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**TESIS DOCTORAL POR COMPEDIO DE PUBLICACIONES**

# CONSERVATION OF BIODIVERSITY IN HYPER-ARID COMMODIFIED PROTECTED AREAS UNDER GRAZING PRESSURE IN DUBAI, UNITED ARAB EMIRATES (UAE)

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## Prefacio

Las investigaciones que han conducido a la redacción de la presente Tesis Doctoral se han realizado en el Departamento de Botánica y Fisiología Vegetal de la Universidad de Málaga, en el ámbito de las actividades del Grupo de Investigación RNM 115 "BIODIVERSIDAD, CONSERVACION Y RECURSOS VEGETALES" -del Plan Andaluz de Investigación, Desarrollo e Innovación de la Junta de Andalucía-.

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Que D. Tamer Ali Khafaga, Graduado en Ciencias, ha realizado, en el Departamento de Botánica y Fisiología Vegetal Fisiología Vegetal de la Facultad de Ciencias de la Universidad de Málaga y en la Dubai Desert Conservation Reserve (DDCR) (EAU), las investigaciones que le han conducido a la redacción de la presente Memoria de Tesis Doctoral, titulada: CONSERVATION OF BIODIVERSITY IN HYPER-ARID COMMODIFIED PROTECTED AREAS UNDER GRAZING PRESSURE IN DUBAI, UNITED ARAB EMIRATES (UAE)

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# ABSTRACT

# ABSTRACT

**Ecosystems as commodity frontiers—challenges faced by land set aside as Protected Areas (PAs) in the Dubai Emirate, United Arab Emirates (UAE)**

Land development in the United Arab Emirates (UAE) rapidly expanded with the arrival of oil wealth in the late 1950s in the Emirate of Abu Dhabi.The rise of the oil economy brought with it the increasing commodification of land. The first manifestation of this was with the introduction of modern agriculture in the mid-twentieth century. British colonial authorities working closely with coastal rulers took a keen interest in developing land and wáter resources during this period, partly in the hopes that this would improve local people standard of living, support emerging urban centres, and allow for the spread of modern agriculture. The emergence of protected areas (PAs) as commodity frontiers must be looked at in the context of the history of land commercialization in the country.

The main difference between the Protected Area (PAs) Dubai desert Conservation Reserve (DDCR), in which most of this PhD study takes place, and other PAs is that clearly articulated objectives informed the commodification of nature, with the primary goal being conservation. Given that the conservation objectives of the DDCR are dissimilar to the activities discussed that impact the PAs ecosystems, in essence, the conservation model implemented by the DDCR is an example of green capitalism whereby aspects of the natural world are being brought into the economic sphere.

The difference at the DDCR in comparison to other PAs is that a balance is maintained between profit gained from the commodity (PA) and implementation of ecologically friendly measures aimed at mitigating degradation of the environment. In a rapidly developing country with a relatively modest surface area in comparison with other countries, land is commodified in several ways, including infrastructure building, urban sprawl, the expansión of industry and other commercial expansions that are in direct competition with conservation agendas.

As highlighted, impacts on PA desert ecosystems are linked to many anthropogenic activities that directly or indirectly reduce biodiversity. In the late 1990s in the very southern part of the Dubai Emirate, an area of the desert was commodified for the construction of an exclusive resort and spa complex that was opened by Emirates Airlines (Al Maha Desert Resort and Spa) on land allocated to them by Dubai Government. The concept of this hotel was to offer visitors a unique wildlife and desert experience in natural surroundings. The southern part of Dubai was primarily home to camel farms and activities impacting the desert in much the same way as has been described above. To build the resort, an area comprising 27 $km^2$ was fenced, excluding grazing camels. From the time of opening of the resort, 5% of the profits have been invested in conservation projects. Following an environmental audit carried out by resort managers of the surrounding area adjacent to the resort in 2001, current and potential threats to the desert ecosystem were highlighted. This led to a proposal of a more comprehensive conservation area to be created around the resort and was presented by the owner of Emirates Airlines to the Ruler of Dubai. The Ruler of Dubai approved the proposal and allocated a total of 225 $km^2$, which includes the land occupied by the resort. The initial steps of creating the DDCR included the establishment of a governing board originally

comprising of the head of Emirates Airlines and other influential leaders of governmental organizations (e.g. utility organizations). The board outlined the goals and values that continue to be the main remit of the reserve, which are: To create a permanent PA which ensures the future of the region desert habitats and biodiversity managed according to sound scientific ecological principles, aimed at protecting natural resources (water being the most obvious one, but extending to many others as well), and maintaining original desert landscapes. To ensure that the community and visitors have access to the Reserve through the sustainable and responsable development of comercial practices that would not impact on the primary role of conservation and habitat protection. To protect the heritage of traditional activities which have become a part of the region history and culture and maintain the identity of Dubai tribal beginnings. To register and gain international recognition for the Reserve under the United Nations PAs Management principles, amongst others and to ensure that the DDCR is adequately protected under law.

In more recent years, activities such as tourism have played a vital role alongside species protection in PAs globally. However, it is essential that effective management practices are put in place as there have been many examples of PAs not meeting their conservation targets due to inadequate management, resulting in the loss of species biodiversity. The PAs in the Dubai Emirate are not unusual in facing pressures from economic development, the difference being that without a clear articulation of conservation targets, the PAs are in danger of only being seen as new profitability frontiers

Currently, neoliberal modes of conservation are tending to replace other forms of conservation of protected natural areas. Managers, public and private entities work actively to commercialize natural resources and the social relationships that determine the use and conservation of these resources.

**Proximity to urban fringe recreational facilities increases native biodiversity in an arid rangeland**

Camel herbivory is frequently cited as the main cause of rangeland decline on the Arabian Peninsula. Camels have been present for millennia, but social, cultural and political effects have resulted in a population explosion since the end of the Second World War. Camel herbivory suppresses phytomass and reduces the proportion of more palatable small perennial plants on all land surfaces, but more severely on gravel substrate. Camel herder settlements are scattered throughout the Dubai rangeland, but camel densities are highest around racetracks and are not directly associated with rangeland provision of feed or water. Land tenure is not always clear and is traditionally based on wáter access rather than geographical boundaries. Rangeland access for camel herders is thus regulated communally within Dubai emirate, with few restrictions through unfenced rangeland or across emirate boundaries.

A primary cause of rangeland degradation in Arabia is open-access livestock herbivory. Ungulates and herders tend to avoid peri-urban rangeland. The results of the Phd study found native biodiversity to be higher in arid rangeland that bordered Dubai (UAE) urban developments, compared with rangeland further inland. The likely mechanism is the influence of anthropogenic fixtures on browsing pressure by camels, oryx and gazelles. Within the study

area, Al Marmoom Desert Conservation Reserve (Dubai), camel browsing faced greater communal regulation in locations bordering anthropogenic fixtures, whereas oryx and gazelles selectively avoided these areas. Anthropogenic fixtures can therefore offer conservation value in this landscape by reducing the impact of elevated ungulate populations. Urban fringes are normally associated with a reduction in native biodiversity and urban expansion is one of the leading causes of local extinctions. However, outer urban fringes sometimes exhibit increased biodiversity, likely due to increased hábitat diversity that includes faunal access to resource-rich gardens. Total phytomass may increase with ground water changes, which typically include an increase in both volumen and pollutants. In such cases, the apparent ecological health is controversial because the modified urban-rural transitional landscapes favour immigrant species.

Urban developments affect neighbouring ecosystems in multiple ways, usually decreasing native biodiversity. An Arabian arid rangeland was studied to identify the primary causes of biodiversity variation. Al Marmoom Desert Conservation Reserve is a 990 $km^2$ area on the urban edge of Dubai, designated for ecological 'enhancement' and outdoor recreational use. The area lacks historical biodiversity data, but is thought to be primarily influenced by Arabian camel herbivory. Perennial floral and faunal diversity was assessed at 54 sites. Counts of reintroduced ungulates; Arabian oryx Arabian gazelle and sand gazelle were made at 79 separate sites. Correlations of observed biodiversity with substrate type, anthropogenic structures, and ungulate distribution were assessed. Native biodiversity was substantially higher in northnorth- west locations near recreational facilities, with the most likely cause being differential browsing pressure. Camel browsing faced greater communal regulation in the north-north-west, whereas oryx and gazelles congregated at feed points in the south-south-east that were farther from human activity. Arid rangeland in this socio-ecological landscape exhibits greater natural biodiversity at the urban fringe. Human activity reduces ungulate density, enabling a greater diversity of perennial flora, which then attracts non-ungulate fauna. Anthropogenic features can therefore offer conservation value in landscapes where ungulate populations are artificially elevated.

Native biodiversity was ~3-fold higher near established anthropogenic facilities in the north of the Al Marmoom Desert Conservation Reserve, and somewhat higher near some but not all communities in the south. Plant biodiversity is low across the UAE, and observed diversity is lower in summer, when ephemeral species are mostly present only in seed form. Some perennial species of ecological significance in the area did not appear in sampling, including *Acacia ehrenbergiana* Hayne and *Calotropis procera* (Aiton) W.T. Aiton. Hence, the true plant species richness may be higher than observed.

Historical data is unavailable to determine whether biodiversity distribution pre-dates anthropogenic structures. Location of anthropogenic structures has been influenced by substrate and proximity to the coast, and is unlikely to have also been significantly influenced by biodiversity. Camel and horse stables, towns, and solar facilities are located on gravel plains, whereas forage production and the desert resort are located on stable dunes. Variation in community self-regulation of camel browsing throughout Al Marmoom Desert Conservation Reserve could have caused the observed spatial variation in biodiversity. Proximity to camel enclosures did not affect plant diversity at the scale observed in this study.

Moderate browsing can sometimes increase plant diversity through the reduction of dominant species, but heavy browsing typically reduces the richness of palatable species. Observations of increaser and decreaser plant species were mixed. The palatable grasses *Panicum turgidum* Forssk., and *Pennisetum divisum* (J.F. Gmel.) Henrard were found only in the north-north-west of Al Marmoom Desert Conservation Reserve, and the palatable tree *Calligonum comosum* L'Hér was not observed during the study, indicating heavier browsing in the central and south-south-east regions. However, *Calotropis procera*, known to flourish under heavy camel browsing, was also not observed, perhaps due to the presence of gazelles. Distribution of the sedge *Cyperus conglomeratus* Rottb., followed a similar pattern, despite being an early recoloniser of stressed habitats.

The results of this PhD study found no correlation between study-site biodiversity and proximity to feeding points, but oryx and gazelle densities were negatively correlated with site biodiversity and proximity to human activity. These ungulates had *ad libitum* access to non-rangeland food, water and shade sources at feed points throughout Al Marmoom Desert Conservation Reserve. It therefore appears they preferentially inhabited areas away from people, using feed points as their primary food source, and browsing on rangeland vegetation nearby. Diurnal movement patterns of oryx and gazelles were disrupted by reliance on feed points that provided all their needs (food, water and shade) at a single location. In the neighbouring Dubai Desert Conservation Reserve (DDCR), oryx utilised feed points, whereas gazelles preferred rangeland vegetation if available. Oryx tend to disperse uniformly during daytime and night-time browsing hours and regroup at sunrise and sunset. Ungulate densities likely far exceed historical levels, but their level of dependence on rangeland vegetation has not been measured. Differential browsing is the most likely cause of the observed spatial variation in biodiversity, due to camel herders using areas that are less communally regulated, and other ungulates avoiding human activity. Nevertheless, several other factors could be contributing, including changes to groundwater, seed bank production and dispersal, and faunal consumption of irrigated vegetation. Groundwater distribution in the UAE has been substantially modified over the last few decades through increased extraction and added recharge sources.

Protection from large herbivores is available for plants in many anthropogenic structures, some of which also have increased water availability. These areas may be important for seed bank recharge of palatable species. Plants can grow far larger with protection, and thus produce far more seeds than plants without protection. Seed dispersal might also be affected by faunal visits to irrigated spaces, and to anthropogenic activity throughout the reserve. Equestrian tracks are regularly graded, and on- and off-road vehicles of all sizes move throughout the reserve. Higher site biodiversity appeared to be more associated with fenced irrigated spaces than unfenced irrigated forests, which is indicative that seed bank recharge might be significant.

