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GYPWORLD Africa: Setting an agenda for gypsum ecosystem research in southern Africa

Significance:

This paper introduces gypsum ecosystem research to southern Africa. It is the result of current joint efforts to compare African gypsum ecosystems with those in other parts of the world. We highlight the expansion of an international network through joint projects and training of young scientists. We propose a research agenda to sensitise the ecological community in Africa to the significance of life on gypsum and to demystify the existence of gypsum soil and associated ecosystems in southern Africa.

Gypsum ecosystem research is rapidly moving up the international research agenda to better understand the dynamics and resilience of the life systems associated with atypical soils that are frequent in semi-arid to arid ecosystems. The southern African soil classification system does not sufficiently recognise the presence of gypsum as a differentiating criterion, hence not much is known about the region's gypsum soil, and gypsum ecology has subsequently been largely neglected. This neglect is unfortunate, as the livelihoods of people are dependent on these gypsum ecosystems and these areas are worthy of protection due to the rare biotas that are adapted to survive in these harsh environments.

One of the key players in gypsum ecosystem research, GYPWORLD (a European H2020-MSCA-RISE GYPWORLD project), approached the GeoEco Lab at the North-West University (NWU) to arrange a first research expedition to major gypsum areas of southern Africa, with a specific focus on the central Namib Desert of Namibia and Namaqualand in the northern Cape, South Africa. The goals of GYPWORLD are to (1) assess plant and lichen diversity associated with gypsum soils; (2) determine the origin of gypsophilic biotas worldwide; (3) understand the processes that regulate plant and lichen ecosystem function; (4) promote the study of gypsum ecosystems; and (5) communicate the ecological and conservation value of these ecosystems to the public.

The expedition from 12 August to 4 September 2022 was attended by 26 experts from Brazil, Namibia, South Africa, Spain, Turkey, and the USA. Participating researchers exchanged skills and knowledge during the expedition and in two public seminars. The seminars provided opportunities for scientists to network and discuss research related to plant, lichen and community dynamics and conservation. The first was hosted by the Unit for Environmental Sciences and Management at NWU on 11 August 2022, and the second by the Gobabeb Namib Research Institute on 23 August 2022. Delegates provided background information on southern Africa's gypsum ecosystems and discussed leading international research dealing with gypsum ecology and associated lichen and plant communities. Two invited Fulbright US Scholars, who are specialists on life in harsh environments, contributed to the discussion about the state of gypsum research in southern Africa, including current knowledge gaps. Young scientists participated to stimulate their thinking on the links between diversity, function, evolutionary history, and disturbance in these ecosystems and contributed interesting perspectives to the discussions.

The seminar participants emphasised that significant knowledge gaps in gypsum characteristics preclude assumptions about the age, origin and ecological significance of the pedogenic gypsum soils along Africa's southwestern coast. A lack of in-depth local knowledge regarding gypsum indicator species, particularly distinguishing between gypsophiles (endemic – restricted to gypsum) and gypsovags (those on both gypsum and non-gypsum soils), when studying gypsum ecology and community assembly, were also highlighted.

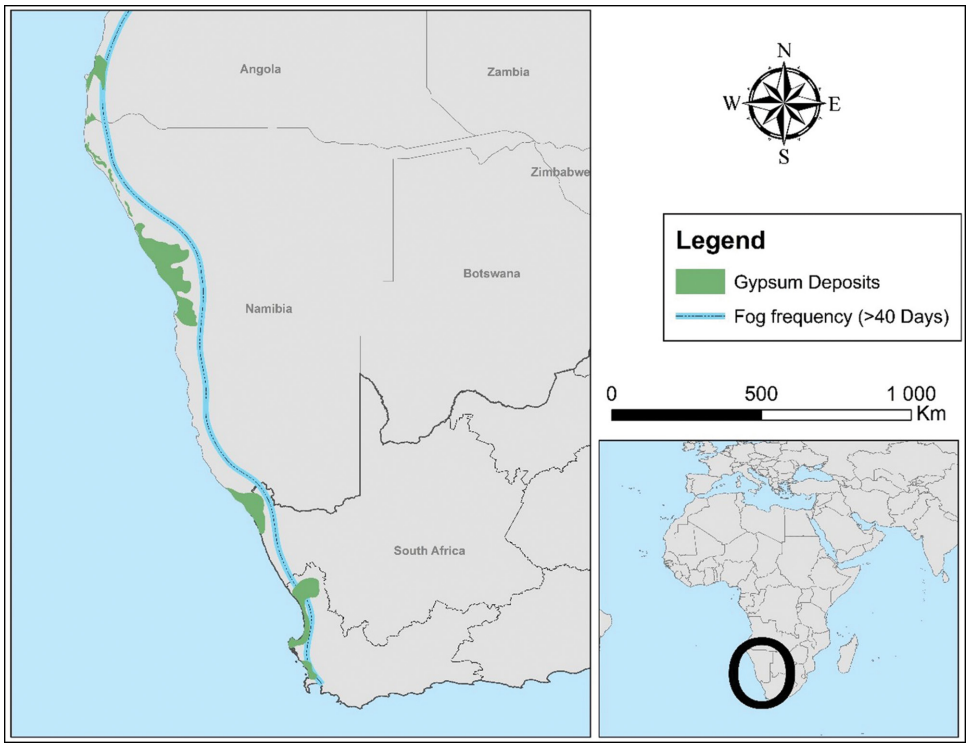
Implications for the broader southern African ecological community

