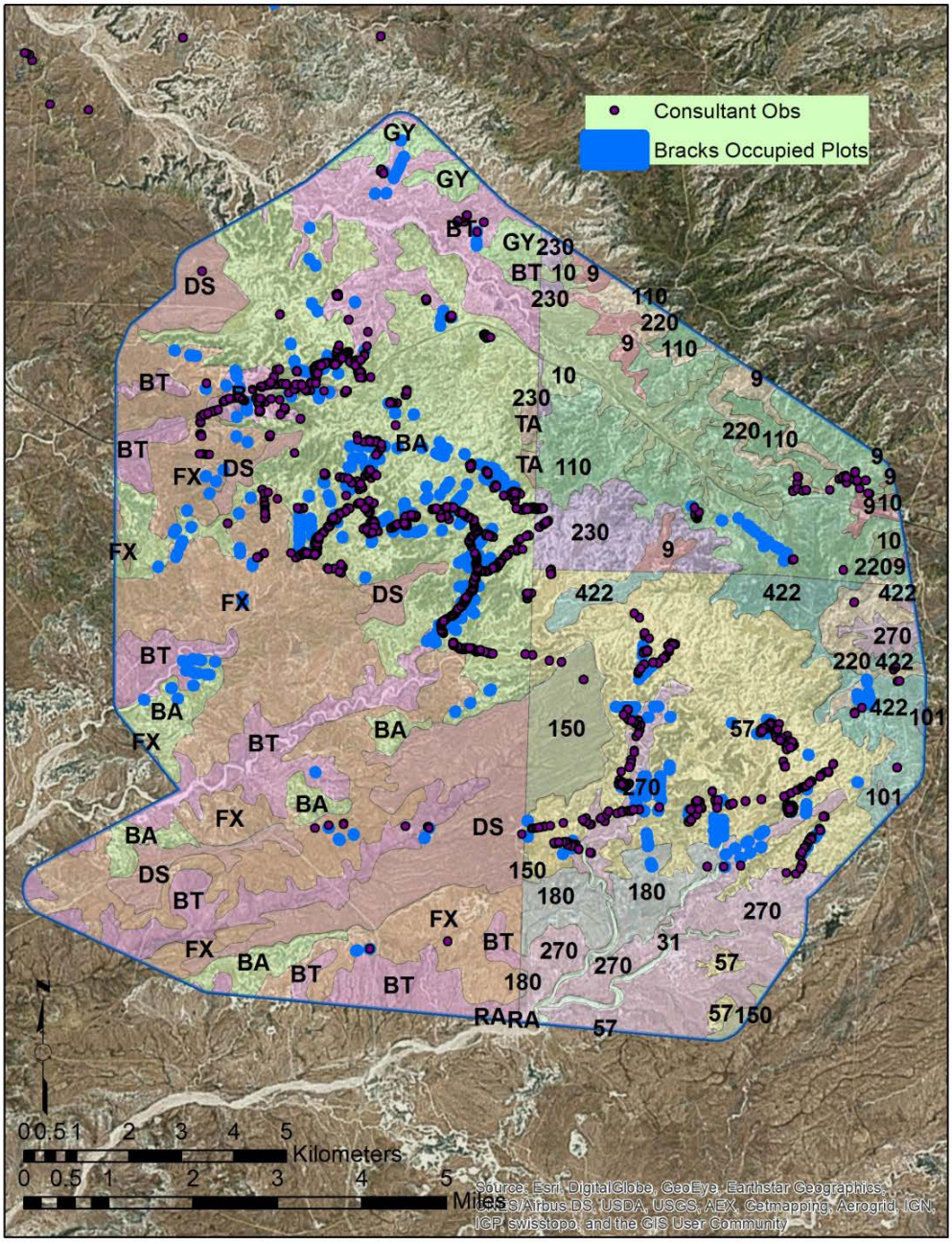


**Figure 12. Lybrook Focal Zone soils as mapped by NRCS. See Table 6 for key to map unit symbols.**

**Table 6. Brack's hardwall cactus habitat type percent distribution by soil types as mapped by Keetch (1980; NM618), Hacker and Banet (2008; NM656), and Roybal (2008; NM650). See Figure 12 for spatial distribution.**

| Soil Mapping Area Symbol | MU Symbol | Map Unit | Habitat | 1a | 1b | 1c | 1d | 2a | 2c | 2e | 3a | 3c | 3e | 4a | 4c | 4d | 5a | 5b | 5c | 5d | 6a | 6c | 6d | 6e | 8e | All |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Density rank | 11 | 20 | 17 | 14 | 15 | 10 | 18 | 12 | 6 | 4 | 9 | 8 | 1 | 13 | 19 | 5 | 2 | 7 | 16 | 3 | 20 | 20 | |
| NM618 | BA | Badland | | | | | | 1.8 | 0.2 | 5.6 | 0.2 | 0.2 | 2.8 | 1.2 | 0.4 | 0.2 | 0.6 | 0.4 | 2.8 | | 0.6 | 0.6 | 0.8 | 0.2 | 0.2 | 19 |
| NM656 | 57 | Badland | | | | | | 0.2 | | 3.8 | 0.2 | | 1.6 | 1.4 | | 0.4 | 0.8 | | 0.8 | 0.6 | 0.8 | 0.2 | 1 | 0.4 | | 12 |
| NM650 | 230 | Badland | | | | | | 0.2 | | 0.6 | | | 0.2 | 0.6 | | | 0.6 | | 0.2 | | 0.2 | | | | | 2.6 |
| NM618 | GY | Gypsiorthids-Badland-Stumble complex, moderately steep | | | | | | | | 0.6 | | | | | | | | | 0.4 | | | | 0.2 | | | 1.2 |
| NM656 | 101 | Blancot-Lybrook association, 0 to 8 percent slopes | | | | 0.2 | | | | | | | | | | | | | | | | | | | | 0.2 |
| NM618 | BT | Blancot-Notal association, gently sloping | | | 0.6 | 0.2 | 0.2 | | | | | | | 0.2 | | | 0.6 | 3.4 | 4.4 | | | 1.4 | 0.2 | 0.4 | 1.4 | 13 |
| NM656 | 270 | Blancot-Councelor-Tsosie association, 0 to 5 percent slopes | | | 0.2 | | | | | 0.4 | | | | | 0.2 | | | 1.2 | 2.6 | | | 0.4 | 0.2 | | 0.2 | 5.4 |
| NM618 | DS | Doak-Sheppard-Shiprock association, rolling | | | 4.4 | 1 | 0.4 | | | | | | | | | | | 0.2 | | | | 0.4 | 0.2 | | 0.2 | 6.8 |
| NM656 | 150 | Doakum-Betonnie fine sandy loams, 0 to 8 percent slopes | | | 0.8 | 0.6 | | | | | | | | | | | | | | | | | | | | 1.4 |
| NM618 | FX | Fruitland-Persayo-Sheppard complex, hilly | | 0.2 | 0.8 | 0.8 | 0.4 | 0.6 | | 0.4 | | 0.2 | | 3.2 | | | 1.8 | 1.8 | 3 | | 1.4 | 0.4 | 0.6 | 0.4 | 0.8 | 17 |
| NM650 | 110 | Vessilla-Menefee-Orlie complex, 1 to 30 percent slopes | | 0.8 | | | | 0.6 | | | 0.2 | | | 3.2 | | | 1.4 | 0.2 | 0.6 | | 0.4 | | | | 0.6 | 8 |
| NM656 | 422 | Vessilla-Menefee-Orlie association, 0 to 30 percent slopes | | 0.8 | 0.4 | 0.2 | | | | 0.2 | | | | 1.6 | | | 0.2 | 0.2 | 0.6 | | | | | | | 4.2 |
| NM656 | 220 | Rock outcrop-Vessilla-Menefee complex, 30 to 40 percent slopes | | | | | | 0.6 | | 1 | | | | 0.4 | | | | 0.2 | | | | | | | | 2.2 |
| NM650 | 10 | Sparank-San Mateo silt loams, saline, sodic, 0 to 3 percent slopes | | | | | | | | | | | | | | | 0.2 | 1.4 | 0.6 | | | 0.2 | | | 0.4 | 2.8 |
| NM650 | 9 | Pinavetes-Florita complex, 2 to 10 percent slopes | | | | | | | | | | | | | | | 0.2 | 0.2 | 0.8 | | | | | | 0.2 | 1.4 |
| NM656 | 180 | Councelor-Eslendo-Mespun complex, 5 to 30 percent slopes | | | | 0.2 | | | | | | | | 0.4 | | | | | 0.2 | | | | | | 0.4 | 1.2 |
| NM656 | 31 | Riverwash | | | | | | | | | | | | | | | | | 0.6 | | 0.2 | 0.2 | | 0.8 | | 1.8 |
| | | | Summary | 1.8 | 7.2 | 3.2 | 1 | 4 | 0.2 | 13 | 0.6 | 0.4 | 4.6 | 12 | 0.6 | 0.6 | 6.4 | 9.2 | 18 | 0.6 | 3.6 | 3.8 | 3.2 | 2.2 | 4.4 | 100 |

# Range-wide distribution of populations and meta populations

## Taxonomic variation

Based on the reconnaissance survey across the Nacimiento Formation, *Sclerocactus cloverae* populations were variable in size and spine density and determinations of subspecies was often difficult based on central spine characteristics alone (see Table 1). Operationally, we classified plants in the survey into either subsp. *brackii*, subsp. *cloverae* or as "Indeterminate" between the two based on a combination of spine characteristics and size. Populations with generally small (<8 cm) cacti with relatively sparse spine cover not obscuring the stem and frequent or occasional mature plants missing hooked central spines on their areoles were classified as subsp. *brackii*. Exceptional cacti within these populations with large stems and/or dense spines including hooked centrals were not important in this decision, if there was a general population trend toward subsp. *brackii* morphology. Populations with relatively large individuals with dense spines were called subsp. *cloverae.* Individuals that did not exhibit strong morphological or phenological features towards one taxon or the other were classified as "Indeterminate" e.g., all reproductive individuals were relatively small, but many had adult arrangements of four longer central spines, or reproductive individuals ranging from small to large stems (<4 cm to >8 cm wide) with short, sparse spine cover. The reconnaissance survey produced 155 positive locations of which only 20, or 13%, were assigned subsp. *cloverae*. Indeterminates accounted for another 46%, or 72 plots. The remaining 41%, or 63 plots, were classified as subsp. *brackii* (Table 6). *A genetic study will be necessary to help clarify the population and regional variability of S. cloverae and efficacy of these assignments.*

Although most populations displayed a tendency towards one subspecies or the other, exceptions could occur within local patches of cacti. Figure 13 illustrates the usual variations that can be found in patches of Brack's hardwall cactus where many small flowering individuals have a juvenile spine arrangement of three central spines (hooked central lacking), but older individuals begin to develop mature areoles with a lower hooked central spine. Occasional older individuals had fairly dense covering of well-developed spines. If Brack's hardwall cactus plants survive to old age, they can eventually attain a size and spine arrangement indistinguishable from typical Clover's hardwall cactus (Ferguson 1998b).

