ROOT GORELICK[1]

Pediocactus knowltonii: a close look at a very rare cactus

I have had the joy of seeing and photographing cacti in habitat in many parts of the world. I was even married at the restricted habitat of *Coryphantha recurvata* (Engelm.) Britton & Rose, near Nogales. While I am enamored with all cacti I have seen in habitat, there is nothing like becoming familiar with individual plants that you grow at home. I have thus had outdoors cactus gardens of winter-hardy plants in Washington DC, southern New Mexico, southern Arizona (well, no real winters there), and now southern Ontario. There is nothing like seeing individual plants every day, although in Canada that is restricted to the seven warm months of the year, with the cacti being below a blanket of snow for the other five months, usually from late November thru late April. So, if anybody asked me what was my favorite cactus species, it would not be one of the charming cephalium or pseudocephalium bearing plants that I often study nor the massive columnar or barrel cacti that I was so fond of growing in Arizona, but rather one of the diminutive species that hunkers down during long Canadian winters. I should also mention that I am a dreadful gardener, therefore I appreciate plants that can tolerate the horrible conditions and blind neglect that I toss at them. In that vein, *Pediocactus knowltonii* L.D. Benson is one of my favorites (Fig. 1).

1: Overview of *Pediocactus knowltonii* in cultivation (18 May 2012). The synchronous flowering may indicate that these are all of a single clone. At the type locality in San Juan County with many different clones, "These plants do not flower simultaneously" (Sivinski & McDonald 2004).

DESCRIPTION

Pediocactus knowltonii is a small plant. Individual shoots are usually 1–2 cm in diameter, rarely to 3 cm. Shoots both in habitat and in cultivation in Canada are usually wider that they are tall. Plants offset readily in cultivation, but supposedly less so in habitat, with each individual mature shoot in cultivation often growing a new offset once every two or three years (Fig. 2). Clumps can easily be composed of a half-dozen shoots, although

[1] root.gorelick@carleton.ca

2: This plant was purchased four-years before this photo was taken as a single shoot that subsequently grew a new shoot each year (23 May 2011).

3: Shoot with five flower buds, all dark red (2 May 2009).

4: Detail of flower and unopened flower buds, all dark red (27 May 2019).

5: Pair of open flowers and pair of offsets (27 May 2019).

6: Open flower (17 May 2010).

7: Offsets less than ½ cm in diameter can flower when attached to their parent (30 May 2019).

I tend to give away cuttings once clumps get large. At least in cultivation for me, every shoot over 1 cm in diameter flowers every year, often with 2–5 flowers per shoot (Fig. 3). When open, flowers are lovely, of about the same diameter as the shoot on which they grow, with buttery yellow styles and stamens (Figs. 4–6). On clumping plants, shoots as small as 0.5 cm in diameter can flower (Figs. 7–8). Tepal (petal/sepal) color varies. Many plants have the outer part of tepals, especially before flowers open, of a dark red color (Figs. 2–4; 8–9). The inner surface of tepals in such plants varies between a light and dark pink. Some plants have the inner surface of tepals being white or almost white, in which case the outer surface of the tepals contains white- or cream-colored margins, with a darker, almost brown broad band surrounding the midvein.

8: Offsets less than ½ cm in diameter can flower when attached to their parent (30 May 2019).

9: Outer part of tepals lighten in color as flowers open, but are still darker than the inner surface (16 May 2010).

10: *P. knowltonii* sets its flower buds in late summer (23 August 2019). Flower buds overwinter like this and only open in spring.

11: Young green fruits/pericarpels. Remnants of dried tepals visible at the top, which will soon dehisce via a circumscissile abscission zone (23 June 2011)

