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Cover Illustration: *Pachypodium namaquanum* (Elephant-trunk; halfmens; Halbmensch). Photograph by Peter Cunningham

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Relocation of *Adenia pechuelii* (Passifloraceae) – a viable rescue option?

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Abstract

Adenia pechuelii*, an unusual pachycaul member of the Passifloraceae family, has restricted range in the Namib Desert and was previously considered threatened on the Namibian Red Data list. The area of a planned uranium mine on farm Valencia in the central Namib Desert supports the largest population found to-date in Namibia. After an initial environmental impact assessment, the mining company commissioned a survey of the* A. pechuelii *population and an experiment to establish the best methodology for relocating plants. Sixty plants were transplanted to a nearby area that would remain unaffected by mining. Different treatments, including watering regimes, were applied but no significant differences were detected between any of these. All plants survived one year after transplanting and showed signs of vitality. Four years after transplanting 80% of plants were alive. The implications these findings have for the conservation and relocation of* A. pechuelii *are discussed.*

Keywords: *Adenia pechuelii*, population survey, restoration, Namibia, southern Africa

Introduction

The global energy crisis and a rise in market prices have prompted an increase in uranium exploration and mining in Namibia, in particular in the central Namib Desert. Valencia Uranium (Pty.) Limited, owned by the Canadian Forsys Metals Corporation, plans to mine uranium on farm Valencia No. 122 on the eastern fringes of the Namib Desert, about 80 km east-north-east of the coastal town of Swakopmund.

As expected from a desert area, rainfall is erratic and often absent with a long-term annual average of 50 to 100 mm (Mendelsohn *et al.* 2002). During the study period, however, above-average rainfall was measured at Valencia. From November 2008 to November 2009 rainfall totalled 229 mm. Coastal fog is also experienced at this site and supplements rainfall. Vegetation is mostly ephemeral with perennial species found mainly along drainage lines and dry river beds. The Namib Desert supports a number of highly adapted, rare and often endemic plant species yet little is known about their life history. This arid environment is extremely sensitive to disturbance. Any post-mining ecological restoration will be a very slow process due to the constraints of this environment and complicated by the scarcity of biological information and restoration methodology applicable in such arid environments.

The environmental impact assessment (EIA) and environmental management plan of Valencia mine (Digby Wells Associates 2008) identified a large population of *Adenia pechuelii* (Engl.) Harms, commonly known as Elephant's Foot. At the time of the EIA, *A. pechuelii* had been assessed as endangered (EN C1C2a) using the 1994 IUCN criteria (Craven & Loots 2002). It was considered endemic to Namibia, occurring in few, small populations within the fog zone along the western coast and sought after in trade (Oldfield 1997; Newton & Chan 1998). *A. pechuelii*, a member of the Passifloraceae, is dioecious and develops a pachycaul stem with stiff, pointed branches (Figure 1) which only produce leaves and flowers or fruit after sufficient rainfall (De Wilde 1976). Little else is known about its biology. Raising plants from seed or reseeding *in situ* is not a viable option for restoration because little seed is produced and it is assumed to be an extremely slow-growing species.

This prompted the investigation into suitable methodologies for relocating and mitigating the impact of mining on these unusual plants.

Figure 1. A large specimen of *Adenia pechuelii* at Valencia (© H. Kolberg)

Materials and Methods

Survey of A. pechuelii population at Valencia

Following some unsuccessful attempts by others to quantify the *A. pechuelii* population at Valencia it was decided on a systematic approach to identify and mark each plant within the exclusive prospecting license (EPL) and surrounding areas. In August 2007 the EPL area of Valencia Uranium was covered (Kolberg & Tholkes 2007a) and in November 2007 (Kolberg & Tholkes 2007b) a band of 2 km width along three sides of the EPL was surveyed (Figure 2). To cover the area systematically, it was divided into strips which were loaded onto Global Positioning System (GPS) units in the form of a route. Initially, for the survey of the EPL, strips were 200 m wide, but based on experience during the first survey, this was changed to 100 m in November 2007.