Another distinguishing characteristic of Brack's hardwall cactus is its ability to flower at a very small size, in the range of 2-3 cm wide, with juvenile spine arrangement (Figure 14). But individual cacti in this size class are difficult to find and most of those that were located were not flowering (very few Brack's hardwall cactus <4 cm in diameter were seen in flower or fruit in 2015). Populations with some relatively large individuals with dense spines that might be called subsp. *cloverae* also occasionally had very small flowering plants in the range of 2.5 to 3.5 cm wide (Figure 15). These had areoles with lower hooked central spines and illustrated the ability of both subspecies to flower at a small stem size.


**Figure 13. Morphological variation within the Brack's hardwall cactus population in the badlands between Lybrook and Nageezi. All photos taken on 22 April 2015 within 1 km of each other in similar soils and habitats. Photo A shows the common juvenile spine arrangement of three central spines (lacking the hooked central) on a flowering plant (see flower buds). Photo B shows the common spine arrangement of older cacti with some or all areoles having four central spines including the lower hooked central. Photo C shows an uncommon old individual with long, dense spines on areoles with three to four central spines. All three cacti are <8 cm wide.**

**Figure 14. Brack's hardwall cactus flower on 2.5 cm wide stem (lacks hooked central spines) with foliose lichen, west of Lybrook (left). Clover's hardwall cactus fruit on 2.7 cm wide stem (has hooked central spines) in Largo Canyon (right).**

**Figure 15. Mature, small, < 8 cm wide *Sclerocactus cloverae* with mostly 3 central spines per areole on sandy cobbley south flank of Mount Nebo near Colorado border (left). Large 12 x 17 cm *S. cloverae* with shadscale on sandy shale of Angel Peak badlands, south of Bloomfield (right).**

## General distribution and range limits

Overall, the 2015 survey, including negative observations along with the legacy data, indicated that Brack's hardwall cactus is confined to discontinuous portions in the northern portion of the Nacimiento Formation in northwestern New Mexico (Figure 16). Its total geographic range is only about 55 miles north to south by 10 miles at it widest point. It extends north of the San Juan River to the vicinity of Aztec on the east side of the Animas River, but then morphological distinctions become more indeterminate further north to Cedar Hill and west to breaks of the La Plata River valley. The length of Gallegos Canyon through Navajo Agricultural Products Industries land west of Kutz Canyon was briefly surveyed and no Brack's hardwall cactus or suitable habitat was found in that area. The upper parts of the De-Na-Zin badlands also occur along the western margin of the Nacimiento Formation. *Sclerocactus cloverae* was observed in the eastern part of these badlands, but was classified as Indeterminate although other nearby populations are clearly subsp. *cloverae*. To the south, a large population of subsp. *brackii* occurs near the junction of the Rio Arriba, Sandoval and San Juan County lines in the extensive badlands that lie between Lybrook and Nageezi north of Highway 550 in the upper breaks of Blanco Wash, and south of the highway along the Sandoval/San Juan County line to the Escavada Wash. Based on the extensive negative surveys, no *Brack's hardwall cactus* populations were found further south on the Nacimiento Formation, but subsp. *cloverae* extended another 15 km southward to just north of Ojo Encino. No other *Sclerocactus* spp. were found in field surveys or in herbarium records further south on the formation all the way to Cuba, New Mexico.

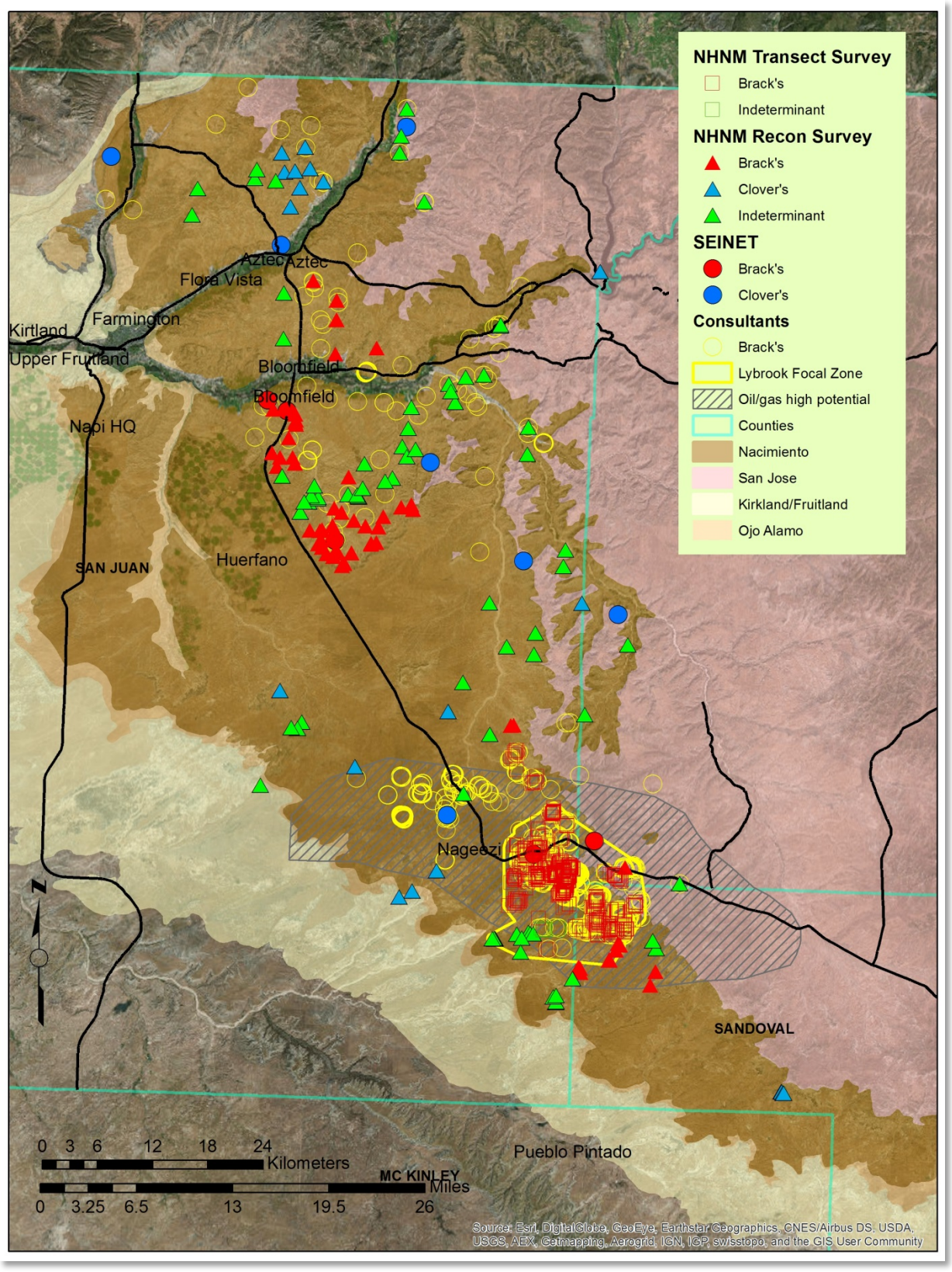


**Figure 16. Distribution of *Sclerocactus cloverae* based on NHNM 2015 plots, herbarium specimens from SEINet (2015), and consultant surveys.**

The reconnaissance survey counted 1,141 live plants of either Brack's or Indeterminates (Table 7). For these, densities averaged about eight plants per 20 m-radius plot but they could have as much as 46 plants. Densities were higher for the Clover's subspecies, but samples were about one third that of the other two. In addition, we recorded dead plants when detected, which averaged about 10% of the total.

**Table 7. Reconnaissance survey total numbers of Brack's and Indeterminate individuals with statistics on a per-plot basis. Plot size 314 sq. m.**

| Status | | Brack's (*n* = 63) | *Indeterminate* (*n* = 72) | Clovers (*n* = 20) |
|---|---|---|---|---|
| Live | Plants | 529 | 612 | 427 |
| | Maximum/plot | 46 | 46 | 314 |
| | Avg/plot | 8.3 | 8.5 | 21.4 |
| | StDev | 8.9 | 10.8 | 68.5 |
| Dead | Plants | 59 | 51 | 51 |
| | Maximum/plot | 9 | 14 | 38 |
| | Avg/plot | 0.9 | 0.7 | 2.6 |
| | StDev | 1.6 | 1.9 | 8.4 |

## Brack's hardwall cactus local and metapopulations

We delineated 56 isolated local populations or "element occurrences" (EOs) of Brack's, Indeterminates and in some cases combinations of the two, plus Clover's (Figure 17). The element occurrence boundaries were based on all the available data as of January 1, 2016 and included the NHNM reconnaissance plots, the Lybrook Focal Zone transect data, consultant observations, and herbarium collections (Table 8). In most cases, these occurrences were separated by three or more km unless there was a significant habitat break at a smaller distance. With respect to subspecies assignment, NHNM determinations took priority over consultant assignments in the same occurrence. Based on site live-plant counts, most of the occurrences (39 or 70%) were represented by less than 50 individuals and were provisionally considered small populations and were given a provisional element-occurrence rank of "D" following NatureServe guidelines for evaluating the condition of occurrences. Another 12 (23%) ranged between 50 and 120 plants and were considered moderate populations and were give a "C" rank. Only four populations (7%) of the 53 occurrences were between 200 and 539 plants, and considered relatively large populations with a Rank of "B" (Blanco6, Kutz, Angel Peak, and Nageezi North). The Lybrook occurrence (2%) had by far the most plants detected, at 13,536, and is considered a very large population with an EO rank of "A." Determining final element-occurrence ranks will require additional sampling at the locations to determine the actual extent of each occurrence and the number plants. Pending that, these are the plant numbers and EO ranks that were used in part to evaluate the status of Brack's hardwall cactus (see Conservation Rank below).

Based on the EOs, negative surveys, and an underlying interpolated density surface, we provisionally defined six metapopulations—groups of local, potentially interacting populations/EOs that represent overall pattern and distribution of the sub-species species at a broader scale (Table 8; Figure 14). We included all Indeterminate EOs in the metapopulations until there is further clarification of their status. The Kutz-Angel Peak is a major metapopulation which encompasses the type locality of Brack's hardwall

cactus (Kutz Canyon) and most of the observations associated with shale badlands in the region of the San Juan River in the Bloomfield area. While there were several Indeterminate EOs and also scattered individuals of subsp. *cloverae*, the central tendency is towards subsp. *brackii*. We also included in this metapopulation the occurrences north of the San Juan River, although it could be argued that the river offers a significant barrier to local population interactions from north to south. But since all of the occurrences are in the same drainage basin with similar geology, we chose to keep them together in the same metapopulation for now.

The Lybrook metapopulation is the largest in terms of plat counts. Although Indeterminates were found more towards the periphery and occasionally mixed within local populations, it was still considered a Brack's hardwall cactus core metapopulation. In contrast, the Nageezi, Blanco, and Largo metapopulations were made up mostly of Indeterminates and plant counts were lower. Largo in particular is located in a region where the Nacimiento Formation become more reticulate and less uniform, which may be leading to ambiguity in the taxon attribution. *Clearly, these metapopulation are in need of further investigation with respect to the taxon distribution and density*.