Flower buds are set in late summer and then overwinter to open in early spring (Fig. 10). This is a very rare phenology in cacti, but much more common in Arctic plant species (Panchen & Gorelick 2015) such as purple saxifrage (*Saxifraga oppositifolia)*, and is perhaps unique in the genus *Pediocactus*. Radial spines are short and thin, either white or pale brown, and highly appressed, with areoles that therefore resemble wispy cobwebs. It is trivial handling these plants with bare hands insofar as the radial spines are so small and appressed. With an exceptional plant to be described later, there are no central spines. Epidermal color seems to always be a vibrant green, without any obvious change in epidermal color due to drought or cold, as occurs in many other cacti when stressed (cf. Gorelick 2022). These shoots also do not appear to dehydrate and do not become relatively flaccid for winter. For the several cultivated plants of *P. knowltonii* in Ontario that I have transplanted, the root systems were fairly small, smaller in extent than the shoots, with nothing resembling a tap root. This might be different in habitat or when cultivated in deserts because *P. knowltonii* is known to have contractile roots that draw shoots underground during droughts (Sivinski & McDonald 2004, Roth 2018). The only *Pediocactus* that has drawn itself underground in cultivation outdoors in Ontario has been *P. winkleri* K.D. Heil. Finally, the fruits (actually, pericarpels (Buxbaum 1950 [1953], Mauseth 2006) of *P. knowltonii*, while not beautiful, are typical for the genus and are unusual for cacti. Floral remains abscise from the top of the fruit via a so-called circumscissile split and later the remaining parts of the fruit/pericarpel dehisce via a vertical slit, after the pericarpel exterior changes from green to reddish brown (Benson 1961, 1962, 1982, Heil & Porter 2004) (Figs. 11 –12). I do not regularly get fruits on my cultivated plants despite several dozen flowers each year, but I also do not hand pollinate flowers, which I should start doing.

ENVIRONMENT

Somewhat remarkably, especially for a dreadful horticulturalist like me, no specimens of *Pediocactus knowltonii* have ever died in my gardens in southern Ontario, where I have been growing them for over a dozen years, and despite usually having a week straight where low temperatures plummet to or below -30°C (-22°F) and high temperatures hover around a balmy +26.5°C (+80°F). The average low temperature in January, the coldest month of the year, at both of my gardens in southern Ontario—in Ottawa and North Kawartha—is approximately -14.5°C (+6°F). This is probably slightly colder than at the type locality of *P. knowltonii*, at which there is no weather station. However, nearby Durango, Colorado has average January low temperatures of -10°C (+14°F). Durango is at a slightly higher elevation (1991 m; 6532 ft) than the type locality of *P. knowltonii* (1905 m; 6250 ft), and Durango is in a valley surrounded by fairly tall hills from which cold air drains, so the type locality is almost certainly warmer than Durango, Ottawa, and North Kawartha during the depths of winter. Furthermore, springs and summers are often extremely cold and wet in southern Ontario compared with at the type locality and the Four Corners area.

P. knowltonii tolerates a range of edaphic (soil) conditions. I first grew this species in Canada in a huge

12: Older fruits/pericarpels that have turned brownish-red, but still have not lost their dried up tepals nor formed a vertical slit through which seeds dehisce (4 May 2007).

mound of pure sand in Ottawa that was, in retrospect, sand that was much too fine-grained and therefore retained a lot of water (e.g. Figs. 1–3; 11–14). Eventually, large clumps of mosses grew all around some of the plants (Fig. 13). Ironically, this has become a decent cactus garden (intentionally) and a decent moss garden (unintentionally). I eventually placed chunks of native limestone below a few of the plants (Figs. 3 and 14). None of these conditions seemed to affect plant growth, flowering or survival of *P. knowltonii*. These early attempts at growing this plant in a mound of fine-grained sand also happened to be in a locale that was partially in the shade of several large sugar maples (*Acer saccharum* Marshall). Eventually, in 2016, I moved some of these specimens to a pair of new gardens in shallow pockets in bedrock in North Kawartha, also in southern Ontario, this time in full sun (e.g. Figs. 4, 7, 8, 10, 15, 16). One of these two new gardens was over top of a mat of decomposing juniper roots (*Juniperus communis* Thunberg); the other was over an old burn pile with lots of burnt old lumber with many rusty metal nails and screws. I slowly am removing all the metal. I covered both of these new gardens on bedrock with about 5 cm of "pea gravel" which are relatively small pieces of smooth river rock. Again, the edaphic conditions seemingly made no difference to *P. knowltonii*. Many of my cacti prefer these new gardens, on bedrock in full sun in North Kawartha to the old gardens on fine-grained sand in partial shade in Ottawa. However, *P. knowltonii* seems to do equally well in both environs.

The tolerance of *Pediocactus knowltonii* to all sorts of growing conditions is curious in light of the recovery plans for this highly endangered species, possibly the most highly endangered cactus species in North America and certainly the most highly restricted endemic range. The native habitat is at the top and sides of a single hill in northwestern

13: *P. knowltonii* growing in a clump of moss (8 May 2015). Note the sporophytes on the moss and flower buds on the *Pediocactus*, i.e. both species look healthy. The moss germinated in and around the cactus, rather than the other way around.