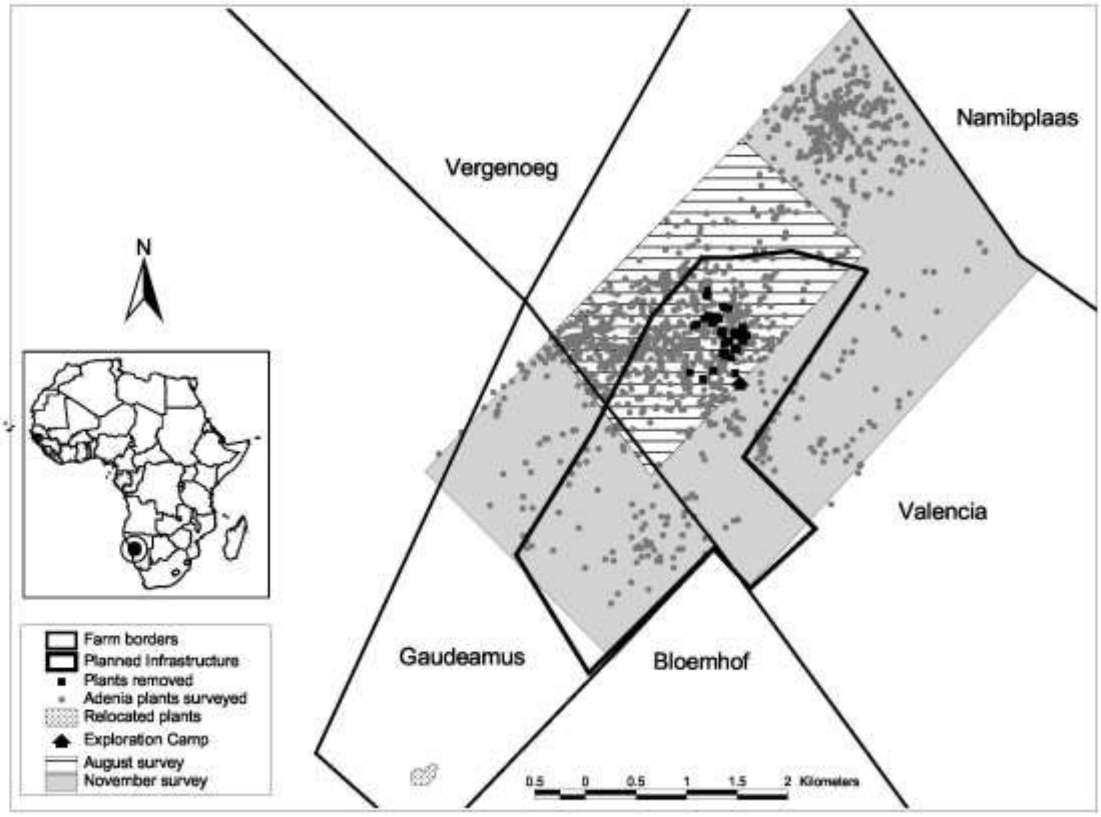

Figure 2. Site location, areas surveyed and distribution of *Adenia pechuelii* at Valencia

In the field the two surveyors followed a mostly zigzag path from border to border of the strips, but were led by the topography of the area in choosing a path so that all areas of a srip could be visually scanned for *Adenia* plants. The surveyors had to ensure that all the sides and the summit of any outcrops were seen, since plants tend to grow hidden under or behind rocks. Plants were marked as waypoints directly onto the GPSs and numbered consecutively. To avoid double counting, the marked plants were tagged with bio-degradable tape onto which the waypoint number was written. Localities of marked plants were mapped using ArcView GIS. The track log facility of the GPSs was also switched on and the tracks followed by the surveyors mapped to check that the area was sufficiently covered.

Experimental relocation of Adenia pechuelii

Selection of relocation site

In selecting an area for relocated *Adenia* plants, besides the obvious criterion of the area falling outside that which will be affected by mine development, other criteria were considered that were linked to observations made in the natural populations of the species and also to logistical considerations. An area was selected about 8 km west of the proposed mine area on neighbouring farm Gaudeamus No. 136. The area houses some plants of *A. pechuelii* and the substrate and topography is similar to areas where the removed plants occurred. The area is relatively flat with a few granite rocks and outcrops and sandy soil; traversed by a few shallow watercourses with deeper soil and was also conducive to easy transplanting and monitoring. There was an existing track on which heavy vehicles could move which limited additional disturbances and used for subsequent watering and monitoring purposes. The few new tracks created were rehabilitated manually by sweeping with brooms and rakes.

Figure 3. Rehabilitating tracks made during planting at the Gaudeamus site by means of sweeping (© T. Tholkes).

Plant selection and removal

In November 2008 plants for this experiment were selected by randomly chosing 60 numbers representing the previously numbered plants in the central area of planned infrastructure (Figure 2). An excavator and small truck with operators were hired, assisted by a team of seven people. The excavator was used to loosen soil and remove large rocks around plants. Thereafter manual digging with spades and crowbars carefully freed the roots from the soil. The main roots of the plants were followed as far as possible towards their tips and damage to any roots was limited as far as possible. Large plants were hoisted onto the truck by the excavator. Care was taken to position the plants either on their sides or on the more elastic branches to minimize breaking of the rather brittle roots (Figures 4, 5 & 6). Of the Elephant's Foot plants growing naturally in the sanctuary area, five were selected at random to serve as control plants.

Figure 4. The excavator was used initially to loosen the soil and remove large rocks around plants (© T. Tholkes).

Figure 5. Roots of plants were freed out of the soil by hand, using crowbars and spades (© H. Kolberg).

