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Welwitschia's water sources

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Untersuchungen der Wurzeln einiger Welwitschia mirabilis Pflanzen, die umgesiedelt werden mussten, ergaben überraschende Einsichten: Zum einen bezüglich der Wurzelarchitektur, welche die bisherigen Wurzelstrukturuntersuchungen ergänzten, zum anderen bezüglich des Ursprungs des genutzten Wassers; eine Isotopenanalyse des in den Wurzeln enthaltenen Wassers erwies, dass diese Pflanze mehrheitlich kontinentales Regenwasser nutzt, neben Nebel und Grundwasser.

Welwitschia mirabilis, an extremely long-lived endemic plant of the hyperarid Namib Desert (Figure 1), appears to flaunt its conditions of water scarcity by being evergreen, broadleaved, continuously growing and maintaining high evapotranspiration (about a liter of water per day). Over centuries to millennia it avoids dehydration by somehow getting sufficient water from somewhere. *Welwitschia's* remarkable water story may not be a Just So Story, as it points to some fundamental principles of desert ecohydrology.

This was recently described by Henschel *et al.* (2019) based on data collected during 2012-2014, when the need for the Husab Uranium Mine to remove seven *Welwitschias* from the Welwitschia Plains population to make way for the construction of a pipeline and road, presented an opportunity to excavate plants (Figure 2) and study the roots and their surrounding soils (Figure 3). Many tons of gravelly soil were moved while digging up the plants (Figure 4). These *Welwitschias* were finally replanted at the Namib Botanical Gardens or at sites elsewhere on the Welwitschia Plains (Figure 5).

By examining root architecture in relation to soil moisture and analysing the isotopic composition of hydrogen and oxygen of samples taken from the plant and soil, a team of investigators established whether *Welwitschia* obtains water from groundwater, which is 57-75 m deep on the gravel plains of the Welwitschia Plains, or whether shallow moisture from fog during the 50-90 events per year

could be a source of water. How does this compare with local rainfall, annually averaging 31 mm of precipitation, as a source of water? First, let's see what the roots tell us.

We mapped roots over lengths of 22 to 62 m per plant. Roots grew sideways from the stem by 2.4-9.0 m, and down to depths of 1.2-1.8 m (Figure 6). The total amount of roots was correlated to stem size (r=0.90); bigger-stemmed plants (presumably older individuals) had more extensive root systems. Though complex, root architecture of the seven plants showed generally similar patterns of branching, with most branching of main roots occurring within a m of the stems (Figure 7-1a,b,2a). It was surprising how such fragile roots could penetrate extremely hard substrates, growing through solid calcrete (Figure 7-5b,c). Roots could suddenly increase diameter up to seven-fold, maybe to store water? They could split to squeeze through narrow cracks, then reunite, and abruptly turn in any direction, including looping back onto themselves (Figure 7-4c,5a), even growing back into the stem (Figure 7-2a,3a,b). In addition, many roots completely merged with other roots of the same plant, continuing as one after fusion (Figure 7-1c,2a,b,3c,4a,b), and there were many examples of splitting and merging in succession, not necessarily with the same roots. Some roots extended independently over several m before joining, forming a large loop, thus a deep root of one plant made a loop with a circumference of 9 m. *Welwitschia* roots were recorded twisting around the roots of other shrubs (Figure 7-2c). Roots typically tapered until they ended in a distal network of fine roots, but sometimes they ended abruptly (Figure 7-6a,b,c).