New Mexico, just south of the Colorado border on a single hill in San Juan County near the Los Piños River. This type and only native locality is a single 10 hectare hill, on land now owned by the Nature Conservancy, plus a small adjacent parcel of U.S. Bureau of Land Management land with less than fifty additional plants (Sivinski & McDonald 2004) describe the habitat as follows:

> *Pediocactus knowltonii* habitat occurs on Tertiary alluvial deposits overlying the San Jose Formation. These deposits form rolling, gravelly hills covered with piñon pine (*Pinus edulis* Englem.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) and black sagebrush (*Artemisia nova* A. Nels.). A relatively dense soil cover of foliose lichen (*Parmelia* sp.) is an unusual aspect of the habitat. This cactus grows in full sun between cobbles and in the understory of sagebrush and conifers.

Given that this species also grows just fine in clumps of moss in sand that is overly fine-grained, the presence of *P. knowltonii* in foliose lichens is not that surprising and may just be coincidental insofar as this is a very tolerant plant. On the other hand, surprisingly, some cacti benefit by growing in association with lichens (Bennett et al. 2003). The recovery plan for P. *knowltonii* noted that (Roth 2018):

> A ten-mile radius south of the *Pediocactus knowltonii* type locality was searched in 1985 and again in 1991 for suitable habitats that are similar to the natural habitat of this species (Ecosphere Environmental Services 1985, Olwell et al. 1987, Sivinski & Lightfoot 1992). Suitability criteria were cobbley substrates in piñon-juniper woodland with a dominant shrub component of black sagebrush. Two locations were selected as suitable reintroduction sites. One was located on Bureau of Land Management land approximately 1.2 miles south of the type locality and another on Bureau of Reclamation land at Navajo Lake approximately 4 miles to the south.

In retrospect, given the tolerance of this species for different growing conditions in cultivation in southern

14: Volunteer seedling (3 June 2015). There is a remote chance that this was simply a dislodged small offset that rooted, rather than a seedling.

Ontario, it is not obvious that such restrictions for potential alternate recovery sites in northwestern New Mexico were necessary. Probably the most important criteria for alternative sites is being able to protect plants from human theft and trampling by cattle. But I also don't blame the decision-makers for being conservative with their recovery plan.

Zlatko Janeba (2011) did a nice job of photographing *Pediocactus knowltonii* at its type locality, just south of La Boca Ranch, in which he also did a superb job of describing how resilient a species this is in terms of both cold and moisture. But it is even tougher than he claimed, being able to tolerate -30°C (not just -20°C) and being able to tolerate lots of water during the hottest parts of summer (we sometimes see heavy rains when temperatures are from +30–35°C in southern Ontario).

DISTRIBUTION

There are occasional undocumented reports of *Pediocactus knowltonii* from Colorado. These reports may be due to this taxon being endemic to an area right by the border, with the state border itself not marked. The Colorado-New Mexico birder is set at 37°N for its entire length, much like the Canadian-US border is set at 49°N from Lake of the Woods to the Salish Sea, i.e. Puget Sound and the Georgia Strait. The problem is precisely identifying where lines of latitudes are, especially in days of yore before GPS. The Canada-US border is delineated by stone markers ("monuments") that were installed between 1872 and 1874 and line segments between them. With the hindsight of GPS, we now know that those boundary markers between Lake of the Woods and the Continental Divide are in error—sometimes north and sometimes south—by an average of 90 m (295 ft), which was very good for a 150 years ago (Rees 2007, Jacobs 2011). See Robert Humphrey's (1987) book on estimating environmental change using repeat photography of border monuments on the straight parts of the Mexican-US border (those not on the Rio Grande) for a similar situation, albeit this time with more cacti. The border between Colorado and New Mexico has not been so well surveyed because…why bother.

The type locality of *P. knowltonii* has been fenced off to protect *P. knowltonii* from cattle. Bob Sivinski, who has been a major player in the monitoring and recovery plan

15: The same volunteer seedling two years later and transplanted to a different garden (20 May 2017).

for *P. knowltonii*, as well as being one of the leading experts on cacti within the State of New Mexico, extensively surveyed the only known locality for *P. knowltonii* and never found this taxon closer than 30 m or 94 ft from the state line (NatureServe 2019; citing an unpublished observation by Bob Sivinski from 2007). Rounded to two significant digits 30 m = 98 ft, while 94 ft = 29 m, which is slight discrepancy that we will ignore. McDonald and Ferguson (1996 [updated 2018]) reported that, "The Bureau of Land Management constructed a new fence on the true NM/CO border about 40 m north of the old fence. In 2008, Bob Sivinski who has monitored plants at the type locality for many years, did a thorough survey on both sides of the fence but did not find it on the Colorado side." In the subsequent decade, still no plants of *P. knowltonii* have been documented from Colorado (Roth 2018). Reports of *P. knowltonii* in La Plata County, Colorado could have simply been due to the fence originally being erroneously placed 40 m south of the actual state border!

