Effects of camel vs oryx and gazelle grazing on the plant ecology of the Dubai Desert Conservation Reserve

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ABSTRACT: Grazing of the Dubai inland desert has changed substantially over the last century, and particularly over the last three decades. Populations of oryx, ostriches and gazelles have been replaced by an increased camel herd, which is at least 2.5 times historical levels. Camel grazing patterns differ to smaller herbivores, affecting plant species composition. Camels are given supplementary feed, so their population is not limited by seasonal availability of vegetation. Desert plants face longer periods of heavy grazing from a larger camel population, and shorter periods for recovery. Plant chemical defenses may also be less effective from the different grazing regime.

Although widely considered to be overgrazed, there is little information in the UAE on appropriate stocking levels for purposes of ecological sustainability or for maximizing pastoral production. The effect of grazing on vegetation was studied within the recently formed Dubai Desert Conservation Reserve (DDCR). Camel farms on the DDCR release camels during the day, allowing them to graze natural vegetation within the Reserve. It also contains an inner enclosure of five years in which camels were replaced by oryx and gazelles, separated by a 20 km fence. Fence line studies were made of (1) small (<1 m high) perennial plants, (2) seedling emergence during the winter of 2004/5, and (3) size and distribution of large shrubs (> 1 m high). In addition, telephone surveys were conducted on DDCR farmers, and spatial distribution of trees was recorded.

Heavy grazing in the DDCR has reduced the cover of small perennial plant species, reducing their capacity for annual forage production. The extent of overgrazing on gravel substrata was severe, but it was also significant on sand substrata. There was some evidence of localized dune stabilization in the camel exclosure, due to increased vegetation. Germination density of perennial species was greater in the camel exclosure, probably caused by higher seed production of the larger plants. Germination density of annual plant species was not affected by grazing, but was much greater in closer proximity to established small shrubs. No germination was observed to be associated with feces of camels, oryx, gazelle or dhub lizards (*Uromastyx aegyptiaca*). Plants reached reproductive maturity at a height of 10 cm or less. Large shrubs were differentially impacted by grazing systems. *Calligonum comosum* was devastated by camel grazing. *Leptadenia pyrotechnica* and *Lycium schawii* were substantially reduced in size, though their long term impact is not yet known. Two species benefited from heavy grazing; the large shrub *Calotropis procera* and the sedge *Cyperus conglomeratus*. Among trees, the regeneration of *Prosopis cineraria* appears to have been severely reduced by herbivory at the small shrub stage, but no evidence of effects on *Acacia tortilis* was recorded.

Observed vegetation differences were primarily due to a greater level of grazing in the DDCR than the exclosure, but the ecological impact of camel grazing differs to that of oryx and gazelles. Rapid recovery within the camel exclosure indicates that plant species are well adapted to periods of heavy grazing, and ecological degradation in the DDCR is reversible. Nevertheless, complete recovery of plant species composition may take decades after a reduction of stocking rate. Recovery would benefit native wildlife, and also farmers by reducing their reliance of supplementary feed. Several options for reducing the impact of camel grazing are considered.

1 INTRODUCTION

The United Arab Emirates is a rapidly developing country with an equally rapid change in land use, largely through urban development of open desert. Plants growing on undeveloped land face an increasing density of livestock herbivores. Recreational off-road vehicles are a further threat in some locations. Animal populations have been affected by the building of highways and fences, which may have subdivided the populations of particular species.

A conservation zone of 225 km^2 was established in Dubai emirate in 2003, encompassing sand dune and intermittent gravel substratum ecological zones. The Dubai Desert Conservation Reserve (DDCR) has the role of preserving these ecological zones for future generations while providing a resource for recreational use, in particular for international tourists. However, the DDCR still contains farms that produce livestock, horticultural products and forage crops. Understanding the relationship between camel management and desert ecology is essential to optimize desert forage production, and to preserve native species. In this paper we will argue that policies related to the management of camels should be revised. Better management of forage through reduced exposure to camel grazing would increase overall forage production, increase plant species richness, and enable native animal populations to recover.

