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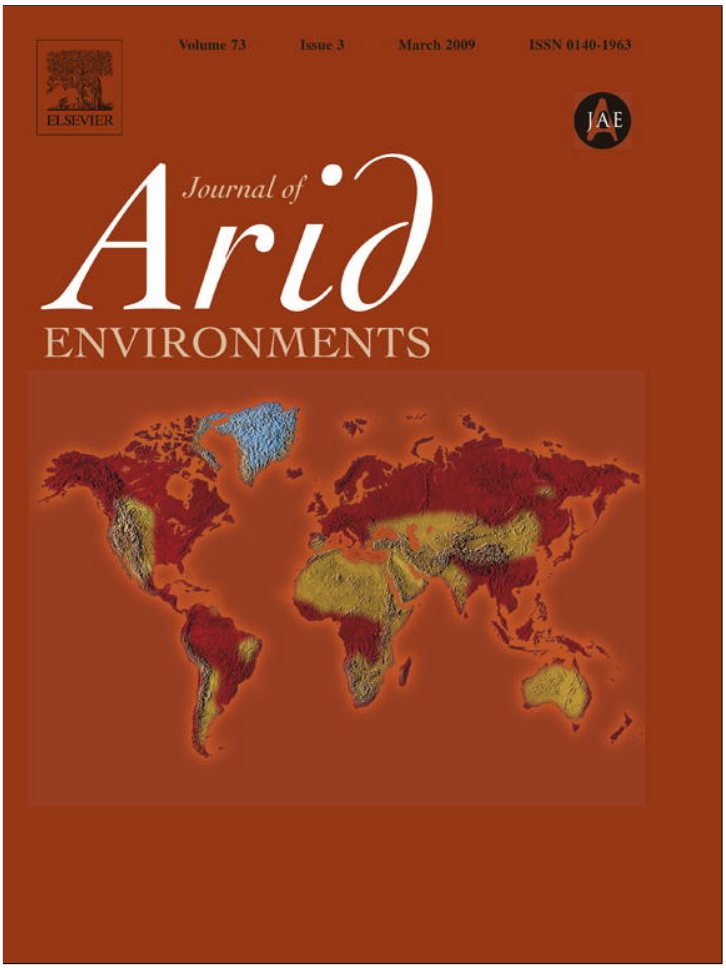

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Grazing itineraries and forage selection of goats in the Al Jabal al Akhdar mountain range of northern Oman

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ABSTRACT

In view of the repeatedly reported overstocking of the high-altitude pastures on Al Jabal al Akhdar, northern Oman, plant species abundance, cover and frequency, and herbaceous mass yield were studied in ungrazed *versus* heavily grazed areas of this mountain range. In addition, plant species selection by goats along a gradient of 1000–2000 m and spatial extent of pasture areas were investigated after abundant rainfall and a subsequent 6-months dry spell by means of manual observation and GPS/GIS tools.

The substantially higher species diversity and herbaceous mass yield in the ungrazed area illustrate the production potential of these mountain pastures or, respectively, the biodiversity and productivity loss resulting from continuous grazing. The concentration of goats' selection on only a dozen herbaceous and ligneous species favours pasture encroachment with poisonous shrubs such as *Nerium mascatense* in the lower and *Dodonaea viscosa* in the higher altitudes. Given the spatially limited extent of pasture areas, these are exposed to high stocking rates. Therefore, grazing and feeding schemes need to be developed which reduce livestock pressure on the pastures, taking into account local property rights, herding skills and the recovery potential of the vegetation, which heavily depends on unpredictable rainfall events.

