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The Importance of Soil Seed Bank Dynamics as Potential Indicators of Desertification Tipping Point

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The importance of soil seed bank dynamics as potential indicators of desertification tipping point

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Key words: [desertification; grazing gradients; soil seed bank; tipping point]

Abstract
Soil seed banks play a major role in the vegetation dynamics of drylands, where annual rainfall is unpredictable and plants depend on a persistent stage (seeds) to survive over the dry season. The purpose of the study is to understand the behaviour of the rangeland system in terms of soil seed bank dynamics before, during and after crossing the "so called" DTP and to determine whether different management systems plays a role in accelerating the desertification process. Through the use of the Space for Time Substitution Approach the study analysed spatial grazing gradients (gradients radiating from water points) to predict how soil seed banks would respond to long term grazing scenarios. Soil seed bank samples were collected along grazing gradients under two management systems (commercial and communal), processed through seedling emergence method and analysed with SPSS statistical package. Though our results indicated larger soil seed bank under the commercial management system, the seed bank size did not differ significantly along both commercial and communal grazing gradients. Commercially managed sites had a larger seed bank of perennial grasses compared to communal sites. Some of which increased gradually with increasing grazing intensity (*Eragrostis trichophora*), while other decreased with the increase in grazing intensity (*Eragrostis rigidior* and *Eragrostis pallens*). Further testing of other seed processes is still ongoing and will be completed in the 1st quota of 2022. Based on the first results soil seed bank size might not be a good indicator of DTP but rather seed bank life form composition as well as species composition of perennial grasses might serve as good indicators of DTP.

Introduction
Desertification is one of the major types of regime shifts that occur in drylands which is mostly driven by climate change and land-use dynamics. Overgrazing, unsustainable agricultural practices, and drought are the major drivers of desertification in semi-arid savannas (Sullivan 2000). Most Namibian savannas are overwhelmingly dominated by annual grasses at the expense of perennial grasses (Sullivan 2000) thus raising concerns on whether the landscape is shifting towards a tipping point. According to Rietkerk et al. (1996), the replacement of perennial grasses by annual grasses could be a sign of land degradation.

The resilience and resistance of such systems depends on the vegetation life stages that buffers it from adverse environmental variability both in space and time. Soil seed banks play a major role in the vegetation dynamics of drylands, where annual rainfall is unpredictable and plants depend on a persistent stage (seeds) to survive over the dry season (Venable 2007; Tielbörger et al. 2012). The ability of the soil seed bank to be distributed both in space and time allows vegetation to escape unfavourable conditions (Kemp 1989). Persistent seed banks, not only serve as a hedge against extinction under variable conditions and across long dry periods, but they can also serve as a buffer for avoiding extinction under otherwise adverse conditions (Jurado and Flores 2005). On the one hand, desertification tipping points may be retarded if despite high mortality of adult plants, persistent seeds are available to restore population stability through the recruitment of suppressed species when conditions become favourable (Dreber et al. 2011). Furthermore, the systems resilience may also be enhanced by the seed banks (Tessema 2011), such that when apparent desertified rangelands are abandoned, dormant seeds may still germinate and initiate a positive regeneration cycle. *Vice-versa*, once the seed banks are depleted, DTPs may occur rapidly via positive feedback loops between seed number and plant number. Unfortunately, very little is known about seed banking for vegetation persistence and/or resilience in savannas, more especially for the rather valuable perennial grasses.

This study investigates the potential use of the soil seed bank as early warning indicator of desertification tipping point by employing the space for time substitution approach. The study addresses the effect of increased grazing intensity on soil seed bank size and composition, and whether these soil seed bank characteristics are influenced by management strategies.

Methods and Study Site
The study was carried out in the Greater Waterberg Landscape Conservation Area (GWLA) approx. 250 km north-east of Windhoek. The GWLA covers an area of about 19 200 km^2 of semi-arid savanna of which about 85% is communal land and about 13% is commercial land (Ministry of Environment and Tourism 2013). The

study site receives an average annual rainfall of 400 - 500 mm, and it experiences maximum temperature of up to 40ºC in the hottest months, and minimum temperatures of below –10ºC in winter months (SASSCAL Weather net; Amputu et al. 2019). The vegetation in the area is typical of Northern and Central Kalahari and Thornbush shrubland (Ministry of Environment and Tourism 2013).