Camels have been significant to the local desert ecology at least since the Bedouin camel-herding lifestyle emerged, but possibly also before then as wild animals. Up until half a century ago the inland desert was grazed by oryx (*Oryx leucoryx*), now extinct in the wild; gazelles (*Gazella* spp.), whose numbers have plummeted, and the Arabian ostrich (*Struthio camelus syriacus*), which became extinct by late 1940 (Gross and Jongbloed, 1996). Hunting of gazelles was banned in 1983, though enforcing the ban has been difficult (Hellyer, 1996) and numbers have not recovered. Grazing by smaller species such as rodents, lizards and the Cape Hare (*Lepus capensis*) continues to fluctuate with the seasons, though overall numbers are probably reduced. Plant species became adapted to grazing by all these herbivores through physical and biochemical defenses, and physiological adaptations.

Recent changes in herbivory are threefold. Firstly, there has been a shift away from a mix of herbivore species toward a single species; the camel. Larger herbivores expend more energy to move, and so are less selective of their food source (Murray, 1991). Camels tend to graze an area heavily and then not return for some time, whereas smaller herbivores graze fewer species over a wider area and may remove less herbage from each plant. Secondly, stocking rates are no longer limited by desert plant production. Camels can survive and even reproduce during drought years from the supplementary feed provided by farmers. Their population has increased accordingly, causing an increased proportion of time in which plants are subjected to heavy grazing. Thirdly, livestock are less restrained by plant chemical defenses against herbivory since they can mix desert plants and supplementary feed in their stomachs.

A plant ecosystem can benefit from herbivory in several ways. Many plant species rely on herbivores for seed dispersal. Removal of above ground biomass reduces the surface area for transpiration, which might lead to a higher survival of grazed plants in dry seasons. Moderate grazing usually increases biodiversity through trampling and the removal of dominant plant species (Fernandez-Gimenez and Allen-Diaz, 1999), but this may not apply to habitats with a low biomass production such as the UAE (Oba et al., 2001). Heavy stocking rates reduce annual plant biomass production by limiting plant size and frequency. This can reduce feed available to camels, as well as to the small wild herbivores. Lower populations of rodents, lizards and cape hare sustain fewer carnivores such as cats, the Arabian red fox (*Vulpes vulpes arabica*), and birds of prey.

1.1 *Study site and objectives*

The DDCR fence line completely surrounds an inner enclosure (Al Maha) of 27 km^2. Camels were removed on completion of the fence in July 1999, and several species of oryx and gazelle were introduced, some indigenous but others exotic to the area. Al Maha stocking rates in April 2005 were approximately 0.092 oryx and 0.075 gazelles per hectare. The DDCR still contains approximately 960 camels (0.043 camels / ha) as well as other livestock that are restricted to the farms. Since April 2005 it also contains some *Oryx leucoryx* and gazelles that were released from the Al Maha enclosure. The site has provided a unique opportunity for the authors to study the recovery of a large expanse of sand desert under a different grazing regime. Previous studies in the Gulf region have reported a rapid regeneration of vegetation from livestock exclosures (Khan, 1980a, 1981, Oatham et al., 1995, Zaman, 1997, Barth, 1999). However, exclosure of large herbivores is neither practical nor desirable in the DDCR, or in open UAE rangeland. Instead, it is necessary to study the relationship between herbivore and plant ecology, to optimize the production of both. The Al Maha fence is 24.12 km in length, of which 150 m crosses gravel substratum and the rest lies on sand that varies from very stable to actively moving. The natural botany of the area is similar to the Prosopis-Calligonum vegetation type described by Ghazanfar (2004) in Oman.

The authors have conducted several studies toward determining how the two management systems affect plant ecology. Three studies were conducted on each side of the Al Maha fence, including:

– Ecology of small (<1 m high) perennial plants, of which most were dwarf shrubs.
– Seedling emergence and survival after the 2004 winter rains.
– Size and spatial distribution of large shrubs (*Calligonum comosum*, *Leptadenia pyrotechnica*, *Lycium schawii*, and *Calotropis procera*). This work is ongoing.