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1. Introduction

In the small-scale oasis agriculture of the Hajar mountain range in northern Oman, goats play a major role in providing cash and meat for farm households (Zaibet et al., 2004) and manure for the irrigated terrace gardens (Buerkert et al., 2005). Although at the homestead goats are offered cultivated green feeds such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* Moench S.L.), oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.) and alfalfa (*Medicago sativa* L.) and concentrate feeds such as dates (*Phoenix dactylifera* L.), dried sardines and old bread, up to 60% of their daily feed intake is covered by forages ingested on the steep slopes and plateaus of mountains surrounding the oasis settlements (Predotova et al., 2006). Already in "The Oman Flora and Fauna Survey 1975", Mandaville (1977) claimed a high grazing pressure of goats in the area of Sayq, a small town on the plateau in the south-eastern corner of the Al Jabal al Akhdar Mountain range. He predicted that this would lead to the loss of plant biodiversity and lower rangeland productivity. Similarly, El-Kharbotly et al. (2003), Zaibet et al. (2004) and Al Harthi et al. (2008) lamented the vegetation degradation in the Hajar Mountains due to grazing, putting at risk the efficiency of livestock husbandry itself. Given the low and highly variable rainfall and frequent multi-year drought on Al Jabal al Akhdar (Luedeling and Buerkert, 2008a), the non-equilibrium vegetation model (Ellis and Swift, 1988) may fit well to these pastures. Following this model, grazing should little affect the vegetation because reduction of livestock numbers during drought years would maintain these below the pastures' carrying capacity (Ellis and Swift, 1988). Against the incongruence between the abovementioned records of continuing pasture degradation and the non-equilibrium vegetation model, the present study aimed at investigating the effects of year-round livestock grazing on plant species abundance, cover and frequency as well as herbaceous mass yield in the Al Jabal al Akhdar mountain range.

2. Materials and methods

2.1. Site and agricultural system

The study was conducted on the Al Jabal al Akhdar range of the Northern Hajar Mountains in Oman. The villages of Ash Sharayjah/Al'Ayn (short: Sharayjah; 23.198°N, 57.398°E; 1900 m asl), Qasha' (23.067°N, 57.670°E; 1640 m) and Masayrat ar Ruwajah (short: Masayrat; 23.044°N, 57.664°E; 1030 m) are situated along a transect of approximately 4 km aerial distance in the Wadi Muaydin

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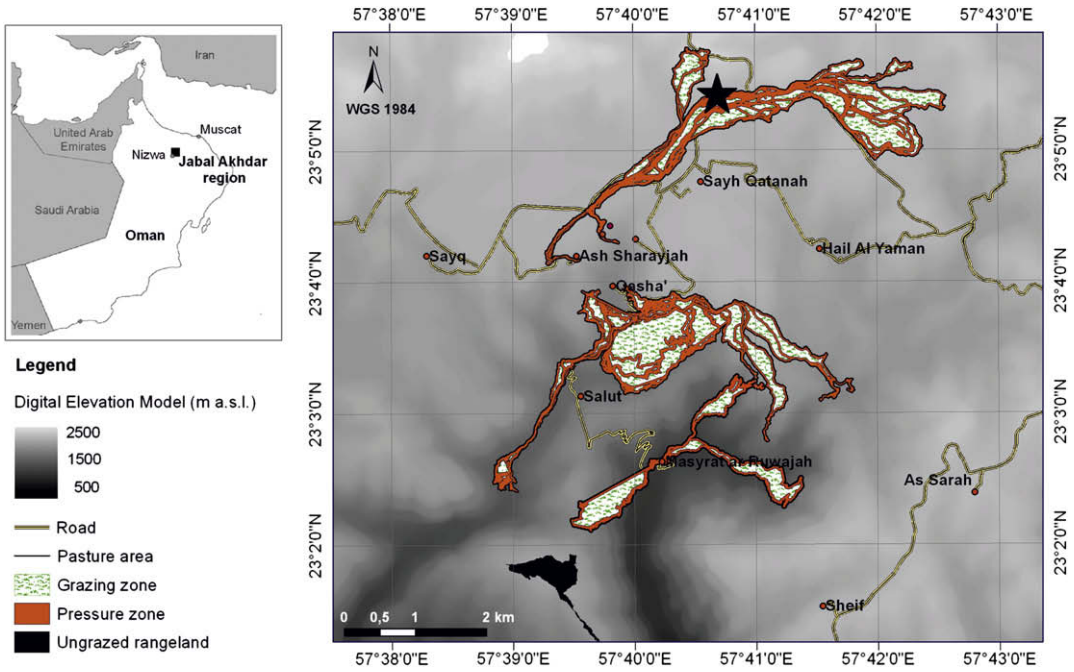