A total of eight sites were selected for this study within the Waterberg region, representing two management systems (4 communal areas and 4 freehold commercial farms). All sites are mainly grazed by cattle with a few wildlife under commercial management system. At the time the data was collected only 6 sites were identified and sampled (3 sites per management system). Two grazing gradients were identified per site, radiating from an active water point for commercial management system, and from the edge of the village homesteads for communal management system (the areas of high grazing pressure) to further away from the water point/ village edge (areas with low grazing pressure). Transects measuring on average of 1800 m were set up along each grazing gradient. Along each transect, 3 plots each measuring 100 m^2 were demarcated in a logarithmic order with a maximum of 9 quadrats each measuring 1 m^2 nested within representing three microhabitats (3 next to an established perennial grass tussock, 3 away from perennial tussocks, and 3 next to woody plants). Soil samples were collected with a 9.8 cm diameter cylinder to the depth of 5 cm. One sample was pooled from each quadrat, put in a plastic bag and all were transported to the nursery at the National Forestry Research Centre. Sampling was done during October and September 2019, right after seed set was completed and just before the rainy season. At the nursery samples were then spread in 12cm x 12cm pots filled halfway with sterile soil and watered daily from the beginning of February 2020 until end of April 2020. The germinated seedlings were identified, counted and recorded. Seedlings that were difficult to identify were transplanted and left to grow to the adult stage to enable identification. For the species whose identity was uncertain, samples were pressed and specimens were send to the National Herbarium of Namibia for identity confirmation. The data was then analysed in SPSS. Univariate analyses of variance (ANOVAs) were conducted to test the effects of grazing pressure and management on soil seed bank size of germinable soil seed bank as well as on seed density of perennial grass species. Tukey's HSD tests were used when a significant ANOVA results were obtained. The similarity in species composition between the two management systems was compared using the Sørensen's similarity coefficient.

Results

Seed bank size

A total of 3276 seedlings belonging to at least 77 species emerged from the soil seed bank. Of this, 60.8% of the seedlings came from the commercial sites while 39.2% came from communal sites. The soil seed bank size was significantly larger in commercial compared to communal management systems $F (1, 34) = 9.982$, $p=0.003$, with no significant differences along the grazing gradients $F (2, 35) =0.562$, $p=0.576$. The emerged seedlings came from 63 species in commercial while 54 species came from communal area, with a similarity coefficient in species composition between the two management systems of 0.615.

Plant life form composition

Annual grasses had the highest number of seeds in the soil seed bank under both management systems (Commercial: 54.2%; communal: 62.1%) followed by forbs and sedges (commercial: 30.3%; communal: 33.7%). But the soil seed bank size of both annual grasses and forbs and sedges did not differ significantly between management systems. While perennial grasses had the lowest number of seeds in the seed bank under both management systems, but their seed bank size differed significantly between management systems $F(1,35)=11.033$, $p=0.002$. Commercially managed sites had a larger perennial grass seed bank (15.5%) compared to the communal management system (4.2%). No significant differences were found in all lifeform seed bank distribution along the grazing gradient under both management systems $F (4, 17) = 1.122$, $p= 0.351$.

Perennial species composition

In commercial sites the two dominant species in the seed bank were *Eragrostis tricophora* and *Eragrostis rigidior*. *E. trichophora* showed a significant increase with an increase in grazing intensity $F (2,159) = 15.045$, $p=0.000$ while, *E. rigidior* seed bank size increased with a decrease in grazing intensity $F (2,159) = 4.305$, $p=0.15$. In communal sites *E. tricophora* and *Eragrostis pallens* showed similar trends to commercial sites, with *E. tricophora* increasing significantly with an increase in grazing intensity $F(2,158)=11.934$, $p=0.000$, while, *E. pallens* increased with a decrease in grazing intensity $F(2,158) = 6.413$, $p=0.002$.

