Patterns of Growth and Mortality in the Endangered Nichol's Turk's Head Cactus (*Echinocactus horizonthalonius* var. *nicholii* L. Benson; Cactaceae) in Southeastern Arizona.

MCINTOSH, M.E.[1], L.A. MCDADE[1,2], A.E. BOYD[3] AND P.D. JENKINS[1].

[1]Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, Arizona 85721
[2]Academy of Natural Sciences, 1900 Ben Franklin Parkway, Philadelphia, Pennsylvania 19103
[3]Warren Wilson College, P.O. Box 9000, Asheville, North Carolina 28815.

ABSTRACT. Nichol's Turk's Head Cactus (*Echinocactus horizonthalonius* var. *nicholii* L. Benson; Cactaceae) occurs in a few isolated populations in the Sonoran desert of south-central Arizona (Pima and Pinal counties). The populations of this variety are disjunct from the more widespread variety that occurs in the Chihuahuan desert of Texas and Mexico. This species occurs only on limestone-derived soils, and the *nicholii* variety was federally listed as endangered in 1979. Since 1995 we have monitored study plots of this cactus in the Waterman Mountains (AZ), measuring growth and reproduction of about 175 tagged individuals. Growth rates were slow, averaging 0.3 cm in height and 0.2 cm in width per year. Plants usually began flowering when they reached around 4 cm high and 8 cm wide. Of the 52 deaths recorded since 1995, about half followed a visible decline in condition; the rest were unanticipated. There was a distinct jump in mortality during the past two years, possibly due to drought.

INTRODUCTION

Although *Echinocactus horizonthalonius* is widely distributed in the Chihuahuan desert of west Texas and Mexico, the variety *nicholii* only occurs in a few locations in southeastern Arizona. Variety *nicholii* thus forms a disjunct population. This cactus was federally listed as endangered in 1979, due to the limited range and known threats to its existence. Because it is endangered, demography information is of interest to land managers and conservationists.

Since 1995, we have monitored ca. 175 individuals in four study plots in the Waterman Mountains of SE Arizona. This population has been estimated at approximately 10,000 plants. Here we present some preliminary descriptive data on plant size, growth, and mortality.

METHODS

Six described species of *Echinocactus* grow in the southwestern U.S. and Mexico. Of the two varieties described by Benson (1969), variety *nicholii* is the only one that occurs in southeastern Arizona. Recent studies suggest that the two varieties may not be as distinct as was once thought (Chamberland 1995). Variety *nicholii* grows on limestone-derived soils in the Upland Division of Sonoran Desert Scrub at elevations ranging from 600 to 1,100 m (Turner et al. 1995). The perceived threats to this plant at the time of listing were mining of limestone deposits, off-road vehicle use and collection.

The study site is in the Waterman Mountains of southeastern Arizona, approximately 50 km WNW of Tucson (32°21′N, 111°28′W, elev. 975 m). The Waterman Mountains and surrounding area became part of the Ironwood Forest National Monument, administered by the Bureau of Land Management, in 2000.

For three of the four study plots, we selected a general location, and then determined the borders and the size of the plot using a random number generator, to avoid favoring plots with an unusually high density of plants. The fourth plot was selected for convenience along both sides of a trail. The study plots range in size from ca. 100 square meters to ca. 550 square meters (total area under study: 1,120 square meters, or about 0.11 hectare). The plots also differ from each other in slope and orientation.

Plants were marked with numbered aluminum tags at the initial survey in the fall of 1995. At each subsequent census, which usually occurred in January (but as late as March in 1999) we recorded height and width of each plant to the nearest 0.5 cm, noted presence/absence of fruits, and took notes on the condition of each plant. The plots were not censused in the winter of 2002-2003.

RESULTS

The density of plants in the study plots has ranged from 0.05 plants per m^2 to 0.29 plants per m^2 (range is across plots and years). Average density (pooled across sites, ranged across years) has ranged from 0.10 plants per m^2 to 0.12 plants per m^2, or from 9 to 10 m^2 per plant.