Lastly, at the northern end of the range we delineated the Aztec metapopulation. This metapopulation had definite tendencies towards the Clover's subspecies, and clear Brack's were less common. Substrates also become more heterogeneous in this region with sedimentary rocks and alluviums becoming more common intermixed with shale badlands. Based on the negative surveys and routes traveled in 2015, other areas of the Nacimiento Formation had little significant suitable habitat (see Figure 1). In particular, there were large expanses of dense sagebrush shrubland or riverine riparian habitats where there was little expectation of *Sclerocactus* occupancy*. Additional surveys may find additional outliers, but we would suggest that metapopulations outlined here constitute the major population centers*.

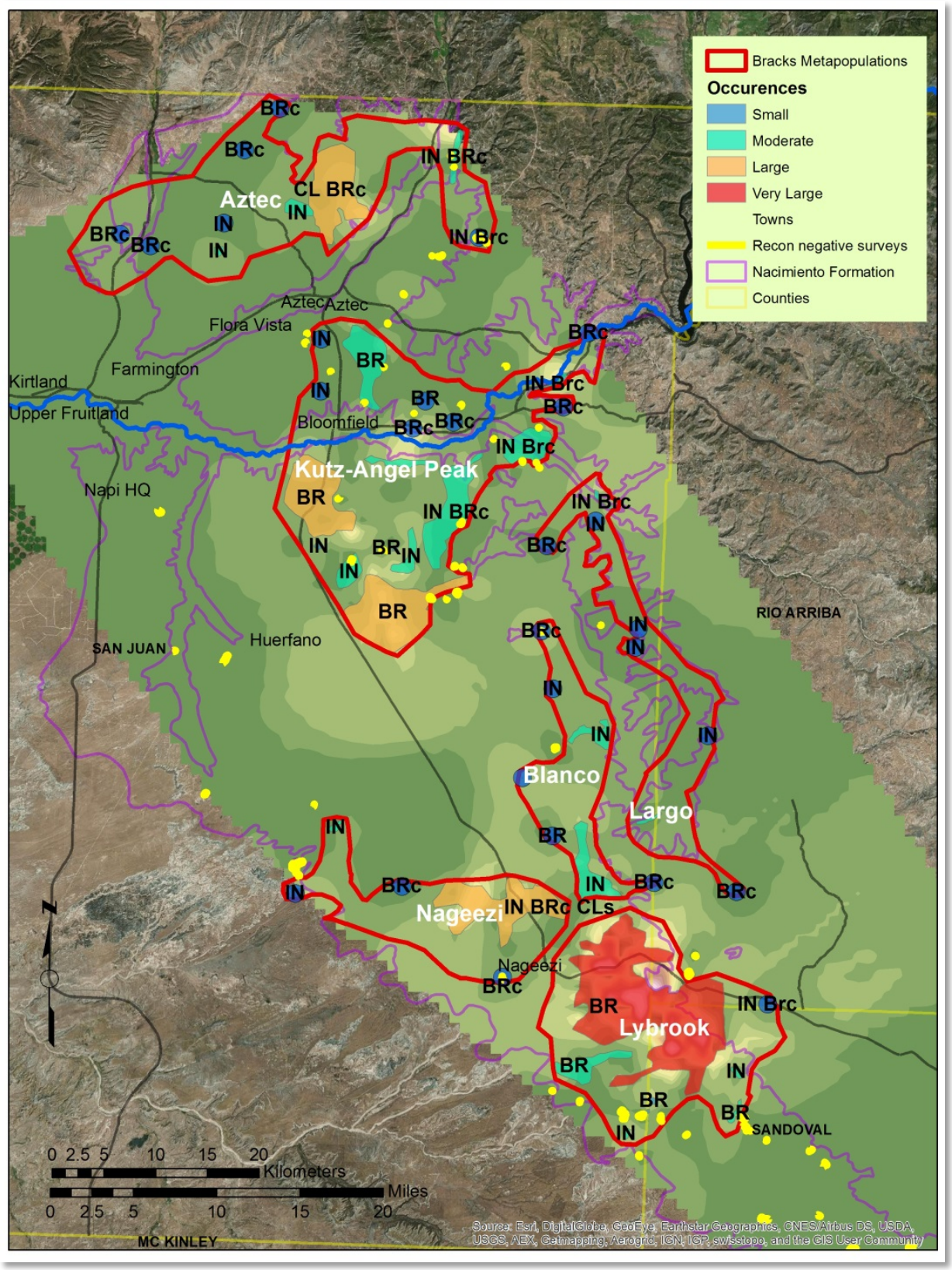


**Figure 17. Brack's hardwall cactus occurences and metapopulations overlain on an interpolated density surface based on field-survey counts of plants. Occurrences are separated by at least 3 km in contiguous potential habitat (most cases) or by 1 km where there are significant habitat barriers. BR = Brack's per NHNM; BTc = Brack's per consultants; IN = Indeterminate per NHNM; and CL = Clover's per NHNM and herbarium records.**

**Table 8. Brack's hardwall cactus element occurences (EOs) across the Nacimiento Formation. Br = Brack's per NHNM; BRc = Brack's per consultants; IN = Indeterminate per NHNM; and CL = Clover's per NHNM and herbarium records. Occuurences are in order from smallest to largest plant counts based on all surveys. See Table 9 for summary by metapopulation.**

| Metapop. No. | Metapopulation | Occ. No | Local Population | Subsp. | Live Plants | Area (ha) | EO Rank |
|---|---|---|---|---|---|---|---|
| 2 | Aztec | 33 | Animas1 | IN (BRc) | 80 | 279.6 | C |
| 2 | Aztec | 34 | Aztec1 | CL (BRc) | 116 | 3362.4 | B |
| 2 | Aztec | 42 | Aztec2 Estes | IN | 19 | 324.3 | D |
| 2 | Aztec | 38 | FamingtonGlade | IN | 5 | 65 | D |
| 2 | Aztec | 46 | FamingtonGlade2 | IN | 2 | 13.5 | D |
| 2 | Aztec | 32 | HartCanyon | IN (Brc) | 7 | 1.8 | D |
| 2 | Aztec | 37 | LaPlata1 | BRc | 10 | 3.8 | D |
| 2 | Aztec | 36 | LaPlata2 | BRc | 1 | 0.7 | D |
| 2 | Aztec | 35 | LaPlata3 | BRc | 1 | 0.4 | D |
| 2 | Aztec | 45 | LaPlata4 | BRc | 1 | 43.1 | D |
| 6 | Blanco | 39 | AdamsCanyon | BRc | 7 | 1.1 | D |
| 6 | Blanco | 3 | Blanco1 | BR | 1 | 14.1 | D |
| 6 | Blanco | 5 | Blanco2 | IN | 25 | 0.7 | D |
| 6 | Blanco | 6 | Blanco3 | IN | 4 | 2.7 | D |
| 6 | Blanco | 4 | Blanco4 | IN | 21 | 486.6 | D |
| 6 | Blanco | 57 | Blanco6 | IN | 201 | 1312.3 | B |
| 6 | Blanco | 22 | Huerfanito | BRc | 15 | 1.8 | D |
| 1 | Kutz-Angel Peak | 14 | AngelPeak | BR | 525 | 4587.2 | B |
| 1 | Kutz-Angel Peak | 24 | Armenta | IN (BRc) | 80 | 2499.6 | C |
| 1 | Kutz-Angel Peak | 26 | BloomField1 | BR | 62 | 1757 | C |
| 1 | Kutz-Angel Peak | 27 | BloomField2 | IN | 1 | 0.5 | D |
| 1 | Kutz-Angel Peak | 51 | BloomField3 | IN | 2 | 13.3 | D |
| 1 | Kutz-Angel Peak | 28 | BloomfieldEast | BRc | 4 | 14.7 | D |
| 1 | Kutz-Angel Peak | 43 | BloomfieldEast1 | BR | 2 | 4.5 | D |
| 1 | Kutz-Angel Peak | 44 | BloomfieldEast2 | BRc | 63 | 13 | C |
| 1 | Kutz-Angel Peak | 15 | Kutz | BR | 222 | 3304.2 | B |
| 1 | Kutz-Angel Peak | 50 | Kutz 2 | IN | 19 | 39.3 | D |
| 1 | Kutz-Angel Peak | 13 | Largo3 | IN (Brc) | 115 | 1185.7 | B |
| 1 | Kutz-Angel Peak | 30 | Manzanatres | BRc | 12 | 1.2 | D |
| 1 | Kutz-Angel Peak | 47 | MiddleKutz1 | IN | 21 | 527.9 | D |
| 1 | Kutz-Angel Peak | 48 | MIddleKutz2 | IN | 116 | 432.1 | B |
| 1 | Kutz-Angel Peak | 49 | MiddleKutz3 | BR | 1 | 25.9 | D |
| 1 | Kutz-Angel Peak | 31 | NavajoLake | BRc | 7 | 2.6 | D |
| 1 | Kutz-Angel Peak | 29 | SanJuanEast1 | IN (Brc) | 106 | 167.2 | B |
| 1 | Kutz-Angel Peak | 25 | SanJuanSouth | BRc | 81 | 404.8 | C |
| 4 | Largo | 23 | Blanco5 | BRc | 3 | 1.4 | D |
| 4 | Largo | 40 | BlueMesa | BRc | 1 | 0.3 | D |
| 4 | Largo | 11 | Carrizo | IN (BRc) | 56 | 65.6 | C |
| 4 | Largo | 9 | Cottonwood | IN | 1 | 7.2 | D |
| 4 | Largo | 10 | Largo1 | IN | 3 | 2.9 | D |
| 4 | Largo | 12 | Largo2 | IN | 2 | 3.5 | D |
| 4 | Largo | 7 | Palluche1 | IN (BRc) | 7 | 77.6 | D |
| 4 | Largo | 8 | Palluche2 | IN | 3 | 0.3 | D |
| 3 | Lybrook | 18 | LybrookEast1 | IN (Brc) | 4 | 2.6 | D |
| 3 | Lybrook | 2 | Lybrook-Nageezi | BR | 13536 | 13144.7 | A |
| 3 | Lybrook | 55 | Lybrook-Nageezi SW | BR | 61 | 954.1 | C |
| 3 | Lybrook | 56 | LybrookSouth1 | IN | 1 | 14.9 | D |
| 3 | Lybrook | 17 | LybrookSouth2 | IN | 15 | 69.8 | D |
| 3 | Lybrook | 53 | LybrookSouth2 | IN | 64 | 54.8 | C |
| 3 | Lybrook | 52 | LybrookSouth3 | BR | 39 | 92.9 | D |
| 3 | Lybrook | 54 | LybrookSouth4 | BR | 40 | 29.8 | D |
| 5 | Nageezi | 19 | Bisti1 | IN | 12 | 70 | D |
| 5 | Nageezi | 20 | Bisti2 | IN | 31 | 9.5 | D |
| 5 | Nageezi | 21 | Nageezi2 | BRc | 9 | 3.7 | D |
| 5 | Nageezi | 1 | NageeziNorth | IN BRc CLs | 503 | 3775.5 | B |
| 5 | Nageezi | 41 | TsahTah | BRc | 1 | 8.6 | D |