Fig. 1. Location of the study area (large map) within the Sultanate of Oman (small map). Pasture areas, grazing zones and pressure zones around the study villages of Ash' Sharayjah, Qasha' and Masayrat ar Ruwajah were determined based on GPS-tracked goat herds. Pasture areas are encircled by the outer borderlines of goats' daily grazing itineraries, grazing zones are the areas in between the itineraries and pressure zones are areas where two or more tracks overlap. The ungrazed rangeland (Ras al Kabul plateau, black area) served as a reference site for the determination of plant species diversity and biomass yield as compared to the heavily grazed Sayq plateau (indicated by the black star).

(Fig. 1). The area is located near the small town of Sayh Qatanah (23.198°N, 57.398°E; 2000 m). The three villages are typical 'core oases' with a central settlement and surrounding terrace systems used for crop cultivation. The region receives a total annual precipitation of 100–340 mm, with rain potentially falling throughout the year but with a higher probability of rainfall in February–March and July–August (Luedeling and Buerkert, 2008a). Just before the start of the present study, 150 mm of rain had fallen during December 2004–March 2005. Thereafter, no more rain was registered until November 2005.

The long-term annual average air temperature at the study location is 18.1 °C, with a minimum of 3.6 °C and a maximum of 36.3 °C, the coolest and hottest month being January and June, respectively (Department of Civil Aviation and Meteorology, Muscat, Oman).

All settlements benefit from a relatively stable water supply from several springs fed by rainwater, which percolates through fracturated calcareous layers sometimes for several years (Luedeling et al., 2005). An elaborate irrigation system of "aini aflaj" (Arabic) conveys the water to small terraced plots where farmers cultivate food crops such as wheat landraces (*Triticum aestivum* L. and *Triticum durum* L. Desf.) and sorghum, and vegetables such as garlic (*Allium sativum* L.), onion (*Allium cepa* L.) and coriander (*Coriandrum sativum* L.). At least half of the arable land of each village is cultivated with fodder plants, mainly alfalfa but also barley, oat, fodder sorghum and maize. Perennial plants cultivated at the higher altitudes are roses (*Rosa damascena* Miller) for rosewater distillation, pomegranate (*Punica granatum* L.), peach (*Prunus persica* L.), apricot (*Prunus armeniaca* L.) and walnut (*Juglans regia* L.); at lower altitudes date palm is the most important crop, interplanted with some lime (*Citrus aurantiifolia*) (Christm. et Panz.) Swingle and a few banana (*Musa* spp.). Sown or spontaneously growing understorey grasses in palm groves and pomegranate plantations are cut regularly and used as feed for the numerous goats and a few sheep and cattle kept in the settlements.

2.2. Goat husbandry system

During daytime, the Jabal Akhdar breed goats (Mahgoub et al., 2005) that are kept by different families (Table 1) are grouped into one or two village herds to graze the vegetation of the surrounding mountain pastures. In all villages, animals set out for pasture between 6:30 and 7:30 a.m. The goats of Masayrat were conducted to the rangeland by two women and were then left to graze on their own (herd-release mode); the majority of goats returned to their homesteads around noon. The animals of Sharayjah were herded for the whole day by a hired male herder who determined the animals' grazing itinerary and daily time on pasture. In Qasha' where two families were alternately taking the goats to pasture, both herding modes occurred: when the male head of one family took care of the animals, he conducted them to pastures northeast of the village and stayed with them for the whole day. On days when the two teenage daughters of the other family were in charge of herding, they turned to the area southwest of the village where they released the animals after 2–3 h. In Sharayjah and Qasha', return of goats from pasture generally occurred between 3:00 and 6:00 p.m. with the later return time applying especially to herded animals. Back home, goats received cultivated forages and weeds, dates, small dried fish and cereal-based supplement feeds (Predotova et al., 2006). For the purpose of the present study, three to four goats of 25–45 kg live weight were selected for GPS tracking (Section 2.5) from different households in each of the three villages.