Figure 6. Large plants were fastened with nylon rope and hoisted onto a truck by the excavator (© H. Kolberg).

Re-planting and Treatments

Plants were moved to the relocation area by truck and offloaded by hand or excavator. Positions for re-planting were selected at random and holes dug with the excavator for large plants and with a pick for smaller plants (Figure 7). Plants were numbered at random and the treatments applied to groups of five randomly chosen plants (Table 1). Treatments 2 and 3 were chosen to counteract any fungal attack that could enter plants through wounds. Treatment 4 was used to promote development of new roots. Three different watering regimes (a, b, c) were applied to each treatment. Planting was done by hand, filling the holes around the positioned plants with spades and shovels (Figure 8). Care was taken to replant the plants to the same depth and vertical angle as they were growing in their original position. After planting, all plants were watered sufficiently to settle the loose soil around the roots (Figure 9).

Table 1. Treatments applied to relocated *Adenia pechuelii* plants.

No.	Treatment	No.	Watering regime
1	Plants replanted immediately (same or next day)	a b c	" without" watering (only water at planting) watering every 2 weeks (10 l per watering per plant) watering every 4 weeks (10 l per watering per plant)
2	Plants stored at planting site for 8 weeks, then replanted	a b c	" without" watering (only water at planting) watering every 2 weeks (10 l per watering per plant) watering every 4 weeks (10 l per watering per plant)
3	Wounds on plants sealed with wound sealer (contains fungicide), then replanted	a b c	" without" watering (only water at planting) watering every 2 weeks (10 l per watering per plant) watering every 4 weeks (10 l per watering per plant)
4	Roots of plants treated with rooting hormone, then replanted	a b c	" without" watering (only water at planting) watering every 2 weeks (10 l per watering per plant) watering every 4 weeks (10 l per watering per plant)
5	Control – naturally occurring plants	p	

Figure 7. Planting holes for smaller plants were dug by pick and shovel (© H. Kolberg).

Figure 8. Plants were replanted at the same vertical angle and depth to their original growing position, filling the planting hole by hand with the loose rocks and soil (© H. Kolberg).

Figure 9. Immediately after planting, sufficient water was applied to saturate and settle the loose soil around roots (© H. Kolberg).

Metal tags with plant numbers fastened to iron fencing posts were inserted near the plant so that the number was visible on photos taken at each monitoring visit. The tips of the stakes were painted in different colours to indicate the watering regime. Water from the exploration camp was transported in a plastic tank to the experimental site in watering cans with 10 l capacity. Watering commenced on 24 November 2008 and continued to 27 April 2009. This period was chosen because rainfall could occur naturally during these months. Watering was skipped when there was rainfall in the week of watering.

Monitoring

Monitoring of the experiment continued for a year on a two-monthly basis. The site was again visited four years after planting in November 2012, but since this was not planned into the initial experiment, no measurements of height could be taken from the fixed points which were removed at the end of one year. Analysis of data was thus done for only one year. Assessment in 2012 consisted of taking photos and subjective scoring of plant vitality as described below for the first year.

During the first year, plant growth was assessed by measuring total plant height from a fixed point at ground level to the tip of the tallest branch (cm). The difference in plant height over one year (height November 2009 – height November 2008) was calculated, averaged per treatment, tested for homogeneity of variance, log-transformed and analyzed by one-way ANOVA (Fowler & Cohen 1994) using GraphPad Prism 5 software.

In the first year, plant health was scored on a 0 to 5 scale where 0 was dead and 5 in excellent health. Although somewhat subjective, this system resulted in highly comparable assessments from one monitoring visit to the next when conducted by the same person. Plant parts dying or damaged (by the relocation or animals) was included in this assessment. The presence of newly formed branches, leaves, flowers and fruit was noted at each monitoring visit. One point was awarded for each of the above categories when present. A score for plant vitality was derived by combining the two factors assessed above. The difference in vitality score over the year (vitality November 2009 – vitality November 2008) was calculated, averaged per treatment, square-root transformed and analyzed by one-way ANOVA (Fowler & Cohen 1994) as for plant growth above.

Since the amount of root remaining on plants may have an impact on establishment, the number of main roots and their length was measured at planting.

In the first year, photos were taken at each visit from a fixed position. During the visit in 2012 the numbered stakes had been removed and photos were not always taken from the exact same position as in the first year.

Results

Adenia pechuelii population

A total of 1,565 *A. pechuelii* individuals were found in an area of approximately 28 km^2; 922 plants (59%) within the EPL and 643 plants (41%) in the area surveyed outside the EPL. The average plant density was calculated at 123 plants/km^2 inside the EPL; 32 plants/km^2 outside the EPL and 57 plants/km^2 for the total surveyed area. An overlay of planned mine infrastructure onto a map of *Adenia* plant distribution at Valencia, showed that at least 693 plants (44 % of total surveyed population) would be directly affected by development of this infrastructure.