**Table 9. Brack's hardwall cactus metapopulations. Occurrence types refers to the taxons assigned to each element occurrence (EO) as follows: Br = Brack's per NHNM; BRc = Brack's per consultants; IN = Indeterminate per NHNM; and CL = Clover's per NHNM and herbarium records. Live plants refers to the number plants that have been observed in the populations across all surveys.**

| | | Occurrence types | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Metapopulation. name | Metapop. Area (ha) | BR | BRc | IN | IN Brc | CL BRc | IN BRc CLs | All EOs | EO Area | Live Plants |
| Kutz-Angel Peak | 51574 | 5 | 5 | 5 | 3 | | | 18 | 14981 | 1439 |
| Aztec | 35589 | | 4 | 3 | 2 | 1 | | 10 | 4095 | 242 |
| Lybrook | 33805 | 4 | | 3 | 1 | | | 8 | 14364 | 13760 |
| Largo | 15796 | | 2 | 4 | 2 | | | 8 | 159 | 76 |
| Nageezi | 18161 | | 2 | 2 | | | 1 | 5 | 3867 | 556 |
| Blanco | 12368 | 1 | 2 | 4 | | | | 7 | 1819 | 274 |
| Summary | 167293 | 10 | 15 | 21 | 8 | 1 | 1 | 56 | 39284 | 16347 |

## Cactus health

The spring of 2015 was unusually wet so the *Sclerocactus cloverae* plants observed in this survey were typically turgid and healthy. Most of the mature cacti flowered during the period from mid-April to mid-June. Flowering cacti usually set fruit and only a few flowers appear to have been aborted. Most flowering individuals had more than one flower and when some aborted, at least one or a few flowers succeeded in making fruit. No pollination studies have been conducted specifically for *Sclerocactus cloverae*, but some rare *Sclerocactus* species in adjacent Utah have been studied and are likely similar to New Mexico *Sclerocactus* species (Tepidino et al. 2010). The two Utah species, *Sclerocactus wetlandicus* and *Sclerocactus brevispinus*, are usually self-incompatible outcrossers and predominantly pollinated by small, native, ground-nesting bees in the subfamily Halictinae. Bees observed in the flowers of *Sclerocactus cloverae* during this survey belonged to Halictinae in the genera *Agapostemon* and *Lasioglossum* (Figure 18). These bees are indiscriminate collectors of pollen and nectar from *Sclerocactus* flowers and other flowering plant species (Tepidino et al. 2010).

**Figure 18. Native bee pollinators for Brack's hardwall cactus west of Lybrook, NM. *Agapostemon* sp. (left), *Lasioglossum* sp. (right).**

New seedlings of both Brack's and Clover's hardwall cactus were found during the 2015 field survey, perhaps in response to the unusually wet spring. Some of the closely examined plots had numerous seedlings in close proximity to living and dead cacti. Seed dispersal, for the most part, appears to be over very short distances.

Both subspecies of *Sclerocactus cloverae* are preyed upon by the native stem-boring insect, cactus longhorn beetle (*Moneilema* sp.) and between 25% and 35% of the samples had evidence of beetle impact (Table 10). Many other sclerocacti in the Four Corners region, including the nearby and endangered Mesa Verde cactus (*Sclerocactus mesae-verdae*), are attacked by the longhorn beetle *Moneilema semipunctatum*, which can cause dramatic levels of mortality in cactus populations (Coles et

al. 2012; Roth 2014). Cactus longhorn beetles feed on a variety of cacti as adults and larvae, but mortality of larval host plants is very high in single-stem barrel cacti such as *Sclerocactus* (Woodruff 2010). Female beetles lay an egg at the base of the plant and the larval stages develop inside the body of the cactus. Late instar larvae are relatively large and a single larva can consume most of the interior cortex of a small *Sclerocactus* (Figure 19A). Pupating adult beetles emerge by burrowing out of the cactus, leaving a gaping hole, which usually kills the host by desiccation or infection from bacteria and fungi (Figure 19B). Individual cacti being parasitized by beetle larvae may have chlorotic blotches on their stem (Figure 19A) or, if large enough, may not show symptoms until after the adult beetle has emerged and left a hole in the side of the cactus. When the soft tissue of the dead cactus decays, the interlocking spine clusters form a hollow basket-shaped pile of spines that persist for a year or two and usually indicate a victim of cactus longhorn beetle (Figure 19C).

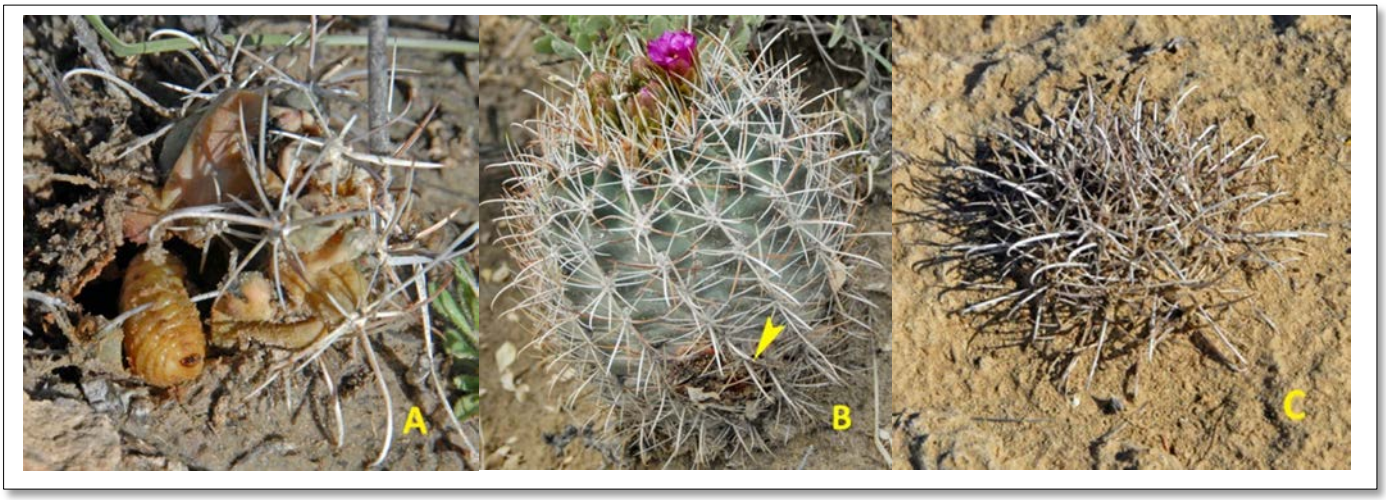


**Figure 19. Photo A shows a small Brack's hardwall cactus west of Lybrook that has been torn open on 7 May 2015 to reveal a large larva of cactus longhorn beetle. Photo B shows a large Brack's hardwall cactus in the same area with a gaping longhorn beetle emergence hole (see arrow). Photo C shows the remnant spine cluster of a dead Clover's hardwall cactus in Largo Canyon that likely was a cactus longhorn beetle victim of the previous year.**

Brack's hardwall cactus were also preyed upon by mammalian herbivores and were likely causalities. Dead and dying individual cacti that had chewed-off stems with only a caudex and scattered spine clusters remaining were frequently encountered during this field survey (Figure 20). Rabbits were assumed to be the primary herbivores responsible because their pellets were sometimes associated with the scattered spine clusters of dead cacti. Severely damaged stems can occasionally produce new stems from surviving tubercles, but most rabbit-damaged cacti will die of desiccation.

The remains of dead cacti were common throughout the populations of Brack's and Clover's hardwall cactus and assumed to be fatalities from the current and previous year. The belt transect count of Brack's in the Lybrook region detected 812 dead plants intermixed among the 2,571 live plants, or 24% of the total plants found both alive and dead. The cause of death could not always be determined, but predation by cactus longhorn beetle and rabbits appeared to be the most frequent agents of natural mortality, with beetle parasitism especially common (Table 10). The number of dead plants detected on the 155 reconnaissance plots across the range of the species was lower at 161 of 1,729 plants or 10% (see Table 7). This is a lower mortality rate that reflects both subspecies across a much larger geographic

range where there may be different local causes and rates of mortality. Overall, rates are comparable to those detected in different episodes for Mesa Verde cactus (Coles et al. 2012; Roth 2014) but lower than those reported recently (2011-13) for *Sclerocactus wrightiae* in Southern Utah (CRNP 2014*). Further studies may help answer why and where the most healthy populations of Brack's exist and determine those that are most at risk.*

**Figure 20. *Sclerocactus cloverae* plants eaten by rabbits. Areoles with spine clusters are chewed off and scattered about the damaged stems.**

**Table 10. Herbivory on Brack's hardwall cactus in 483 belt transect plots in the Lybrook Region and 155 reconnaissance plots with Brack's and Clover's hardwall cacti throughout the Nacimiento Formation in 2015. Most of the herbivore-damaged cacti in these plots had died within the last year.**

| Herbivore Impact | No Herbivore Damage | Cactus Longhorn Beetle Damage | Rabbit Damage | Beetle and Rabbit Damage | Herbivore not Identified |
|---|---|---|---|---|---|
| No. Transect Quads | 268 | 149 | 24 | 25 | 17 |
| Percent of Transect Quads | 55% | 31% | 5% | 5% | 4% |
| No. Recon Plots | 94 | 33 | 14 | 9 | 5 |
| Percent of Recon Plots | 60% | 21% | 9% | 6% | 3% |

# STATUS ASSESSMENT

## Threat Analysis – 5 Factors

### 1. *Present or Threatened Destruction, Modification, or Curtailment of the Species' Habitat or Range*

The prevailing and most destructive land use in the habitats of Brack's hardwall cactus is exploration and development of oil and natural gas. San Juan and Rio Arriba are the largest natural gas-producing counties in New Mexico and also provide a significant portion of the state's oil production (NMEMNRD 2014). Natural gas wells have long been producing from the Nacimiento Formation and the formations directly below the Nacimiento are reservoirs for oil (Engler et al. 2001). New well-field development is currently impacting a large area of the Nacimiento Formation in the Lybrook region (see Figure 24). Engler et al. (2001) predicted construction of 16,615 new wells in the San Juan Basin over a 20-year period (with three acres of associated disturbance/well), but the number of wells within Brack's hardwall cactus habitat will be a much smaller subset. For instance, only 100 wells were predicted to be drilled into the Nacimiento/Ojo Alamo Formation pools during the 20-year period from 2002-2022. The Mancos Formation was anticipated to be much more developed throughout the San Juan Basin, but mostly for natural gas. This prediction apparently did not anticipate the recent development of horizontal fractured oil wells and new pipeline requirements in the Lybrook region. A more recent assessment of reasonably foreseeable Mancos shale oil well production (Engler et al. 2014) identifies the highest potential for development in the Lybrook region – mostly within Brack's hardwall cactus habitats (see Figure 1). This oil pool is expected to support up to five wells per section for a total build-out of 1,600 oil wells and associated infrastructure. Approximately 2,000 additional wells are also anticipated to make natural gas available from the Mancos shale – mostly from the central part of the formation near the Colorado boarder. This could continue to impact the Bloomfield/Aztec region habitats for Brack's cactus, which is an area already densely developed by more traditional vertical wells (Engler et al. 2014).

