Survival and plant vigor of *Sclerocactus parviflorus* (Clover and Jotter) following different transplanting techniques

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Mitigating the presence of cacti growing within the rights-of-way of pipelines or roads can be accomplished by transplanting these individuals. The current procedure used in transplanting cacti has little scientific basis and is the culmination of experience and opinion of numerous botanists and landscape architects. An example of this conventional method is given in the Biological Opinion regarding *Coryphantha scheeri* (Pima pineapple cactus) (Brabander 1998). The procedure was to (1) excavate the cactus to a depth of 15 to 20 cm, (2) prune small and damaged roots, (3) dust cut roots with sulfur, (4) harden off cacti by placing them in a shady and airy location for at least 10 days, (5) transplant so as to maintain the original solar orientation before excavation, and (6) avoid transplanting during flowering and fruit production. Several reports have been written documenting the results of transplanting *Sclerocactus parviflorus* with high long-term survival can be done by any of these procedures, at any time of year, and with or without an associated nurse plant.

**ABSTRACT.**—Cacti are transplanted when their occurrence conflicts with road and pipeline construction and mitigation requires relocation, or they are transplanted for personal use. Methods used in transplanting have credence by virtue of common practice; however, there are few scientific studies comparing different methods. Our objective was to determine if different transplanting techniques, time of year of transplanting, and association with a nurse plant upon transplanting affected the long-term survival (8 years) and vigor of *Sclerocactus parviflorus* (Clover and Jotter). The 3 transplanting procedures were as follows: (1) cacti excavated, soil removed from roots, roots trimmed, plants placed in shaded open environment for 2 days and then transplanted (modification of conventional procedure); (2) cacti excavated to maintain a root ball and transplanted within 2 hours; and (3) cacti excavated, soil shaken off the roots and transplanted within 2 hours. Mortality was documented every spring and fall for 8 years. Plant vigor was determined in the eighth year by measuring flower and tubercle production. There was no difference in cactus survival among the 3 transplanting techniques, time of year of transplanting, and association with a nurse plant. There was no difference in vigor among the treatments as measured by flower and tubercle production. Three years after transplanting, 97% of the cacti were alive, and after 8 years 84% were alive. Based on this study, transplanting of *S. parviflorus* with high long-term survival can be done by any of these procedures, at any time of year, and with or without an associated nurse plant.

**RESUMEN.**—Los cactus son trasplantados cuando su presencia está en conflicto con la construcción de carreteras o ductos y el alivio requiere el traslad o para uso personal. A los métodos empleados en el trasplante se le dan crédito en virtud de prácticas comunes; sin embargo, existen pocos estudios científicos que comparan los distintos métodos. Nuestro objetivo fue determinar si varios métodos de trasplante, la época del año del trasplante, y la asociación con la planta contraindicada al efectuar el trasplante impactaban la supervivencia a largo plazo (8 años) y el vigor de *Sclerocactus parviflorus* (Clover y Jotter). Los tres procedimientos de trasplante eran 1- La excavación del cactus, la tierra sacada de las raíces, las raíces recortadas, las plantas colocadas dentro de un ambiente abierto y en sombra durante dos días entonces trasplantada (modificación del método convencional); 2- El cactus es excavado para mantener un cepellón y trasplantado dentro de dos horas; 3- El cactus excavado, la tierra sacudida de sus raíces y trasplantado dentro de dos horas. La mortalidad fue documentada cada primavera y otoño durante ocho años. El vigor de la planta fue determinado que octavo año al medir la producción de la flor y del tubérculo. No hubo diferencia en la supervivencia del cactus entre las tres técnicas de trasplante, la época del año del trasplante, y la asociación con la planta contraindicada. No hubo diferencia de vigor entre los tratamientos según las mediciones de la producción de flores y tubérculos. Tres años después del trasplante, 97% de los cactus estaban vivos y 84% estaban vivos después de ocho años. Basado en esta investigación, el trasplante de *S. parviflorus* puede efectuarse siguiendo cualquiera de estos procedimientos, cualquier época del año, y con o sin una planta contraindicada con el resultado de supervivencia a largo plazo.
and dipped in dilute Clorox solution, cacti were stored in a greenhouse for 2 weeks to allow the roots to harden off, and then cacti were transplanted. There is no comment in these studies as to whether solar orientation was maintained.