Two further studies pertain to the DDCR as a whole.

– Telephone survey of farmers. Interviews were conducted, translated and transcribed by Nasra Al Juma, a Zayed University graduate.
– Spatial distribution of *Prosopis cineraria* (ghaf) and *Acacia tortilis*.

Rainfall was unusually low from the period the Al Maha fence was constructed until the 2004 winter, but rains in 2004 produced a mass germination event. The closest rainfall data comes from the Dubai International Airport, which indicates an average annual rainfall of 93.8 mm that falls mostly between December and April (World Meteorological Organization, 2005), but which fluctuates widely both temporally and spatially.

1.2 *Camels in the UAE*

Agricultural settlement on the Arabian peninsula began around 2500 to 2000 BC with the domestication of the date palm (*Phoenix dactylifera*), which enabled an oasis based lifestyle (Potts, 2001). Dromedary camels (*Camelus dromedarius*) were probably first domesticated in southern Arabia, with their use spreading northward to reach Syria around 1100 BC (Bulliet, 1990). Fossil evidence of domesticated camels has been attested for the Iron Age (1200 to 300 BC) in the UAE (Stephan, 1995), but may have occurred as early as the 4th millennium BC (Peters, 1997). Use of the camel for transport, along with *falaj* irrigation technology, enabled a rapid increase in the number of settlements in the region (Potts, 2001). However, the greatest impact on plant ecology of the inland desert would have occurred with the broad scale emergence of nomadic camel herding. This lifestyle probably emerged later than the spread of settlements, but could still be thousands of years old. Camels can be used to provide milk, meat, transport of people or goods, mechanical power, entertainment, products from their leather or hair, and can be a store of wealth (Bulliet, 1990).

During winter if the feed was good, camels could obtain most of their water requirements by eating plants Their herders could also survive temporarily without fresh water by drinking camel milk (Heard-Bey, 2001). People would move camp throughout the season each time feed supply for camels dwindled. Wells were dug in frequently visited places, enabling people to extend their nomadic range. In some places permanent settlements were established, such as Liwa (Abu Dhabi emirate) which has been continuously occupied since at least the 16th century (Heard-Bey, 2001). By these mechanisms the entire inland sand desert of the UAE became exposed to camel grazing, though it was not evenly distributed. Land surrounding permanent settlements were more heavily grazed, while land surrounding semi-permanent settlements were periodically grazed and then given time to recover. Other areas were labeled as restricted (Arabic: *harim*), and only accessed during drought periods when no other feed was available (Aspinall, 2001). Tribes used these areas to survive irregular weather patterns that could produce a drought for several years at a time.

Following unification of the Emirates in 1971, the government instituted policies to increase agricultural production and to establish permanent settlements and income for nomadic people.

The density of wells was dramatically increased, and semi-permanent farms or occasionally used areas became permanent year-round farms. Camel numbers initially waned after unification, falling from approximately 97 000 to 39 500 in 1976, but they then steadily increased to 250 000 today (FAOSTAT, 2004). Other livestock industries have increased even faster since unification, notably goats (125 000 to 1 450 000) and dairy cattle (5 000 to 115 000). However, only camels are permitted to graze open desert throughout the Emirates. Irrigated forage production has increased commensurately, but the livestock sector still relies on imported feed. At 2.99 camels / km^2, density in the UAE is second only to Qatar and far higher than that of Saudi Arabia (3.36 and 0.12 camels / km^2 respectively) (FAOSTAT, 2004). Within Dubai emirate, camel farms displaced by urban expansion were moved deeper into the emirate, thereby increasing camel density on the remaining range.

Every camel in the UAE is owned by somebody. Farms are scattered throughout the open range, typically with an employee in residence and an owner who visits weekly. Land tenure is not always clear. Most camels are allowed to graze the desert on an 'open access' basis that is common throughout West Asia (Ferguson et al., 1998). DDCR farms usually feed camels at the farm in the afternoon (3 to 4 pm) and perhaps also in the morning (7 to 8 am), so most camels return to the farms at these times. Some camels stay away for days at a time if desert forage is sufficient, and some stay permanently at the farm if it isn't.