**Hyper-arid tall shrub species have differing long-term responses to browsing management**

Hyper-arid rangeland vegetation is typically dominated by large woody species which are often overlooked in herbivory studies. Long-term responses of tall shrub populations to herbivory change are poorly understood in the Arabian Peninsula. Population and size of 1559 individuals from four shrub species were assessed over an 11-year period under two herbivory regimes, one in which domestic livestock (camels) were replaced by semi-wild ungulates (oryx and gazelles) before, and the other during, the study period. Each shrub species exhibited a different response to the change in herbivory. Populations of *Calotropis procera* (Aiton) W.T. Aiton decreased dramatically. Populations of both *Calligonum polygonoides* L., and *Lycium shawii* Roem. & Schult., increased through sexual reproduction, but the spatial distribution of recruits indicated different modes of seed dispersal. Average lifespans were estimated at 22 and 20 years respectively. The persistence strategy of *Leptadenia pyrotechnica* (Forssk.) Decne., was similar to tree species of this habitat in that vegetative regrowth was prioritized over recruitment, and average lifespan was estimated at 95 years. Shrub responses to changes in ungulate management are therefore species-specific. The response of individual plant size was faster than the response of population size, which was limited by slow sexual recruitment (*L. pyrotechnica*) or localized seed dispersal (*C. polygonoides*). Each shrub species exhibited a different response to the change in herbivory from livestock to semi-wild ungulates.

Population changes were as hypothesized but plant size changes differed from our expectations. Populations of *C. procera* decreased dramatically. Populations of both *C. polygonoides* and *L. shawii* increased through sexual reproduction, but the spatial distribution of recruits supported the different presumed modes of seed dispersal; recruitment of *C. polygonoides* was very high but localized around maternal plants, while recruitment of *L. shawii* was slower and partially associated with the canopies of *L. pyrotechnica.* The strategy of *L. pyrotechnica* was most similar to that previously reported for tree species in this habitat, in which vegetative reproduction is more frequent than sexual. Individuals of *L. pyrotechnica* had a high survival rate despite sometimes large reductions in plant size, resulting in a relatively long estimated life span. For *L. pyrotechnica*, the response of average plant size to changed herbivory occurred within the 11 years, but the response of population density was still in the early stages. Distribution of *Calligonum polygonoides* across the study area in 2017. Plants observed in 2006 were classified in 2017 as survived, dead or missing, and new recruits were classified as successful (alive) or unsuccessful (dead). Substantial differences in the tall shrub populations were observed in 2006, when camels were present in Dubai Desert Conservation Reserve (DDCR) and had been absent in Al Maha Reserve for 6.5 years. *C. polygonoides* was absent from DDCR, *L. shawii* shrubs were smaller, and *L. pyrotechnica* shrubs were smaller and less densely distributed. Some of these differences were visibly clear; six of eight farm owners who were interviewed in a 2005 ethnobotanical study reported an increase in *C. procera* populations over the previous decade, and three reported a decline in *C. polygonoides*, but they did not mention changes in the density or structure of *L. pyrotechnica*. Density of this species is spatially heterogeneous, making it difficult for ground observers to detect even the large differences measured here. Size of *L. pyrotechnica* was also affected, as was hypothesized, resulting in a much greater frequency in Dubai Conservation

Reserve (DDCR) of the microhabitats that are produced by the largest shrubs in this habitat. Larger shrubs were significantly associated with under canopy *L. shawii*. *L. pyrotechnica* was observed to shelter perennial grasses *Cenchrus divisus* (J.F. Gmel.) Verloove, Govaerts and Buttler and *Panicum turgidum* Forssk., and the bulk of seed production of these species within this hábitat appeared to occur within the shelter of *L. pyrotechnica* canopies. Camels appear to cause greater mechanical damage to *L. pyrotechnica* than do oryx or gazelles when they forage through the shrubs for these more palatable associated species. By 2017 the size differences of *L. pyrotechnica* among enclosures had largely disappeared but density differences remained. The number of new recruits was similar among enclosures, though they had grown larger in Al Maha Reserve. Therefore, this species recovers from heavy camel browsing by increasing both size and density, but the former is much faster than the latter, as hypothesized. Successful recruitment is normally very rare in perennial shrubs of arid ecosystems. Average lifespan was estimated at 95 years, differing markedly from the 15-20 years' average lifespan reported previously. These observations also indicate that the 2006 population difference among enclosures was caused by a decline of population in Dubai Deset Conservation Reserve (DDCR), rather than a recovery of population from prior over-browsing in Dubai Deset Conservation Reserve (DDCR). Recruitment of *L. shawii* showed a loose proximal association with potential maternal plants, but it is unclear from this study whether this is attributable to seed dispersal mechanism or suitability of microhabitat (dune stability). Recruitment was more common under the shelter of *L. pyrotechnica* canopies. Two possible explanations for this are that faunal dispersers of *L. shawii* seeds also frequent *L. pyrotechnica* canopies, or that seedlings are more protected from herbivory in this microhabitat. Survival of established *L. shawii* plants was unaffected by *L. pyrotechnica* protection. Reproductive success of *L. shawii* may have been affected by the grazing regime. Plant size is often a better indicator of fecundity and survival than age, and may, therefore, be a preferable measure of life history. It is not known why a higher mortality of L. shawii was observed in Al Maha Reserve during the study. It is possible that they are preferentially browsed by oryx more than camels. Domesticated oryx in Taif, Saudi Arabia, were observed to eat both leaves and roots of *L. shawii*, the latter by digging around the base of the plant with their front hooves, but this behavior has not been observed in the DDCR.

Distribution of *C. polygonoides* recruitment was tightly clustered into two groups, indicating that seeds had dispersed into Al Maha Reserve from two surviving maternal individuals located in DDCR. This clustering pattern has been observed elsewhere throughout DDCR, and is consistent with seeds being anemochoric. The habitat is similar to dune deserts in Oman that have been classified as a *Prosopis-Calligonum* vegetation type, indicating that a much larger density of *C. polygonoides* may have occurred previously. Recovery from camel over-browsing is relatively slow since destruction was more complete, and most recruitment occurs within a few hundred meters of a surviving plant. Camels avoid *C. procera* but eat most other plants, thus the species thrives in areas of dense camel populations. The almost complete decline of the species in 2017 is likely due to gazelle herbivory. Lower leaves on the two surviving plants, and others throughout Al Maha Reserve, have been removed and plant structure modified from multiple to a single stem. It is likely that this species was historically

uncommon in this habitat, and its demise represents a return toward a former ecological balance.

Two plant size observations were contrary to our hypotheses. *L. shawii* plants did not increase in size with reduced herbivory, indicating that the heavier grazing pressure of the 2006 DDCR regime did not substantially modify plant structure. *C. polygonoides* plants did not increase in height, as predicted, but their canopies increased substantially. Camel herbivory thus appears to affect woody stems in addition to the palatable leaves of this species. This might be through direct mechanical damage, or through the plant abandoning branches that lack photosynthetic tissue. The change in herbivory from camels to oryx and gazelles resulted in a decline of *C. procera* and an increase in the other three species as was hypothesized, but the response differed markedly among species. Existing *L. pyrotechnica* shrubs responded rapidly in size but recruitment was slow, with the species exhibiting a long lifespan and relying more on recovery and/or recruitment from rootstock than sexual reproduction. In contrast, *C. polygonoides* and *L. shawii* exhibited a short lifespan and showed no evidence of asexual reproduction. *C. polygonoides* relies on rapid growth and sexual recruitment, and the population can recover quickly around the maternal plant. However, heavy camel browsing can destroy established plants and the soil seed bank, resulting in local extinctions. *L. shawii* population recovery is slower but more dispersed. The species benefits from but is not reliant on its association with large *L. pyrotechnica* shrubs, which appear in the absence of heavy camel browsing. A healthy tall shrub community in this habitat can be recognized by an abundance of *C. polygonoides*, infrequent occurrences of *C. procera,* and large *L. pyrotechnica* shrubs that show little sign of mechanical damage from camels. Recovery from heavy camel herbivory would be hastened by (1) artificially distributing seeds of *C. polygonoides* and (2) promoting the presence of large unbrowsed *L. pyrotechnica* shrubs. The results of the study demonstrate that a ten-year timeframe is sufficient to see only the early stages of plant community recovery.

## RESUMEN

**Los ecosistemas mercantilizados: un desafío al que se enfrentan las áreas protegidas (AP) en el Emirato de Dubai (EAU)**

El desarrollo de los Emiratos Árabes Unidos (UAE) se realizó de una forma rápida con la llegada de la riqueza petrolera a finales de la década de 1950 en el Emirato de Abu Dhabi. El auge de la economía petrolera trajo consigo la creciente mercantilización de la tierra. La primera manifestación de esto fue con la introducción de la agricultura moderna a mediados del siglo XX. Las autoridades coloniales británicas, que trabajaban en estrecha colaboración con los gobernantes costeros, mostraron un gran interés en desarrollar los recursos terrestres y hídricos durante este período, en parte con la esperanza de que esto mejoraría el nivel de vida de la población local, apoyaría los centros urbanos emergentes y permitiría la expansión de la agricultura moderna. El surgimiento de Areas Naturales Protegidas (AP) debe considerarse en el contexto de la historia de la comercialización de tierras en el país.

La principal diferencia entre el Área Protegida (AP) de la Reserva de Conservación del Desierto de Dubai (DDCR), en la que se lleva a cabo la mayor parte de esta memoria de tesis doctoral, y otras AP es que el objetivo principal de la creación de esta Reserva es la conservación de la naturaleza basada en el principio de mercantilización. En esencia, el modelo de conservación implementado en la DDCR es un ejemplo de capitalismo verde mediante el cual aspectos del mundo natural se están incorporando a la esfera económica-mercantil.

La diferencia en la DDCR en comparación con otras AP es que se mantiene un equilibrio entre las ganancias obtenidas del producto básico (AP) y la implementación de medidas ecológicamente amigables destinadas a mitigar la degradación del medio ambiente. En un país en rápido desarrollo con una superficie relativamente modesta en comparación con otros países, la tierra se mercantiliza de varias maneras, incluida la construcción de infraestructura, la expansión urbana, la expansión de la industria y otras expansiones comerciales que compiten directamente con las agendas de conservación.

Los impactos en los ecosistemas desérticos de las AP de los UAE están vinculados a muchas actividades antropogénicas que reducen directa o indirectamente la biodiversidad. A finales de los años 1990, en la parte más meridional del Emirato de Dubai, se mercantilizó una zona del desierto para la construcción de un exclusivo complejo turístico y spa que fue inaugurado por Emirates Airlines (Al Maha Desert Resort and Spa) en un terreno que les había sido asignado por el Gobierno de Dubai. El concepto de este hotel era ofrecer a los visitantes una experiencia única de vida silvestre y desierto en un entorno natural. La parte sur de Dubai albergaba principalmente granjas de camellos y actividades que impactaban en el desierto de forma muy parecida a la descrita anteriormente. Para construir el complejo se valló una superficie de 27 $km^2$, excluyendo el pastoreo de camellos. Desde el momento de la apertura del resort, el 5% de los beneficios se han invertido en proyectos de conservación. Tras una auditoría ambiental realizada por los administradores del área circundante adyacente al complejo en 2001, se destacaron las amenazas actuales y potenciales al ecosistema del desierto. Esto llevó a una propuesta de creación de un área de conservación más completa alrededor del complejo y fue presentada por el propietario de Emirates Airlines al gobierno de Dubai. El gobierno de Dubai aprobó la propuesta y asignó un total de 225 $km^2$, que incluye el terreno ocupado por el resort. Los pasos iniciales para la creación de la DDCR incluyeron el establecimiento de una junta directiva compuesta originalmente por el director de Emirates Airlines y otros líderes influyentes de organizaciones gubernamentales (por ejemplo, organizaciones de servicios públicos). La junta describió los objetivos y valores que siguen siendo el cometido principal de la reserva, que se enumeran a continuación: Crear una AP permanente que garantice el futuro de los hábitats desérticos y la biodiversidad de la región gestionados de acuerdo con sólidos principios ecológicos científicos destinados a proteger los recursos naturales (el agua es el más obvio, pero se extiende a muchos otros también) y mantener el desierto original. Asegurar que la comunidad y los visitantes tengan acceso a la Reserva a través del desarrollo sosteniblr y responsable de prácticas comerciales que no impacten el rol principal de conservación y protección del hábitat. Proteger el patrimonio de las actividades tradicionales que se han convertido en parte de la historia y la cultura de la región y mantener la identidad de los inicios tribales de Dubai. Registrar y obtener reconocimiento internacional para la Reserva según los principios de gestión de AP de las

Naciones Unidas, entre otros, y garantizar que la DDCR esté adecuadamente protegida por la ley.

En años más recientes, actividades como el turismo han desempeñado un papel vital junto con la protección de especies en las AP a nivel mundial. Sin embargo, es esencial que se implementen prácticas de gestión efectivas, ya que ha habido muchos ejemplos de AP que no cumplen con sus objetivos de conservación debido a una gestión inadecuada, lo que resulta en la pérdida de biodiversidad de especies. Las AP en el Emirato de Dubai tienen que hacer frente a las presiones del desarrollo económico, la diferencia es que, sin una articulación clara de los objetivos de conservación, las AP corren el peligro de ser utlizadas como un recurso natural rentable económicamente.