The above reports incorporate a hardening-off period which consists of placing the cactus in a shady, open environment, such as a greenhouse, for 7–14 days. During this time a callus, an undifferentiated mass of cells, forms on the cut root surfaces. This structure prevents water loss from the cut surface and inhibits pathogens from entering the plant. However, there are very few scientific reports documenting the advantage of hardening off in cacti. The requirement to harden off the roots of cacti during transplanting appears to be a common practice that has become accepted over the years but may have little scientific basis.

Survival of transplanted cacti could also depend on when the transplanting is conducted. Time of year reflects the phenological state of the cactus and possibly carbohydrate reserves. Strong correlations between plant carbohydrate levels and phenological status have been documented for several range species, including 2 Opuntia species (Menke and Trlica 1981, Daer and Willard 1981). These reserves can fluctuate throughout the year as carbohydrates are used in flower, seed, and tubercle production in the spring and early summer; are replenished during summer; are used for additional tubercle production in the fall; and remain relatively stable during winter dormancy. Brabander (1998) recommended that transplanting [of Coryphantha scheeri] not be done from 15 June to 1 November to avoid disturbing cacti that are actively flowering and producing fruit. However, relocation is usually governed by the timeline of the construction project.

Transplanting with an associated nurse plant is a third variable to consider. Nurse plants can increase the survival of desert species by enhancing levels of soil water content (Joffre and Rambal 1993) and attenuating temperature extremes (Valiente-Banuet and Ezcurra 1991). The study by Carrillo-Garcia et al. (1999) in the Sonoran Desert demonstrated an increase in the presence of mycorrhizae under nurse plants which contributed to plant health and growth. Atriplex confertifolia (shadscale), the dominate shrub at the relocation site, is known to have mycorrhizal associations (Miller et al. 1983), and members of the Cactaceae family also have mycorrhizal associations (Bethlenfalvay et al. 1984). The potential mutualistic association between the nurse plant, A. confertifolia, and S. parviflorus could positively affect transplant survival.

The corresponding author was involved in mitigating the occurrence of Sclerocactus glaucus Colorado hookless cactus [J.A. Purpus ex K. Schum.] L.D. Benson (currently a Threatened species) along a proposed natural gas pipeline in the spring and early summer of 1998. Over 1000 individual cacti were transplanted to approximately 30 relocation sites in Mesa, Delta, and Montrose Counties, Colorado. In this situation (1) a root ball was excavated around each plant 10–17 cm in diameter and 8–10 cm deep (rocks impeding the excavation had to be considered in obtaining a reasonable root ball), (2) cacti were then placed in a small plastic bucket, and (3) plants were moved to the relocation site and planted within 2 hours. In the spring of 1999, 5 relocation sites were selected to monitor cacti health and survival. The results showed 87% survival after 3 years (Eric Rechel personal communication). No roots were trimmed, no Clorox or sulfur were applied to the roots, no hardening-off period was attempted, and no consideration was given to solar orientation.

Because S. glaucus is on the threatened species list we chose S. parviflorus for this study. Our objectives were to determine the long-term survival and vigor of S. parviflorus when transplanted (1) by the conventional method, as described above, compared to procedures where there is less manipulation of the cacti; (2) in 4 different seasons; and (3) in association with or without a nurse plant.

**Methods**

*Sclerocactus parviflorus* (Clover and Jotter) is one of 13 species within the genus *Sclerocactus*. The plant stem is globose, cylindroid, 5–27 cm in height and 4.5–13 cm in diameter; central spine hooked; flowers apical, 3–5.7 cm long and 2.5–5.5 cm in diameter; and inner tepals rose, pink, yellow, or purple in color (Fig. 1). A full taxonomic description has been given by Heil and Porter (1994). We used *S. parviflorus* because (1) it is not on the Threatened and Endangered list, (2) it has habitat and natural history similar to *S. glaucus*, and (3) it is locally abundant in Mesa County of western Colorado.
Our study site was in western Colorado approximately 32.8 km due west of Grand Junction, and 2.8 km east of the Utah state line at 39°12′ N, 108°05′ W at an elevation of 1472 m (Fig. 2). Topographically the site is ovoid in shape and composed of 3 flat-topped benches rising approximately 30 m above the surrounding landscape. The site is classified as a sandy salt desert ecosystem dominated by Hilaria jamesii, A. confertifolia, Juniperus spp., and Oryzopsis spp. The soil is of the Avalon-Mack-Skumpah series with a taxonomic description of loamy, mixed, active, calcareous, mesic, shallow Typic Torriorthents. Annual precipitation averages 22 cm per year.

