



Restoration techniques of rangelands in the hyper-arid area of central Saudi Arabia

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Abstract

Restoration efforts are influenced by previous human use and management actions which have contributed to different levels of habitat degradation and biodiversity loss. We discuss the monitoring and evaluation of restoration activities tailored to study sites in two adjacent Royal Reserves located in the hyper-arid desert area of central Saudi Arabia. One reserve has been fenced for over 40 years with limited public use. The other was open to life stock grazing until recently and has over one million visitors each year in the winter. Ecological assessments in both reserves identified the extent and scale of degradation which informed restoration priorities. Planned restoration techniques were based on nature-based solutions suitable for these areas. In the more ecological intact reserve, restoring the ecological dynamics was the main focus through the reintroduction of native grazers, i.e. gazelles and oryx. Restoration activities of native flora included rainwater harvesting on an experimental scale. In the open reserve, restoration primarily focuses on restoring the floristic composition. Here we implemented a pilot study to assess if tilling the compacted top crust facilitated germination and establishment of plants. Monitoring the impacts of restoration efforts is crucial to be able to evaluate if targets are met. We implemented various monitoring techniques to assess changes in vegetation structure and composition, and spatial abundance and presence of newborns of reintroduced animals. Results were used to evaluate if reintroduced animals established themselves and if assisted regeneration led to the germination and growth of plants in the pilot studies. This paper highlights the preliminary empirical assessments of these different restoration techniques for rangelands in hyper-arid areas.

Introduction

In the current Anthropocene era, unsustainable use, habitat destruction, introduction of invasive species and overexploitation has led to the alarming loss of biodiversity and reduced ecosystem services (Díaz et al., 2019). Safeguarding habitats is one of the most effective conservation strategies for combatting this biodiversity crisis and desertification (Barth, 1999). Typically, habitat restoration efforts focus on the re-establishment of plant communities. Restoration efforts should, however, integrate the restoration of both key plant and animal groups, especially those animals that change habitat directly, such as herbivores, and

indirectly, such as carnivores (Suraci et al., 2016). Re-establishing plant-animal interaction and trophic complexity is crucial to achieving all the ecosystem services nature provides, including nutrient cycling, soil formation, pollination, and seed dispersal that rely on the plant-animal dynamics.

Hyper-arid, arid, and semi-arid lands form about one third of the Earth's terrestrial surface. These lands contain unique biological and cultural diversity, and biodiversity loss can have a disproportionate impact on these ecosystems due to low redundancy and a high risk of trophic cascades (Zhang et al., 2023). The Kingdom of Saudi Arabia hosts 32.5% of the global hyper-arid areas and hence plays a significant role in the conservation of biodiversity in these ecosystems (Keith et al., 2022). In recent years, contributing to global commitments, large areas have been established as protected areas in Saudi Arabia with the aim to have 30% of its terrestrial area protected by 2030. Two adjacent protected areas established in 2018 are the King Khalid Royal Reserve (KKRR) and the Imam Abdulaziz bin Mohammed Royal Reserve (IARR). They are located in central Saudi Arabia, and the area is characterised by low rainfall, high diurnal and seasonal fluctuating temperatures with predominantly sandy, gravelly soil and low levels of nutrients. Rangeland vegetations consist of slow growing perennials and ephemeral plants with long-lived soil seed banks. Understanding the full complexity and integrity of the ecosystem as well as the sources of degradation (prior land use) and implemented restoration practices will enhance the success of habitat restoration efforts (Atkinson et al., 2022). An ecological assessment using the Recovery Wheel and a 5-star scale assessment approach (McDonald et al., 2016), is a widely used tool and was implemented in each reserve to assess the integrity of the ecosystem and to prioritize restoration efforts (IARDA internal report).

In this study, we highlight different restoration strategies in the two reserves. In KKRR we discuss the reintroducing of key herbivores and in both reserves we conducted a pilot study to increase the native plant community through assisted regeneration (McDonald et al., 2019). Specifically, in KKRR we assessed if the reintroduced ungulates remained close to the release site and if they produced offspring, two indicators for establishment success. Additionally, we assessed if rainwater harvesting pits increased the germination of annuals from the seed bank. In IARR, we assessed if tilling the compacted top crust resulted in the initial growth of annuals and the subsequent establishment of perennials.

Methods

The study areas are within KKRR and IARR, approximately 100 km northeast of Riyadh. KKRR is 1,160 km² and has four main habitats, the pediplain, plateau, wadi (valley) and catchment. The pediplain is about 250 km² and contains numerous catchment areas. It is bordered by the escarpment of the Urumah Mountain plateau to the east and at all other sides by roads and has been fenced for over 40 years. This area was used to reintroduce 242 native ungulates between 2021 and December 2024. The rainwater harvesting (RWH) pilot study of 4.35 ha was also located in this pediplain, on a slightly sloping surface at the foothills of the escarpment with pits of ~ 1 x 1.5 m and 10-15 cm deep. IARR is 11,300 km² and has six main habitats, the pediplain, plateau, wadi, catchment, sand plain, and sand dune. This reserve harbours 13 catchment areas with Rawdhat Khuraym being the largest with eight main wadis draining into it and is a very popular destination for people in the winter. Adjacent to Rawdhat Khuraym, was the experimental tilling area of 680 ha.