The effects of different treatments and watering regimes on survival, growth and vitality of relocated plants

Plant survival

After one year, all relocated plants had survived. In November 2012, four years after relocation, 48 of the relocated plants (80%) were still alive. This figure is also reflected in the control plants, where four of five plants were alive; one plant was destroyed by wildlife (a combination of zebra and rodents). Of the 60 relocated plants only one died without the visible causes being destruction by wildlife; the other 10 plants were completely destroyed by wildlife (Figure 10a). Most of the 52 surviving plants (48 relocated plus 4 control) were damaged by wildlife to some extent (average 26 - 50% of plant damaged or removed), varying between 0 and 75% destruction of the plant (Figure 10b). Only two of the control plants showed no damage.

a) b)

Figure 10. Damage to plants by wildlife a) plant completely destroyed and b) plant up to 75% destroyed - four years after relocation (photo: H. Kolberg)

Plant growth

Plant height increased and decreased over the year during which measurements were taken. Increase in plant height could be recorded the month after rainfall peaks for all treatments. The graph in Figure 11 depicts the total monthly rainfall for November 2008 to November 2009.

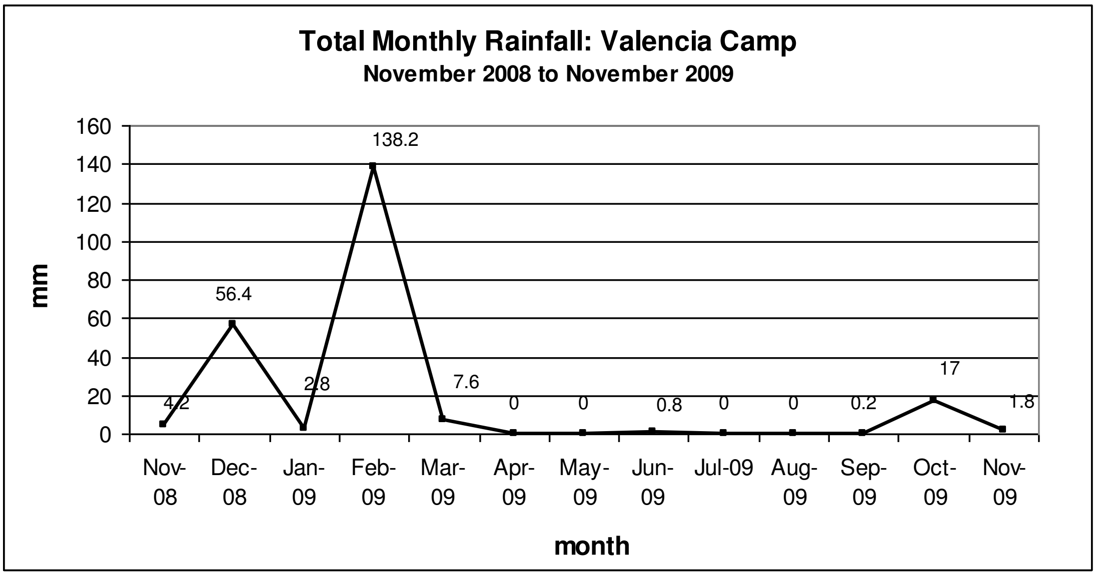

Figure 11. Total monthly rainfall (mm) at Valencia Exploration Camp from November 2008 to November 2009

Figure 12 shows the average plant height per treatment for randomly selected treatments over the study period. The highest measurements for plant height were taken in March 2009 after the 138.2 mm of rain in February, while the lowest heights were recorded in July and September 2009 after four to six months of no rainfall. New branches generally formed at the base of existing branches near the main stem and were never observed to extend above existing branches meaning this new growth did not result in an increase in plant height. The measured fluctuation in height is due to the expansion and contraction of the stem with increase and decrease in available moisture and not due to an increase in branch length.