Camel production in the UAE today is primarily for racing. There are 14 000 actively racing camels competing on 15 race tracks throughout the country (Anonymous, 2005), and the camel population is distributed around racetracks rather than food or water sources (Yagoub and Hobbs, 2003). Females comprise 74% of the current herd (FAOSTAT, 2004).

2 PLANT RESPONSES TO GRAZING

Plant categories used in this study are based primarily on size. Although taxonomically arbitrary, this classification is useful for grouping species according to their rooting depth and their exposure to grazing. Ephemeral species use temporary, shallow moisture and minimize grazing exposure by producing large numbers of plants in a short time. Germination occurs only in Spring when moisture is more likely to last long enough for seedling growth. Trees can use permanent groundwater and grow above the reach of herbivores. Shrubs and perennial grasses are thought to tap water of medium depth, though knowledge of root depth is based on observations of above ground growth rather than direct measurement. Small shrubs are permanently exposed to grazing by all herbivores, while large shrubs can outgrow all herbivores except camels.

The sand surface rapidly dries after rain, but then acts as a protective layer for preserving deeper moisture (Al Wadie, 2002). Changes in water table depth are known from farm wells, but usage and relative permanence of plant-available water above this level is not known. Roots are generally deeper in arid areas where surface water is unreliable, and these conditions provide an advantage for trees and woody shrubs over herbaceous species (Abd el-Ghani, 2000).

2.1 *Large shrubs*

Most vegetal biomass within the DDCR occurs as *Leptadenia pyrotechnica* shrubs, one of four species that grows higher than 1 m but in which most or all photosynthetic tissue is within reach of camels (approximately 310 cm, based on browse line measurements of 55 trees). Response to the different grazing regimes is species specific. *Calotropis procera* benefits from heavy camel grazing, but *Calligonum comosum* is severely reduced in number while *Lycium schawii* and *Leptadenia pyrotechnica* are reduced in size.

Leptadenia pyrotechnica comprised 90.1% of all large shrubs growing near the Al Maha fence. Palatability is moderate (Ould Soulé, 1998) and it contains latex, but camels, oryx and gazelles all graze it. Livestock graze it to a low hedge in high traffic areas. Farmers in the DDCR considered it valuable as fodder and for killing intestinal worms of livestock. They commented that plant numbers have decreased in recent decades, but six years without camels in Al Maha did not produce significantly different numbers. This indicates that population shifts occur on a longer time scale. However, camel exclosure resulted in a greater median height (2.8 and 3.4 m in the DDCR and Al Maha respectively) and canopy cover (10.0 and 15.2 m^2). Shrubs with a large canopy (e.g.; > 50 m^2) contained noticeably more gazelle resting sites underneath them. Large canopies were common in Al Maha (6% of the population) but the largest observed in the DDCR was just 48 m^2. Large canopy plants appear to provide a unique microhabitat, though it is not known if the habitat favors survival of other species. The authors disturbed one hare (*Lepus capensis*) and one fox (*Vulpes vulpes arabica*) while measuring 897 *L. pyrotechnica* shrubs, so there were insufficient observations of small mammals for comment.

The species is well adapted to heavy grazing, as evidenced by survival in the DDCR. Maximum plant herbage production probably requires some grazing, though how much is not known. Roots occur at whatever depth contains moisture, and have been recorded to 11.5 m (Batanoun and Wahab, 1973), enabling it to grow through the summer.