Gas and oil wells and their associated road and pipeline infrastructure are already established or actively developing throughout all Brack's hardwall cactus habitats, regardless of surface ownership. Direct impacts of gas and oil development are mostly associated with the surface activities of creating well pads and connecting them with broad and extensive networks of pipelines and roads. Most of the currently producing vertical-well oil and gas fields within the range of Brack's hardwall cactus have well spacing of one well per 80 to 160 acres, but could be allowed to in-fill up to a maximum of one well every 40 acres (16/ square mile) if the resource is economical (Engler et al. 2001). Vertical well pads cover about two acres with an additional one acre of disturbance for associated infrastructure (Engler et al. 2001). Therefore, the worst-case oil and gas field development of the Angel Peak, Bloomfield and Aztec habitats would likely destroy about 48 acres per section, or 7.5% of the land surface. Horizontal oil wells such as those currently being constructed in the Lybrook region are not as dense, but the existing well pads are larger (4 to 5.5 acres) and require at least the same amount of infrastructure as a vertical-well oil field. If the anticipated maximum of five wells per section were constructed at 5.5 acres per pad and an equal amount of land impacted by infrastructure, then 55 acres per section, or 8.6% of the land

surface in the Lybrook region could potentially be destroyed. This impact would be reduced if each well pad hosted more than one well.

Well-field pipeline and road alignments often purposely avoid the steep slopes of valley sides and the large drainage channels of valley bottoms, which are not especially good habitats for Brack's hardwall cactus. The best and most densely occupied cactus habitats are the grasslands and open shrublands of valleys and channel margins (see Table 5), which are also preferred areas for pipeline and road placement. Even though the surface disturbance of energy development may ultimately impact less than 10% of the surface area, the percentage of occupied Brack's hardwall cactus habitat impacted by this activity will likely be larger because the cactus and well-field development prefer similar locations.

Plants not directly impacted by energy exploration and development can suffer indirect impacts when in close proximity to roads and pipelines including impacts of dust, chemicals, air pollution, invasive species, and impacts on pollinators (FWS 2014). Fugitive dust from vehicles traveling unpaved roads will settle on nearby plants and can reduce photosynthesis and decrease water-use efficiency (Sharifi et al. 1997). Disturbance may also attract cactus predators, such as rabbits, because of new growth of weedy plant species and emerging new seedlings of forage plants used in reclamation seed mixes. Some impacts can be subtle, e.g., it has been suggested that Brack's hardwall cacti in the Lybrook region that had been pin-flagged during the surveys at the edges of new roads and pipelines might be subject to higher rabbit predation than unmarked cacti far away from surface disturbing activities (Greenlee 2015; Sivinski, unpublished observations).

Roads and pipelines also fragment habitats into smaller pieces and that potentially creates smaller patches of cacti from fewer larger patches. These fragments might not be as stable as the larger undisturbed patches, but the long-term impacts of habitat fragmentation in well fields has not been studied for plants.[4] Distribution of Brack's hardwall cactus is naturally very patchy with distances between patches often exceeding 100 m and some patches containing only a few individuals. Gene flow between patches may be almost entirely mediated by small native bees carrying pollen. Habitat fragmentation by 10 m-wide roads is unlikely to inhibit pollinator movement and cactus gene flow. Seed dispersal for this cactus is generally localized around maternal plants, but occasional longer distance dispersal by ants and cyclonic whirlwinds likely occurs. If ants are important to longer distance seed dispersal a 10 m-wide road could inhibit recolonization of any habitat fragment that has, for some reason, lost its cactus patch. *Further understanding of the mechanisms of dispersal and colonization of Brack's is key to understanding its conservation and management.*

Brack's hardwall cactus cacti in the Kutz-Angel Peak metapopulation have persisted within the intensive development of the Angel Peak oil and gas field over the years, but there has been no monitoring of the population and the overall trend and long-term viability of the populations is unknown. This badland region has been widely impacted by oil and gas wells and crisscrossed with roads and pipelines for

[4] Studies of dune sagebrush lizard habitat in southeastern New Mexico suggest that as well pad density approaches eight per section, the habitat becomes irreparably fragmented and unsuitable for the species (Keetch and Fitzgerald 2013).

several decades. It is a mature well field that is in production mode with almost no detectable change between the 1997 and 2015 aerial images, but future redevelopment of the field with new techniques remains a possibility. Currently, cacti are widely distributed in scattered patches of fragmented habitat. Many adult cacti made fruit in 2015 and a few new seedlings were located during the survey*. The geo-referenced reconnaissance plots established in 2015 can provide the foundation for monitoring trends in this population into the future to assess the indirect impacts of habitat fragmentation and fugitive dust on the remaining population within a developed well field. In addition, a density analysis similar to that conducted in the Lybrook Focal zone in conjunction with GIS assessment of the degree of actual disturbance can provide the necessary information for determining the status of this metapopulation and its importance to sustaining the species as a whole.*

Porter and Prince (2011) identify off-road vehicle (ORV) traffic as an ongoing threat to Brack's hardwall cactus because ORVs run over the cacti and indirectly impact habitat by destruction of nurse plants and fragile soil crusts necessary for germination and establishment, damage or destroy annual and perennial plants leading to soil erosion, cause soil compaction, alter drainage patterns, form and distribute dust, and facilitate the proliferation of weeds. The 2015 survey of both Brack's and Clover's hardwall cactus did find significant amounts of soil disturbance from bicycle and motorized ORV traffic on most BLM lands north of the San Juan River in the regions around Bloomfield, Aztec and La Plata, especially along ridges. ORV impacts to habitats in that region were not as severe as the disturbance caused by roads and pipelines supporting energy development, but were quite noticeable. South of the San Juan River and through the southern part of the Nacimiento Formation no off-road bicycle traffic was observed and there was very little evidence of motorized ORV use. *Overall, habitat degradation from ORV use is a management concern in habitats north of the river, and changes in ORV use to the south should be monitored.*

Livestock grazing can be a threat to rare plant populations for many of the reasons listed above for ORV traffic. Livestock will not eat Brack's hardwall cactus, but these cacti are occasionally stepped on (Figure 21) and long-term livestock grazing can change the structure and function of ecosystems – especially in the arid west (Fleischner 1994). In the Lybrook Focal Zone, 80% of the transect quadrats had evidence of recent use by large grazing animals (Table 10). Domestic horses were the most prevalent type of livestock, at 62% of the plots, while cattle were detected at 30% of cactus plots. No evidence of sheep was detected at any of the cactus plots in this region. The regional reconnaissance plots had a lower incidence (56%) of grazing mostly to the south on Navajo Nation lands and BLM, but the plots further north had limited evidence of recent livestock use. Regardless, these are comparable incidence numbers to that reported for *Sclerocactus wrightiae* in Southern Utah (CRNP 2014) where direct tramping by livestock was considered a significant impact factor*. Accordingly, stocking rates and specifics of grazing management programs should address Brack's impacts in the future to help limit impacts on the species.*

**Table 11. Percentage by type of large-mammal grazing evidence in the reconnaissance plots and transect quadrats occupied by *Sclerocactus cloverae* in 2015. NG = No Grazing; C = Cattle; H = Horse; S = Sheep; D = Mule Deer; E = Elk.**

| Grazer | *n* | NG | C | C, D | C, H | C, H, D | H | H, D | H, E | S | D | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Recon plots | 155 | 43.9 | 22.6 | 1.9 | 3.2 | 0.0 | 19.4 | 0.0 | 0.0 | 1.3 | 7.1 | 0.6 |
| Transect quads | 483 | 20.1 | 14.9 | 1.0 | 13.5 | 0.4 | 45.5 | 2.3 | 0.4 | 0.0 | 1.9 | 0.0 |

**Figure 21. *Sclerocactus cloverae* smashed by horse hoof in the badlands west of Lybrook.**

Disturbed soils are also susceptible to invasive, non-native weeds that compete with native plants and can alter ecological processes, such as seasonal soil moisture available to native plants and the frequency of wildfire (Brooks and Pike 2001; Parkinson et al. 2013). Fortunately, most of the Brack's and Clover's hardwall cactus habitats in 2015 had very little cover of non-native plant species even though the spring and early summer were unusually wet, with frequent rainfall. Common non-native plants associated with Brack's hardwall cactus were Russian thistle (*Salsola tragus*), cheatgrass (*Bromus tectorum*), halogeton (*Halogeton glomeratus*) and curveseed butterwort (*Ceratocephalus testiculatus*). *None of the cactus plots had cover values greater than 25% of these exotic plants and most (81%) lacked them*.

### *2. Overutilization for commercial, recreational, scientific, or educational purposes*

All species in the cactus genus *Sclerocactus*, especially rare taxa, have some commercial value for cactus hobbyists. The number of these hobbyists is difficult to quantify, but several cactus growers and collectors have successful businesses supplying the worldwide demand for horticultural cacti, especially

now in the age of Internet commerce. Illegal take, transport, and offer for sale of *Brack's hardwall cactus* is evident in a few places on the Internet. Hochstätter (http://www.fhnavajo.com/newmexico.html) lists his illegal collections of Brack's hardwall cactus that violate the New Mexico Endangered Plant Species Act and offers seeds for sale. Igor Dráb also lists an illegal 2009 collection of Brack's hardwall cactus (http://ralph.cs.cf.ac.uk/Cacti/locality.php?Locality=Bloomfield) among some other pre-law collections of this rare cactus.

Heil and Porter (1994) identify Kutz Canyon south of Bloomfield as the type locality for subsp. *brackii,* so that location is most likely to be the most desirable illegal collection locality for cactus hobbyists who want unambiguous specimens. Even though the type locality of Brack's hardwall cactus is well known to collectors, cactus number and frequency appeared generally similar in 2015 as other less well-known locations around Bloomfield. Sivinski (unpublished observations) has visited the Kutz Canyon population many times over more than 20 years and has an impression of relatively stable trend for number and frequency of cacti at this type location. Illegal collection appears to be relatively infrequent at this time and Porter and Prince (2011) also predict that "Collection is likely to remain a low-level threat for the foreseeable future." Some cacti may occasionally be taken from other locations of this subspecies – especially where new roads and trails increase public access.

Recent specimen collections for scientific and educational purposes are very infrequent. Ken Heil collected two specimens of Brack's hardwall cactus in 2013 for the herbarium at San Juan College (SEINet 2015) and Sivinski collected two specimens for this 2015 survey, which will be deposited at the University of New Mexico Herbarium.