In total nine Arabian oryx, one sand gazelle and two Arabian gazelles were deployed with satellite-based GPS collars to assess site fidelity. The collars were programmed to drop off after one year. Camera traps were positioned at 53 locations in the pediplain next to water sources, burrows, and on wildlife trails to estimate newborn animals and relative occupancy. Relative occupancy was calculated as the number of locations with species-specific observations divided by the total number of camera locations. Since water is a limiting resource, locations next to water sources likely attract animals and are therefore not

representative of capture rates and were excluded from the relative occupancy calculations. Newborn individuals were identified by the distinctive brown collar for oryx and absence of horns for gazelles. The monthly maximum number of newborns at each location was recorded.

The succession of plants in the RWH pits was monitored by recording the percentage cover and species abundance every two months at 60 randomly selected pits and adjacent control sites from November 2023 to July 2024. For the tilling experiment in IARR, we collected data using the line-intercept method along a 100-m transect placed in the furrows at five sample sites in each of the three experimental plots (tilling to 5, 10 and 15 cm in plot A, B, and C resp.) and three sample sites in a nearby control plot. The first transect location was randomly selected as being the 10th furrow from the eastern edge. The following four sample sites were approximately five furrows to the west. All germinated plants were recorded under and to 10 cm left and right of the transect line from January 2023 to June 2024. Observed species in both pilot studies were classified to the highest taxon possible and into their life span as annual or perennial.

Results

Establishment of reintroduced ungulates in KKRR

Based on the GPS data from the collars, the three gazelles predominantly stayed in the catchment areas of approximately 60 km² close to the release site with the one sand gazelle travelling a maximum distance of 10 km and the male Arabian gazelle moving in and out of KKRR to the adjacent IARR but staying within a few km from the border of KKRR. Of the nine tracked Arabian oryx, four individuals climbed up the escarpment and left KKRR, they followed the wadi into IARR, three of them died in IARR. Three other individuals also climbed up the escarpment but stayed in the wadis on the plateau of KKRR, and one died. The other two individuals predominantly stayed within 50 km² along the escarpment just north of the release site (Fig 1).

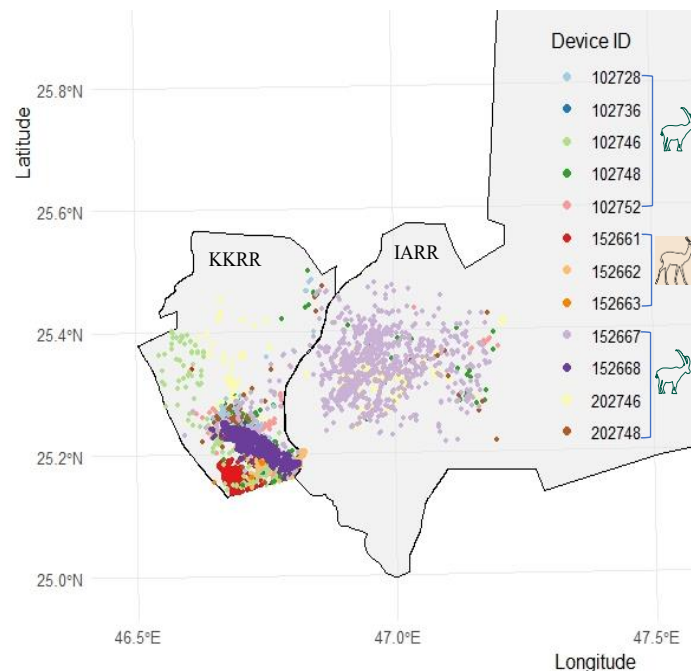


Figure 1. Movement patterns derived from GPS data of 12 tracked individuals for one year. Device ID 15661 is a sand gazelle, 152662 and 15663 is Arabian gazelle and the other nine are Arabian oryx.

Spatial occupancy data from the camera trap data showed that oryx and sand gazelles roamed widely but the Arabian gazelle was most restricted in its relative occupancy (Table 1). Camera trap data showed newborns of all species.

Table 1. Relative occupancy (rel. occ.) and demographics per species for the period 2021-2024

Characteristic	Arabian oryx	Sand gazelle	Arabian gazelle
Reintroduced	45	120	11
No of cameras with observations (rel, occ.)	19 (56%)	17 (50%)	3 (9%)
No of newborn	9-14	40-48	1
No of mortalities	4	11	5*

*4 assumed, 1 confirmed

Rainwater harvesting in KKRR

Creating a shallow pit to collect rainwater had a positive effect on the germination of predominantly annuals (Fig. 2). The mean cover of plants increased from approximately 3% at the start of the experiment in November 2023 to 21% in the following four months, then slightly decreased to 19% in May and then decreased sharply to 6% in July when most remaining plants were dry. The control area never showed more than 1% cover. The abundance had a slightly different pattern as it steeply increased from 5 plants to 40.6 plants in January but only 8% were perennials. Afterwards, abundance steadily decreased to 32.4 plants in March, 17.0 in May, and finally dropped to 4.5 in July of which 100% were perennials predominantly *Zygophyllum indicum*.