Calotropis procera roots reach 1.7-3.0 m in sandy desert soils, with few to no roots near the surface (Sharma, 1968). It is a succulent species that absorbs a lot of water after rainfall (Aziz and Khan, 2003). Plant numbers usually increase with camel density through the removal of competition (Khan, 1980b, Al Wadie, 2002). DDCR farmers unanimously reported that its numbers had increased over the last decade, particularly on the sand substratum, and it has become the dominant large shrub species in some areas of the DDCR. Latex consumption causes nervousness, frequent urination, frothing at the mouth, dyspnoea and diarrhea in goats (El Badwi et al., 1998). Ungulates graze on it sparingly, but it can be combined with other feed sources to prevent harmful effects (Nehra et al., 1987, Abbas et al., 1992). Over time, gazelles in Al Maha removed all leaves and flowers within reach. Plants in Al Maha therefore became tall (>2.5 m) and thin (<10 m^2 canopy), while plants in the DDCR exhibited a wider range of both variables (0.5 - 4.0 m height, 0 - 30 m^2 canopy). As gazelle numbers increase in the DDCR, recruitment of new plants can be expected to decline.

Calligonum comosum is one of the most important plants in UAE bedu folklore (Khan, 1979). It is common in Al Maha but only rarely seen in the DDCR, due to it being a favored food source of camels. It typically grows on sandy substrate where underground water has low salinity (Brown, 1978, Khan, 1979), though roots also absorb rainwater quickly (Asher, 1996). It is eaten readily by camels and less readily by sheep and goats (Ould Soulé, 1998), but plants within Al Maha indicate that oryx and gazelles browse it only very lightly. Camels eat all non-woody tissue, making plants appear lifeless and unrecognizable until producing limited foliage and flowers in February and March (Khan, 1980b, Western, 1988). DDCR farmers agreed that it had decreased to very small numbers, but its rapid recovery in Al Maha indicates that plants still exist as stumps or rootstock.

The authors have observed just three plants in the DDCR, though none were seen during a structured study of fence line vegetation. Two plants were single-trunk trees with a camel height browse line, while the other was a small sprout from rootstock. Growth form in Al Maha was a woody shrub of up to 4.5 m height, often containing multiple trunks. A strong relationship between height and canopy indicated that plant growth was well proportioned.

Lycium schawii occurs across both Al Maha and the DDCR, but its growth form is very different between enclosures. Camel grazing removes the apical dominance of leading stems, which then produce thick, woody side branches. This produces a thickly hedged shrub in which leaves and flowers are protected by a thorny, woody exterior. Plants in Al Maha showed almost no grazing from oryx and gazelles, hence the leading stems grew long and spindly. Remnants of the former hedging structure could be seen on most plants, dating from before camels were removed from the enclosure. The species is moderately palatable and difficult to propagate from seed (Heywood, 2004).

Ten of the 64 observed *L. schawii* plants were found growing within the canopy of *L. pyrotechnica* shrubs, indicating a link among the two species. Eight of the ten plants were located within two clusters in Al Maha, both in areas where *L. pyrotechnica* was densely populated. We hypothesize that seeds were deposited by birds that eat the fruit of *L. schawii* but nest in *L. pyrotechnica*. Other authors have noted *L. schawii* shrubs growing under the protection of *Acacia tortilis* (Western, 1983, Jongbloed, 1996), but we haven’t observed this in the DDCR.

2.2 *Trees*

The tree species of greatest importance to the natural ecology of the UAE are *Prosopis cineraria* and *Acacia tortilis*, both of which commonly occur in clusters within this habitat. There are no clusters within Al Maha, so a comparison of management systems is not possible. Other tree species exist in anthropogenically modified locations. The two *Tamarix aphylla* trees are unlikely to have occurred naturally in this environment (Jongbloed et al., 2003). Several individuals of the invasive exotic *P. juliflora* exist and the species is very common in the towns surrounding the DDCR, raising the risk of invasion. There is a possibility that *P. juliflora* could crossbreed with *P. cineraria* (Pasiecznik *et al.*, 2004), though this has not been observed. *Acacia tortilis* grows mostly on gravel substratum, while *P. cineraria* grows on sand substratum bordering gravel. DDCR farmers reported that both species have decreased in number, but the extent of decline is not known. Gravel plains are preferred locations of farms and towns, which would contribute to the decline of trees.