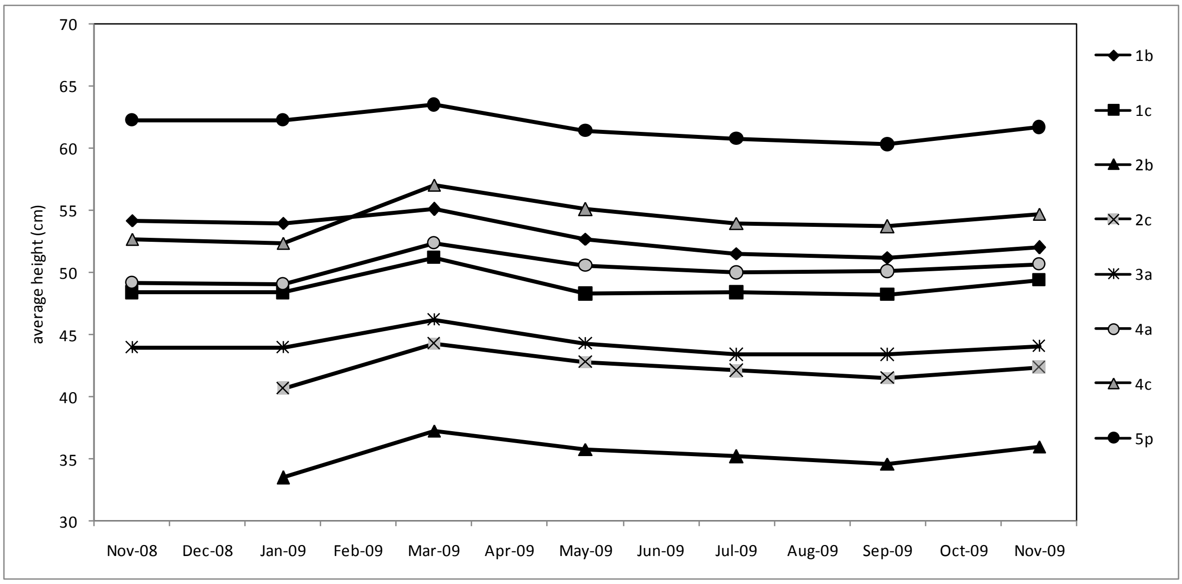

Figure 12. Fluctuation of average plant height (cm) over time at the Gaudeamus study site. Since the pattern was the same for all treatments, only selected treatments are shown.

1b = Plants replanted immediately (same or next day); watering every 2 weeks (10 l per watering per plant).

1c = Plants replanted immediately (same or next day); watering every 4 weeks (10 l per watering per plant).

2b = Plants stored at planting site for 8 weeks, then replanted; watering every 2 weeks (10 l per watering per plant).
2c = Plants stored at planting site for 8 weeks, then replanted; watering every 4 weeks (10 l per watering per plant).
3a = Wounds on plants sealed with wound sealer (contains fungicide), then replanted; “without” watering (only water at planting).
4a = Roots of plants treated with rooting hormone, then replanted; “without” watering (only water at planting).
5p = Control – naturally occurring plants. Explain the treatments here, so that the reader does not have to hunt in the text.

Figure 13 shows the base of a stem during the wetter months (a) and the gap forming between the stem and the surrounding soil in dry months (b) upon contraction of the stem.

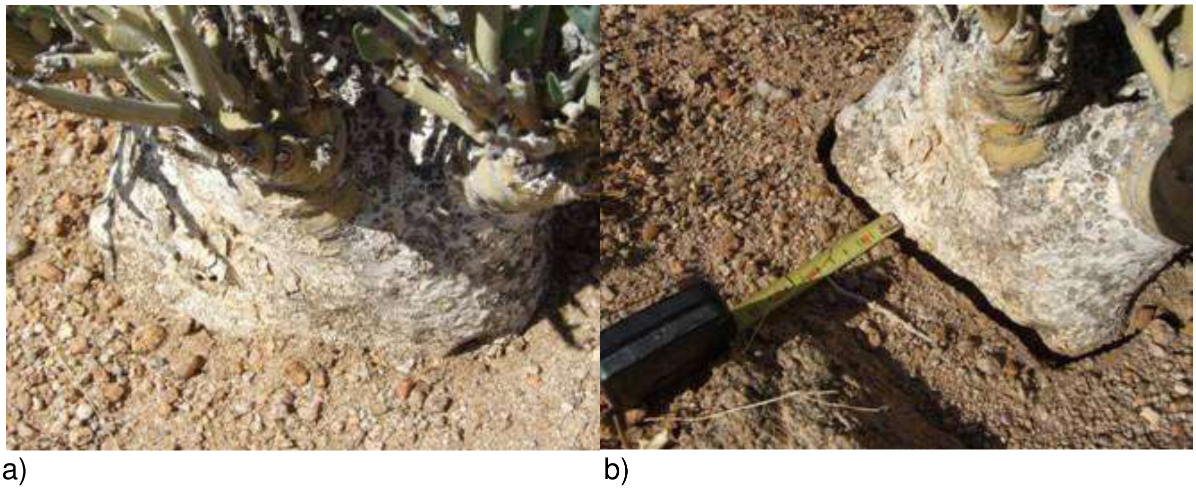
a) b)

Figure 13. Expansion and contraction of main stem according to available soil moisture: a) base of stem in November 2009 after some rain; b) base of the same stem during the driest time in July 2009 (© H. Kolberg).