Some other sources report *Pediocactus knowltonii* from even farther afield. Gucker (2007) reports *P. knowltonii* from San Juan and Rio Arriba Counties in New Mexico, as well as Archuleta County (but, oddly, not La Plata County) in Colorado, albeit without any documentation. Archuleta and Rio Arriba Counties are over 10 km from the only known native locality of *P. knowltonii*.

RECOVERY PLAN

The recovery plan for *Pediocactus knowltonii* encompassed transplanting stem cuttings of plants from the type locality to a pair of nearby locales 2 km and 6 km south of the type locality (Sivinski & McDonald 2004, Roth 2018). *P. knowltonii* offsets fairly often, both in habitat and cultivation. Success rate for rooting cuttings has been very high in the recovery effort. This comes as no surprise given my experience with cultivated plants. Each year, I probably give away about one-quarter of the offsets from my cultivated plants, seemingly without any detrimental effects. In the recovery plan, the only issue was transplanting cuttings in autumn, in which case heaving of soil due to freeze-thaws pulled plants out of the ground, where they needed to be replanted the following spring. Cuttings are easy to take. The vascular bundles connecting an offset to its parent plant are never very lignified. I usually just pinch off offsets using my fingernails.

A less successful portion of the recovery plan was to plant seeds at the nearby locales. Unfortunately, only a small number of seeds were dispersed and even fewer have germinated. It is also unknown for how long seeds can survive in the seed bank, other than "it seems likely that seed viability of the original seeds planted declined after 8 years in the ground" (Roth 2018). Furthermore, *P. knowltonii* seedlings and mature plants are so small that it may take a few years for a seedling to grow tall enough to be readily noticeable. Consistent with this, two volunteer seedlings of *P. knowltonii* have appeared in my gardens over the past decade, each time germinating about 15 cm from plants that had been in fruit in previous years (Figs. 14–16). Three years ago, I also purchased seed from a vendor, but seemingly none of these have yet germinated or, if they have, are still invisible because of being hidden by the 5 cm top layer of gravel in this garden.

One caveat about the aforementioned seedlings is that I do not have definitive proof that they are actually seedlings, i.e. separate clones. There is a small chance that instead these are small offsets that got detached/dislodged by a medium-sized animal.

While there is, thus far, no decent evidence that *Pediocactus knowltonii* is native anywhere but the single hill just south of the Colorado border in northeastern San Juan County, NM, the population on this hill used to be greater. Soon after this species was described by Lyman Benson in 1960, speculation was that there were approximately 100,000 individual *P. knowltonii* plants on this hill, but that by 1979 only approximately 1,000 individual plants remained (Roth 2018). This rapid decline was largely due to good intentions of some people believing that construction of the 123 m (402 ft) Navajo Dam between 1959 and 1962 would flood this site, therefore virtually extirpating the only known locality, much as was done for the population of *Echinocactus grusonii* Hildmann [synonym *Kroenleinia grusonii* (Hildmann) Lodé] along the Rio Moctezuma in Querétaro with construction of the Zimapán Dam at the border of Hidalgo and Querétaro. The problem for *P. knowltonii* was that water levels behind Navajo Dam never rose high enough to flood the type locality, with the Rio Los Piños still being approximately 15 m (50 ft) below the level of any plants of *P. knowltonii*. But population numbers cited above were only very approximate and may simply be exaggerated, with the first systematic survey using a series of belt transects only occurring in 1992 and concluding that 12,000 individual plants of *P. knowltonii* existed on this hill at that time (Sivinski and McDonald 2004).

CONCLUDING REMARKS

I am not sure where *Pediocactus knowltonii* evolved from, but its extremely limited range on a single 10 hectare hill indicates that it may be of recent origin given how tolerant this taxon is to a wide range of climatic and edaphic conditions. Like *Echinocactus (Kroenleinia) grusonii*, *P. knowltonii* is extremely rare in the wild and may have even been threatened by dam construction, but both taxa are rightfully extremely popular horticulturally, in part because they are so easy to grow and so readily flower in cultivation. Any plant that can survive underneath snow for five months each year and then produce relatively huge flowers mere weeks after the snow melts can't be all that bad!