2.3. Vegetation cover and herbaceous mass

On the heavily grazed plateau area near Sayh Qatanah and in the main wadi crossing through that plateau the canopy cover of the herbaceous and the ligneous stratum was determined in October 2005, along with the abundance and frequency of individual plant species. The local name for this plateau is 'Al Ronda', but it is referred to as Sayq/Saiq plateau by Mandaville (1977) and Al Harthi et al. (2008); we therefore further refer to the 'Sayq plateau' and the

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Table 1
Number of goat keeping households and size of goat herds in three study villages on the Al Jabal al Akhdar range, Oman, at the time of study (2005).

Village	Sharayjah	Qasha'	Masayrat
Altitude (m asl)	1900	1640	1030
Households, total (n)	20	10	13
Goat keeping households (n)	15	7	11
Goats per village (n)	152	112	245
Goat management at pasture	Herded	Herded and herd-release	Herd-release

'Sayq wadi'. The vegetation was assessed in eight randomly distributed plots of $10 \times 10\ m^2$ on the plateau and in six plots of $20 \times 20\ m^2$ size in the wadi. Species dominance and abundance was determined according to Braun-Blanquet (1964). The vascular plant nomenclature followed Ghazanfar (1992, 2003), Jongbloed et al., (2003) and Patzelt (2006). Samples of unknown species were identified by Dr. Annette Patzelt (Oman Botanic Garden) and Prof. Dr. Karl Hammer (Department of Agrobiodiversity, University of Kassel, Germany).

Within each of the assessed plots, four representative $1\ m^2$ quadrates were chosen to characterize different herbaceous cover classes – one quadrate representing a sparsely, two a moderately and one a highly vegetated spot. In each quadrate, all herbaceous plants were clipped at 1 cm above ground and collected into a cotton bag. Species cover, abundance and frequency as well as total herbaceous mass were also determined in five randomly chosen $4 \times 4\ m^2$ sized plots and twelve $1\ m^2$ quadrates on the isolated, poorly accessible and therefore ungrazed Ras Al Kabul Plateau (1980 m asl) located 1.5 km southwest of Sharayjah (Fig. 1). All harvested plant material was dried in the shade and air-dry herbaceous mass (DM) was determined by weighing the samples on a scale with 1 g precision. The samples were analysed for concentrations of nitrogen (N), phosphorus (P) and neutral detergent fibre (NDF) as well as organic matter digestibility (OMD) following standard procedures (Menke and Steingass, 1987; Van Soest et al., 1991; Naumann et al., 2004). The proportion of the three herbaceous cover classes and of spots of bare surface was determined for each 10 m segment along two 3 km linear transects (Tracol et al., 2006) crossing the Sayq plateau and the Sayq wadi, respectively. For the Kabul plateau, the relative importance of bare surface and the three herbaceous cover classes was obtained from an overall assessment of the monitored area. The weighted herbaceous mass was calculated by multiplying the proportional contribution of bare spots and the three cover classes with the respective average mass yield.

2.4. Selection behaviour of goats

To determine plant species selection of goats at pasture, grazing observations were carried out during four consecutive days per village, once in spring (February–April) 2005 and once in autumn (October–November) 2005. In Masayrat, a grazing day lasted 4–6 h, whereas the goats of Sharayjah and Qasha' spent 8–10 h d^{-1} on pasture. Every 3 min, the observer recorded the number of animals in sight and reported how many were feeding on the shrub and tree stratum or on herbaceous vegetation, respectively. Whenever possible, individual plant species grazed by the goats were recorded. The average time during which goats were observed feeding on individual plants or on plant strata, respectively, was calculated by multiplying the observed number of animals with the lengths of observation intervals. The resulting value was divided by the total number of observed goats multiplied with the total daily observation time, yielding the proportion of the animals' time spent feeding on a particular plant or stratum. This value was taken as an indicator for the animals' preference of forage plants and strata, respectively.