In April 2003, 120 S. parviflorus cacti, designated for use in the experiment, were located within the study site. These plants were at least 4 cm in diameter and 4 cm in height and not larger than 9 cm in diameter and 20 cm in height. For each individual, GPS position was determined and location marked with a wooden stake and a tag numbered between 1 and 120. All cacti used in this experiment were growing in situ within the study site. The relocation sites were located on the tops of the benches within the study site to isolate the cacti from cows and human traffic.

Three different methods for transplanting the cacti were examined. (1) Cacti were excavated with a soil surface diameter of 15–20 cm around each plant to a depth of 15–20 cm, the soil was shaken off and all roots that were damaged and <3 mm in diameter were clipped from the plant. The plants were placed within the drip zone on the north side of a juniper tree for 48 h to allow hardening off of the roots. The cacti were then transplanted into holes dug on the bench tops. This treatment represents a modification of the conventional method of transplanting cactus. (2) Cacti were excavated in the same manner as above but the soil was not removed, thus creating a root ball (which included associated rocks when not too encumbering). Plants were placed in a plastic bucket 18 × 18 × 12 cm and transported to the relocation sites where they were transplanted within 2 hours. (3) Cacti were excavated in the same manner as above; soil was shaken from the roots, equivalent to a bare root plant; and the cacti were transported to the relocation site and transplanted within 2 hours.
Cacti were transplanted at 4 different times of the year: 29–31 May 2003, 6–8 August 2003, 29–31 October 2003, and 8–10 March 2004. Phenologically these dates were representative of (1) time of flowering, (2) summer dormancy due to heat and low water availability, (3) late fall growth due to decreasing temperatures and an increase in soil moisture from fall rains, and (4) winter dormancy, respectively. Following the May transplanting, all flowers and developing fruit were removed on 8–10 June.

*Atriplex confertifolia*, a common shrub in the area, was the nurse plant. Cacti were either relocated to the north side of an *Atriplex* and within 20 cm or less of the drip line or planted in a spot where there were no other *A. confertifolia* within at least 1 m.

The study was a completely randomized design using 120 plants. There were 3 transplanting procedures, 4 seasons of transplanting, presence or absence of nurse plants, and 5 replications of each treatment combination. Cacti were randomly assigned treatment combinations and relocation holes. Kaplan–Meyer survival analysis and Cox proportional hazards regression were performed to determine differences between treatment life lengths (Kleinbaum and Klein 2012). Multifactor ANOVA was used to determine any possible differences in average plant vigor as measured by tubercle and flower production.

All cacti were planted to their original soil depth. Soil used to complete the transplant was taken from the diggings of the relocation hole. No consideration was given to maintaining original plant solar orientation.

On each date of transplanting, 30 relocation holes were dug, approximately 20 cm in diameter and 20 cm deep, on the top and southern exposure of the benches where 15 were associated with a nurse plant, *A. confertifolia*, and 15 were located in the open landscape. All relocation holes were filled with water and allowed to drain, taking approximately 30 min. Thirty cacti, randomly selected to represent the treatment combinations for that transplant date, were excavated, received transplant treatment, and were transplanted into the relocation holes. Transplanted cacti were then thoroughly watered to ensure contact between the soil of the relocation hole and the soil encompassing the plant roots. A hardware cloth cage, approximately 25 cm tall and 25 cm in diameter with no top, was placed around each transplanted cactus. This cage provided a means to attach treatment identification information to each cactus and discourage rodents from disturbing the plants (Hunter et al. 1980).
Documentation on cacti mortality was taken in the spring and fall of each year starting in fall 2004 and ending in fall 2011. Flower production was determined on 26–27 May 2011. Yearly tubercle production for each cactus was determined by painting the tip of the central spine of the tubercles surrounding the apex with a dab of yellow paint on 17–20 April 2011, before the plants bloomed and after the plants had swollen with water. These tubercles had been produced in 2010 or later. From 27 September to 6 October 2011, the tip of the central spine from tubercles produced during the 2011 season, a result of meristematic growth, was painted with a dab of red paint. This facilitated counting tubercles produced in 2011 and distinguishing them from the 2010 tubercles. Plant volume was determined by measuring plant height and diameter and using the equation for a cylinder to derive volume. Plant volume in the spring was used in the analysis because plant volume in the fall is very unreliable, with the plants starting to shrink and losing turgidity in response to decreasing temperatures and day length.