### *3. Disease or Predation*

No diseases were found in the Brack's hardwall cactus populations studied in 2015 nor are any symptoms of disease published in the literature concerning this plant. Predation by cactus longhorn beetles and rabbits appeared to be the leading agents of natural mortality in both subspecies of *Sclerocactus cloverae* in 2015 (40%), although any mortality from drought could have been misinterpreted as beetle predation (see Cactus Health section above). Porter and Prince (2011) also describe severe population declines from beetle parasitism and identify it as a serious threat to subsp. *brackii*. Woodruff (2010) describes severe reductions of *Sclerocactus* populations in Utah because of cactus longhorn beetle and believes that its impact is a relatively recent phenomenon, starting in the 1960s. Likewise, cactus longhorn beetle infestation of threatened *Sclerocactus mesae-verdae* populations in New Mexico and adjacent Colorado were not noted until the severe drought of 1996-2002 and simultaneous die-off of cacti from native beetle predation. These beetle-induced population crashes of cacti may be relatively new on the Colorado Plateau, or are simply recently being noticed because conservationists began monitoring rare cactus populations in the 1970s when they began to be listed under the federal Endangered Species Act.

Rabbit predation of *Sclerocactus cloverae* was found throughout the range of the 2015 survey and in various transplant locations (Ecosphere 2015; Greenlee 2015; Roth 2015). Very little fresh predation was observed and most of the remains appeared to have occurred several months previous. Moderate

to severe drought had gripped this region for the previous four years and was just breaking in 2015 (Western Regional Climate Center 2015). Cactus predation by rabbits and rodents is more severe during dry periods when other green forage is less available (Sivinski, unpublished observations).

### *4. The inadequacy of existing regulatory mechanisms*

The BLM listed Brack's hardwall cactus as a Sensitive Species in the Farmington District Resource Management Plan in 2003 (BLM 2003). The BLM Special Status Species Management Manual (BLM 2008) instructs managers to avoid actions that could cause a sensitive species to become listed as threatened or endangered under the ESA. This written policy, however, has not prevented the destruction of hundreds or thousands of Brack's hardwall cactus in the recent construction of the Lybrook oil and gas well field. BLM has required transplantation of as few as 25% of these Special Status cacti when they are in the path of development (Ecosphere 2015) and NM State Land Office has required transplanting 100% Brack's hardwall cactus as mitigation (Greenlee 2015). Data is still limited on the efficacy of transplanting these cacti. Ecosphere (2015a) reported a survivor rate from only 6.7% up to 66.8% depending on location. Others have also reported poor rates of cactus survival (Greenlee 2015; Roth 2015). No special management areas exist on BLM-Farmington District for the protection of Brack's hardwall cactus. BLM did have an Area of Critical Environmental Concern (ACEC) for the Aztec gilia (*Aliciella formosa*) just east and south of Aztec which also contained part of the Brack's hardwall cactus population of that area. This ACEC was abandoned and discontinued when Aztec gilia was located in some additional areas that seemed less threatened by energy development (BLM 2003).

The Navajo Nation includes Brack's hardwall cactus in Group 4 of its endangered species list, which is a group of plants the Navajo Nation monitors for new information that might support their listing as threatened or endangered. Yet the Navajo Nation does not require botanical consultants to look for Brack's hardwall cactus prior to constructing roads or energy development projects within the habitats of this rare cactus (Andrea Hazelton, Navajo Nation Botanist, personal communication).

Brack's hardwall cactus was listed as endangered under the New Mexico Endangered Plant Species Act (Section 75-6-1 NMSA 1978) in 1995 (NMAC 19.21.2). This law only protects state endangered plants from unauthorized collection from their natural habitats. State endangered plants are not protected from other types of destruction and their habitats are not protected. The greatest benefit to the species being listed as state endangered is the public education opportunities and notoriety gained from endangered status. State, federal and tribal land management agencies may acknowledge this special status, but also have the option of ignoring it.

### *5. Other natural or manmade factors affecting its continued existence*

The 2015 Brack's hardwall cactus survey immediately followed four consecutive years of moderate to severe drought (Western Regional Climate Center 2015). This cactus has survived much longer droughts in recent millennia (Grissino-Mayer et al. 1997). Future droughts, however, will be coincident with higher temperatures (Woodhouse et al. 2010), which may be more lethal. This rare plant has remarkable tolerance to drought, but a climate changing towards drier conditions with higher temperatures could become a serious threat to the survival of this rare cactus. A NatureServe analysis of climate change vulnerability of several plant taxa on BLM lands found *S. cloverae* (*Sclerocactus whipplei* of authors) and

nearby *Sclerocactus parviflorus* and *Sclerocactus mesae-verdae* to be only moderately vulnerable to climate change (Treher et al. 2012). Subspecies *brackii*, however, often occurs in shaley/mudstone badlands while subspecies *cloverae* is more often associated with sandier soils. Munson et al. (2011) monitored vegetation on various soil types of the Colorado Plateau and found that *Atriplex* species on clayey/silty soils lost more canopy cover over a 20-year period than other shrub communities on sandier soils, indicating deeper soil moisture reserves on sandy substrates during drought than are available to shallow-rooted *Atriplex* on less permeable clay soils. Brack's hardwall cactus often occurs on clayey/silty soils with *Atriplex confertifolia* and *Atriplex obovata*, which may indicate a greater vulnerability to climate change. Its few populations are already relatively localized. *Further shrinkage of habitat patches into smaller microclimates of suitable soil or exposure may eventually reduce population sizes towards a level of unviability.*

## Conservation Status Rank

Based on the population analyses, the delineations of occurrences and the threat analysis, we conducted a review of NHNM state conservation rank using the NatureServe rank calculator. The previous NHNM state rank was S1 (Critically imperiled). The NatureServe national rank of T1 follows suit since the subspecies is mostly restricted to New Mexico where it was documented from only a few occurrences in the Aztec/Bloomfield area. The subspecies was last ranked in 1997 before the advent of the rank calculator process and associated spreadsheet, which provides a uniform and consistent approach to evaluating the status of a species based on a suite of weighted rarity, threats, and trend variables. For additional details see the rank calculator for this subspecies provided in the digital addendum.

As a result of this study and additional data received since the 1995 ranking, the current rank for Brack's hardwall cactus was moved from S1 (Critically Imperiled) to S2 (Imperiled). This rank is driven primarily by numbers of plants, our understanding short term trends and known treats. With respect to numbers, the S2 reflects the relatively high numbers of plants known from the Lybrook metapopulation, but is limited by the relatively few large occurrences range wide (particularly those considered predominantly Brack's versus Indeterminate; see Table 5). That is, beyond the Lybrook metapopulation, numbers are uncertain particularly in Kutz-Aztec Peak metapopulation, the other core population center for the species. In addition, the plants known from the Lybrook metapopulation are at immediate risk because they were mostly located as part of clearance surveys for energy development. The expectation is that in the short term these plants will be significantly impacted, and ongoing oil and gas development in the Lybrook area presents a significant threat that could lead to an ongoing downward trend for this core population. This could be further accelerated because individuals are highly clustered within suitable habitats and hence when a local population is disturbed the impacts can be out of proportion to the overall density of the species, particularly given the suitable and occupied habitats are most often where development is happening (careful avoidance planning can help mitigate this impact). There are also the indirect impacts of fragmentation by roads and pipelines spoken to above that can put the species further at risk. Climate and herbivory impacts and their interaction will likely play a role as well in population dynamics if recent trends in other *Sclerocactus* sp. (Coles et al. 2012; Roth 2014) are representative, and this has been considered in the rank as well.

Given the limited number of high-quality local populations and metapopulations, the already high human footprint in suitable habitat in the Lybrook Focal Zone (and elsewhere) and the expectation of significant further development and fragmentation, coupled with potential climate, herbivory, and livestock trampling impacts, an S2 (Imperiled) rank is clearly supported. An S2 rank (and by extension a Global rank of G2), still represents significant imperilment. While S1/G1s commonly listed as federal Endangered or Threatened species, several S2s, and even S3s have also found their way to the Federal list (Figure 22). *Accordingly, the S2 rank should serve as a useful guideline to developing management guidelines to avoid future federal listing.*

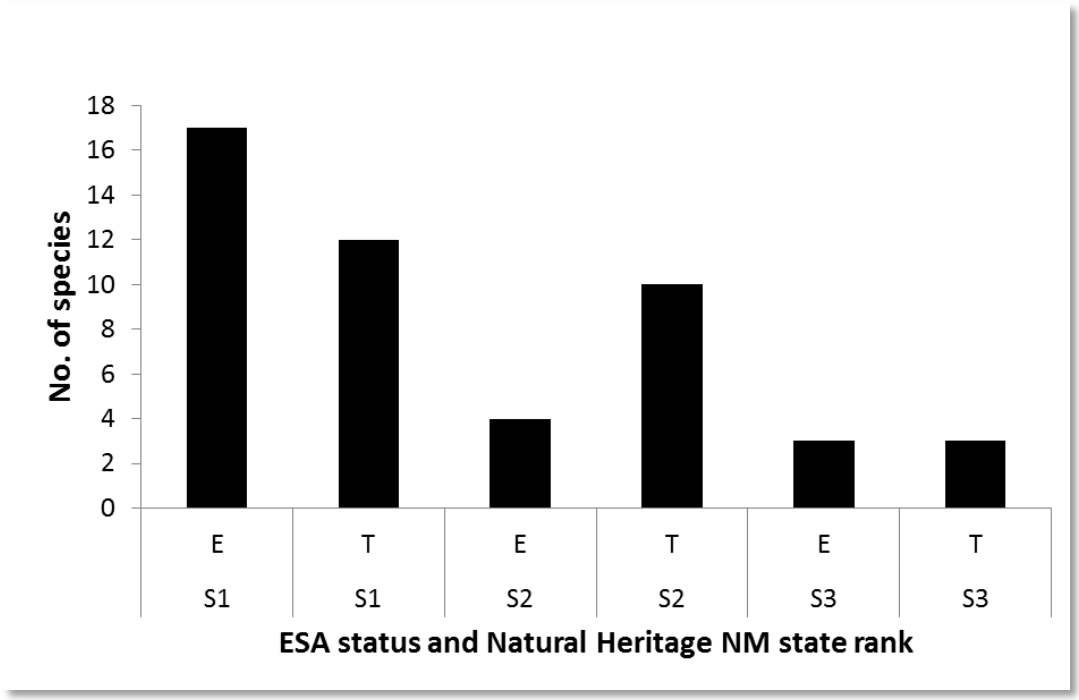


**Figure 22. The relationship between NHNM state conservation status ranks (S1-S5) and federal status (E -Endangered or T – Threatened) for species that have been ranked in the last 10 years.**

## Reducing threats and conservation opportunities

While Brack's hardwall cactus remains a species at risk under current BLM management guidance, there are potentially viable options for reducing threats that can also accommodate the primary threat of oil and gas development. For example, the spatial clustering and habitat specifics of the subspecies that we have described here offer a cost-efficient opportunity for impact avoidance through careful planning of roads, well pads, and pipeline installations. Much of the current development is happening in areas that also contain the higher ranked suitable habitats for the species, but there are adjacent habitats such as dense sagebrush shrublands where the species is not found and where small design changes can be implemented to avoid the most significant impacts on clustered populations. This may be most efficiently accomplished via the development of a habitat maps based on the classification provided here, which then can be brought into the development planning process in early stages--the key to determining cost-effective alternatives. In addition, using habitat maps, surveys can more efficiently detect areas at broader scales that are not occupied and thereby lower overall risks (there are

indications there may be some relatively large areas with suitable habitat but where cacti occupancy is low).