2.5. Grazing itineraries of goats

Goats' grazing itineraries were recorded by means of Global Positioning Systems (GPS) during 4–5 days in each of the three villages, once in February–April 2005 and once in October–November 2005. When the goat herds set out for pasture in the morning, a lightweight GPS collar (Buerkert and Schlecht, 2008) was fixed around the neck of one animal and was switched on to record the goat's position every 5–30 s. Whenever possible, GPS raw files were differentially corrected using a Trimble ProXRS base station at Sayh Qatanah (for details see Buerkert and Schlecht, 2008). Before the onset of the study, dummies of the collars were tested on individual goats to check whether their grazing behaviour would be affected, which according to the herders' observations was not the case. Data sets obtained from animals that separated from the herd and stayed out over night and from animals staying less than three hours on pasture were discarded.

2.6. Processing of GPS data

The horizontal distance (D_H) in meters covered between two successive positions (x_1/y_1; x_2/y_2) was calculated according to Equation (1), whereby d_1 equals 110,713 m per longitudinal degree and d_2 equals 102,100 m per latitudinal degree at the study location. The vertical distance (D_V) covered was derived from the difference in altitude between position 1 (z_1) and position 2 (z_2; $D_V = z_2 - z_1$). The total distance between the two positions, D_T, was then calculated according to Equation 2. The distances covered between individual points were summed up to daily distances walked. The speed of position change (v) was calculated dividing distance D_T by the time elapsed between two successive position loggings. Based on previous studies (Schlecht et al., 2006) it was assumed that if either the horizontal or the vertical component of the distance covered by a goat within 1 s exceeded 3 m, this was due to an erroneous position registry and therefore the data point leading to the faulty distance was omitted. After this first cleaning of individual data sets, all distances between the remaining corrected positions were calculated anew.

$$D_H = \sqrt{(x_2 - x_1)^2 d_1 + (y_2 - y_1)^2 d_2} \quad (1)$$

$$D_T = \sqrt{(D_H)^2 + (D_V)^2} \quad (2)$$

From the cleaned GPS data, the daily time on pasture, itinerary length, horizontal and vertical distances covered and average speed of movement on pasture were determined. Based on extensive observations of goats' grazing behaviour in the study region and in the Sahelian drylands (Schlecht et al., 2006), the speed of movement during 1-min intervals (moving average) was taken as an indicator of the animals' behaviour at pasture. Movements at $v \leq 0.2\ m\ s^{-1}$ were classified as resting or grazing on the spot. Movements at a speed of $0.2 < v \leq 0.7\ m\ s^{-1}$ were interpreted as the continuum of short term-grazing and subsequent movements to a nearby feeding station, while movements at $v > 0.7\ m\ s^{-1}$ were interpreted as directional walking uninterrupted by feeding. Based on this categorization, daily activity profiles of grazing goats were computed.

Using the software package ArcGIS 9.2 (ESRI Corp, Redlands, CA, USA), the cleaned GPS tracks were overlaid on a digital elevation model of the study region (Luedeling and Buerkert, 2008b). Buffers

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of 15 m width to both sides of individual tracks were created and the area of the resulting polygon was calculated in ArcGIS. All buffered tracks were then merged and the external borderline of the merged tracks was taken to delimit the grazing area of the herds in each village. To determine the size of patches exposed to a continuous livestock pressure, individual buffered tracks (shape files) were intersected with each other using XTools (ESRI, 2003). This resulted in shape files for the intersected segments of different tracks (≥2 tracks), which were merged to produce an aggregated area of intersection per village.

2.7. Statistical analyses

Statistical analyses of data were performed using SAS 8.1 (SAS, 2000). Analysis of variance and post-hoc least significant difference test were carried out to determine the effect of village ($n = 3$) and season ($n = 2$) on the daily time on pasture, itinerary length, sum of uphill movements, average speed of movement at pasture, selection patterns and GPS-derived daily activity profiles. Moreover, the analysis of variance tested the effects of location (and thus grazing pressure) on herbaceous mass.