Discussion [Conclusions/Implications]

Our results showed that commercial management sites had a significantly larger and more diverse soil seed bank than the communal management sites. A variation that seem to be resulting from the density of perennial grasses, which were found to be significantly high in commercial than in communal management sites. This might be due to differences in management systems, such as controlled animals' carrying capacity, resting of rangeland and the provision of supplementary fodder. These aforementioned strategies are known to be applied by commercial farmers (Olbrich et al. 2012) which results in lower grazing pressure, leading to high vegetation cover and the ability of the herbaceous vegetation to complete their life cycles. Therefore, explaining the high seed density under the commercial management system. In contrast communal areas are subjected to poor rangeland management (Falk 2008), which might have resulted in overgrazing of such rangelands. Overgrazing triggers a decrease in the soil seed bank density of perennial grasses (Bisigato, 2000) and the overall plant species density and richness decreases with rangeland degradation, although not always in significant ways (Kassahun et al. 2009).

Though we predicted a low soil seed bank closer to water point which increases with the decrease in grazing intensity, we found no significant influence of grazing intensity on annual grasses, forbs and sedges seed bank size. Annual grasses dominated the seed bank which was also high throughout the grazing gradient even at the highly utilized areas (close to the water point/homesteads). Annuals persistence even under high grazing pressure can be a result of several characteristics such as the production of small sized seeds that get buried easily and their ability to deter grazing during reproduction stage (Dreber et al. 2011). Annuals also reach reproduction maturity fast, and produce large number of seeds (Fenner and Thompson 2005) and disperse their seeds shortly after maturation (Gutterman 2000). Furthermore, they are also known to have an adaptive germination rate, meaning it decreases with decrease in habitat favourability (Ritland and Jain 1984,). On the other hand perennials reproduce late in the growing season and they stay alive for long making them a target or preferred forage material during the dry season. Hence, causing potential changes in vegetation composition which has been correlated with reduction in reproduction success through herbivory (Milton and Dean 1990). Thus severe grazing pressure on seed bearing adult plants coupled with prolonged droughts might be the potential cause of lower soil seed banks of perennial grasses (Solomon et al. 2006) as compared to annual grasses and forbs. It has also been found that overgrazing leads to a decline in the soil seed bank density of perennial grasses (Bisigato 2000).

Although the overall seed bank density for perennial grasses did not vary with grazing intensity, there were some species-specific responses to grazing intensity among the different perennial grass species. As expected, areas with low grazing intensity had high number of *Eragrostis rigidior* seeds; a desirable sub-climax perennial grass species (Bester et al. 2003; Müller 2007) which is tolerant to moderate overgrazing (Roodt 2015). Seed bank density of *Eragrostis rigidior* also decreased significantly with increasing grazing intensity. On the other hand, and contrary to our expectations, the area with high grazing intensity was dominated by grass seeds of a perennial grass species (*Eragrostis trichophora*) (Müller 2007), with the species' seed bank density decreasing with decreasing grazing intensity. This may however not be so strange an observation considering that the species has been reported to be a pioneer species (Müller 2007), that is tolerant to severe grazing (Roodt 2015).

Therefore, the seed bank size and composition of perennial grasses responded to both the management strategies and specific species responded to grazing intensity thus providing us with insights on the possible future changes in the state of the rangeland. Such that if the grazing intensity continues to increase, the soil seed bank of more palatable perennial grass species that are intolerant to heavy grazing eg. *Eragristis rigidior* might get depleted and replaced by perennial grass species that are less prefered as fodder but highly tolerant to overgrazing, and are indicators of severe overgrazing such as *E. trichophora* and vice versa. Therefore, the perennial grass seed bank species composition and abundance may serve as possible indicators of rangeland condition (Zimmermanno et al. 2001) and as early warning signals of looming desertification tipping points.