Changes in height of individual plants were between 1.5 and 8 cm with the average difference being 4 cm. The average height difference per treatment was between 2.8 cm and 5 cm. There was a statistically significant positive correlation between plant height and height difference (r = 0.364, p = 0.003, n = 60), which supports the assumption that change in height is due to expansion and contraction of the stem and not due to growth of plants – the bigger the plant the greater the difference in height due to stem expansion or contraction. There was no statistically significant difference in the change of plant height from November 2008 to November 2009 between treatments ($F_{12,52}$ = 0.62, p = 0.815).

Plant vitality

During the year in which assessments were conducted, individual plant health varied between a score of 1 and 5 with the average being 3.5, irrespective of treatment. The average plant health score per treatment was between 3.1 and 4.

Four plants never had any new growth or flowering over the year. Treatment 3a (plants treated with wound sealer, no watering) had least development of new growth, while treatment 1c (plants replanted immediately, watered every four weeks) had on average most new growth. Plant 2.b.3 (stored for eight weeks before replanting, watered every two weeks) was the only one that developed fruits during the time of this experiment. It could not be verified whether seed was also formed because the fruit had disappeared prior to maturity.

Plant 3.c.1 (treated with wound sealer, watered every four weeks) had the highest vitality score (8) over the year while the average vitality score of all plants irrespective of treatment, was 4. Vitality per treatment ranged from 2 to 3.4. There was no statistically significant difference in change of vitality between treatments ($F_{12,52}$ = 0.89, p = 0.564).

Number of roots and total root length

The number of roots varied between 0 (all roots were broken off during removal of the plant) and 9 with a mean of 4.5. The total root length of individual plants was 0 to 401 cm with a mean of 158 cm. There was no statistically significant correlation between root number and plant height difference ($r = 0.086$, $p = 0.515$, $n = 60$), root number and plant vitality ($r = 0.087$, $p = 0.507$, $n = 60$), root length and height difference ($r = -141$, $p = 0.281$, $n = 60$) and root length and plant vitality ($r = 0.066$, $p = 0.619$, $n = 60$) over the period of the experiment.

Treatment 2b (plants stored for eight weeks before replanting, watered every two weeks), with relatively short roots, showed above average plant health and development of new growth, whereas treatment 4c (treated with rooting hormone, watered every four weeks) with long roots had lower values for these two parameters. It was astonishing to find that even the plants where roots were completely broken off, did not die and in fact produced some new growth.

Discussion

The number of *A. pechuelii* plants in the Valencia population (1,565) is considerably higher than that found in any other population in Namibia. The largest population recorded in a national survey had close to 900 plants and the population size for Valencia was reported as being 412 individuals (Loots 2013). Densities of other populations are reported to vary between 5 and 2,100 plants/km^2 with the average between 100 and 200 plants/km^2 (Loots 2013). The areas surveyed for these populations were very small (most less than 2 km^2) and surveys were not aimed at identifying every plant present at a site. The method used by Loots (2013) to calculate plant density (Nearest Neighbour plotless method) and extrapolation from small areas or small samples could explain these high densities compared to the comparatively low density found in this study and calculated through dividing number of plants found by surface area surveyed. The density at Rio Tinto's nearby Rössing Uranium Mine, where 32 km^2 were systematically surveyed, is only 7 plants/km^2 (Loots 2013). At 57 plants/km^2 density at Valencia is thus much higher than at the comparable Rössing site. Reasons for this are unclear but may be linked to the great variety of micro-habitats at Valencia which are also suitable for the assumed seed dispersal vectors. Slightly higher rainfall at Valencia may have been responsible for periodic establishment of plants leading to this large population.

The age structure of the *Adenia* population showed a healthy number of both small (< 20 cm high) and very large (> 80 cm high) plants with the majority of plants being in the middle height-classes. No detailed data was collected to confirm this observation and the relationship between maturity and plant size is unknown. Data reported by Loots (2013), however, corroborate this observation.

The occurrence of *A. pechuelii* could not be linked to any features of the environment observed during the survey or from map overlays of several environmental features. Map overlays of geological, mineralogical, radiation and hydrological information gathered by the mining company could also not explain the distribution of *Adenia* in the area (R. Joly *pers. comm.*). Loots (2013) did collect habitat information nationally at *A. pechuelii* sites and found the species prefers granite, W and NW-facing slopes of 0 to 30°, clay-loam soils that were somewhat alkaline and altitudes between 500 and 750 m.

During visits to the Valencia population in March and April 2007, it was observed that the flowering of male and female plants was not synchronized. The female plants had immature fruit in March and immature and mature fruit in April, while the male plants only had small buds in March and were in full flower in April. Some fruits that appeared to be almost mature did not contain any seed. This may be because the male plants were not flowering and producing any pollen when the female flowers were receptive. Only seven plants had mature fruit in April from which about 150 presumably viable seeds were collected. Another reason for poor seed harvest is the considerable competition from birds and rodents, that are attracted to the fleshy red fruit and seed covering (Figure 14). The small number of seed could also partly be attributed to destruction of young branches by wildlife. In March 2007 plants were in very good condition bearing fresh shoots, leaves and flowers or immature fruit. In August 2007, a large proportion of the fresh growth was heavily browsed, presumably by zebra and rodents, or completely destroyed by caterpillars. Since flowers, and therefore fruit, are borne on young shoots, factors affecting these plant parts have an influence on seed production.