3. Results

3.1. Pasture vegetation

The dominating tree species on the Sayq plateau were *Juniperus excelsa* subsp. *polycarpos*, *Olea europaea* subsp. *cuspidata* and *Sideroxylon mascatense* (plant names including the authorities are given in Table 2), accompanied by the abundant shrubs *Dodonaea viscosa* and *Euryops arabicus*, as well as by *Grewia erythraea* and *Sageretia thea* (Table 2). In the Sayq wadi, *Acacia gerrardii*, *Ziziphus spina-christi* and small palmoids (*Phoenix dactylifera*) complemented the tree stratum. The herbaceous vegetation on the Sayq plateau and in the Sayq wadi was composed of grasses such as *Aristida adscensionis*, *Cenchrus ciliaris*, *Cymbopogon schoenanthus*, *Cymbopogon commutatus*, *Cynodon dactylon* and *Tetrapogon villosus*. The main dicotyledonous species were *Helichrysum glumaceum*, *Salvia aegyptiaca*, *Teucrium mascatense* and *Teucrium stocksianum*.

The herbaceous vegetation on the Sayq plateau was sparse (average cover of 1.5%) and with low diversity ($n = 10$ species), compared to the species diversity ($n = 12$) and cover (average 4%) in the Sayq wadi (Table 3). In addition to the herbaceous species encountered on the Sayq plateau, the herbaceous vegetation on the ungrazed Kabul plateau also included the grasses *Enneapogon persicus*, *Fingerhuthia africana* and *Heteropogon contortus*, and the dicotyledons *Helianthemum lippii*, *Linum corymbulosum* and further species (Table 2). The tree and shrub stratum of the Kabul plateau was characterized by *S. mascatense*, *S. thea* and *G. erythraea*, while *D. viscosa* was less abundant than on the Sayq plateau. At 7%, the average canopy cover of the tree and shrub stratum on the Kabul plateau was higher than on the Sayq plateau (average 2%), but was only one sixth of the value determined for the Sayq wadi (42%; Table 3).

In October 2005, the weighted average herbaceous mass (Table 4) on vegetated patches of the Kabul plateau (753 kg DM ha^{-1}) was more than 50 times higher than the values obtained for the vegetated patches on the Sayq plateau (35 kg DM ha^{-1}) and the Sayq wadi (62 kg DM ha^{-1}). The bare surface accounted for 15%, 60% and 67% of the Kabul plateau, Sayq plateau and Sayq wadi, respectively, which, if taken into account, reduces the weighted herbaceous mass to 640 kg DM ha^{-1}, 14 kg DM ha^{-1} and 21 kg DM ha^{-1} in the respective areas. Herbage samples collected on the Kabul plateau contained less N, P and DOM than samples collected on the Sayq plateau, while their NDF concentration was about 24% higher (Table 4).

3.2. Selection behaviour of grazing goats

The proportion of time that goats spent grazing on the tree and shrub stratum and on the herbaceous vegetation, respectively (Table 5), varied strongly between the three villages: in spring, the differences for both strata were significant between Masayrat and the other two villages ($P < 0.01$). In autumn the values obtained for Sharayjah differed from those of Masayrat and Qasha ($P < 0.01$); interactions between village and season were significant at $P < 0.01$. The data obtained for Qasha' and Sharayjah showed that after the abundant spring rainfall (Section 2.1) goats dedicated more feeding time to the herbaceous vegetation than in autumn ($P < 0.05$), after 6 months of drought. In Masayrat, however, goats spent more than 70% of their feeding time on trees and shrubs in spring as opposed to 39% in autumn ($P < 0.01$). This is related to the particular vegetation on the slopes surrounding Masayrat, where the shrubs *Euphorbia larica* and *Pteropyrum scoparium* grow up to 1350 m altitude (Mandaville, 1977; Brinkmann et al., submitted for publication). The emerging flowers and leaves of *P. scoparium* were preferentially consumed by the goats in spring; in addition, they nibbled on the flower buds of *E. larica*.