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References

Amputu, V., Joubert, D.F. and Mapaure, I., 2019. Vegetation secondary succession in response to time since last fire in a broad-leaved savanna in central Namibia. *Namibian Journal of Environment*, *3*, pp.A-65

Bester, J., Matjuda, L.E., Rust, J.M. and Fourie, H.J., 2003. The Nguni: a case study. *Vilakati, D., Morupisi, C., Setshwaelo, L., Wollny, C., von Lossau, A. and Drews, A.(eds)*, pp.45-68.

Bisigato, A.J. 2000. Dinamica de la vegetacion en areas pastoreadas del extremo austral de la Provincia Fitogeografica del Monte. PhD Thesis. University of Buenos Aires. Buenos Aires

MaDreber, N., Oldeland, J. and van Rooyen, G.M., 2011. Species, functional groups and community structure in seed banks of the arid Nama Karoo: Grazing impacts and implications for rangeland restoration. *Agriculture, ecosystems & environment*, *141*(3-4), pp.399-409.

Falk, T., 2008. Communal Farmers' Natural Resource Use and Biodiversity Preservation. A New Institutional Economic Analysis from Case Studies in Namibia and South Africa. Cuvilier Verlag, Göttingen.

Fenner, M., Thompson, K., 2005. The Ecology of Seeds. Cambridge University Press, Melbourne.

Gutterman, Y. (2000). Environmental factors and survival strategies of annual plant species in the Negev Desert, Israel. *Plant Species Biology*, *15*(2), 113-125.

Jurado, E. and Flores, J., 2005. Is seed dormancy under environmental control or bound to plant traits?. *Journal of Vegetation Science*, *16*(5), pp.559-564.

Kassahun, A., Snyman, H. A., & Smit, G. N. (2009). Soil seed bank evaluation along a degradation gradient in arid rangelands of the Somali region, eastern Ethiopia. *Agriculture, Ecosystems & Environment*, *129*(4), 428-436.

Milton S.J. and Dean W.R.J. 1990. Seed production in rangelands of the southern Karoo. South African Journal of Science 86: 231–233.

Ministry of Environment and Tourism. 2013. *Strategic environmental assessment of the tourism sector for the Greater Waterberg Landscape.* Namibia.

Müller, M.A.N., 2007. *Grasses of Namibia*. Ministry of Agriculture, Water, and Forestry.

Rietkerk, M., Ketner, P., Stroosnijder, L. and Prins, H.H., 1996. Sahelian rangeland development; a catastrophe?. *Rangeland Ecology & Management/Journal of Range Management Archives*, *49*(6), pp.512-519.

Roodt, V., 2015. *Grasses & grazers of Botswana and the surrounding savanna*. Penguin Random House South Africa.

Solomon, T.B., Snyman, H.A. and Smit, G.N., 2006. Soil seed bank characteristics in relation to land use systems and distance from water in a semi-arid rangeland of southern Ethiopia. *South African Journal of Botany*, *72*(2), pp.263-271.

Sullivan, S., 2000. Getting the science right, or introducing science in the first place? Local 'facts', global discourse– 'desertification'in north-west Namibia.

Tessema, Z.K., 2011. *Recovery of rangelands: the functioning of soil seed banks in a semi-arid African savanna*.

Tielbörger, K., Petrů, M. and Lampei, C., 2012. Bet-hedging germination in annual plants: a sound empirical test of the theoretical foundations. *Oikos*, *121*(11), pp.1860-1868.

Venable, D.L., 2007. Bet hedging in a guild of desert annuals. *Ecology*, *88*(5), pp.1086-1090.

Zimmermanno, I., Graz, F.P., Berry, M.H., Imasiku, N.N.T., Muroua, N.D., Sibalatani, M.M. and Sikopo, C.S., 2001. Quantified range condition assessment of open Camelthorn savanna along a degradation gradient. *African Journal of Range and Forage Science*, *18*(2-3), pp.111-116.

Olbrich, R., Quaas, M.F. and Baumgärtner, S., 2012. *Characterizing commercial cattle farms in Namibia: risk, management and sustainability* (No. 248). Working Paper Series in Economics.

Ritland, K. and Jain, S., 1984. The comparative life histories of two annual Limnanthes species in a temporally variable environment. *The American Naturalist*, *124*(5), pp.656-679.