The commonly-assumed idea of *Welwitschia* being a phreatophyte (tapping into groundwater) was not applicable, because none of the roots penetrated deeper than 2 m, whereas the groundwater was still located >50 m deeper. That these plants did not reach groundwater was confirmed in the analyses of isotopes. Although 40% of the *Welwitschia's* total distribution range in the Namib Desert is in areas where fog occurs regularly, as on the Welwitschia Plains, the isotopic water analysis indicated that our study plants obtained only a small proportion of water from fog. Interesting enough, we recorded 14% of all fine roots growing upwards from deeper levels, and reaching the soil surface in a 1.5 m wide band around each plant. It is quite possible that it is through these fine roots at the surface that *Welwitschias* collect fog water deposited on the soil or from runoff from the corrugated leaves. In the Namib, fog and dew are the most frequent source of free surface water, and could thus sustain *Welwitschias* during prolonged intervals between rainfalls. Our most surprising finding from isotopic analyses was that local rainfall turned out to be the principal water source, although it is so extremely erratic and rare in the Namib (minimum-median-maximum at Rössing Uranium Mine: 1-25-98 mm per annum, coefficient of variation 80%).

A concrete-like flat layer of calcrete – termed petrocalcic horizon – at depths of 93-125 cm seems to prevent rainwater from infiltrating any deeper, resulting in high levels of moisture at this depth. About a quarter of *Welwitschia's* major roots and fine roots grew horizontally in this thin, moist layer on top of the solid calcrete floor (Figure 8). The water trapped on this floor could perhaps be seeping sideways towards *Welwitschias* from surrounding areas, to replenish the water supply. If that is the case, then cracks or breaches of this petrocalcic horizon, e.g., mining activities, could impede the water supply.

Surprisingly, most (55%) *Welwitschia* roots were concentrated in a dense network in a higher layer between 10-66 cm deep, a layer where gypsum infused the gravel (Figure 3 & 8). Gypsum is a hydrophilic salt, which would presumably draw water from roots. So why did over half of the roots grow in this layer? In the field, soil at 10-66 cm warms up a bit by one or more degrees during the day, and cools down again at night. In the laboratory we found that warming released some 600 ml of water per 1°C of warming in the gypsum layer around *Welwitschia* roots, and gained this water again from atmospheric moisture when cooling. If *Welwitschia* roots managed to collect water released during warm hours of the day, and move it away from the gypsum layer before it cooled at night, it could effectively harvest water from gypsum. The gypsum may, in turn, replenish its hydrophilic demand from evaporated moisture coming from deeper layers or vapor penetrating from the soil surface at night.

The mechanisms employed by *Welwitschia* roots to obtain and retain water remains to be confirmed and understood, but it is clear that roots enable this extremely long-lived evergreen to reduce risks of running out of water even in the driest phases of a hyperarid desert. The demonstration of *Welwitschia's* resilience against dehydration – though coming from a case study of an extremophile – is instructive for future studies of ecohydrology of soil at root level in deserts. It also demonstrates so clearly that long-held assumptions and inferences cannot replace empirical studies. Given that prolonged drought and heatwaves that increase evapotranspiration is currently a topic of such looming importance across southern Africa, there is comfort in the idea that there is one plant that has seemingly overcome the risks of drought: the *Welwitschia*, an enigmatic plant which never ceases to amaze anew.

Acknowledgements

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Henschel, J.R., Wassenaar, T.D., Kanandjembo, A., Kilbourn Louw, M., Shuuya, T., Neef, G., Soderberg, K. (2019) Roots point to water sources of Welwitschia mirabilis in a hyperarid desert. Ecohydrology 12(1): e2039 1-12. https://doi.org/10.1002/eco.2039.