Figure 14. The bright red, mature fruit of *Adenia pechuelii* attract birds and rodents (© H. Kolberg).

Ants were in abundance on plants especially when new growth and flowers were present. Whether these insects play a role in pollination is unknown, but not likely, since the distance to the nearest plant of the opposite sex is often considerable. Some plants had branches encased with mud deposited by ants or termites. This did not influence plant health as scored in the relocation experiment. Other insects, scorpions, spiders, reptiles (snakes, lizards) and rodents were observed on, under and around plants. All of the above points to the importance of this plant in the ecology of the area.

This study, and those by Loots (2013) and Jankowitz & Loots (2008), showed that *A. pechuelii* is more widespread in Namibia than previously believed. The plant also occurs in a very limited area of the Namib Desert of south-western Angola (Craven & Vorster 2006). The species is therefore not endemic to Namibia, but is an indicator species of the Kaokoveld Centre of Endemism (Craven 2009). Population sizes were also found to be larger than previously estimated and the species' conservation status has been down-listed from endangered (EN C1C2a) to near-threatened (NT) (Loots 2005) and subsequently to least concern (LC) (Loots 2013) using the 2001 IUCN categories. IUCN evaluation, however, does not take trade data and aspects of the plant's biology into consideration, factors which may still threaten the species so that it should remain flagged as of conservation concern, possibly listed as a protected species.

Although a photograph was taken from the same position at each visit, it was difficult to achieve comparable pictures to show changes in plants on successive photos. Differences in the time of day and year at which the pictures were taken were the main problems. For short periods, as in this experiment, the use of photography to compare plant vitality or development over time in the case of such slow-growing plants therefore has its limits and may not be worth the added effort involved but may be useful only in the long-term. A selection of photos is shown in Figure 15.