The DDCR contains 771 *Prosopis cineraria* trees and shrubs in four distinct clusters, and approximately 30 that are associated with current or abandoned farms. The species can reproduce vegetatively from root suckers (Brown, 1988) but it is not known if clustering exists entirely because of asexual reproduction, or because only certain habitats are suitable for growth. Flower and seed production in the DDCR appear low, but seedling production is difficult to quantify. Most trees within a cluster appear to be a similar age, since trunk diameters fit a logarithmically normal distribution. Shrubs of 2-3 m height occur in a section of just one cluster that was previously fenced to exclude camels. Sprouts of up to 50 cm length were observed in three of the clusters, but none were observed to survive over summer. These observations indicate that regeneration of the species is severely limited under current herbivory levels. Death occurs at a size in which plants are vulnerable to all herbivores, though it is likely that camel density is the main cause.

Acacia tortilis is limited to the eastern side of the DDCR. Of the 184 observed trees, 181 were in 11 clusters ranging in size from 2 to 50 plants. Eight clusters contained just one dominant tree surrounded by many smaller trees, each of which could have emerged from the roots of the dominant tree. Farmers reported the existence of two subspecies in the UAE; *salam* (possibly *A. tortilis* ssp. tortilis) and *samer* (possibly *A. tortilis* ssp. raddiana),. *Salam* is smaller with more stems, and more common in the DDCR. Livestock readily eat leaves of *samer*, but not *salam*, which might explain the difference in growth form. Fruit of both subspecies is eaten by livestock. Livestock will graze on *salam* leaves when other sources are depleted (Hobbs, 1989). Rapid growth tends to occur after rainfall periods when herbivores have many other species on which to graze (Springuel et al., 1995).

Large mammalian herbivores are the main means of seed dispersion (Rohner and Ward, 1999). Animals improve seed survival by carrying them away from insect seed predators that surround the parent tree, and germination is facilitated by passage through the gut. Passage through a camel gut takes longer than through an oryx or gazelle, and thus germination may be improved more by camels than other livestock. However, a high camel density might impact seedling survival through grazing and trampling. Large trees exhibit hydraulic lift in wetter seasons, though this may not benefit understory vegetation (Ludwig et al., 2003).

2.3 *Small perennial plants*

Results of the authors' work on this plant category has been reported (Gallacher and Hill, in press). Plots were chosen to represent localized maximum plant density to reduce the confounding effect of spatial variation in plant cover. Within Al Maha, plots contained almost three times the median plant cover, a higher species richness and biodiversity, and a 36% higher median number of plants. Regeneration within Al Maha was substantial on all substrates (gravel, stable sand, and semi-stable sand) but was greatest on the gravel substrate.

Camels probably graze gravel substrate areas more than smaller herbivores because they provide a higher ratio of energy gain to energy expenditure (see Murray, 1991). The DDCR gravel substrate appeared to be devoid of plants in this category, but closer inspection revealed that plants of several perennial species existed with just a few leaves and a much larger root structure. This ability to survive under heavy grazing has enabled vegetation to recover quickly on the Al Maha gravel substratum. Al Maha vegetation on this habitat is dominated by *Heliotropium kotschyi*, most likely representing a seral transitional state.

Cyperus conglomeratus was the only species of this category to benefit from heavy camel grazing. Most other species exhibited reduced plant size, with some also exhibiting reduced number or range. *C. conglomeratus* has previously been reported as a disturbance species and an indicator of excessive grazing (Ferguson et al., 1998, Barth, 1999). Nevertheless, its use as a plant indicator of disturbance is limited to extreme cases, since dune microenvironments regularly face disturbance under natural conditions.

2.4 *Germination events*

Germination in the DDCR occurs less that once a year, since it requires both the correct season (Spring) and sufficient soil moisture. The authors studied one event only, after the rains of winter 2004. Spatial variation in germination density was very large, as has been reported in other arid environments (Guo et al., 2000, Brown, 2003, Robinson, 2004). Highest densities in an area always occurred at the base of the wayward wind side of steep dunes. Rain water penetrated deeper into the sand in these locations and remained there for longer. Almost no germination occurred on top of active dunes, though valleys in active dune areas still contained seedlings. Sand plots were dominated by *Eremobium aegyptiacum*, *Arnebia hispidissima*, *Cyperus conglomeratus*, *Indigofera colutea* and *Silene villosa* while gravel plots were dominated by *A. hispidissima*, *Monsonia nivea*, *Dichanthium foveolatum* and *Neurada procumbens*.