Figures

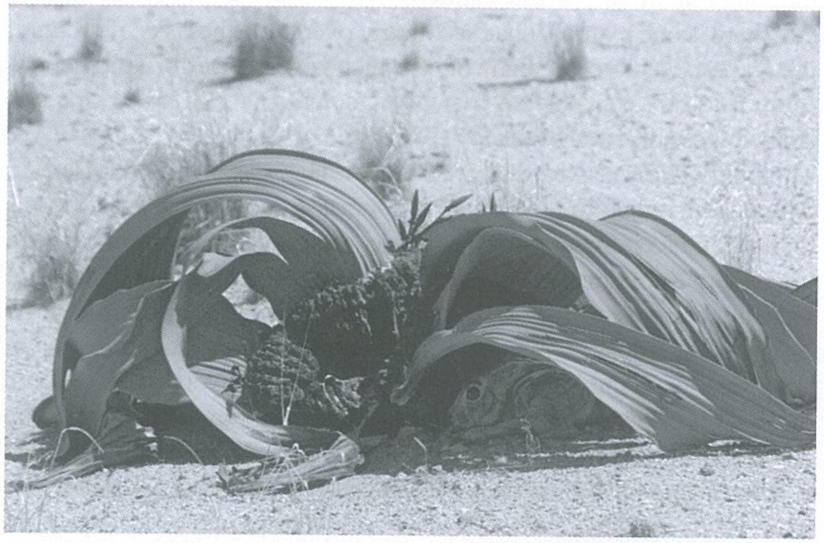

Figure 1: *Welwitschia mirabilis* on the Welwitschia Plains near Swakopmund, Namibia (Source: picture p34 of Henschel 2012)

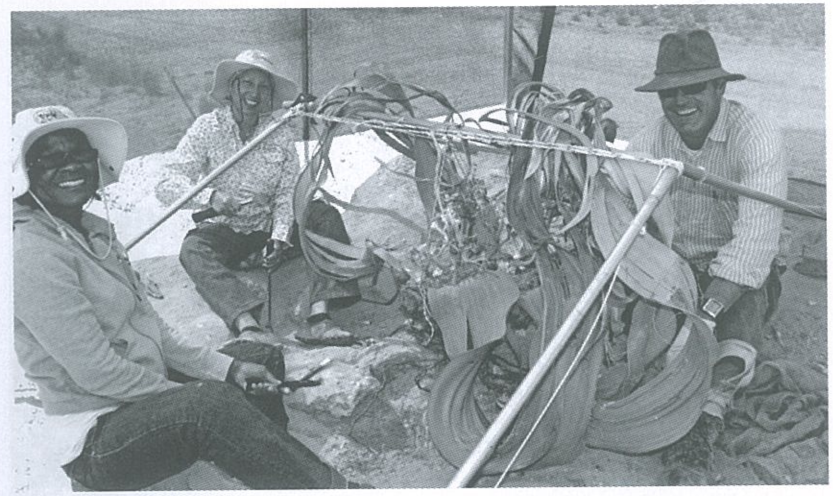

Figure 2: Many dedicated hands made the task of excavating and mapping *Welwitschia* roots possible, including (l-r) Dr Ndafuda Shiponeni from the University of Namibia, Theresa Henschel from EnviroMend and Frank Löhnert from the Namib Botanical Gardens, Swakopmund (photo Joh Henschel)

Figure 3: A dense root network of this female *Welwitschia* penetrates gypsum layers at 10-66 cm depth (photo Joh Henschel)

Figure 4: It took a total of 37 days in the field to excavate seven *Welwitschia* plants and map their roots, often entailing die-hard efforts to get to the bottom; the yellow stem next to Theresa Henschel marks the original position of the removed *Welwitschia* stem (photo Joh Henschel)

Figure 5: Excavated *Welwitschia* plants were moved, roots and all, to new sites where they were replanted, but only one transplant survived, this being the smallest plant shown here, for which the volunteer field assistant, otherwise tour operator, Werner de Hilster, carefully embedded the roots among blocks of gypsum (photo Joh Henschel)