Plants are round disks when young, becoming cylinder- to pyramid-shaped as they grow. Width increases until it reaches ca. 15 cm, then levels off (Fig. 1). Height continues to increase throughout the life of the plant. Only in the very tallest plants does height ever exceed width (Fig. 1).

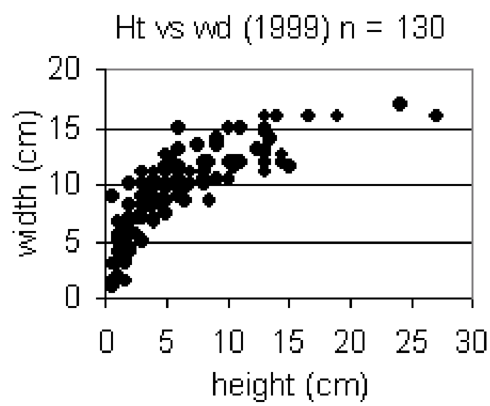

Figure 1. Plant height versus width for 130 plants in 1999. Each point represents one plant.

Because growth in height continues indefinitely whereas growth in width levels off, size classes based on height may be more useful than those based on width (however, it is easier to measure width accurately). We show both types of size classes in order to compare our data to that of Reid et al. (1983) (Fig. 2a, b). The distribution of individuals among size classes based on height is similar for 1995 and 2003, although there are more individuals in size class 3 (height = 6.0 to 8.5 cm) in 2003 than in 1995 (Fig. 2a).

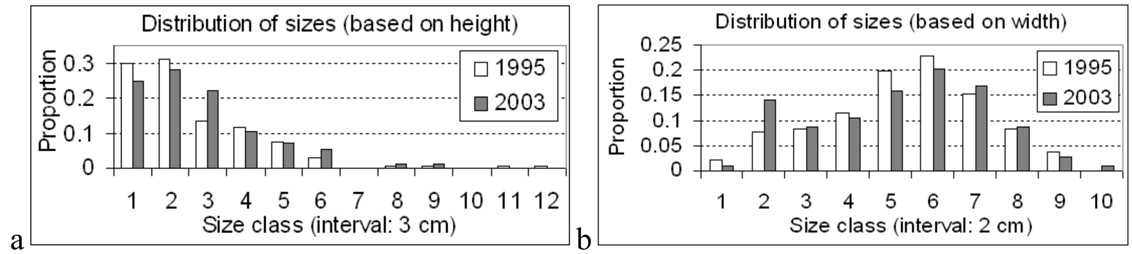

FIGURE 2. Proportion of individual plants in size classes. a) size classes based on plant height using equal intervals of 3 cm. b) size classes based on plant width using equal intervals of 2 cm.

Size at first reproduction is usually 8 cm in width and 4 cm in height, although a few individuals as small as 6 cm width and 2 cm height have flowered. Therefore, individuals in height size class 2 and up, and width size class 5 and up, may be considered adults (Fig. 2).

Growth is slow. From 1995 to 2003 (8 yr), plants grew about 2.3 cm in height and 1.5 cm in width, or 21 cm^3 in plant volume (Table 1). Thus plants grow an average of 0.18 cm per year in width, and 0.29 cm per year in height. Growth rates for both height and width decrease gradually as size increases (Fig. 3a, b). The number of plants in our study plots (plots pooled) has declined during the survey, with a particularly sharp drop during the last two years, possibly as a result of prolonged drought (Fig. 4). The differences in mortality rates among the different size classes are not significant, suggesting that there is no size class that is particularly vulnerable (data not shown).

TABLE 1. Average growth of individual plants during the 8 yr period 1995-2003. N = 78 plants. Plant volume is calculated as the volume of a cylinder.