**La proximidad a instalaciones periurbanas aumenta la biodiversidad nativa en zonas áridas**

La herbivoría por camellos se cita con frecuencia como la principal causa de la disminución de la vegetación en las regiones áridas de EAU y de la Península Arábiga. Los camellos han estado presentes durante milenios, pero los efectos sociales, culturales y políticos han provocado una explosión demográfica desde el final de la Segunda Guerra Mundial. La herbivoría por camellos suprime la fitomasa y reduce la proporción de pequeñas plantas perennes más apetecibles para los ungulados en todas las superficies terrestres, pero más severamente en los sustratos de grava. Los asentamientos de pastores de camellos están dispersos por todas las regiones áridas de Dubai, pero las densidades de camellos son más altas alrededor de los hipódromos y no están directamente asociados con el suministro de alimento o agua. La tenencia de la tierra no siempre es clara y tradicionalmente se basa en el acceso al agua más que en límites geográficos. Por lo tanto, el acceso a las regiones de pastos para los pastores de camellos está regulado de manera comunitaria dentro del emirato de Dubai, con pocas restricciones a través de zonas de pastoreo no cercados o a través de las fronteras del emirato.

Una de las principales causas de la degradación de la vegetación en Arabia es la herbivoría de libre acceso. En general, los ungulados y los pastores tienden a evitar las regiones periurbanas. Los resultados del estudio de esta tesis doctoral muestran que la biodiversidad nativa es mayor en las regiones áridas que limitan con los núcleos urbanos de Dubai (EAU), en comparación con las regiones más hacia el interior. La posible explicación es la influencia de elementos antropogénicos sobre la presión del ramoneo por parte de ungulados como los camellos, orix y gacelas. Dentro del área de estudio, la Reserva de Conservación del Desierto de Al Marmoom (Dubai), el pastoreo de camellos fue más intensa en lugares que bordeaban elementos antropogénicos, mientras que los orix y las gacelas evitaban selectivamente estas áreas. Por lo tanto, los elementos antropogénicos pueden tener una influencia positiva en la conservación del paisaje en regiones áridas de UAE al reducir el impacto del pastoreo por ungulados. Las franjas urbanas normalmente se asocian con una reducción de la biodiversidad nativa y la expansión urbana es una de las principales causas de extinciones locales. Sin embargo, las franjas urbanas exteriores a veces exhiben una mayor biodiversidad, probablemente debido a una mayor diversidad de hábitat que incluye el acceso

de la fauna a jardines ricos en recursos. La fitomasa total puede aumentar con los cambios en el agua subterránea, que generalmente incluyen un aumento tanto en el volumen como en los contaminantes. En tales casos, la aparente salud ecológica es controvertida porque los paisajes de transición urbano-rural modificados favorecen a las especies invasoras.

Los desarrollos urbanos afectan a los ecosistemas vecinos de múltiples maneras, generalmente disminuyendo la biodiversidad nativa. Se estudió una zona de pastoreo en una región árida de Dubai para identificar las causas principales de la variación de la biodiversidad. Esta zona fue la Reserva de Conservación del Desierto de Al Marmoom, un área de 990 $km^2$ en el borde urbano de Dubai, designada para la "mejora" ecológica y el uso recreativo al aire libre. El área carece de datos históricos sobre biodiversidad, pero se cree que está influenciada principalmente por la herbivoría del camello árabe. Se evaluó la diversidad floral y faunística perenne en 54 sitios. Conteos de ungulados reintroducidos; orix árabe, gacela árabe y gacela de arena que se capturaron en 79 sitios separados. Se evaluaron las correlaciones de la biodiversidad observada con el tipo de sustrato, las estructuras antropogénicas y la distribución de ungulados. La biodiversidad nativa fue sustancialmente mayor en las ubicaciones del noroeste cercanas a instalaciones recreativas, siendo la causa más probable la presión diferencial de ramoneo. El pastoreo de camellos presentó una mayor congregación en el noroeste, mientras que los orix y las gacelas se congregaban en puntos de alimentación en el sur-sureste, que estaban más alejados de la actividad humana. El paisaje exhibe una mayor biodiversidad natural en la periferia urbana. La actividad humana reduce la densidad de ungulados, lo que permite una mayor diversidad de flora perenne, que luego atrae a la fauna no ungulada. Por lo tanto, las características antropogénicas pueden ofrecer valor de conservación en paisajes donde las poblaciones de ungulados se elevan artificialmente.

La biodiversidad nativa era ~3 veces mayor cerca de las instalaciones antropogénicas establecidas en el norte de la Reserva de Conservación del Desierto Al Marmoom, y algo mayor cerca de algunas, pero no de todas las comunidades en el sur. La biodiversidad vegetal es baja en todos los Emiratos Árabes Unidos y la diversidad observada es menor en verano, cuando las especies efímeras están presentes en su mayoría sólo en forma de semillas. Algunas especies perennes de importancia ecológica en el área no aparecieron en el muestreo, incluidas *Acacia ehrenbergiana* Hayne y *Calotropis procera* (Aiton) W.T. Aiton. Por lo tanto, la verdadera riqueza de especies vegetales puede ser mayor que la observada.

No hay datos históricos disponibles para determinar si la distribución de la biodiversidad es anterior a las estructuras antropogénicas. La ubicación de las estructuras antropogénicas ha sido influenciada por el sustrato y la proximidad a la costa, y es poco probable que también haya sido influenciada significativamente por la biodiversidad. Los establos de camellos y caballos, las ciudades y las instalaciones solares se encuentran en llanuras de grava, mientras que la producción de forraje y el centro turístico del desierto se encuentran en dunas estables. La variación en la autorregulación comunitaria del ramoneo de camellos en la Reserva de Conservación del Desierto Al Marmoom podría haber causado la variación espacial observada en la biodiversidad. La proximidad a los recintos de camellos no afectó la diversidad de plantas en la escala observada en este estudio.

El pastoreo moderado a veces puede aumentar la diversidad de plantas mediante la reducción de especies dominantes, pero la intensa reduce normalmente la riqueza de especies. Las especies de gramíneas que son pastoreadas como *Panicum turgidum* Forssk. y *Pennisetum divisum* (J.F. Gmel.) Henrard se encontraron sólo en el noroeste de la Reserva de Conservación del Desierto Al Marmoom, y el arbusto palatable *Calligonum comosum* L'Hér no fue observado durante el estudio, lo que indica un pastoreo más intenso en las regiones central y sur-sureste. Sin embargo, tampoco se observó *Calotropis procera*, que se sabe que es favorecida bajo el pastoreo intenso de los camellos, tal vez debido a la presencia de gacelas. La distribución de *Cyperus conglomeratus* Rottb*.,* siguió un patrón similar, a pesar de ser una de las primeras recolonizadoras de hábitats perturbados.

Los resultados obtenidos en este estudio de doctorado no encontraron correlación entre la biodiversidad del sitio de estudio y la proximidad a los puntos de alimentación, pero las densidades de orix y gacelas se correlacionaron negativamente con la biodiversidad del sitio y la proximidad a la actividad humana. Estos ungulados tenían acceso *ad libitum* a fuentes de alimento, agua y sombra fuera de los pastizales en puntos de alimentación en toda la Reserva de Conservación del Desierto Al Marmoom. Por lo tanto, parece que habitan preferentemente en áreas alejadas de la gente, utilizando los puntos de alimentación como principal fuente de alimento y ramoneando la vegetación de las zonas cercanas. Los patrones de movimiento diurno de orix y gacelas se vieron alterados por la dependencia de puntos de alimentación que cubrían todas sus necesidades (comida, agua y sombra) en un solo lugar. En la vecina Reserva de Conservación del Desierto de Dubai (DDCR), los orix utilizaban puntos de alimentación, mientras que las gacelas preferían la vegetación natural si estaba disponible. Los orix tienden a dispersarse uniformemente durante las horas del día y de la noche y se reagrupan al amanecer y al atardecer. Es probable que las densidades de ungulados superen con creces los niveles históricos, pero no se ha medido su nivel de dependencia de la vegetación de los pastizales. El pastoreo diferencial es la causa más probable de la variación espacial observada en la biodiversidad, debido a que los pastores de camellos utilizan áreas que están menos reguladas comunitariamente y otros ungulados evitan la actividad humana. Sin embargo, varios otros factores podrían estar contribuyendo, incluidos los cambios en las aguas subterráneas, la producción y dispersión de bancos de semillas y el consumo de vegetación irrigada por parte de la fauna. La distribución de aguas subterráneas en los Emiratos Árabes Unidos ha sido modificada sustancialmente en las últimas décadas mediante una mayor extracción y fuentes de recarga adicionales.

En muchas estructuras antropogénicas, las plantas están protegidas frente al pastoreo además de contar con una mayor disponibilidad de agua. Estas áreas pueden ser importantes para la creación de bancos de semillas de especies palatables. Las plantas pueden crecer mucho más con protección y, por lo tanto, producir muchas más semillas que las plantas sin protección. La dispersión de semillas también podría verse afectada por las visitas de la fauna a espacios irrigados y por la actividad antropogénica en toda la reserva. Las pistas ecuestres se nivelan periódicamente y los vehículos dentro y fuera de las carreteras circulan por la Reserva. La mayor biodiversidad vegetal en la Reserva parece estar más asociada con espacios

irrigados cercados que con los espacios irrigados no cercados, lo que es indicativo de que la creación de los bancos de semillas podría ser significativa.

**Los grandes arbustos de regiones hiperáridas presentan diferentes respuestas al pastoreo a largo plazo**

La vegetación de las zonas hiperáridas pastoreadas suelen estar dominada por grandes especies leñosas que a menudo se pasan por alto en los estudios de pastoreo. Las respuestas a largo plazo de las poblaciones de grandes arbustos al cambio en el régimen de pastoreo no se conocen bien en la Península Arábiga. En este trabajo se evaluó la población y el tamaño de 1559 individuos de cuatro especies de arbustos durante un período de 11 años bajo dos regímenes de pastoreo, uno en el que el ganado doméstico (camellos) fue reemplazado por ungulados semisalvajes (orix y gacelas) antes, y el otro durante, el periodo de estudio. Cada especie de arbusto exhibió una respuesta diferente al cambio en el pastoreo. Las poblaciones de *Calotropis procera* (Aiton) W.T. Aiton disminuyeron drásticamente. Las poblaciones de *Calligonum polygonoides* L., y *Lycium shawii* Roem. & Schult. aumentaron mediante la reproducción sexual, pero la distribución espacial de las plantulas indicó diferentes modos de dispersión de semillas. La esperanza de vida media se estimó en 22 y 20 años respectivamente. La estrategia de persistencia de *Leptadenia pyrotechnica* (Forssk.) Decne., fue similar a la de las especies de árboles del hábitat estudiado en las que se priorizó el crecimiento vegetativo sobre la renovación por plántulas y donde la esperanza de vida promedio se estimó en 95 años. Por lo tanto, las respuestas de los arbustos a los cambios en el manejo de los ungulados son específicos de cada especie. La respuesta del tamaño individual de la planta fue más rápida que la respuesta del tamaño de la población, que estuvo limitada por la lenta renovación mediante plántulas de *L. pyrotechnica* o la dispersión localizada de semillas (*C. polygonoides*). Cada especie de arbusto exhibió una respuesta diferente al cambio en el régimen de pastoreo de ungulados.