Prioritising gypsum ecosystem research in southern Africa will further increase the opportunities for international collaboration. Already, new opportunities for joint efforts to compare African and European gypsum ecosystems have been identified. There is also potential for greater access to international funding given the global relevance of the research. Such funding initiatives will afford young scientists with a unique and valuable opportunity to work with world leaders in the field and lay the foundations for future networking and collaboration. It is our aim that knowledge transfer will continue and not be limited to the 2022 engagement. We will achieve this by expanding our international network through joint projects and training of young scientists to sensitise the ecological community to the significance of research of life on gypsum and demystify the existence of gypsum soil and ecosystems in southern Africa.

Priority research required to bolster gypsum ecology research in southern Africa

Gypsum characterisation

Gypsum is a soft sulfate mineral ($CaSO_4 \cdot 2H_2O$) that forms deposits along the coast from southern Angola to South Africa and into the interior of South Africa (Figure 1). In some areas of the Namib Desert, pure gypsic deposits of up to 4 m deep and extending up to 100 km inland have been reported.[1] Detailed geological maps for gypsiferous deposits in southern Africa are not readily available[2], thus characterisation of gypsum distribution, depth of the soil profile, and gypsum content (%), is a crucial first step to study the region's gypsum ecosystems.



Source: Data obtained from various sources[2,3,4]

Figure 1: Pedogenic gypsisols are associated with the Benguela Upwelling System in southern Africa.[2,3] Mean annual rainfall for most of this coastal region with >40 fog days per year is less than 50 mm.[3,4]

Most South African deposits are derived from bedrock materials,[2] with those along the Namaqualand coast of similar pedogenic origin as deposits along the coast of Namibia and Angola. It is likely that pedogenic gypsum in the Namib Desert originates from marine H_2S derived from phytoplankton decomposition in the highly productive Benguela Upwelling System (BUS) that is transported inland together with advective fog.[1] The mixing of marine sulfates with calcareous dust from the interior results in the formation of calcium sulfate minerals[2], primarily gypsum. The close association between the formation of extensive gypsum deposits and the evolution and northwards extension of the BUS and Namib Desert aridity is clear, but debate about the process, age and rate of deposition is ongoing.

Precipitation

The Benguela Current draws surface water away from the west coast of southern Africa and carries it northwards, which results in the upwelling of cold, but nutrient-rich, deep ocean water. Cold, coastal waters inhibit the development of convective rain clouds and inflow of atmospheric moisture over the southwest coast of Africa. The arid conditions imposed by the proximity of the BUS, which are alleviated by distance from the coast, are a distinctive feature of the region's pedogenic gypsum soils. Water availability, provided by meagre rainfall and advective marine fog closer to the shore, is the most important factor driving environmental processes. Along the coast, fog (usually formed at night and dissipated during the day) and low clouds are advected over the adjacent coastal plains by onshore sea breezes from the South Atlantic Ocean[4], depositing varying quantities of fog water (Figure 1). The water has a low salt content and is a relatively predictable, though temporary, source of water for biota. Rainwater is rarely available on the surface, yet sporadic rain events are critical for many life forms and are the trigger for plant germination and growth. An improved understanding is required of how changes in the patterns of rainfall, likely resulting from global change, would alter seasonal and daily soil moisture levels and influence patterns of plant and lichen community composition.

Floristics

Although lichen and plant species growing in gypsisols in southern Africa have been described in regional floras and ecological studies, a comprehensive list of those species strictly linked to gypsum soils is still lacking. A first step is to identify gypsophiles and gypsovags[5] by performing an exhaustive survey of gypsum and surrounding non-gypsic areas (Table 1). A special effort should be devoted to annual plants that are only intermittently present and may not have been observed during our recent survey. Similarly, microlichens and biological soil crusts should be described to better document cryptic diversity. Once the diversity is better documented, identification keys for both plants and lichens should be prepared. This floristic work will greatly benefit further research and global comparisons of diversity of gypsum ecosystems. Specifically, comparing gypsum diversity of southern Africa with those of other world regions would aid in completing the list of families, genera and species adapted to gypsum and to determine if there is a characteristic gypsum flora in southern Africa. This would be an important step to advance the study of evolutionary processes driving adaptation to gypsum soils and ecological processes determining gypsum community assembly.