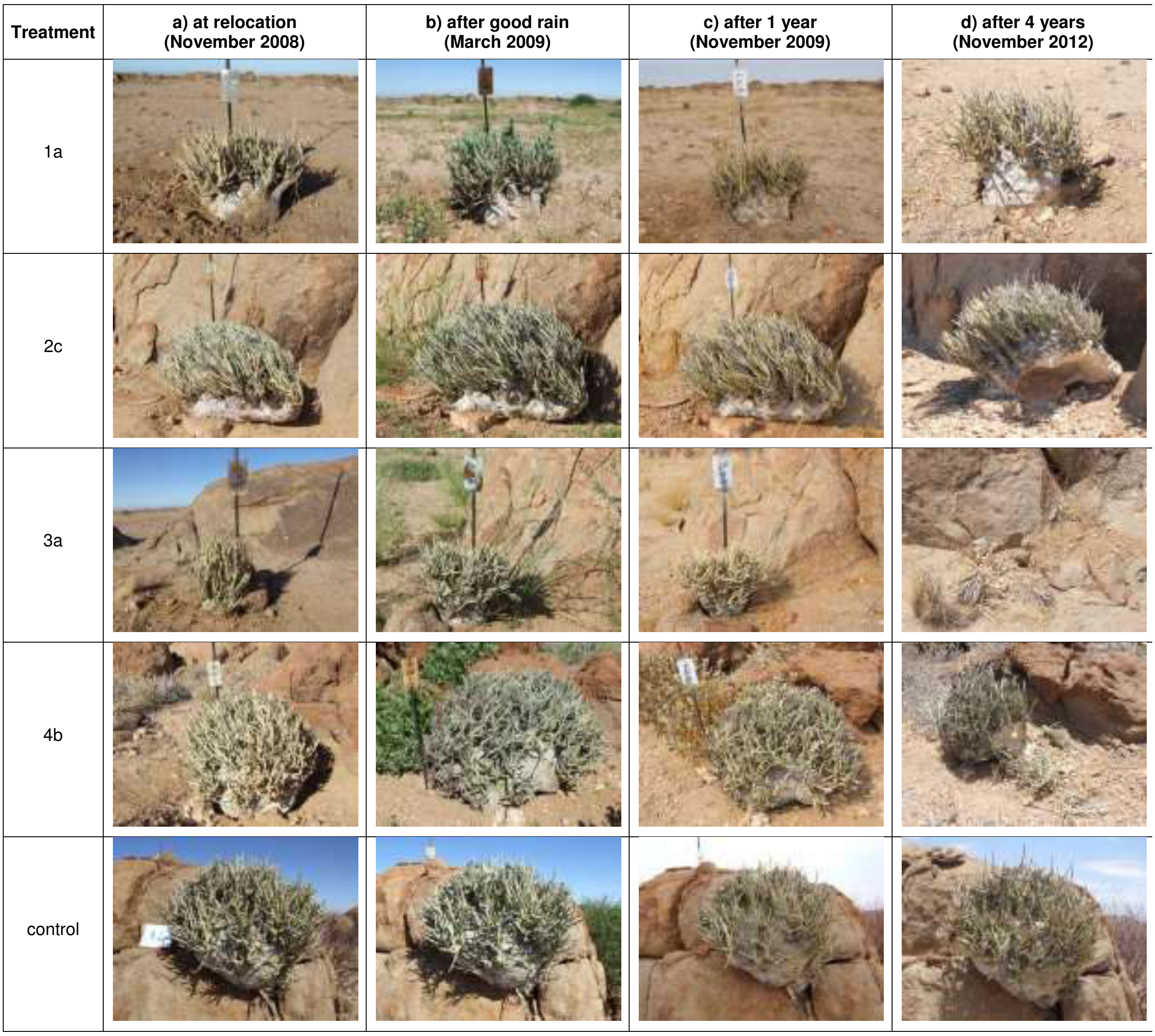

Figure 15. Time series photographs of randomly selected plants:
a) at planting;
b) after good rain (March 2009);
c) after one year (November 2009); and
d) after four years (November 2012) (© H. Kolberg).

Implications for mitigating mining impacts on *Adenia pechuelii*

As 80% of relocated plants survived and showed some signs of growth four years after relocation, it can be concluded that relocating *Adenia pechuelii* is a viable option. Of the 12 plants that died, only one died presumably due to transplanting; the other plants, including one control plant, were all destroyed by wildlife. This in effect means that the survival rate was 98.5%. The destroyed plants were mostly smaller, possibly due to being less woody or fibrous and therefore more palatable. Larger plants can probably also survive a proportion of the stem being destroyed more easily than small plants. The destruction of plants by wildlife can be explained by the few good rain years followed by very dry years in the area. Wildlife numbers increased in the good years and scarcity of food then forced them to feed on *A. pechuelii* in the dry years. As shown by destruction of a control plant and signs of severe browsing of plants in the Valencia population in August 2007, this is a natural occurrence and not linked to relocation. Some of the very strange stem shapes may be due to gnawing by animals. A plant was found in August 2007 of which the stem had been almost completely hollowed (Figure 16). On the inside of this stem, tissue had formed that looked the same as the outside bark.

Figure 16. During times of food scarcity, animals damage *A. pechuelii* plants. The stem of this plant was hollowed completely by some rodent (tracks and dung present) but scar tissue similar to the outside bark had formed on the inside (© H. Kolberg).

Since the amount of root remaining on removed plants did not have an effect on plant establishment and growth in this experiment, excessive care may not be needed when removing and transporting plants. In practical terms this means that reasonable effort in retaining maximum number of roots should suffice for the survival of relocated plants.

No conclusive difference in plant condition between the different pre-planting treatments was found in this study. The effort and associated costs could rather be invested in ensuring that plants are replanted at the same depth and vertical angle as their original position. Although plants should only be removed when necessary, immediate replanting is not essential. Plants could be stored for up to eight weeks before replanting. This has important implications for the management of a large-scale relocation of *A. pechuelii*, as is anticipated at Valencia.

Since an unusual amount of rain fell in the area during the study period, no firm conclusion can be made about the effect of prolonged watering after relocation. Initial watering to bring the disturbed roots into close contact with the loose soil and to stimulate growth of new roots is, however, considered to be essential. Further watering of relocated plants does not seem to be essential provided there is some rainfall. If there is no rainfall, plants should be watered again at least once, about four weeks after replanting to increase the chances of new roots being formed. Since water is a scarce resource in this area and the logistics of watering large numbers of relocated plants becomes rather complicated and costly, this result can contribute to the success of relocating this species.

Rain fell shortly after plants were transplanted and again three to four months later and plants were also in the ground in time for the natural growing season. This timing may have contributed to the good results. The effect on plants relocated at a different time of year or in a year with different rainfall patterns, is unknown. If possible, transplanting should be done from September to December in anticipation of rainfall and the natural growing season.

Disturbance of a previously undisturbed area for relocation of plants may be considered counterproductive by some. In the case of this study disturbance in the relocation area could be kept to a minimum because of careful selection of the site and subsequent management of signs of disturbance. The few new tracks that had to be made could no longer be seen after one year. This was possibly aided by good rainfall. Larger rocks that are brought to the surface when digging holes for planting were placed back in the holes with the plant as far as possible and covered with finer soil. This was not always possible and some lose stones remained at the surface and a sign of disturbance. The effects of this are probably more aesthetic than damaging to the ecology of the area.

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