Se estudiaron dos reservas: la Reserva para la Conservación del Desierto de Dubai (DDCR) y la Reserva Al Maha. Los cambios en las poblaciones fueron los planteados en la hipótesis, pero los cambios en el tamaño de las plantas difirieron de las expectativas previstas. Las poblaciones de *C. procera* disminuyeron drásticamente. Las poblaciones de *C. polygonoides* y *L. shawii* aumentaron mediante la reproducción sexual, pero la distribución espacial de las plantulas dependió de los diferentes modos de dispersión de semillas; la formación de plantulas de *C. polygonoides* fue muy alto, pero se localizó alrededor de la planta-madre, mientras que la de *L. shawii* fue más lento y parcialmente asociado con las copas de *L. pyrotechnica*. La estrategia de *L. pyrotechnica* fue muy similar a la descrita previamente para especies arbóreas en este hábitat, en las que la reproducción vegetativa es más frecuente que la sexual. Los individuos de *L. pyrotechnica* tuvieron una alta tasa de supervivencia a pesar de, a veces, grandes reducciones en el tamaño de la planta, lo que resultó en una esperanza de vida estimada relativamente larga. Para *L. pyrotechnica*, la respuesta del tamaño medio de la planta al cambio de pastoreo se produjo dentro de los 11 años, pero la respuesta de la densidad de población aún se encontraba en las primeras etapas. En el caso de *Calligonum polygonoides*, las plantas observadas en 2006 se clasificaron en 2017

como supervivientes, muertas o desaparecidas, y las nuevas plantulas se clasificaron como exitos (vivas) o no exitos (muertas). Se observaron diferencias sustanciales en las poblaciones de grandes arbustos en 2006, cuando los camellos estaban presentes en la Reserva de Conservación del Desierto de Dubai (DDCR) y habían estado ausentes en la Reserva Al Maha durante 6,5 años. *C. polygonoides* estuvo ausente en DDCR, los arbustos de *L. shawii* eran más pequeños y los arbustos de *L. pyrotechnica* eran más pequeños y estaban menos densamente distribuidos. Algunas de estas diferencias eran visiblemente claras; seis de ocho propietarios de granjas que fueron entrevistados en un estudio etnobotánico de 2005 informaron de un aumento en las poblaciones de *C. procera* durante la década anterior, y tres informaron una disminución en *C. polygonoides*, pero no mencionaron cambios en la densidad o estructura de *L. pyrotechnica*. La densidad de esta especie es espacialmente heterogénea, lo que dificulta que los observadores terrestres detecten grandes diferencias. El tamaño de *L. pyrotechnica* también se vio afectado, como se suponía, lo que resultó en una frecuencia mucho mayor en la Reserva de Conservación de Dubai (DDCR) de los microhábitats que se producen por los arbustos grandes de este hábitat. Los arbustos más grandes se asociaron significativamente con *L. shawii* bajo su dosel. Se observó que *L. pyrotechnica* albergaba pastos perennes de *Cenchrus divisus* (J.F. Gmel.) Verloove, Govaerts & Buttler y *Panicum turgidum* Forssk., y la mayor parte de la producción de semillas de estas especies dentro de este hábitat parecía ocurrir bajo el refugio de las copas de *L. pyrotechnica*. Los camellos parecen causar mayor daño mecánico a *L. pyrotechnica* que los orix o las gacelas cuando buscan entre los arbustos estas especies que son más apetecibles. Para 2017, las diferencias de tamaño de *L. pyrotechnica* entre los recintos habían desaparecido en gran medida, pero las diferencias de densidad persistían. El número de nuevas plantulas fue similar entre los recintos, aunque habían aumentado en la Reserva Al Maha. Por lo tanto, esta especie se recupera del intenso ramoneo de los camellos aumentando tanto el tamaño como la densidad, pero el primero es mucho más rápido que el segundo, como se planteó en la hipótesis inical. El crecimiento exitoso de las plántulas normalmente es muy raro en arbustos perennes de ecosistemas áridos. La esperanza de vida promedio se estimó en 95 años, lo que difiere notablemente del promedio de vida de 15 a 20 años conocido anteriormente. Estas observaciones también indican que la diferencia de población entre recintos en 2006 fue causada por una disminución de la población en la Reserva de Conservación Deset de Dubai (DDCR), en lugar de una recuperación de la población de una exploración excesiva previa en la Reserva de Conservación Deset de Dubai (DDCR). La formación de plantulas de *L. shawii* mostró una asociación proximal vaga con plantas maternas potenciales, pero en este estudio no queda claro si esto es atribuible al mecanismo de dispersión de semillas o a la idoneidad del microhábitat (estabilidad de las dunas). La formación de plantulas fue más común bajo *L. pyrotechnica*. Dos posibles explicaciones para esto son que los vectores de dispersión faunísticos de semillas de *L. shawii* también frecuentan las copas de *L. pyrotechnica*, o que las plántulas están más protegidas del pastoreo en este microhábitat. La supervivencia de las plantas establecidas de *L. shawii* no se vio afectada por la protección de *L. pyrotechnica*. El éxito reproductivo de *L. shawii* puede haber sido afectado por el régimen de pastoreo. El tamaño de la planta es a menudo un mejor indicador de fecundidad y supervivencia que la edad y, por lo tanto. No se sabe por qué se observó una mayor mortalidad de *L. shawii* en la Reserva Al Maha durante el estudio. Es posible que los orix los busquen preferentemente más

que los camellos. Se observó que los orix domesticados en Taif, Arabia Saudita, comían hojas y raíces de *L. shawii*, estas últimas excavando alrededor de la base de la planta con sus pezuñas delanteras, pero este comportamiento no se ha observado en el DDCR.

La distribución de las plantulas de *C. polygonoides* estuvo estrechamente agrupada en dos grupos, lo que indica que las semillas se habían dispersado en la Reserva Al Maha de dos individuos maternos sobrevivientes ubicados en DDCR. Este patrón de agrupamiento se ha observado en otras partes del DDCR y es consistente con que las semillas sean anemocóricas. El hábitat es similar a los desiertos de dunas en Omán que han sido clasificados como un tipo de vegetación *Prosopis-Calligonum*, lo que indica que anteriormente pudo haber habido una densidad mucho mayor de *C. polygonoides*. La recuperación del exceso de exploración de camellos es relativamente lenta ya que la destrucción fue más completa y la mayor parte del de la formación de plantulas ocurre a unos pocos cientos de metros de la planta sobreviviente. Los camellos evitan *C. procera,* pero comen la mayoría de las otras plantas, por lo que la especie prospera en áreas con densas poblaciones de camellos. La disminución casi completa de la especie en 2017 probablemente se deba al pastoreo por gacelas. Se eliminaron las hojas inferiores de las dos plantas supervivientes y de otras en toda la Reserva Al Maha, y se modificó la estructura de la planta pasando de múltiples tallos a un solo tallo. Es probable que esta especie haya sido históricamente poco común en este hábitat y su desaparición represente un retorno hacia un equilibrio ecológico anterior.

Dos observaciones del tamaño de las plantas fueron contrarias a nuestras hipótesis. Las plantas de *L. shawii* no aumentaron de tamaño con la reducción del pastoreo, lo que indica que la mayor presión de pastoreo del régimen DDCR de 2006 no modificó sustancialmente la estructura de la planta. Las plantas de *C. polygonoides* no aumentaron en altura, como se predijo, pero sus copas aumentaron sustancialmente. Por lo tanto, el pastoreo por camellos parece afectar los tallos leñosos además de las hojas apetecibles de esta especie. Esto podría deberse a un daño mecánico directo o a que la planta abandone ramas que carecen de tejido fotosintético. El cambio en el pastoreo de camellos a orix y gacelas resultó en una disminución de *C. procera* y un aumento en las otras tres especies, como se había planteado la hipótesis, pero la respuesta difirió marcadamente entre especies. Los arbustos de *L. pyrotechnica* existentes respondieron rápidamente en tamaño, pero la formación de plántulas fue lenta, y la especie exhibió una larga vida útil y dependió más de la recuperación vegetativa que de la reproducción sexual. Por el contrario, *C. polygonoides* y *L. shawii* exhibieron una vida útil corta y no mostraron evidencia de reproducción asexual. *C. polygonoides* depende de un rápido crecimiento y formación de plantulas, y la población puede recuperarse rápidamente alrededor de la planta madre. Sin embargo, el ramoneo intenso de los camellos puede destruir las plantas y el banco de semillas del suelo, lo que provoca extinciones locales. La recuperación de la población de *L. shawii* es más lenta pero más dispersa. La especie se beneficia, pero no depende de su asociación con grandes arbustos de *L. pyrotechnica*, que aparecen en ausencia de un intenso ramoneo de camellos. Una comunidad de grandes arbustos en este hábitat puede reconocerse por la abundancia de *C. polygonoides*, apariciones poco frecuentes de *C. procera* y grandes arbustos de *L. pyrotechnica,* que muestran pocos signos de daño mecánico por parte de los camellos. La recuperación del intenso pastoreo de camellos se aceleraría

mediante (1) la distribución artificial de semillas de *C. polygonoides* y (2) la promoción de la presencia de grandes arbustos de *L. pyrotechnica*. Los resultados del estudio demuestran que un período de diez años es suficiente para ver las primeras etapas de recuperación de la comunidad vegetal.

# INTRODUCTION

# INTRODUCTION

In the arid desert ecosystems, due to harsh natural conditions and the impact of anthropogenic causes, biodiversity constantly threatens, which might sometimes lead to species extinction. All the Arabian Gulf oil-producing countries are rapidly developing, which lead to human activities expansion that threatened wildlife populations. The establishment and the development of the Arabian Peninsula flora and vegetation have passed long-term geological and climatic changes and the effect of anthropogenic interference which cause a significant desertification effect of the natural vegetation due to overgrazing, urban and agricultural expansion and practices, over-collection of woody plants for firewood, introducing alien and invasive species, plus the natural causes of climate change and its drought effect consequences (Miller and Cope, 1996; Böer, 1998; Ghazanfar and Fisher, 1998; Shabana, 2019).

In the UAE, the improvement of the standards of living brought by oil and gas revenues lead to significant changes in the human population size due to the flood of emigrants hired as human power for oil sectors first, then for other economic development sectors. Habitat fragmentation in a desert ecosystem resulting from urbanisation and road construction alters and encroaches upon native desert species habitats and possibly results in their decline over time. Expansion of cultivation and forestry plantations change the desert landscape from a sparsely vegetated area to a dense forestry plantation. In addition; invasive species have a negative impact on native desert flora through competition for the limited resources (Tourenq and Launay, 2008).

Camels have been bred for millennia in the Arabian Peninsula. With the fast UAE development, camels breeding, and racing have been promoted to preserve the past traditional practices. These practices resulted in a massive increase in camel herds with a significant change in livestock management systems. In the 1960s, the Arabian Peninsula traditional gazing management system facilitated the sustainable use of rangelands and other natural resources by setting aside and abandoned large reserves during stressful times. In Saudi Arabia, about 3,000 reserves existed in 1969, only 71 were still in existence under various degrees of protection in 1984, and only nine were on the 1997 Protected Areas list. In Arabian Peninsula, groundwater extraction for cultivation and other recreational purposes is a significant impact factor added to the domestic animals overgrazing and resulted in a considerable loss of desert habitats with national importance and, in returns, impact unique faunal species (Tourenq and Launay, 2008).

There are some conservation policies in the Arabian Peninsula, such as establishing nature conservation areas (*in-situ* conservation) and seed banking for saving the seeds of native plants (ex-situ conservation) for a long time. Still, these policies are variable from one country to another. the establishment of most protected areas boomed within the last 25 years, and all countries still actively consider

establishing new reserves. However, some areas of high diversity and endemism that urgently require conservation (Socotra and Yemen mainland, south-western and north-western highlands of Saudi Arabia, southern region of Oman and UAE) currently receive relatively formal protection (Ghazanfar and Fisher, 1998).

## The Arabian Peninsula

The Arabian Peninsula (Fig. 1) falls within the Saharo-Sindian sub-region of the Palaearctic region. This sub-region includes the desert and arid zone belt from the Western Sahara, through North Africa, Arabia and as far eastwards as the Sind in Pakistan and northwards through the deserts and semi-deserts of Afghanistan to Kazakhstan, Uzbekistan and Turkmenistan, and could also be extended to include the Great Indian Desert of Rajasthan.

The Arabian Peninsula covers 2.7 million km$^2$ which an area equal to half of Europe, 8% of Asia and approximately 2% of the world land surface. The Peninsula is gently tilted rectangular with diverse topography of rugged mountains, vast sand and rock deserts (including some of the hottest and driest deserts on earth). There are no permanent rivers and only a few permanent streams in the high and wet areas of the mountains (Miller and Cope, 1996; Huggett, 2007; Bahadur et al., 2015). The Arabian desert occupay the entire Arabian Peninsula and include part of the Iraqi and Jordanian deserts. It is the second largest desert after the Sahara Desert in northern Africa and comprises of seven countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE and Yemen (Fig. 1).


**Figure 1**. Map of the Arabian Peninsula and its countries.

The Arabian Peninsula bordering to the north the Syrian desert, to the north east and the east by the Arabian gulf and the Gulf of Oman, to the south east and south by the Arabian Sea and to the west by the Red Sea. This desert is charactrised as the most harsh climatic conditions in the world and described by low rainfalls, high evaporation rates, highest temperature, and high rate of soil and water salinity (Miller and Cope, 1996; Boer, 1997; Ghazanfar and Fisher, 1998; Peacock et al., 2003; Shabana, 2019).