Camel grazing had no impact on annual species, but reduced the number of seedlings of perennial plants ($P < 0.001$). This supports the theory that annual species outgrow the rate of grazing. The fall in perennial seedlings is likely to reflect lower seed production in heavily grazed areas and restricted seed transportation. Seedling densities of *Haloxylon salicornicum* and *Indigofera* spp. were noticeably highest near established plants.

The authors observed feces of camels, oryx, gazelles and dhub (*Uromastyx aegyptiaca*) lizards, but found no germination in association with them. *Acacia tortilis* seeds are likely to be transported through animal consumption, but at a very low frequency. Most other species appear not to use this mechanism. Middens were noticeable for their lack of germination, rather than their facilitation of it.

3 DISCUSSION

3.1 *Impact of grazing in the DDCR*

Heavy grazing in the DDCR has reduced the cover of small perennial plant species, reducing their capacity for annual forage production. The extent of overgrazing on gravel substrata is severe, but it is also significant on sand substrata. Large shrubs have been differentially impacted. *Calligonum comosum* has been devastated by camel grazing. *Leptadenia pyrotechnica* and *Lycium schawii* have been substantially reduced in size, though their long term impact is not yet known. Two species have benefited from heavy grazing; the large shrub *Calotropis procera* and the sedge *Cyperus conglomeratus*. The desert squash *Citrullus colocynthis* also appears to flourish in areas of high camel traffic and defecation, though the authors have not yet conducted studies on this species. Among trees, the regeneration of *Prosopis cineraria* appears to have been severely reduced by herbivory at the small shrub stage, but no evidence of effects on *Acacia tortilis* has been recorded. Grazing did not have any direct impact on ephemeral species.

The main cause of observed differences among enclosures (DDCR stocked with camels vs Al Maha stocked with oryx and gazelles) is the amount of forage removed by livestock. Lower grazing intensity within Al Maha has enabled almost all perennial species to show signs of recovery. However, camels impact plant species differently to oryx and gazelles. They decimate plants on gravel substrata, and facilitate the increase of *C. procera* and *C. conglomeratus* on sand substrata through removal of competing species. Furthermore, camels affect the shape of some larger species differently due to their greater height. Trees must grow twice as high before vegetation is above the browse line of camels, and *L. pyrotechnica* shrubs are modified.

Substituting some of the camels with other herbivores would enable a higher sustainable stocking rate, while lessening the impact on plant species composition

Structure of *L. pyrotechnica* showed clear differences between enclosures. The increased canopy in Al Maha provided sites for sheltering gazelles and oryx, and provided a greater choice of nesting sites for birds and small mammals. Whether the smaller animals benefited significantly from this is not known, but use of the larger Al Maha shrubs by oryx and gazelles was clear. Camels reduced height of shrubs more than canopy cover, since they can graze from above. Size reduction of *L. schawii* limited the availability of fruit for consumption by wildlife.

3.2 *Models of recovery*

Ecological degradation is frequently blamed on overgrazing, but its effect on irreversible decline of plant communities is often overrated (Dean and Macdonald, 1994). Existing shrub and perennial grass species in Al Maha recovered substantially during five years of drought. Similar observations have been reported in camel exclosures throughout the region (Khan, 1980a, 1981, Oatham et al., 1995, Zaman, 1997, Barth, 1999). This indicates that species are adapted for survival under heavy grazing, as would have occurred during the frequent multiple-year droughts. It is possible that less adapted plant species have become extinct in the area, but the authors have found no supporting evidence. Irreversible decline of rangelands is mainly caused by a change to soil structure or infiltrability (Wilson and Tupper, 1982), to which sand substrata are relatively resistant (Scoones, 1992). Significant ecological decline has occurred, but most is reversible by changing land management. The only proven irreversible degradation is the extinction of the Arabian Ostrich (*Struthio camelus syriacus*), though genetic erosion of other species is likely.