**Results and Discussion**

Ninety-seven percent of the cacti were alive after 3 years and 84% after 8 years. There was little difference in the number of cacti that died among the 3 different transplanting methods and whether the transplanted cactus was associated with a nurse plant (Fig. 3). From the mortality observations, season of transplanting appears to have an effect on cactus survival, with approximately twice the number of cacti dying when transplanted in March 2004 as compared to the other seasons (Table 1). However, 4 of these 9 cacti died between the summer of 2010 and spring of 2011, which was 7 years after transplanting. It is assumed that by that time, the death of these cacti was due to factors other than ones associated with transplanting.

A total of 18 cacti died during this 8-year study, due to a variety of environmental reasons and insect or fungal damage, resulting in an average loss of 1.9% per year. Three cacti died from cow damage and were removed from experimental observations and calculations. The mortality rate observed in this study is similar to that observed by others. Hreha and Meyer (2001) observed an average mortality of 4.4% per year for *Pediocactus sileri* during 5 years of monitoring. Coles et al. (2012) observed an average mortality of 2% per year for *S. mesae-verde* from 20 years of monitoring. By comparison, an average mortality of 4% per year for *S. mesae-verde* can be calculated from the data presented by Roth (2008) for 6 years.

The Kaplan–Meier estimator, also known as the product limit estimator, estimates the
survival function from lifetime data. In this study, the estimator, which compares only one factor at a time, concluded that each factor individually was nonsignificant. \( P \) values associated with a chi-squared test for season, method, and nurse plant were 0.641, 0.717, and 0.436, respectively. The Cox regression analysis considers all factors together. Again all factors were nonsignificant with all \( P \) values >0.247 and an overall log-likelihood \( P \) value of 0.83. There was no difference in survival due to transplanting technique, time of year of transplanting, or whether plants were associated with the nurse plant \( A. \) confertifolia.

There was an average of 0.8 flowers and 2.2 tubercles produced per 100 cc of cactus volume in 2011. These 2 parameters measure plant health (i.e., reproductive capability and vegetative growth; Wise et al. 2004, Webster et al. 2005). Multifactor ANOVA was performed on flower production per volume and tubercle production per volume. There was no significant difference among treatments in flower or tubercle production in the eighth year of the study (Table 1). There was a slight violation of the constant variance assumption (\( P = 0.04 \)) for the flowers per volume with respect to season. The lack of significant differences 8 years after transplanting demonstrates similar plant health among treatments.

Determining whether hardening off of cacti was required for transplant success was also examined. The broad definition of hardening off usually refers to the physiological changes needed for an indoor plant to survive outdoors. In relocating cacti, it refers to callus tissue forming on the ends of the trimmed roots and in some cases refers to an overall physiological change in the cacti. The procedure involves trimming the small roots and then, in some cases, dipping them in Clorox or sulfur to prevent pathogenic problems, and then placing the cacti in a greenhouse or in a shaded outside environment for 1–3 weeks (Brabander 1998, Ironwood Consulting Inc. 2012). Plants from transplant methods 2 and 3 were transplanted within 2 hours of removal from the original location (i.e., with no long-term hardening off). These plants showed no difference in survival over 8 years compared to those plants that were hardened off (i.e., procedure 1), where the hardening-off period was 48 h in the shade of a juniper tree.

The results from this study demonstrate that \( S. \) parviflorus can be successfully transplanted by any of the 3 methods described, at any time of year, and with or without an associated nurse plant. Similar results may be expected from transplanting cacti of similar size (e.g., individuals from other species of the genus \( Sclerocactus \), or possibly \( Coryphantha \) or \( Pediocactus \), growing in similar environments). Using method 2 or 3 will decrease the time, travel, and expense involved in transplanting.

**ACKNOWLEDGMENTS**

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### Table 1. Completely randomized ANOVA design for flower and tubercle production per volume of cactus (\( Sclerocactus parviflorus \)) in the final year, 2011.

<table>
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<th>Transplant variable</th>
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<th>( P )</th>
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<td></td>
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<tr>
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</tbody>
</table>

*All interactions were nonsignificant.

**All interactions were nonsignificant except Season × Method.
Junction Field Office, and the local nonprofit Desert Ecosystem Analysis and Restoration.

**LITERATURE CITED**


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