## The United Arab Emirates (UAE)

### A Hyper-Arid Desert Ecosystem in the Arabian Peninsula

The UAE is a subtropical desert country geographically located at the southeastern part of the Arabian Peninsula, between the Latitudes of 22 º 40' and 26 º 00' North and the Longitudes of 51 º 00' and 56 º 00' East. The UAE boundaries are the Arabian Gulf from the north, Sultanate and Gulf of Oman from the east, and Saudi Arabi from the south and the west. UAE has two coasts, the western coast, which extends around 600 km of the Arabian Gulf, and the eastern coast, which extends around 75 km along the Gulf of Oman. The UAE comprises seven emirates: Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al Quwain, Ras Al Khaimah and Fujairah (Fig. 2). The UAE total area is about 83.600 $km^2$ (Böer, 1998; Sherif et al., 2009; Shabana, 2019). The desert of the UAE is typified by the dominance of the Aeolian landform system; the geomorphology features of the UAE include mountains, gravel plains, sand sheets and saline flats (Böer and Chaudhary, 1999; Karim and Fawzi, 2007; El-Keblawy et al., 2016). The geomorphological conditions characterising the UAE are four major landform classes: sand sheets, gravel plains, saline flats and mountains, each with characteristic vegetation adapted to the local soil conditions where the soils are generally nutrient-poor (Shabana, 2019). Typically, the UAE landmass divided into two clear zones, the low-laying zone and the mountains zone. The low-lying zone is mainly a 90% sandy desert of the whole country area, extending from the northwest to the eastern part of the country, where the mountains zone truncates it (Sherif et al., 2009).

The lowland zone varies in altitude from sea level up to 300 m. It is characterised by dunes that rise gradually from the coastal plain, reaching elevation up to 250 m above sea level and the Alluvial Plains. The Arabian Gulf coast is punctuated by primaeval raised beaches of calcareous sand and secluded hills that may reach 40 m asl. The coastal ecological zone consists of two separate coastal areas, the 600 km sandy and low Arabian Gulf Coast and the 70 km rocky and sometimes steep Gulf of Oman Coast. The Arabian Gulf coast characterised by narrow raised beaches of calcareous sand, with saline flat (Sabkhas) extended up to 30 km inland. In the far west of the coast, sabkhas reaching as far as 100 km inland, sabkhas do not support any visible vegetation due to the extremely high salt concentrations and often impermeable layers of gypsum and anhydrite. The Gulf of Oman coast (East Coast) consists of narrow gravel plains between the sea and mountains. The sand desert covers most of the UAE, contains a mixture of

low dunes, high dunes and intervening sand flats. In the south and south-east of the country dunes, ridges can reach up to 100 m, entrapping salt flats (Sabkha). On the other hand, the mountains zone consists of north-south mountains ranges parallel to the east coast, extending north-south to about 150 km to 50 km east-west. The highest mountain peak of UAE reaches up to 2000 m asl, and many wadies networks dissect all mountains. The Hajar mountains, consists of igneous rocks of the former oceanic crust and mantle (Jongbloed, 2003; Sherif et al., 2009; Shabana, 2019).

The international USDA-NRCS to soil taxonomy and the energetic soil survey that a group of scientists have conducted showed that the UAE landscape is covered mainly by low-lying sandy desert, mega barchan dunes, extensive coastal salt flats and alluvial and gravelly plains. This soil survey revealed a diversity of subsurface features that led to categorising soils into 74 soil series. These 74 soil series confirm the UAE soil diversity in chemistry, physics, mineralogy, fertility and suitability for different uses and vulnerability to land degradation (Shahid et al., 2014).

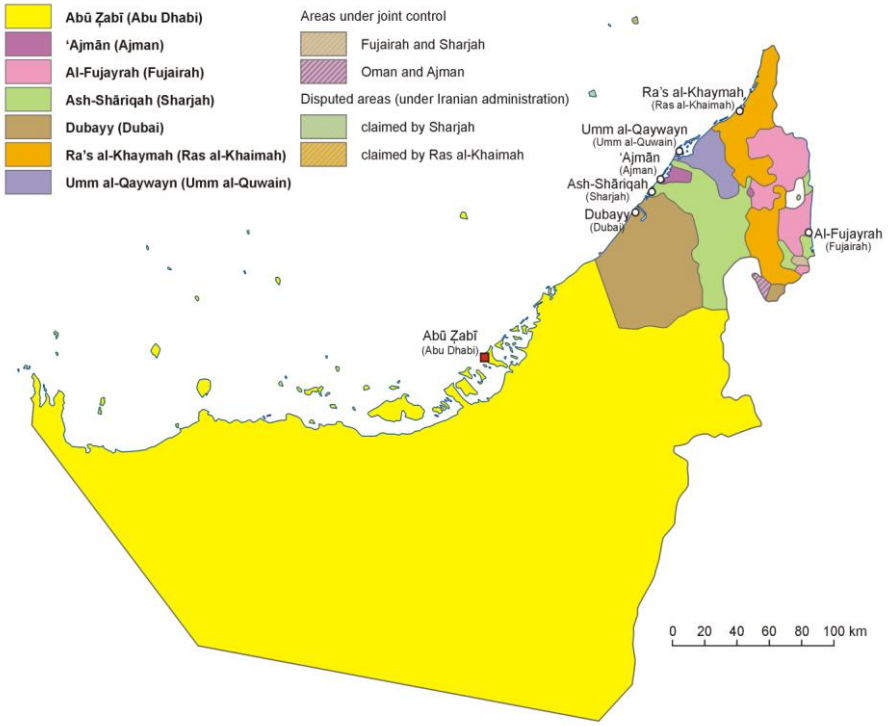


**Figure 2**. Administrative Map of United Arab Emirates (UAE) (source: Wikipedia Commons).

**Climate**

The Arabian Peninsula is part of the Arid Zone that extends from North Africa to South Asia and from the Sahara Desert to the Sindh Desert in India and Pakistan. The cloudless sky with very low relative humidity and very high evaporation characterise this arid zone. The Arabian Peninsula climate influenced by the polar continental air mass

during the winter and the tropical continental air mass during the summer. The UAE is situated in the tropic of cancer and described as a hyper-arid hot desert ecosystem for its extreme aridity climate and high summer temperature. There are only two main seasons: a long hot summer and a short, mild winter. The rain falls in the winter season between November and March, with maximum intensity during February and March. Rainfall is scarce, random, and infrequent; the mean annual rainfall is about 110 mm, with extreme variability in space and time. The lowest annual precipitation was found in Abu Dhabi (about 45 mm/year), inland desert (28-90.7 mm/year) and western coast (97.7-105 mm/year). The highest annual precipitation found in the northeast mountainous region ranges between 125.6 and 172 mm/year. The annual average temperature is approximately 27 °C and humidity 45.0%. For the winter, the mean temperature is around 20°C, while the mean temperature of summer ranges between 35 - 40 °C that can reach above 50°C. The average humidity reaches over 90.0% in summer and autumn (Miller and Cope, 1996; Boer, 1997; Feulner, 2006; Sherif et al., 2009).

**Vegetation**

The UAE natural vegetation include; evergreen and deciduous woodlands, drought-deciduous open thorn woodlands, sclerophyllous and succulent shrublands, dwarf shrublands, open xeromorphic grasslands and the sparse vegetation of the rock, gravel and sand deserts (Miller and Cope, 1996; Ghazanfar and Fisher, 1998; Shabana, 2019).

Vegetation of the gravel plains is relatively poor with low species diversity; most of the plains lack substantial soil, resulting in low vegetation cover. Most of the vegetation dominating the plains are thorny, halophytic and succulent shrubs. The amount of rain controls the annual vegetation.

Vegetation of the sands is characterised by low species diversity, uniformity of the life-form, species composition and adaptation to the harsh and unstable substrates. There are some disadvantages to grow the plants in the sand habitat where the sands have high porosity, permeability and wettability, where all rainfalls will be absorbed, and it will not result in run-offs. The disadvantages will be in the active dunes areas, the low nutritive qualities and the fast water infiltration from the surface soils. The vegetation of the UAE desert is very well adapted to the extreme conditions where the desert plants can avoid, resist and tolerate by very sophisticated mechanisms the prolonged drought. The main feature describing any dessert is the trees rarity and sparse vegetation, either shrubs height. The empty quarter covers nearly half a million square meters and is considered the largest sand desert in the middle east and one of the driest and harshest deserts on earth. The vegetation of the Arabian Peninsula traits copes with the harsh arid environment and impose different adaptation aspects to survive the hostile surroundings.

The UAE flora contains around 830 species with specific physiological and morphological adaptations to survive harsh environmental conditions. Interestingly, the mountains area, which occupies only 10.0% of the UAE total area, has more than 50.0% of the total plant species (Jongbloed 2003, Karim and Fawzi 2007, Shabana 2019). In general, the UAE has four vegetation ecosystems. The coastal lowlands region is characterised by mangrove vegetation composed of *Avicennia marina* (Forssk.) Vierh. and halophytic plant communities. The mountainous region corresponds to the Hajar Mountains series that extend from the UAE to the neighbouring Oman, which dominated by *Euphorbia larica* Boiss., *Pulicaria glutinosa* (Boiss.) Jaub. & Spach and *Ochradenus aucheri* Boiss. The other two habitats (sand desert and alluvial plains) are the main habitats in the study area, so the focus and explanation will be on their vegetation. The UAE sand desert that occupies most of the land surface of the country includes three areas: (A) Western dunes, which are yellow or orange because of the iron oxide and quartzite grains, the vegetation dominating these dunes are *Cyperus conglomeratus* Rottb. and *Calligonum comosum* L'Hér.; (B) The central desert has calcareous sand near the coast and quartz sand further inland and dominated by *Acacia tortilis (*Forssk.) Hayne*, Citrullus colocynthis* (L.) Schrad. and *Stipagrostis plumose (L.) Munro ex T. Anderson.* The dunes of the central desert are low and stable; limestone outcrops formation occur in a thin line and running north from Al Ain city. It is dominated by shrub plants such as *C. conglomeratus* and *Zygophyllum mandavillei* Hadidi, and grasses like; *Setaria verticillata* (L.) P. Beauv.*, Stipagrostis plumosa* (L.) Munro ex T. Anderson; (C) the deep sand, which has *Heliotropium digynum* (Forssk.) Asch. ex C.Chr. and *Limeum arabicum* Friedrich. In the Dubai region (study area), *Leptadenia pyrotechnica* (Forssk.) Decne., dominates the desert while *C. comosum* flourishing in fenced areas with no grazing of camels. In the region with heavy grazing, *Calotropis procera* (Aiton) W.T.Aiton is dominant (Jongbloed, 2003). The alluvial plains are the gravel plains near the Hajar Mountains. The gravel of alluvial plains is dominated by *Haloxylon salicornicum (*Moq.) Bunge ex Boiss.*, A. tortilis* and *Lycium shawii* Roem. & Schult. (Jongbloed. 2003; Karim and Fawzi 2007a; Shabana, 2019).

**Protected Areas**

Protected areas play an essential role in biodiversity conservation as they protect the critical elements of biodiversity and play a significant role in social and economic aspects. The Arabian Peninsula lacks a network of effectively managed reserves that include key high biodiversity areas, endemism, and unique habitats (Seddon et al., 2008, 2009), while some countries have extensive protected area networks, such as Saudi Arabia, Oman, and Jordan. Nevertheless, there has yet to be systematic regional planning for protected areas across all countries of the Arabian Peninsula (Holness et al., 2010). Eleven countries in the Arabian Peninsula region shared standard features of geology, arid climate, ecosystems, and cultural history. From ancient history, the efforts to protect the landscapes of the Arabian region. Approximately 230 reserves are currently in the Arabian Peninsula region, covering about 15% of the land area (Table 1)

(Omari, 2011). Arabian Peninsula countries are still actively considering the establishment of new reserves. However, some areas of high diversity and endemism require conservation efforts. They receive little or no formal protection (Shabana, 2019).

**Table 1.** Protected areas in the Arabian Peninsula (Omari, 2011).

| Country | Total area protected ($km^2$) | Number of reserves |
|---|---|---|
| United Arab Emirates | 4559 | 19 |
| Bahrain | 60 | 4 |
| Iraq | 5 | 8 |
| Jordan | 9,734 | 36 |
| Kuwait | 597 | 7 |
| Lebanon | 78 | 24 |
| Oman | 29,828 | 6 |
| Qatar | 137 | 13 |
| Saudi Arabia | 826,432 | 81 |
| Syria | 3,583 | 28 |
| Yemen | Approx. 28,000 | 4 |
| Total | 1,153,412 | 894 |

In-situ conservation is considered one of the leading conservation strategies in the UAE. The UAE declared several areas as protectorates with different conservation targets. Nineteen reserves were designated to cover around 9.5% of the country total area (Table 1). In one year (2006), the UAE declared 14 protected areas with a total surface area of 4.406 $km^2$ to be protected. A concrete example of the results of protection strategies against overgrazing in two regions of Abu Dhabi Emirate is a significant increase in richness and diversity of species and plant density and cover (Omari, 2011; Shabana, 2019).

To preserve the biodiversity of Dubai in UAE, Dubai Municipality designated eight protected areas. Dubai protectorates cover approximately 31% of the total area of Dubai. The eight natural reserves represent all major ecosystem types of the UAE, such as mountain, desert, coastal, and marine. These reserves aimed to achieve primary goals such as protecting, restoring, and promoting the ecosystems and natural biodiversity of the regions through implementing scientific research, monitoring, educational, and sustainable recreational initiatives. Among the eight protected areas in Dubai, the study area comprises Al Marmoom and Dubai Desert Conservation Reserve.