Conversely, there are likely areas where oil and gas potential may be limited but the subspecies is present. These offer opportunities as conservation areas (Figure 23). As an example, we provisionally outlined a set of ten Conservation Opportunity Areas (COAs) in the Lybrook Focal Zone that meet the joint criteria of supporting the cacti while lying currently outside of the mainstream of oil and gas development based on the current impact areas (Figure 24). While it was beyond the scope of this project*, COAs should be identified throughout the range of the species to avoid a concentration of conservation activities in one particular place, particularly with respect to issues beyond oil and gas development.* For example, there are concerns that a warming, drying climate may favor increased beetle predation (Coles et al. 2012) or have a direct impact on cactus mortality (Shyrock et al. 2014), and increase the overall downward trend in cacti species globally (McGough et al. In press). *A COA network, if carefully planned to account for the range of genetic diversity and that captures significant subpopulations, may help buffer and mitigate against these impacts to ensure the long-term sustainability of the species.*

The results of this study, including the habitat analysis and potential COAs, should be the foundation for the development of a conservation plan. *A conservation plan will provide guidance to land managers and project planning to ensure the protection of the species from this and other threats over the long term, while minimizing conflicts arising from inadequate planning.*

**Figure 23. An example of Potential Conservation Area (PCA) with Brack's habitat, which has yet to be developed for oil and gas.**

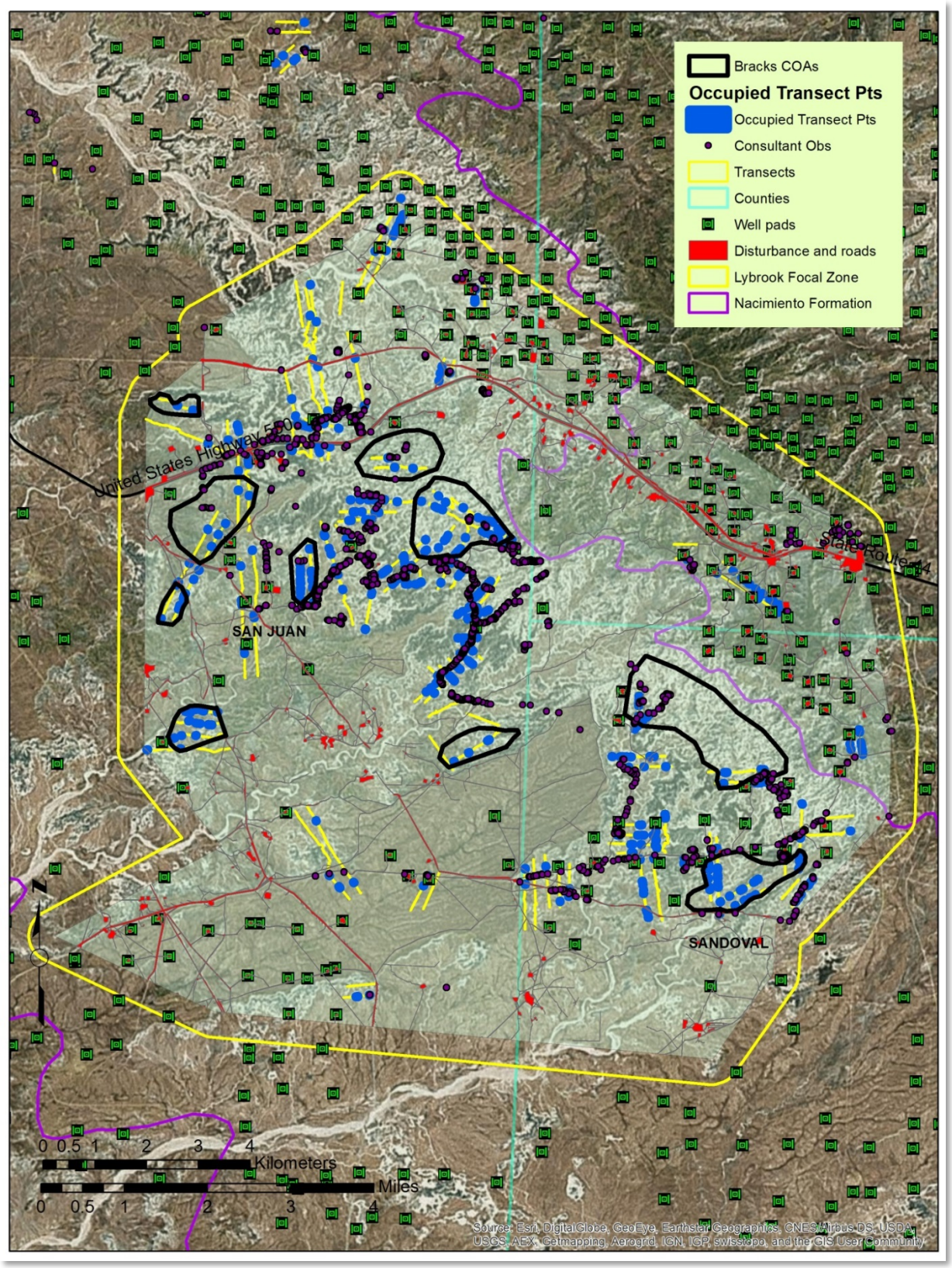


Figure 24. Conservation Opportunity Areas (COAs) for Brack's hardwall cactus in the Lybrook Focal Zone.

# DISCUSSION

The 2015 NHNM survey of the distribution and habitat of Brack's hardwall cactus (*Sclerocactus cloverae* subsp. *brackii*) represents the most comprehensive analysis to date, but much remains to be understood about the species. The range-wide reconnaissance survey more or less set the range limits of potential habitat for Brack's and help identify six metapopulations and 52 local populations, but it also yielded significant variation within and among taxons. More work is need on the systematics of the species with an emphasis getting a genetic underpinning that may separate the subspecies. The habitat analysis presented here was able to differentiate and rank in importance 19 suitable habitats, but it was based on data from belt transects anchored on known cactus locations and aerial photo interpretation. *While this provided a good initial understanding of the relative abundance of cacti among habitats and their extent, subsequent validation is needed using randomized sampling points to generate unbiased estimates of plant densities by habitat.*

*Brack's hardwall cactus remains a species at risk*. Based on the 2015 survey data and legacy observation data, and analysis of trends and threats, a conservation state status rank S2 (Imperiled) was assigned to the species using the NatureServe rank calculator. There is a high need for future monitoring of population trends of the subspecies across its range to further validate this ranking. In the meantime, there are opportunities for conservation and resource planning that have potential for alleviating conflict and avoiding further impacts on the species.

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**Appendix A**. List of plant species occurring on the belt transects in the Lybrook Focal Zone Survey.