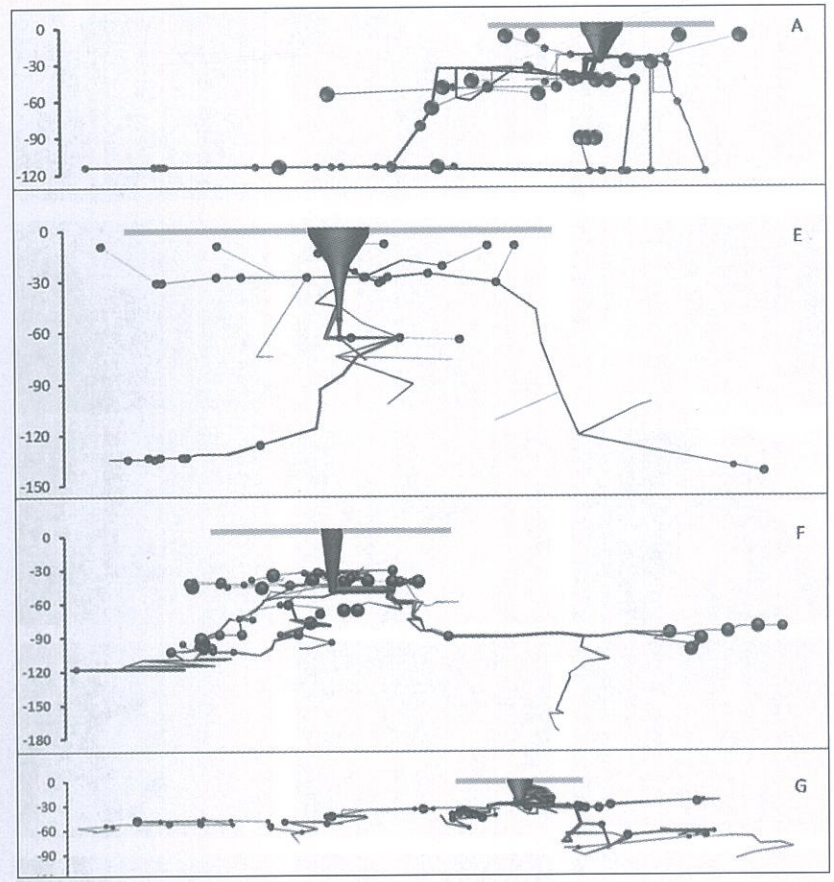

Figure 6: Side view of the root pathways in the ground of four *Welwitschias* (labelled A, E, F and G) growing from the conical stem between two 1 m long green bars for scale on the x-axis. The y-axis scales show 10 cm intervals of depth into the ground. The most dense networks of fine roots are shown as blue spheres of different sizes. All plants had fine roots near the surface in a 1.5 m radius of the stem, but these are only mapped for plants A and E (Source: Fig. 3 from Henschel *et al.* 2019)