The current species mix in Al Maha probably represents a seral transitional state. Species life span affects the time taken for a natural vegetation state to emerge. In a habitat dominated by perennial shrubs this may be 20-50 years (Allen-Diaz and Bartolome, 1998, Todd and Hoffman, 1999). Even so, the vegetation state to emerge may be unnatural if vegetation dynamics follow a non-equilibrium model. The authors have previously argued that small perennial plants follow an equilibrium model (Gallacher and Hill, in press), and that stable natural vegetation states are likely to emerge with appropriate livestock management.

The authors have not found evidence of population shifts among plant groups (annual / perennial, herbaceous / woody, shrub / tree), but some can be expected. Expansion of large shrubs in Al Maha is likely to partially displace smaller perennial plants through competition for water, and trees could return. Perennial grasses are expected to increase since they are intolerant to heavy grazing (Jeffries and Klopatek, 1987, Beeskow et al., 1995, Todd and Hoffman, 1999), but this has not yet been observed. *Pennisetum divisum* increased in canopy cover, but not plant number, and its recovery was less than the recovery of many dwarf shrub species. Annual species are unlikely to be affected, since they are not impacted by grazing in this habitat.

3.3 *Solutions*

The DDCR is chronically stressed from overgrazing by camels, but has the capacity to recover. Most plant species exhibit reduced size and / or number. Reduced foliage has a direct impact on the populations of small (non-livestock) herbivores, which then affects the populations of carnivores. Direct evidence of wild animal population decline is currently limited to Dhub lizards (*Uromastyx aegyptiaca*), whose population increased rapidly within Al Maha. However, Al Maha unarguably has a higher capacity to support wildlife.

Rangeland resources are also being mismanaged from a pastoralist viewpoint. Reduced plant size of most species is so severe that the carrying capacity of the desert is clearly reduced. Vegetation cover on the gravel substratum increased by 100 fold within Al Maha, enabling a much greater annual herbage production when camels were excluded. Changes on sand substrata were less dramatic, but still significant. Farmers could lower their feed costs by reducing the exposure of desert plants to camel grazing, since larger plants would have a higher annual herbage production.

The impact of camel grazing could be addressed in several ways, each with its own policy and ecological considerations:

- Reduction of the national herd. This would have no effect in the short term, since farmers would compensate by reducing supplementary feed. There would probably be no difference to desert ecology until camel numbers were reduced back to around 100 000, or 40% of current numbers. It could be achieved in the longer term by reviewing agricultural subsidies and market guarantees, though not all farmers will be sensitive to economic constraints.
- Allocation of rangeland to farmers or farmer groups. This could be politically difficult, but would enable people to take greater responsibility for the land they use. This approach would need to be coupled with research and farmer education programs, and would move camel husbandry further away from traditional methods. Hence it would not be appropriate for preserving culture, but should enable a return of natural ecology in the medium term.
- Reduction of camel exposure to open rangeland. Assuming a stable population of camels, rangeland grazing could be reduced by limiting the number of camels allowed to exit a farm each day. Given this option, farmers are likely to rotate the animals they release, since native plants are widely believed to improve the health of livestock. This system could be difficult to enforce, but would enable the most rapid recovery of desert ecology once implemented. The diet of fewer camels with a lot of time on rangeland will differ from the diet of more camels with less time on rangeland, thus affecting plant species composition. The former would probably enable greater recovery of *Calligonum comosum*, for example. However, reduction of total camel exposure to desert rangeland is currently more important than the method of reduction.
- Protection of most threatened habitats. In the DDCR, gravel substrata have been decimated by camel grazing. Protection of these habitats would be expensive but possible, but doing so would put greater pressure on the remaining unprotected areas. This is a temporary option that could be considered in conjunction with other options.

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