## Al Marmoom and Dubai Desert Conservation Reserve (DDCR). The Essential Protected Areas in Dubai

Al Marmoom and Dubai Desert Conservation Reserve are the first and second largest protected areas (PA) in Dubai Emirate, respectively. DDCR is located in the southeastern part of the Dubai Emirate, extending northward near the Sharjah Emirate border, and is the most biodiverse and prosperous environment in the Dubai Emirate. Al Marmoon is situated in the desert area of Saih Al Salam, stretching along the sands of the vast desert. Al Marmoum is bordered by the fenced 225 $km^2$ Dubai Desert Conservation Reserve. The climate is the first factor determining these two ecosystems, characterised by mild winters and scorching summers, with the mean humidity around 60% (between 50% in May and 65% in January and February). Between April and September, temperatures range from 38°C to 42°C (the hottest days reached 50°C).

The climate of this area is of a bi-seasonal Mediterranean type, characterised by high summer temperatures and low rainfall. Most precipitation is expected in the winter and spring between December and April. Very little was known about weather conditions in the UAE until the 1950s when oil prospecting began. Rain is always localised, sporadic and erratic and shows a great variation from year to year. The average annual rainfall for Sarjah airport for the 12 years 1992-2004 was 50mm (Alqamy, 2004). Weather systems in the region are associated with the Sub-Tropical Jet Stream, which lies over the Middle East at this time of the year. Rain and storms can still occur but are more likely over the northern Gulf. Maximum temperatures increase rapidly. Summer, June to September, is characterised by hot and dusty conditions. Autumn, October to November, is characterised by the most settled weather conditions. The recreation pressure (anthropogenic effect) is high, particularly from November to March.

## Protected Areas as Commodity Frontiers. The Case of Dubai Desert Conservation Reserve (DDCR)

The commodification of nature is an area of research within environmental studies that deals with how natural entities and processes become interchangeable through the market and its implications.

The concept of commodity frontiers was developed by Moore (2000) in order to detail the processes through which capitalism expands to the 'frontiers', e.g., a. non-commodified spaces that have an abundance of cheap labour, land, food and natural resources. This author highlighted the rapid social, political, ecological and economic changes accompanying commodity frontier expansion and the appropriation of the unpaid labour of both humans and nature. Work in this field has primarily focused on land-based resources, leaving capitalist expansion at sea and in coastal areas comparatively understudied.

The UAE declared protected areas (PAs) to utilise for recreational/economic purposes while mitigating habitat fragmentation. The concept of the 'commodity frontier' demonstrates how the PAs have contributed to the ongoing commodification of land that began with the rise of modern agriculture in the mid-twentieth century. The rise of the oil economy in the mid-twentieth century stimulated significant development that, over time, has resulted in ecological degradation. In line with state conservation agendas aimed at greening the desert and preserving biodiversity, PAs also serve as a mechanism for promoting tourism. These activities have further pressured the country natural resources and desert ecology. We present the Dubai Desert Conservation Reserve (DDCR) as an example of a PA that has been effectively managed and could serve as a model of sustainable development.

**Dubai Desert Conservation Reserve (DDCR). The Protected Area with the Most Biological Diversity in the UAE**

DDCR is one of the most biodiverse and rich ecosystems in the Dubai Emirate (https://www.ddcr.org/en/index.aspx) and it is the prime destination for desert lovers and wildlife safaris. The reserve contains around 562 known species of wildlife, including the Arabian oryx, gazelles, foxes, lizards and birds, as well as several species new to science (Khafaga, 2009). Second largest of the protected areas in the Emirate of Dubai, DDCR is located in the southeastern part of the Emirate, extending northward near to the Sharjah border (Fig. 3).

The DDCR represents an outstanding example of the high level of success which can be achieved through active collaboration between the Public (Dubai Government) and Private sector, the Emirates Group which has sponsored and supported wildlife conservation programmes and including a Research Committee with participation of International Universities (Fig. 4).

The history of the DDCR is very recent (c.f. www.ddcr.org). In 1999 the Al Maha Resort and Spa (Fig. 5) was established with an area of 27 $Km^2$ as a conservation reserve for the protection of the desert fauna and flora. Seventy Arabian oryx were introduced and indigenous trees and shrubs were planted. In 2002 the resort managers began an environmental audit of the surrounding areas. Researchers were tasked with exploring the then current and potential threats to endangered species and disappearing desert habitats. The Al Maha management then submitted proposals to the government for the formation of a formal national park.

The proposal was accepted and the Dubai Desert Conservation Board was established. In 2003 the DDCR with an area of 225 $Km^2$ was proclaimed. The Reserve constitutes 4.7% of Dubai total land area. The first wildlife releases into the newly created reserve took place in 2004. The Al Maha Resort (Fig. 5) lies within the boundaries of the Reserve but is being managed independently. The DDCR is a member of IUCN and UNEP.

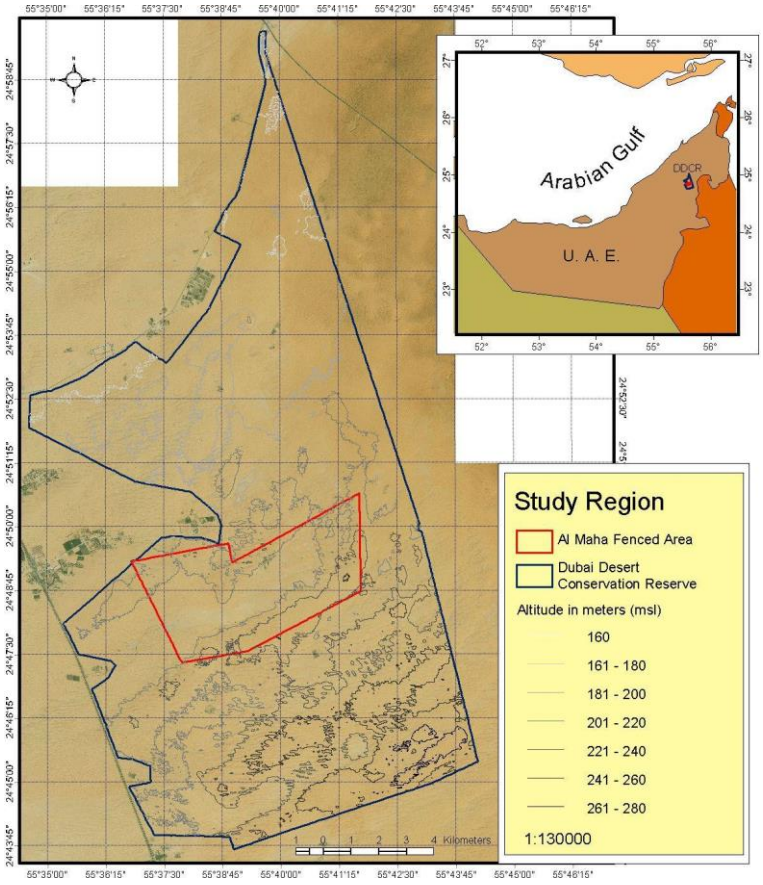


**Figure 3**. Map showing the location site of Dubai Desert Conservation Reserve (DDCR) and Al Maha area in the Dubai Emirate.

The vision for it is to create a permanently protected area which ensures the future of the region desert habitats and bio-diversity managed according to sound scientific ecological principles, aimed at protecting natural resources (water being the most obvious one, but extending to many others as well), and maintaining original desert landscapes. The area enclosed to form the DDCR is principally made up of low to medium sized sand dunes interspersed with sand flats and gravel plains. At the extreme north of the reserve there is a rocky outcrop, Quarn Nazwa.

Dubai Desert Conservation Reserve (DDCR) is a haven for desert wildlife and an example of traditional Arabian lifestyles related to camel use cultural heritages. A number of threatened species thrive in the desert environment of the DDCR, including the Arabian oryx (Fig. 6), Mountain Gazelle, Sand Gazelle (Fig. 6), and culturally important bird species such as Macqueen Bustard. Endangered and vulnerable birds which find refuge in the reserve include the Pharaoh Eagle Owl, and Lappet-face Vulture. Moreover, the occurrence of regional endemic species such as the Spiny-tailed Lizard and Gordon Wildcat makes DDCR truly unique on the world map.

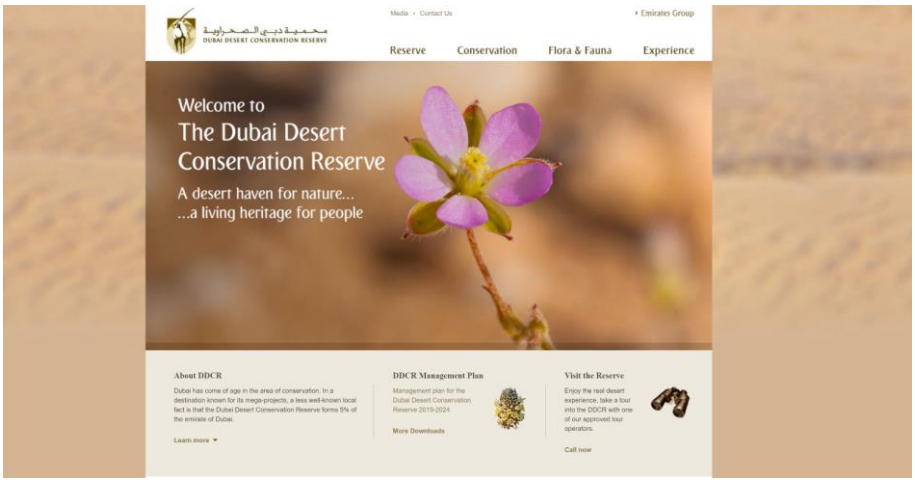


**Figure 4**. Dubai Desert Conservation Reserve (DDCR) webpage (https://www.ddcr.org/en/index.aspx).

Other large and small mammals that occur naturally in the reserve are: The Cape Hare, Ethiopian Hedgehog, Arabian Red Fox, Cheesman Gerbil, and Arabian Jird. There are also a number of reptiles such as Sand Boa, Crowned Leaf-nosed Snake, Hooded Malpolon, Schokari Sand Racer, Horned Viper and Sindh Saw-scaled Viper.

Dubai Desert Conservation Reserve is a protected area that is completely fenced (Fig. 3) where it contains numerous floral and fauna species in different type of topography. Different combinations of these floral and terrain elements could produce multiple intricate patterns of habitats (El Alqamy, 2004). DDCR has its policy of research and monitoring (Khafaga, 2009) that any conducted Research within the DDCR, should assist in applying sound scientific ecological principles to the decision-making process and adding new knowledge about the species and habitats of the DDCR. Promot The DDCR as a destination for applied research in the hyper-arid land ecosystems by national and international academic institutions. The DDCR Research Committee regularly evaluate all research proposals based on relevance to the reserve, ethical and practical implications (Dubai Desert Conservation Reserve, 2019), the last repport published in 2021-2022 (https://www.ddcr.org/media/z1opsv1a/ddcrannualreport2021-22.pdf).

Two vegetation surveys have been conducted in the Al Maha reserve and the DDCR since the proclamation of the DDCR (El Alqamy, 2004; Khafaga, 2009). For example, the total number of species recorded from the gravel plains within the DDCR in 2004 was 15 compared with 27 in 2009, and the surveys are updated annually. This was considered to represent positive rehabilitation of the gravel plains during the five years between the two surveys. Similarly, the total number of species recorded for the sand dunes in 2004 was 16 compared with 34 in 2009.

DDCR floral diversity includes about 37 species, 6 of which are trees, one of most relevant species is the *Prosopis cineraria* (L.) Druce and 26 shrubs and five grasses. However, some species, mostly shrubs, are more abundant and more common than

**Figure 5**. Al Maha Resort in the Dubai Desert Conservation Reserve (DDCR). Tourists in the Al Maha Resort instalations (top) and views from the Resort (bottom).

**Figure 6**. Dubai Desert Conservation Reserve (DDCR). Arabian oryx over the sand dunes (top) and arabian gazelle near to the Al Maha Resort (bottom).

others. Tree species are considered essential since they represent a hot spot for the diversity of floral and faunal elements around them.

**Al Marmoom Desert Conservation Reserve. The First Protected Area in Dubai**

Al Marmoom Desert Conservation Reserve is the first unfenced nature conservation reserve in the UAE. This Protected Area is located in the desert area of Saih Al Salam in the Emirate of Dubai, with an area of 990 km$^2$ that represents around 25% of the total area of the Dubai Emirate (Fig. 7). Some reserve areas are wetlands, including artificial lakes such as Al Qudra Lakes (Elhassan et al., 2021) (Fig. 8). Freshwater lakes are replenished with desalinated seawater pumped inland from the Arabian Gulf (Dubai Municipality, 2023). There are relatively dense tree plantations dominated by Ghaf (*Prosopis cineraria*) trees.