Community ecology

An exhaustive review of studies (on the Web of Science database) that deal with plant and lichen community composition on gypsum soils in southern Africa (south of latitude 17°S), rendered a bleak framework for gypsum community ecology in the region (Table 2). The only study that explicitly considered the species composition of natural vegetation growing on gypsum soils was performed almost 50 years ago in Botswana.[6] This study reported distinctive floristic composition, but no clear evidence of exclusive species. The lack of studies is very striking considering that plant communities have been profusely surveyed in Namibia[7] and in arid and semiarid regions of South Africa, such as the diverse Succulent Karoo biome.[8] Given the large land extensions with some degree of gypsum content in soils, we suggest the likelihood that many vegetation studies were performed on gypsum soils without an explicit mention. Similarly, no studies were found dealing with plant–plant interactions or seed germination of plants growing on gypsum soils (Table 2). Therefore, an imperative first research step is to characterise and compare plant community composition, diversity, and structure between gypsum and non-gypsum soils under similar environmental conditions. This would allow identification of gypsum indicator species and a better understanding of the relevance of gypsophily. Since gypsum outcrops confer additional harsh conditions compared to non-gypsum soils, especially in arid environments, we might expect a

Table 1: Families and genera of vascular plants and lichens recorded from gypsum soil during the 2022 expedition

Vascular plant families	Number of species	Lichen families	Number of species
Aizoaceae	18	*Teloschistaceae*	10
Asteraceae	9	*Ramalinaceae*	7
Amaranthaceae	5	*Parmeliaceae*	4
Crassulaceae	4	*Acarosporaceae*	3
Fabaceae	4	*Caliciaceae*	2
Solanaceae	4	*Lecanoraceae*	2
Zygophyllaceae	4	*Lichinaceae*	2
Euphorbiaceae	3	*Physciaceae*	2
Poaceae	3	*Verrucariaceae*	2
13 other families	13	12 other families	13
Total	67	Total	47

Table 2: Search terms included in the Web of Science for all databases from 1901 to 2022 (search data 21 October 2022)

Search terms	Reference	Observation
Plant **community** AND Africa AND gyps* NOT bird NOT disease NOT Algeria NOT Somalia NOT Egypt NOT Tunisia* NOT Morocco* NOT Ethiopia*	Wild[6]	None studied plant community composition
Plant AND **germination** AND Africa AND gyps* NOT bird NOT disease NOT Algeria NOT Somalia NOT Egypt NOT Tunisia* NOT Morocco* NOT Ethiopia*	Atlas of Namibia Team[3]	None studied germination biology
Plant AND **interact*** AND Africa AND gyps* NOT bird NOT disease NOT Algeria NOT Somalia NOT Egypt NOT Tunisia* NOT Morocco* NOT Ethiopia*	Burke and Strohbach[7]	None studied plant–plant interactions
Plant AND **compet*** AND Africa AND gyps* NOT bird NOT disease NOT Algeria NOT Somalia NOT Egypt NOT Tunisia* NOT Morocco* NOT Ethiopia*	Eckardt and Spiro[1]	None studied plant competition
Plant AND **facilit*** AND Africa AND gyps* NOT bird NOT disease NOT Algeria NOT Somalia NOT Egypt NOT Tunisia* NOT Morocco* NOT Ethiopia*	Greyling and Van Rooy[2]	None studied facilitation

strong bottleneck in plant establishment and regeneration that deserves investigation. Also, understanding the role of soil seed banks, plant–plant interactions (i.e. interference and facilitation), and cross-kingdom interactions on gypsum plant community dynamics would be relevant for providing specific recommendations to land managers.

Functional strategies

Key to analysing plant life on gypsum is to understand the mechanisms of plants to cope with the characteristics of gypsum soils and potential convergence with gypsophiles in other parts of the world. Due to the subsurface accumulation of pedogenic gypsum in southern Africa, it would be crucial to evaluate the root penetration of potential gypsophiles to ascertain if root distribution within the soil profile concentrates on, or avoids, gypsum soils. Taxa that are specific to gypsum soils should be characterised for functional traits of known significance that allow them to cope with the environmental restrictions typical of gypsum soils. For example, gypsophiles from other regions of the world accumulate elements found in excess on gypsum soils (S, Ca and Mg) in their leaves[9], while gypsovags seem to block the uptake of these elements at the root level[10] showing lower foliar concentrations. Identifying functional traits related to water and nutrient use that have an impact on plant fitness and how they vary within and among populations is vital for understanding plant adaptation to gypsum soils and how they would respond to global change.[11]

Way forward

During the recent expedition, 24 long-term monitoring plots were established in Namibia and South Africa. Continued sampling of these plots and long-term collaborative research will improve our understanding of gypsum ecosystem dynamics and help us identify potential threats to both species and functional diversity.

Further, funding for skills development and capacity building of African researchers is available through the GYPWORLD project. This enables young and established researchers to visit partner countries for research and collaboration on gypsum ecology.

The recent signing of a Memorandum of Understanding between NWU and Gobabeb signified the commitment of researchers in Namibia and South Africa to invest time and resources in the advancement of gypsum ecosystem research in southern Africa.

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Competing interests

We have no competing interests to declare.

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