	Mean	SE	Range
Change in plant height (cm)	2.33	0.18	6.0 to -3.0
Change in plant width (cm)	1.45	0.15	4.0 to -3.0
Change in plant volume (cm^3)	20.6	2.53	76 to -57

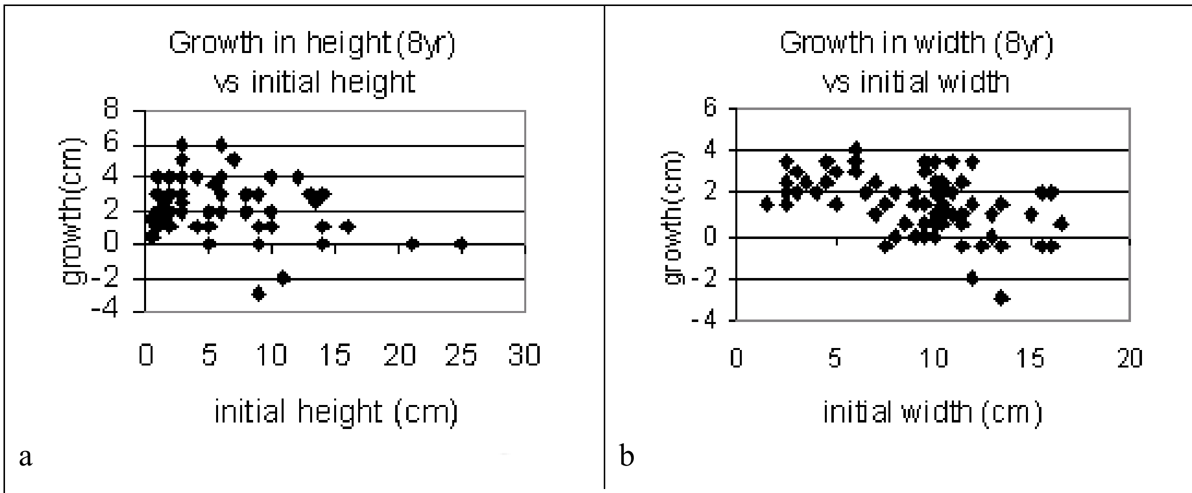

FIGURE 3. Growth 1995 to 2003 as a function of initial size. a) growth in height. b) growth in width.

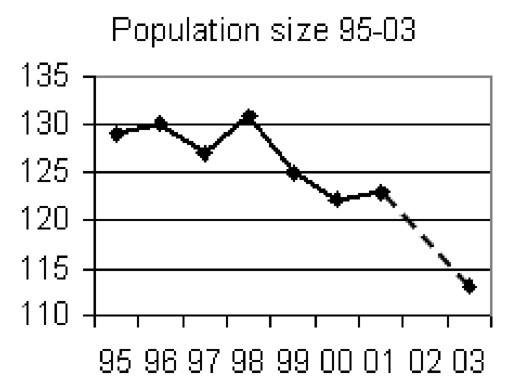

Figure 4. Population size (pooled across study plots) over time, 1995 to 2003. The population was not censused in 2002.

During our surveys, we note the condition of each plant. In some cases, plants sustain obvious damage such as gouging or being dug up. Other conditions noted include surface discoloration, which is quite common, desiccation evidence such as puckering or wrinkling, surface irregularities such as blistering or flaking, and patches of dead or rotting tissue. Some of these indicators are associated with the subsequent death of the plant, others less so. For example, signs of desiccation are relatively common among the "trouble reports," but are relatively rare as a precursor of death (Table 2). On the other hand, necrosis is not often mentioned, but when it is, the plant is very likely to die during the next year (Table 2). However, of plants that died, only about 48% showed signs of trouble the previous year, suggesting that "sudden death" is quite common.

DISCUSSION

Reid et al. (1983) measured 174 individuals of *E. horizonthalonius* in Texas just outside of El Paso, and created size classes based on 2 cm intervals of plant width (as we do here). Their distribution of individuals among size classes was more irregular than ours, but it is worth noting that in both studies, the proportion of individuals peaked in size class 6 (width = 10 to 12 cm) (Fig. 2b).