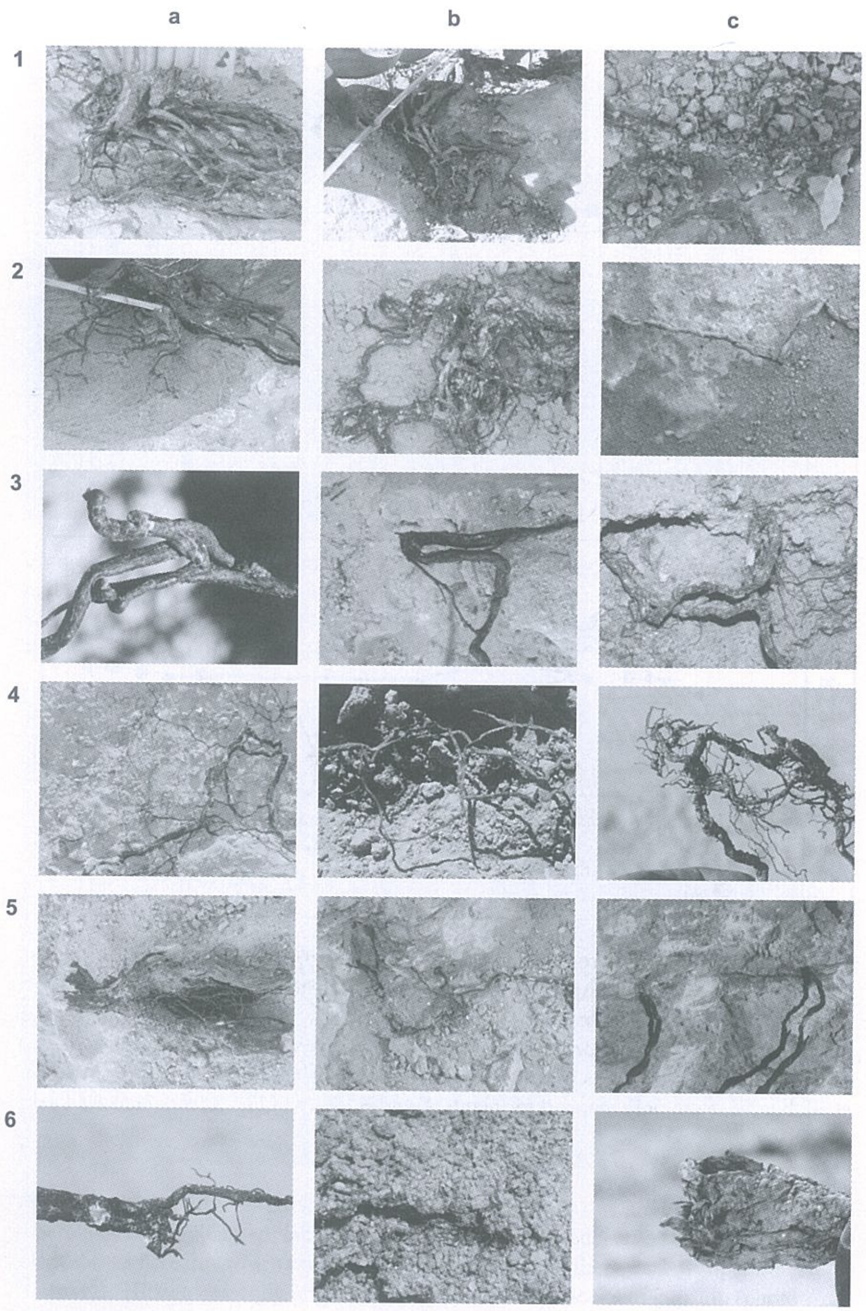

Figure 7: Photos of *Welwitschia* roots which illustrate their complexity: 1a) interlacing; 1b) repeated splits and merges; 1c) merge and split; 2a) root returns to stem; 2b) twisted roots; 2c) fine roots wrap foreign root; 3a) root knot; 3b) cross-connections; 3c) split, loop, merge; 4a) loop with interconnection; 4b) parallel junction; 4c) fine roots cross loop; 5a) fine roots fill gap at junction; 5b) split before hard substrate; 5c) penetrate calcrete; 6a) terminal ending; 6b) abrupt ending; 6c) dead end (Source: Fig. S3 from Henschel *et al*. 2019)

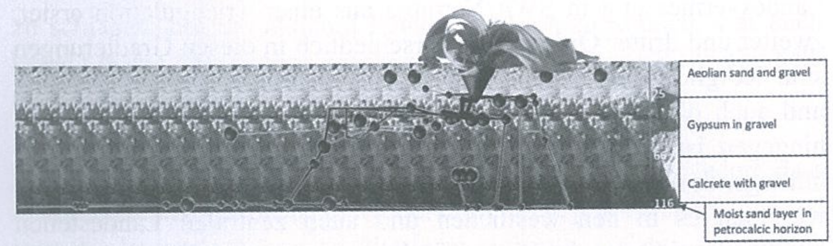

Figure 8: Main roots (lines) and fine roots (blue spheres) of a *Welwitschia* (plant A) in different soil layers from the surface down to depths indicated by the white numbers (cm) to the left of the legend and to the right of the vertical tape measure (Source: Fig.6 from Henschel *et al*. 2019)