References

Bennett, J.P., C.R. Bomar, and C.A. Harrington. 2003. Lichens promote flowering of *Opuntia fragilis* in west-central Wisconsin. American Midland Naturalist 150: 221-230.

Benson, L.D.1960. A new *Pediocactus*. Cactus and Succulent Journal 32: 193.

Benson, L.D. 1961. A revision and amplification of *Pediocactus*, I. Cactus and Succulent Journal 33: 39-54.

Benson, L.D. 1962. A revision and amplification of *Pediocactus*, II-IV. Cactus and Succulent Journal 34: 17–19, 57–61, 163–168.

Benson, L.D. 1982. The cacti of the United States and Canada. Stanford University Press, .

Buxbaum, F. 1950 [1953]. Morphology of cacti – section 2: the flower [edited by Edwin B. Kurtz; drawings by Friedl Buxbaum]. Abbey Garden Press

Ecosphere Environmental Services.1985. Endangered and threatened plant inventory: *Pediocactus knowltonii*, distribution and habitat - unpublished report. U.S. Department of Interior, Bureau of Land Management.

Gucker, C.L. 2007. *Pediocactus knowltonii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.fed.us/database/feis/plants/cactus/pedkno/all.html.

Heil, K.D., J.M. Porter.2004. *Pediocactus* Britton & Rose (Cactaceae). In: Flora of North America - Volume 4. Editors: Flora of North America Editorial Committee. Pages 211–216. Oxford University Press.

Humphrey, R.R. 1987. 90 years and 535 miles: vegetation changes along the Mexican border University of New Mexico Press.

Jacobs, F. 2011, November 28 A not-so-straight story. New York Times. http://opinionator.blogs.nytimes.com/2011/11/28/a-not-so-straightstory/#.

Janeba, Z. 2011. Visiting *Pediocactus knowltonii* in the field. Cactus World 29: 9–12.

16: Another volunteer seedling (7 June 2019).

Mauseth, J.D. 2006. Structure-function relationships in highly modified shoots of Cactaceae. Annals of Botany 98: 901–926.

McDonald, C., D.J. Ferguson. 1996 [updated 2018]. *Pediocactus knowltonii* (Knowlton cactus) http://nmrareplants.unm.edu/rarelist_single.php?SpeciesID=127.

NatureServe.2019. *Pediocactus knowltonii* - L. Benson (Knowlton's cactus). NatureServe Explorer: an online encyclopedia of life; Version 7.1 http://explorer.natureserve.org.

Olwell, P., A. Cully, P. Knight, and S. Brack. 1987. *Pediocactus knowltonii* recovery efforts. In: Conservation and management of rare and endangered plants: proceedings from a conference of the California Native Plant Society. Ed.: T.S. Elias. Pgs. 519-522. California Native Plant Society.

Panchen, Z.A., R. Gorelick. 2015. Flowering and fruiting responses to climate change of two Arctic plant species, purple saxifrage *(Saxifraga oppositifolia)* and mountain avens (*Dryas integrifolia*). Arctic Science 1: 45-58.

Rees, T. 2007. Arc of the Medicine Line: mapping the world's longest undefended border across the western plains. University of Nebraska Press and Douglas & McIntyre.

Roth, D. 2018. *Pediocactus knowltonii* (Knowlton's cactus) – summary report (Section 6, Segment 32). U.S. Fish & Wildlife Service, Region 2, Albuquerque, NM. New Mexico Energy, Minerals & Natural Resources Department - Forestry Division, Santa Fe. [Daniela Roth gives full credit to Bob Sivinski for previous versions of this report]

SEINet (n.d.) SEINet Arizona-New Mexico chapter http://swbiodiversity.org/seinet/taxa/index.php?taxon=Pediocactus+simpsonii&formsubmit=Search+Terms.

Sivinski, R. C.and K. Lightfoot.1992. Summary of Knowlton's cactus (*Pediocactus knowltonii*) recovery efforts - unpublished.U.S. Fish & Wildlife Service, Region 2, Albuquerque, NM. New Mexico Energy, Minerals & Natural Resources Department - Forestry Division, Santa Fe.

Sivinski, R. C. and C. McDonald. 2004. Knowlton's cactus (*Pediocactus knowltonii*): eighteen years of monitoring and recovery actions. In: Southwestern rare and endangered plants: Proceedings of the Fourth Conference (22-26 March 2004). Eds.: Barlow-Irick P, J. Anderson, and C. McDonald. Pgs. 98–107. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station (RMRS-P-48CD), Las Cruces, New Mexico.