Table 2. Fatal versus non-fatal plant conditions. *N* = number of plants. Only plants that were recorded as having a problem or condition are included.

Condition	Percent plants with this condition that died (*n*)	Percent plants with this condition that lived (*n*)	No. plants with this condition (percent of all plants)
Necrosis (necrotic, rotting, dead flesh)	37% (3)	63% (5)	8 (7%)
Discoloration (cuticle red, yellow, brown, burned-looking)	30% (14)	70% (33)	47 (38%)
General poor condition (not specified)	20% (1)	80% (4)	5 (4%)
Damage (gouge, exit hole, torn open)	14% (3)	86% (19)	22 (18%)
Surface irregularity (cracks, blisters, dimples, peeling, flaking, "warts")	11% (1)	89% (8)	9 (7%)
Desiccation (wrinkled, puckered, shriveled)	9% (3)	91% (29)	32 (26%)
TOTAL	20% (25)	80% (98)	123

Dimension measurements such as height and width depend on the water status of the plant (some plants actually shrank in overall size over the eight years of the study). Previous studies have suggested that these plants require ten to thirty-two years to reach a height of 5 cm (cited in AGFD 1994). Extrapolating from our growth data would give an age of 17 years for a plant 5 cm high. These extrapolations are probably of limited value. For example, we found that size at first reproduction is about 8 cm wide and 4 cm high; extrapolating from our growth rates would give a cactus of this size an age of 14 yr (based on height) to 44 yr (based on width).

An alternate method for measuring growth is to count the number of new areoles that appear in a time period—this could be done by marking the central spine of each spine cluster (May et al. 1986). New areoles represent actual new tissue generated at the apical meristem. It has been suggested that plants of the same height and width can be very different ages (May et al. 1986), and the high variance in growth rates among individual plants that we found is consistent with that suggestion. If, as has been suggested (May et al. 1986), these plants generate one new areole per rib per year, counting areoles could be a much better method for correlating size with age. We plan to include this method in our further monitoring of these plants.

Our study was inspired in part by a monumental but somewhat obscurely published study of *Sclerocactus polyancistrus* following 350 individual plants over 15 years at six study sites (May 1994). Of particular interest was the author's detailed analysis of causes of mortality. Careful observation and dissection of carcasses enabled him to develop a unique system of carcass classification. Small mammal predation resulted in "open" carcasses, in which the flesh of the plant was chewed, torn apart, or completely consumed, with mammal scat being found nearby. "Closed" carcasses could be attributed to insect infestation, indicated by bore holes, exit holes, and the remains of pupal cells in the soil directly below the plant. Mammal predation was much more common than infestation.

Without further study, our condition notes cannot accurately inform us about the ultimate or even proximate causes of death of the plants in our study. For example, we classified wrinkling and puckering as signs of desiccation, but other signs such as surface discoloration may also be due to desiccation. May (1994) found stem discoloration to be associated with insect infestation. A distinction can also be made between proximate and ultimate causes of mortality; for example, a plant weakened by drought may be more susceptible to insect infestation. Finally, about half of the plants that died during our study showed no signs of trouble in the previous year; this could be more suggestive of predation than of environmental factors. However, environmental stressors such as frost damage can lead rapidly to necrosis and death.

Many plants that have died are found as intact, standing corpses, which may suggest infestation. For example, of the 20 plants that died between the 2001 census and the 2003 census, eight were found as intact carcasses. Of the rest, three were found as shreds of a carcass, for four we found only scattered spine clusters, four were gone without a trace (although we found the tags), and one was buried under a pile of soil at the entrance to a rodent burrow. Dissection of living and dead plants would be needed to confirm the possible presence of burrowing insects such as the cactus beetle (*Moneilema* spp., Cerambycidae).

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