Figure 2. Succession of plants in the rainwater harvesting pits

Tilling in IARR

Tilling the top crust led to germination and growth of various species of plants including perennial plants. The number of unique species recorded was 39, about three times higher compared to the control with just 12 species. The great majority of the observed species (84%) were herbaceous plants, 10% were shrubs and 6% grasses. No seedlings of trees were observed. The vegetation was dominated by annual plants of which *Malva neglecta* was most represented both in abundance and cover (Fig. 3). The perennial shrub *Zilla spinosa* was the second most represented. Tilling to a depth of 15 cm (plot C) resulted in the highest cover and abundance. The species *Erucaria hispanica* and *Zilla spinosa* were responsible for the high cover in May. Both species were still present in June but had partially died off in plot B resulting in the subsequent decline in cover. However, in plot C they did establish and flourished to at least double their cover in June (Fig.2). A year later, the same trend in cover is still present with C having the highest cover and abundance, but the composition has changed to only perennials in all plots.

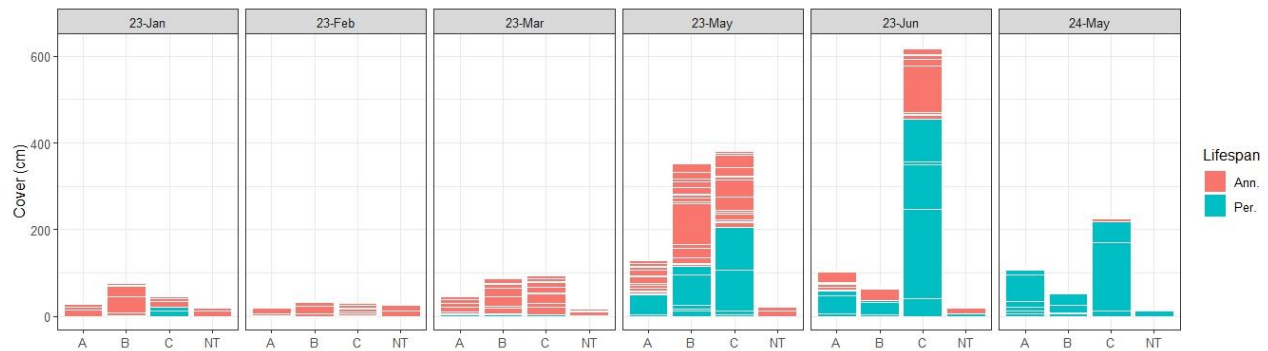


Figure 3. Trend in vegetation cover by lifespan and per treated plot (NT=No Treatment and is the control area)

Discussion

Monitoring and evaluation are essential to determine whether restoration projects are successful so that we achieve the intended benefits (Otiendo, 2019). These assessments also help to ensure that project and program resources are used efficiently and effectively. Using complementary monitoring techniques can provide a more comprehensive evaluation as the GPS tracking devices in combination with the camera traps demonstrated for the assessment of indicators of establishment of reintroduced animals in this study. The data showed newborn of all reintroduced species indicating that KKRR can sustain pregnancies. Additionally, results showed the high site fidelity of gazelles but less so for oryx as they did move out of the pediplain. These roaming oryxes either established them on the plateau of KKRR or followed the wadi to the adjacent IARR, underscoring the importance of safe wildlife corridors between the reserves. This roaming behaviour could indicate that space was a limiting factor in retaining animals at release sites since food resources were plentiful (IARDA Carrying Capacity internal report). With the many reintroduction programs currently on-going in the Kingdom of Saudi Arabia (Alatawi, 2022), we believe these results can inform other programs of the benefits of monitoring using different techniques to evaluate success.

Natural generation is a preferred restoration method as it mimics nature and leads to a sustainable establishment of plants following the natural succession processes after external threats (grazing, logging, off-roading) are removed. However, natural generation is only possible when the ecosystem is intact and fully functional. In our study sites, assisted regeneration was implemented and monitored for 6 months to 1 year. Both pilot studies showed rapid germination of annuals after rainfall with the establishment of some perennials indicating the presence of viable seeds in the seedbank and the outset of restoring native vegetation. Other factors could also have contributed to this success, such as the closeness to surrounding vegetation and topography. Also, the rougher surface that resulted from the tilling and the creation of shallow pits could have trapped more windblown seeds which could explain the higher germination in both pilot studies. Conducting pilot studies to evaluate the appropriateness of the used technique is an important step before implementing it on a large scale.

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