Dubai is devoted to encouraging ecotourism and environmental conservation, not only because of its rapid population and economic expansion but also because of sustainable locations effect on visitor decisions.

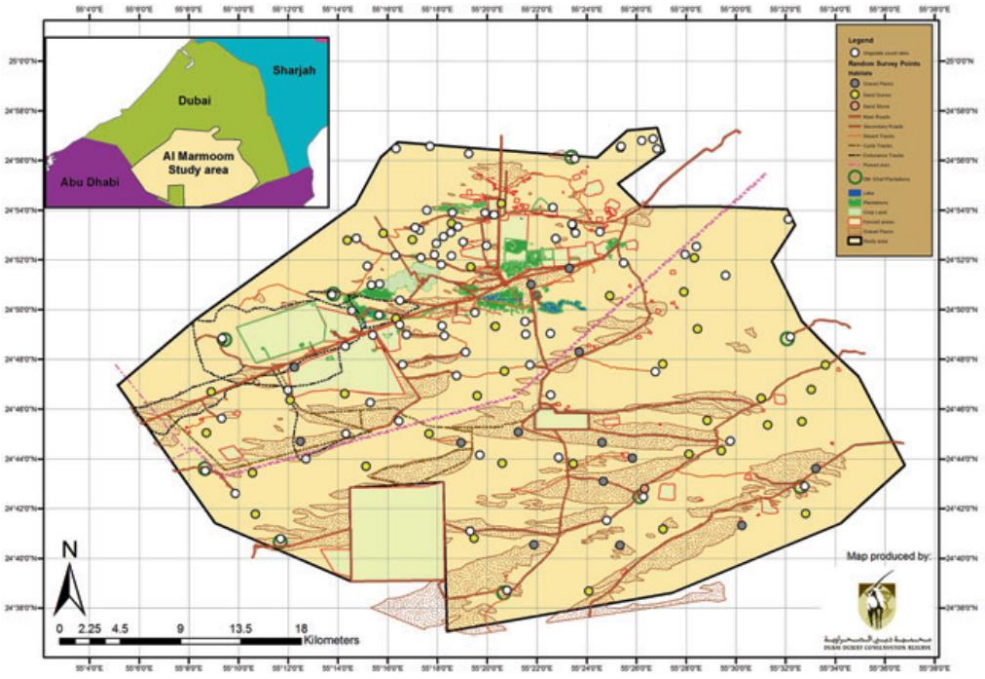


**Figure 7**. Map of Al Marmoom Desert Conservation Reserve in the Dubai Emirate.

**Figure 8**. Artificial lakes in th Al Marmoom Desert Conservation Reserve (source: https://www.moccae.gov.ae/en/home.aspx).

**Grazing Challenges for the Conservation of Boidiversity in the UAE Protected Areas**

The effect of large herbivore grazing on plant species diversity has been investigated in various terrestrial ecosystems (Milchunas and Lauenroth, 1993). However, few have dealt with the UAE desert ecosystem (El-Keblawy, 2003). Camel grazing affects over 90% of the area of the Arabian Peninsula, of which 44% is severely or very severely degraded (Ferguson et al., 1998). In the inland desert ecosystems of the UAE, excessive grazing by camels has been recognised as the single greatest threat (Gallacher and Hill, 2006). Camels are allowed to wander freely throughout the UAE desert to graze, while other livestock, such as goats, must be kept permanently in pens (Gallacher and Hill, 2006). The increase in grazing pressures, due to the sharp increase in the number of livestock in many Gulf countries, including the UAE (Gallacher and Hill, 2006), has resulted in significant deterioration of desert rangelands (Brown et al., 2003). Batanouny (1990) indicated that over 30% of the grazing land in the Arab Gulf countries is in a depleted condition due to large numbers of livestock, unrestricted grazing, and destructive gathering of wood and dry farming. The UAE camel herd increased from 39,500 in 1976, to approximately 250,000 in 2004. Consequently, the camel population density in the UAE is much higher (2.99 camels/km$^2$), than in other countries of the region, e.g. Saudi Arabia (0.12 camels/km$^2$) (Gallacher and Hill, 2006). Furthermore, camels represent an important part of the heritage of the UAE, and the government generously subsidises their production. Camel grazing can affect plant community composition. Camels generally graze on a broad spectrum of fodder plants, including thorny bushes, halophytes and aromatic species, usually avoided by other domestic herbivores. In addition, camels are adapted to the poor feeding conditions of deserts by selecting diets of high quality throughout all the seasons. El-Keblawy (2003) showed that overgrazing by camels in the UAE resulted in a significant reduction in the palatable plants *Crotalaria aegyptiaca* Benth., *Indigofera articulate* Gouan, *Pennisetum divisum*

*(*J.F. Gmel.) Henrard*, Stipagrostis plumosa* (L.) Munro ex T. Anderson*,* and *Panicum turgidum Forssk.,* suggesting that these species constitute an important part of camel diets in arid rangelands. While the above species were abundant inside the enclosures, they were not recorded in the overgrazed areas (El-Keblawy, 2003).

Understanding the dynamics of arid rangelands is a prerequisite for their proper management (Retzer, 2006). Arid rangelands are often fragile and subject to accelerated soil erosion. In addition, heavy grazing by livestock can change plant community composition, especially in arid regions, where plant communities generally evolved in the absence of a heavy grazing by wild herbivores (Ayyad, 2003). Protection of vegetation against grazing in desert environments has been suggested as a feasible approach to halting land degradation in order to rehabilitate rangelands (Ayyad, 2003). The impacts of protection against livestock grazing on plant communities of arid and semiarid rangelands have been studied in many regions of the world, however with contradictory results. The impact of grazing on desert plant communities is usually moderated by managing grazing intensity, duration, and type of grazing animal. Light to moderate grazing improved plant diversity (El-Keblawy, 2003). Similarly, in the UAE, a four-year program of protection resulted in a significant increase in species richness and abundance, compared to a 15-year program (El-Keblawy, 2003). The Dubai Desert Conservation Reserve (DDCR) offers a valuable opportunity to study the impact of different types of grazing animals and grazing intensities under the harsh desert conditions of the UAE. This reserve provides two grazing arrangements; one with a low wildlife stocking rate, such as oryx and gazelles (Al Maha Resort) and an outer perimeter with a high camel stocking rate (referred to as DDCR). Gallacher and Hill (2006) compared the impact of the replacement of camel grazing by oryx and gazelles

The Dubai Desert Conservation Reserve (DDCR) offers a unique opportunity to study regeneration of the Dubai inland desert under two management systems; one containing oryx and gazelles (Al Maha) and the other containing camels (DDCR). This is preferable to study livestock exclosures, since exclosures are neither natural nor preferable for managing plant ecology. Camels are allowed to graze the desert each day on an 'open access' land use basis that is common throughout West Asia (Ferguson et al., 1998). The UAE desert is now divided into several open-access zones, demarcated mainly by fenced highways and urban encroachment. Farms therefore impact a much wider area than that of the buildings and irrigation plots. It is arguable whether the farms should be considered part of the natural ecosystem, or whether they should be removed to favor wildlife. The purpose of the DDCR is to preserve a part of the natural desert for future generations, while at the same time providing a resource for the tourism industry.

## Objectives

The commodification process of nature and landscape is a continuation and evolution of the capitalist transformation instigated by the marketable use of protected lands, where camel farming practices are the dominant activity in this transformation. The concept of the commodity frontiers permits an understanding of the development and function of the Protected Area, as it has been done in Dubai Desert Conservation Reserve (DDCR), where it is commodified for constructing a luxury resort in a desert land region where camel farms and grazing activities that impacted the desert ecosystem. Creating the DDCR ensures the future of the desert habitats and biodiversity management according to scientific ecological principles to protect the heritage of traditional activities under recognition from the United Nations and high academic institutions and research. This study highlights the importance of biodiversity conservation and sustainability in Protected Areas in desert regions especially threatened by climate change and anthropisation.

It also shows how the leading cause of degradation and disturbance of Arabia ecosystems is free-access herbivory and how plant biodiversity is more significant in the peri-urban areas of Dubai than in the non-peri-urban areas. The reason is that peri-urban areas are subject to less grazing pressure from camels, oryx and gazelles. In this case, the anthropogenic effect in peri-urban areas prevents grazing and favours native plant diversity. This result is significant because urban development is vital in the UAE, predominantly Dubai.

Since the importance of studying the effect of grazing is crucial in desert ecosystems and especially in the Arabian Peninsula and specifically in the UAE. For the first time, the long-term response of two different grazing regimes, camels and ungulates, on the characteristic shrub species of the vegetation of the UAE ecosystems is studied. Revealing how each species presents a different specific response to the change in the grazing regime and the potential natural renewal of the plant communities they comprise.

The specific objectives of the study are:

1. To describe the Dubai Desert Conservation Reserve (DDCR) as a prime example of an effective biodiversity conservation management model within the commodified protected desert areas in the United Arab Emirates (UAE).

2. To study how human activities in the desert protected areas, especially the protected areas that have been designated for outdoor recreational use (Al Marmoum), impact the population density of large herbivores (camels, oryx and gazelles) and, therefore, the grazing pressure facilitating a greater diversity of perennial flora and consequently an increase in biodiversity.

3. To study the individual and population long-time responses of desert dominant large shrubs (*Calotropis procera* (Aiton) W.T. Aiton*, Calligonum polygoides* L.*, Lycium shawii* Roem. & Schult.*,* and *Leptadenia pyrotechnica* (Forssk.) Decne.) to the changes in herbivory regimes: domestic livestock (camels) replaced by semi-wild ungulated (oryx and gazelles) in desert ecosystems of Dubai (UAE).

## Importance of this Study for the United Arab Emirates (UAE)

Today, the UAE is considered a middle power, it is the Middle East third largest economy, and one of the wealthiest countries in the region on a per capita basis with rapid development and a great problem for the conservation of natural ecosystems historically degraded by the effect of grazing and currently under pressure from human activities and especially tourism. In this context, the importance of this study for the UAE is essential because it studies two crucial and key aspects in this region, which are the effect of grazing and the importance of the conservation of natural ecosystems through commodity frontiers protected areas in desert regions under the effect of climate change, anthropisation, tourism and dizzying development of large cities like Dubai and with the particularity of the importance of the conservation of cultural heritage in this country that is closely linked to the free breeding of camels in almost the entire territory.

## Structure of PhD Memory

This PhD Memory is structured in three chapters which correspond with two articles published in scientific journals included in the ISI web knowledge (JCR) and a book chapter. Below are the names of the co-authors, the titles of the publication, the reference of the journal or book chapter, the DOI and a brief summary in English and Spanish.

**Chapter 1:** Howarth, B., Khafaga, T., Simkins, G., & Joseph, S. (2019). Ecosystems as Commodity Frontiers—Challenges Faced by Land Set Aside as Protected Areas (PAs) in the Dubai Emirate, United Arab Emirates (UAE). *Commodity Frontiers and Global Capitalist Expansion: Social, Ecological and Political Implications from the Nineteenth Century to the Present Day*, 111-136. https://doi.org/10.1007/978-3-030-15322-9_5

The main difference between the DDCR and other PAs is that clearly articulated objectives informed the commodification of nature, with the primary goal being conservation. Given that the conservation objectives of the DDCR are dissimilar to the activities discussed that impact the PAs ecosystems, in essence, the conservation model implemented by the DDCR is an example of green capitalism whereby aspects of the natural world are being brought into the economic sphere. The difference at the DDCR in comparison to other PAs is that a balance is maintained between profit gained from

the commodity (PA) and implementation of ecologically friendly measures aimed at mitigating degradation of the environment. In a rapidly developing country with a relatively modest surface area in comparison with other countries, land is commodified in several ways, including infrastructure building, urban sprawl, the expansión of industry and other commercial expansions that are in direct competition with conservation agendas. In his article discussing the commodification of nature, scales allude to the taming of nature through technologies, and several examples of this are seen in proposed developments for the PAs (e.g. hydroelectric power production in the Hatta Mountain Reserve). Within the PAs discussed, there is a risk that the implementation of projects will adversely affect species biodiversity and therefore ecosystem services they render as well as overall ecosystem health. Quite frequently, capitalism is placed at the centre of the reasoning behind the current ecological crisis. However, in ancient history, it was not unusual for areas of land to be protected for reasons other than protecting the natural environment altruistically, but for safeguarding common land or resources for instrumental reasons, e.g. hunting for food, in parts of the world. In more recent years, activities such as tourism have played a vital role alongside species protection in PAs globally. However, it is essential that effective management practices are put in place as there have been many examples of PAs not meeting their conservation targets due to inadequate management, resulting in the loss of species biodiversity. The PAs in the Dubai Emirate are not unusual in facing pressures from economic development, the difference being that without a clear articulation of conservation targets, the PAs are in danger of only being seen as new profitability frontiers.