| Lifeform | Scientific Name | Common Name | Family | NHNM Symbol | USDA Symbol | Count of Plots |
|---|---|---|---|---|---|---|
| Trees | | | | | | |
| | Juniperus monosperma | oneseed juniper | Cupressaceae | JUNMON | JUMO | 7 |
| | Juniperus osteosperma | Little Utah juniper | Cupressaceae | JUNOST | JUOS | 122 |
| | Pinus edulis | pinyon pine | Pinaceae | PINEDU | PIED | 85 |
| | Tamarix chinensis | saltcedar | Tamaricaceae | TAMCHI | TACH2 | 1 |
| Shrubs | | | | | | |
| | Amelanchier utahensis | Utah serviceberry | Rosaceae | AMEUTA | AMUT | 1 |
| | Artemisia nova | black sagebrush | Asteraceae | ARTNOV | ARNO4 | 141 |
| | Artemisia tridentata | big sagebrush | Asteraceae | ARTTRI | ARTR2 | 320 |
| | Atriplex confertifolia | shadscale saltbush | Chenopodiaceae | ATRCON | ATCO | 234 |
| | Atriplex spp. | saltbush | Chenopodiaceae | ATRIPL | ATRIP | 1 |
| | Cercocarpus montanus | mountain mahogany | Rosaceae | CERMON | CEMO2 | 17 |
| | Cylindropuntia whipplei | Whipple cholla | Cactaceae | CYLWHI | CYWH | 5 |
| | Ephedra cutleri | Cutler's jointfir | Ephedraceae | EPHCUT | EPCU | 1 |
| | Ephedra torreyana | Torrey's jointfir | Ephedraceae | EPHTOR | EPTO | 55 |
| | Ephedra viridis | mormon tea | Ephedraceae | EPHVIR | EPVI | 3 |
| | Ericameria nauseosa | rubber rabbitbrush | Asteraceae | ERINAU | ERNA10 | 218 |
| | Ericameria parryi | Parry's rabbitbrush | Asteraceae | ERIPAR | ERPA30 | 3 |
| | Eriogonum corymbosum | crispleaf buckwheat | Polygonaceae | ERICOR | ERCO14 | 1 |
| | Eriogonum microthecum | slender buckwheat | Polygonaceae | ERIMIC | ERMI4 | 71 |
| | Fendlera rupicola | cliff fendlerbrush | Hydrangeaceae | FENRUP | FERU | 1 |
| | Purshia tridentata | antelope bitterbrush | Rosaceae | PURTRI | PUTR2 | 40 |
| | Sarcobatus vermiculatus | greasewood | Chenopodiaceae | SARVER | SAVE4 | 93 |
| | Yucca baileyi | Navajo yucca | Agavaceae | YUCBAI | YUBA2 | 55 |
| Sub-shrubs | | | | | | |
| | Artemisia bigelovii | Bigelow's sagebrush | Asteraceae | ARTBIG | ARBI3 | 8 |
| | Artemisia frigida | fringed sagewort | Asteraceae | ARTFRI | ARFR4 | 2 |
| | Artemisia pygmaea | pygmy sagebrush | Asteraceae | ARTPYG | ARPY2 | 10 |
| | Atriplex obovata | mound saltbush | Chenopodiaceae | ATROBO | ATOB | 48 |
| | Brickellia oblongifolia | Mojave brickellbush | Asteraceae | BRIOBL | BROB | 1 |
| | Chrysothamnus depressus | longflower rabbitbrush | Asteraceae | CHRDEP | CHDE2 | 17 |
| | Chrysothamnus greenei | Greene's rabbitbrush | Asteraceae | CHRGRE | CHGR6 | 120 |
| | Gutierrezia sarothrae | broom snakeweed | Asteraceae | GUTSAR | GUSA2 | 219 |
| | Isocoma pluriflora | southern jimmyweed | Asteraceae | ISOPLU | ISPL | 1 |
| | Isocoma rusbyi | Rusby's goldenbush | Asteraceae | ISORUS | ISRU2 | 2 |
| | Opuntia fragilis | brittle pricklypear | Cactaceae | OPUFRA | OPFR | 9 |
| | Opuntia phaeacantha | tulip pricklypear | Cactaceae | OPUPHA | OPPH | 6 |
| | Opuntia polyacantha | plains pricklypear | Cactaceae | OPUPOL | OPPO | 73 |
| | Picrothamnus desertorum | bud sagebrush | Asteraceae | PICDES | PIDE4 | 69 |
| | Zuckia brandegeei | siltbush | Chenopodiaceae | ZUCBRA | ZUBR | 3 |
| Graminoides | | | | | | |
| | Achnatherum hymenoides | Indian ricegrass | Poaceae | ACHHYM | ACHY | 101 |
| | Aristida purpurea | purple threeawn | Poaceae | ARIPUR | ARPU9 | 11 |
| | Bouteloua curtipendula | sideoats grama | Poaceae | BOUCUR | BOCU | 1 |
| | Bouteloua gracilis | blue grama | Poaceae | BOUGRA | BOGR2 | 436 |
| | Bromus tectorum | cheatgrass | Poaceae | BROTEC | BRTE | 56 |
| | Elymus elymoides | bottlebrush squirreltail | Poaceae | ELYELY | ELEL5 | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Erioneuron pulchellum | fluffgrass | Poaceae | ERIPUL | ERPU8 | 26 |
| | Hesperostipa comata | needle-and-thread grass | Poaceae | HESCOM | HECO26 | 126 |
| | Hesperostipa neomexicana | New Mexico needlegrass | Poaceae | HESNEO | HENE5 | 8 |
| | Hordeum jubatum | foxtail barley | Poaceae | HORJUB | HOJU | 8 |
| | Muhlenbergia pungens | sandhill muhly | Poaceae | MUHPUN | MUPU2 | 8 |
| | Pascopyrum smithii | western wheatgrass | Poaceae | PASSMI | PASM | 1 |
| | Pleuraphis jamesii | galleta | Poaceae | PLEJAM | PLJA | 554 |
| | Poa fendleriana | muttongrass | Poaceae | POAFEN | POFE | 2 |
| | Poa pratensis | Kentucky bluegrass | Poaceae | POAPRA | POPR | 1 |
| | Poa secunda | Sandberg bluegrass | Poaceae | POASEC | POSE | 8 |
| | Sporobolus airoides | alkali sacaton | Poaceae | SPOAIR | SPAI | 266 |
| | Sporobolus cryptandrus | sand dropseed | Poaceae | SPOCRY | SPCR | 5 |
| | Sporobolus nealleyi | gyp dropseed | Poaceae | SPONEA | SPNE | 1 |
| Forbs | | | | | | |
| | Abronia elliptica | fragrant white sand verbena | Nyctaginaceae | ABRELL | ABEL | 1 |
| | Abronia fragrans | snowball sand verbena | Nyctaginaceae | ABRFRA | ABFR2 | 1 |
| | Aliciella formosa | Aztec gilia | Polemoniaceae | ALIFOR | ALFO3 | 2 |
| | Allium macropetalum | largeflower wild onion | Liliaceae | ALLMAC | ALMA4 | 21 |
| | Arenaria eastwoodiae | Eastwood's sandwort | Caryophyllaceae | AREEAS | AREA | 8 |
| | Astragalus flavus | yellow milkvetch | Fabaceae | ASTFLA | ASFL | 31 |
| | Astragalus missouriensis | Missouri milkvetch | Fabaceae | ASTMIS | ASMI10 | 10 |
| | Astragalus mollissimus | woolly milkvetch | Fabaceae | ASTMOL | ASMO7 | 1 |
| | Astragalus newberryi | Newberry's milkvetch | Fabaceae | ASTNEW | ASNE6 | 1 |
| | Astragalus praelongus | stinking milkvetch | Fabaceae | ASTPRA | ASPR5 | 2 |
| | Astragalus proximus | Aztec milkvetch | Fabaceae | ASTPRO | ASPR8 | 4 |
| | Boechera stricta | Drummond's rockcress | Brassicaceae | BOESTR | ARDR | 1 |
| | Calochortus nuttallii | sego lily | Liliaceae | CALNUT | CANU3 | 13 |
| | Castilleja angustifolia | northwestern Indian paintbrush | Scrophulariaceae | CASANG | CAAN7 | 7 |
| | Castilleja rhexiifolia | Indianpaintbrush | Scrophulariaceae | CASRHE | CARH4 | 1 |
| | Ceratocephala testiculata | curveseed butterwort | Ranunculaceae | CERTES | CETE5 | 9 |
| | Chaetopappa ericoides | rose heath | Asteraceae | CHAERI | CHER2 | 6 |
| | Comandra umbellata | bastard toadflax | Santalaceae | COMUMB | COUM | 2 |
| | Cordylanthus wrightii | Wright's birdbeak | Scrophulariaceae | CORWRI | COWR2 | 2 |
| | Cryptantha flava | Brenda's yellow cryptantha | Boraginaceae | CRYFLA | CRFL5 | 13 |
| | Cryptantha fulvocanescens | tawny cryptantha | Boraginaceae | CRYFUL | CRFU | 24 |
| | Cymopterus acaulis | plains springparsley | Apiaceae | CYMACA | CYAC | 1 |
| | Cymopterus constancei | Constance's springparsley | Apiaceae | CYMCON | CYCO22 | 36 |
| | Cymopterus purpurascens | widewing springparsley | Apiaceae | CYMPUR | CYPU | 5 |
| | Cymopterus spp. | springparsley | Apiaceae | CYMOPT | CYMOP2 | 2 |
| | Delphinium scaposum | tall mountain larkspur | Ranunculaceae | DELSCA | DESC | 30 |
| | Descurainia pinnata | western tanseymustard | Brassicaceae | DESPIN | DEPI | 5 |
| | Erigeron concinnus | Navajo fleabane | Asteraceae | ERICON | ERCO27 | 4 |
| | Erigeron utahensis | Utah fleabane | Asteraceae | ERIUTA | ERUT | 2 |
| | Eriogonum alatum | winged buckwheat | Polygonaceae | ERIALA | ERAL4 | 1 |
| | Eriogonum hieraciifolium | hawkweed buckwheat | Polygonaceae | ERIHIE | ERHI3 | 1 |
| | Eriogonum jamesii | James' buckwheat | Polygonaceae | ERIJAM | ERJA | 2 |
| | Eriogonum polycladon | sorrel buckwheat | Polygonaceae | ERIPOL | ERPO4 | 1 |

| | Eriogonum shockleyi | Shockley's buckwheat | Polygonaceae | ERISHO | ERSH | 1 |
|---|---|---|---|---|---|---|
| | Eriogonum spp. | buckwheat | Polygonaceae | ERIOGO | ERIOG | 2 |
| | Erodium cicutarium | redstem stork's bill | Geraniaceae | EROCIC | ERCI6 | 1 |

| Lifeform | Scientific Name | Common Name | Family | NHNM Symbol | USDA Symbol | Count of Plots |
|---|---|---|---|---|---|---|
| | Frasera albomarginata | desert frasera | Gentianaceae | FRAALB | FRAL5 | 1 |
| | Gaura parviflora | velvetweed | Onagraceae | GAUPAR | GAPA6 | 1 |
| | Halogeton glomeratus | saltlover | Chenopodiaceae | HALGLO | HAGL | 22 |
| | Heterotheca villosa | hairy goldenaster | Asteraceae | HETVIL | HEVI4 | 5 |
| | Hymenopappus filifolius | fineleaf hymenopappus | Asteraceae | HYMFIL | HYFI | 3 |
| | Hymenoxys richardsonii | pingue hymenoxys | Asteraceae | HYMRIC | HYRI | 1 |
| | Krameria lanceolata | trailing krameria | Krameriaceae | KRALAN | KRLA | 5 |
| | Lappula occidentalis | flatspine stickseed | Boraginaceae | LAPOCC | LAOC3 | 2 |
| | Lepidium virginicum | Virginia pepperweed | Brassicaceae | LEPVIR | LEVI3 | 1 |
| | Linanthus pungens | granite prickly phlox | Polemoniaceae | LINPUN | LIPU11 | 33 |
| | Lupinus brevicaulis | lupine | Fabaceae | LUPBRE | LUBR2 | 40 |
| | Mentzelia albicaulis | whitestem blazingstar | Loasaceae | MENALB | MEAL6 | 1 |
| | Mentzelia sivinskii | Sivinski's Blazingstar | Loasaceae | MENSIV | | 1 |
| | Monolepis nuttalliana | Nuttall's povertyweed | Chenopodiaceae | MONNUT | MONU | 1 |
| | Oenothera caespitosa | tufted eveningprimrose | Onagraceae | OENCAE | OECA10 | 2 |
| | Orobanche fasciculata | clustered broomrape | Orobanchaceae | OROFAS | ORFA | 1 |
| | Oxytropis lambertii | purple locoweed | Fabaceae | OXYLAM | OXLA3 | 2 |
| | Petradoria pumila | rock goldenrod | Asteraceae | PETPUM | PEPU7 | 96 |
| | Phacelia spp. | phacelia | Hydrophyllaceae | PHACEL | PHACE | 1 |
| | Phlox hoodii | spiny phlox | Polemoniaceae | PHLHOO | PHHO | 17 |
| | Physalis longifolia | longleaf groundcherry | Solanaceae | PHYLON | PHLO4 | 1 |
| | Plantago patagonica | woolly plantain | Plantaginaceae | PLAPAT | PLPA2 | 8 |
| | Platyschkuhria integrifolia | basindaisy | Asteraceae | PLAINT | PLIN7 | 48 |
| | Ranunculus spp. | buttercup | Ranunculaceae | RANUNC | RANUN | 1 |
| | Salsola tragus | prickly Russian thistle | Chenopodiaceae | SALTRA | SATR12 | 59 |
| | Schkuhria pinnata | pinnate false threadleaf | Asteraceae | SCHPIN | SCPI3 | 2 |
| | Sphaeralcea coccinea | scarlet globemallow | Malvaceae | SPHCOC | SPCO | 2 |
| | Sphaeralcea grossulariifolia | gooseberryleaf globemallow | Malvaceae | SPHGRO | SPGR2 | 15 |
| | Stanleya pinnata | desert princesplume | Brassicaceae | STAPIN | STPI | 1 |
| | Stenogonum salsuginosum | salty buckwheat | Polygonaceae | STESAL2 | STSA3 | 10 |
| | Stenotus armerioides | thrift mock goldenweed | Asteraceae | STEARM | STAR10 | 4 |
| | Tetraneuris ivesiana | Ives' fournerved daisy | Asteraceae | TETIVE | TEIV | 33 |
| | Townsendia annua | annual townsend daisy | Asteraceae | TOWANN | TOAN | 1 |
| | Townsendia incana | hoary Townsend daisy | Asteraceae | TOWINC | TOIN | 11 |
| | unidentified forb | unidentified forb | unknown | UNIDF | 2FORB | 1 |
| | unidentified spp. | unidentified plant | | UNID | 2PLANT | 1 |
| | Xanthisma grindelioides | rayless tansyaster | Asteraceae | XANGRI | MAGR2 | 7 |
| | Xanthisma spinulosum | lacy tansyaster | Asteraceae | XANSPI2 | MAPI | 4 |