*La principal diferencia entre la DDCR y otras Areas Protegidas (AP) es que la mercantilización de la naturaleza en esta AP es el objetivo principal la conservación. Dado que los objetivos de conservación de la DDCR son diferentes de las actividades que impactan los ecosistemas de las AP, en esencia, el modelo de conservación implementado por la DDCR es un ejemplo de capitalismo verde mediante el cual aspectos del mundo natural se incorporan a la esfera económica. La diferencia en la DDCR en comparación con otras AP es que se mantiene un equilibrio entre las ganancias obtenidas del producto básico (AP) y la implementación de medidas ecológicamente compatibles destinadas a mitigar la degradación del medio ambiente. En un país en rápido desarrollo con una superficie relativamente reducida en comparación con otros países, la tierra se mercantiliza de varias maneras, incluida la construcción de infraestructura, la expansión urbana, la expansión de la industria y otras expansiones comerciales que compiten directamente con las agendas de la conservación natural de los ecosistemas. En su artículo sobre la mercantilización de la naturaleza, Scales alude a la domesticación de la naturaleza a través de tecnologías, y se ven varios ejemplos de esto en los desarrollos propuestos para las AP (por ejemplo, la producción de energía hidroeléctrica en la Reserva de la Montaña Hatta). Dentro de las AP, existe el riesgo de que la implementación de proyectos afecte negativamente a la biodiversidad de las especies y, por lo tanto, a los servicios ecosistémicos que prestan, así como a la salud general de los ecosistemas. Con bastante frecuencia el capitalismo se sitúa en el centro del*

*razonamiento detrás de la actual crisis ecológica, sin embargo, en la historia antigua, no era inusual que las áreas de tierra se protegieran por razones distintas a la protección altruista del entorno natural, sino para salvaguardar tierras o recursos comunes por razones instrumentales, e.g. cazar para alimentarse, en algunas partes del mundo. Recientemente, actividades como el turismo han desempeñado un papel vital junto con la protección de especies en las AP a nivel mundial. Sin embargo, es esencial que se implementen prácticas de gestión efectivas, ya que ha habido muchos ejemplos de AP que no cumplen con sus objetivos de conservación debido a una gestión inadecuada, lo que resulta en la pérdida de biodiversidad de especies. Las AP en el Emirato de Dubai no son inusuales al hacer frente a las presiones del desarrollo económico, la diferencia es que, sin una articulación clara de los objetivos de conservación, las AP corren el peligro de ser vistas sólo como nuevas fronteras de rentabilidad.*

**Chapter 2:** Khafaga, T., Simkins, G., & Gallacher, D. (2018). Proximity to urban fringe recreational facilities increases native biodiversity in an arid rangeland. The Rangeland Journal, 40(6), 555-563. DOI: 10.1071/RJ17041

Urban developments affect neighbouring ecosystems in multiple ways, usually decreasing native biodiversity. Arabian arid rangeland was studied to identify the primary causes of biodiversity variation. Al Marmoum is a 990 $km^2$ area on the urban edge of Dubai, designated for ecological 'enhancement' and outdoor recreational use. The area lacks historical biodiversity data, but is thought to be primarily influenced by Arabian camel (*Camelus dromedarius* Linnaeus, 1758) herbivory. Perennial floral and faunal diversity was assessed at 54 sites. Counts of reintroduced ungulates (Arabian oryx - *Oryx leucoryx* (Pallas, 1777); Arabian gazelle - *Gazella gazella* subsp. *cora* (C.H. Smith, 1827); and sand gazelle - *G. subgutturosa* subsp. *marica* (Thomas, 1897) were made at 79 separate sites. Correlations of observed biodiversity with substrate type, anthropogenic structures, and ungulate distribution were assessed. Native biodiversity was substantially higher in north-north-west locations near recreational facilities, with the most likely cause being differential browsing pressure. Camel browsing faced greater communal regulation in the north-north-west, whereas oryx and gazelles congregated at feed points in the south-south-east that were farther from human activity. Arid rangeland in this socioecological landscape exhibits greater natural biodiversity at the urban fringe. Human activity reduces ungulate density, enabling a greater diversity ofperennial flora, which then attracts non-ungulate fauna. Anthropogenic features can therefore offer conservation value inlandscapes where ungulate populations are artificially elevated

*El desarrollo urbano afecta a los ecosistemas vecinos de múltiples maneras, generalmente disminuyendo la biodiversidad nativa. Se han estudiado pastizales áridos de Arabia para identificar las causas principales de la variación de la biodiversidad. Al Marmoum es un área de 990 $km^2$ en el límite urbano de Dubai, designada para "mejora" ecológica y uso recreativo al aire libre. El área carece de datos históricos sobre biodiversidad, pero se cree que está influenciada principalmente por la herbivoría del*

*camello árabe (Camelus dromedarius Linnaeus, 1758). Se evalua la diversidad floral y faunística perenne en 54 sitios y se realizan recuentos de ungulados reintroducidos (orix árabe - Oryx leucoryx (Pallas, 1777); gacela árabe - Gazella gazella* subsp. *cora (C.H. Smith, 1827); y gacela de arena - G. subgutturosa subsp. marica (Thomas, 1897) en 79 sitios diferentes. Se establecieron las correlaciones de la biodiversidad observada con el tipo de sustrato, las estructuras antropogénicas y la distribución de ungulados. La biodiversidad nativa fue sustancialmente mayor en las ubicaciones del noroeste cercanas a instalaciones recreativas, siendo la causa más probable la presión diferencial del pastoreo. La cria de camellos está mas regulada en el noroeste, mientras que los orix y las gacelas se congregan en puntos de alimentación en el sur-sureste, que estaban más alejados de la actividad humana. Los pastizales áridos en este paisaje socioecológico exhiben una mayor biodiversidad natural en la periferia urbana. La actividad humana reduce la densidad de ungulados, lo que permite una mayor diversidad de flora perenne, que luego atrae a la fauna no ungulada. Por lo tanto, las características antropogénicas pueden ofrecer un valor de conservación en paisajes donde las poblaciones de ungulados se elevan artificialmente.*

**Chapter 3:** Gallacher, David J., and Tamer Khafaga. "Hyper-arid tall shrub species have differing long-term responses to browsing management." Arid Land Research and Management 34.1 (2020): 99-116. https://doi.org/10.1080/15324982.2019.1605631

Hyper-arid rangeland vegetation is typically dominated by large woody species which are often overlooked in herbivory studies. Long-term responses of tall shrub populations to herbivory change are poorly understood in the Arabian Peninsula. Population and size of 1559 individuals from four shrub species were assessed over an 11-year period under two herbivory regimes, one in which domestic livestock (camels) were replaced by semi-wild ungulates (oryx and gazelles) before, and the other during, the study period. Each shrub species exhibited a different response to the change in herbivory. Populations of *Calotropis procera* (Aiton) W.T. Aiton decreased dramatically. Populations of both *Calligonum polygonoides* L., and *Lycium shawii* Roem. & Schult increased through sexual reproduction, but the spatial distribution of recruits indicated different modes of seed dispersal. Average lifespans were estimated at 22 and 20 years respectively. The persistence strategy of *Leptadenia pyrotechnica* (Forssk.) Decne., was similar to tree species of this habitat in that vegetative regrowth was prioritised over recruitment, and average lifespan was estimated at 95 years. Shrub responses to changes in ungulate management are therefore species-specific. The response of individual plant size was faster than the response of population size, which was limited by slow sexual recruitment (*L. pyrotechnica*) or localised seed dispersal (*C. polygonoides*).

*La vegetación de los pastizales hiperáridos suele estar dominada por grandes especies leñosas que a menudo se pasan por alto en los estudios de pastoreo. Las respuestas a largo plazo de las poblaciones de grandes arbustos al cambio de herbivoría no se conocen bien en la Península Arábiga. Se evaluó la población y el tamaño de 1559*

*individuos de cuatro especies de arbustos durante un período de 11 años bajo dos regímenes herbívoros, uno en el que el ganado doméstico (camellos) fue reemplazado por ungulados semisalvajes (orix y gacelas) antes, y el otro durante, el periodo de estudio. Cada especie de arbusto exhibió una respuesta diferente al cambio en la herbivoría. Las poblaciones de Calotropis procera (Aiton) W.T. Aiton disminuyeron drásticamente. Las poblaciones de Calligonum polygonoides L., y Lycium shawii Roem. & Schult aumentaron mediante la reproducción sexual, pero la distribución espacial de las plántulas indicó diferentes modos de dispersión de semillas. La esperanza de vida promedio se estimó en 22 y 20 años respectivamente. La estrategia de persistencia de Leptadenia pyrotechnica (Forssk.) Decne., fue similar a la de las especies de árboles de este hábitat en que se priorizó la renovacion vegetativa sobre la germinacion de plantulas y la esperanza de vida promedio se estimó en 95 años. Por lo tanto, las respuestas de los arbustos a los cambios en el manejo de los ungulados son específicas de cada especie. La respuesta del tamaño de la planta individual fue más rápida que la respuesta del tamaño de la población, que estuvo limitada por el lento reclutamiento sexual (L. pyrotechnica) o la dispersión localizada de semillas (C. polygonoides).*

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# CONCLUSIONS

# CONCLUSIONS

1. The concept of commodity frontiers ecosystem facilitates the conservation of biodiversity in desert Protected Areas in United Arab Emirates (UAE).

- The function and development of the Dubai Desert Conservation Reserve (DDCR), a desert Protected Area subjected to the impact of grazing by ungulates (oryx, gazelles and camels), is facilitated by the commodification resulting from the construction of a luxury tourist center inside.

1. *La aplicación del concepto de mercantilización en ecosistemas naturales facilita la conservación de la biodiversidad en Areas Protegidas del desierto de los Emiratos Arabes Unidos (UAE).*

- *La función y el desarrollo de la Dubai Desert Conservation Reserve (DDCR), un Área Protegida sometida al impacto del pastoreo por ungulados (orix, gacelas y camellos), se vé facilitada gracias a la mercantilización resultante de la construccion de un centro turistico de lujo en su interior.*

2. The conservation of biodiversity can be favored by the effect of human activities in desert Protected Areas in United Arab Emirates (UAE) specially designated for ecological improvement and outdoor recreational use.

- Human activity in Al Marmoum Dubai Protected Area reduces the population density of artificially elevated ungulates (oryx, gazelles and camels) facilitating the increase of native perennial plants and fauna.

2. *La conservación de la biodiversidad está favorecida por el efecto de la actividad humana en Áreas Protegidas desérticas de los Emiratos Árabes Unidos (EAU) especialmente designadas para la "mejora ecológica y el uso recreativo al aire libre".*

- *La actividad humana en el Area Protegida de Dubai Al Marmoum reduce la densidad de las poblaciones de ungulados (orix y gacelas) criados artificialmente facilitando así el aumento de plantas perennes y de fauna.*

3. Dominant desert shrub species in UAE desert (*Calotropis procera (*Aiton) W.T. Aiton, *Calligonum polygonoides* L., *Lycium shawii* Roem. & Schult. and *Leptadenia pyrotechnica* (Forssk.) Decne.) exhibet different response to the change in hervivory regimes. The long-time response to changes in ungulate management therefore species-specific. The response of individual plant size was faster than the response of population size, which was limited by slow sexual recruitment.

- Changes in herbivory regimes: domestic livestock (camels) replaced by semi-wild ungulated (oryx and gazelles) result in a dramatically population decreasing of *C. procera. L. pyrotechnica* prioritise vegetative regrow. Populations of both *C. polygonoides* and *L. shawii* increased through sexual reproduction, but the spatial distribution of the recruits varies and depend of seed dispersal modes.

3. *Los arbustos dominantes del desierto de los EAU (Calotropis procera (Aiton) W.T. Aiton, Calligonum polygonoides L., Lycium shawii Roem. & Schult. y Leptadenia pyrotechnica (Forssk.) Decne.) exhiben respuestas diferentes al cambio en el régimen de herbivoría por ungulados. La respuesta a largo plazo es específica de cada especie. La respuesta en el tamaño de la planta es más rápida que la respuesta en el tamaño de la población, la cual está limitada por un lento crecimiento de las plántulas.*

- *Los cambios en el régimen de herbivoría: el ganado doméstico (camellos) reemplazado por ungulados semisalvajes (orix y gacelas) resulta en una significativa disminución de la población de C. procera, mientras que Leptadenia pyrotechnica prioriza la renovación vegetativa. Las poblaciones de C. polygonoides y L. shawii aumentan mediante reproducción sexual, pero la distribución espacial de sus plántulas varía dependiendo de los modos de dispersión de las semillas.*