3.3. Goats' grazing itineraries

The collared animals were mostly moving in the core of the herds; they did not show any abnormal behaviour and seemed to be fully accepted by their peers. The daily grazing itineraries of the herds were limited in space by natural obstacles such as steep slopes, cliffs and gorges (Fig. 1) as well as by use rights pertaining to each village or even family (personal communication of herders). Additional boundaries were set by villages and gardens and by a military area on the Sayq plateau. Given these constraints, the maximum 'pasture area' of the goats, defined by the outer boundaries of the merged buffered tracks (Section 2.5) increased with the topographic openness of the terrain and was 97 ha in Masayrat, 298 ha in Qasha' and 297 ha in Sharayjah. The actual area grazed ('grazing area') within that outer border amounted to 52 ha, 138 ha and 121 ha, respectively. The 'pressure zone', that is patches of frequent intersection of daily grazing itineraries, accounted for 46%, 53% and 59% of the 'pasture area' in the three villages (Fig. 1).

On average, the goats spent 9–10 h d^{-1} on the pastures (Table 6). Their average speed of movement was higher in spring than in autumn ($P < 0.01$) and was influenced by the length of the daily itinerary (co-variable, $P < 0.01$). Based on the speed-deduced activity patterns, the daily proportion of time spent on directional movements (walking) averaged 0.26 (SD 0.285) in Sharayjah and 0.12 (SD 0.160) in Qasha' in autumn as opposed to 0.41 (SD 0.277) and 0.28 (SD 0.247) in spring, whereby only the seasonal differences were significant ($P < 0.05$). In spring, the proportion of time spent on resting and slow motion grazing averaged 0.13 (SD 0.192) and 0.25 (SD 0.249) in Sharayjah and in Qasha', and increased to 0.38 (SD 0.275) and 0.44 (SD 0.245) in autumn ($P < 0.001$).

The distances goats moved up- and downhill are approximated by their aggregated vertical movements. The slopes surrounding Masayrat are steeper than those between Sharayjah and the Sayq plateau (Fig. 2), and the pastures of Qasha' occupy an intermediate position. In spite of this, the sum of daily uphill movements (Table 6) did not differ significantly between the three locations, which may be related to the limited number of GPS-tracked itineraries in Masayrat.

4. Discussion

4.1. Species occurrence and biomass yield of pasture vegetation

In October 2005, trees and shrubs such as *Olea europea* ssp. *cuspidata, Sideroxylon mascatense*, *Dodonea viscosa* and *Sageretia*

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Table 2
Life form, life span, Raunkiar life form, frequency and canopy cover of individual plant species on the ungrazed Ras al Kabul plateau (KP) and the heavily grazed Sayq plateau (SP) and Sayq wadi (SW), in October 2005. For abbreviations, see legends.

Species	Life form	Life span	Raunkiar life form	Total number of plots (*n*) containing the species			Plots (*n*) with canopy cover of species: 5–25%			Plots (*n*) with canopy cover of species: <5%		
				KP	SP	SW	KP	SP	SW	KP	SP	SW
Acacia gerrardii Benth.	Tr	P	Phan	–	–	1						1
Juniperus excelsa M. Bieb. subsp. *polycarpos* (K. Koch)	Tr	P	Phan	–	–	1			1			
Phoenix dactylifera L.	Tr	P	Phan	–	–	3			2			1
Sideroxylon mascatense (A. DC.) Penn.	Tr	P	Phan	4	4	5	2	4	4	2		1
Commiphora sp.	Sb	P	Phan	–	–	6			2			4
Dodonaea viscosa (L.) Jacq.	Sb	P	Phan	3	5	6		5	3			3
Euryops arabicus Steud. ex Jaub. & Spach	Sb	P	Phan	3	2	6			4			2
Ochradenus arabicus Chaudhary	Sb	P	Phan	3	–	2				3		2
Argyrolobium crotalarioides Jaub. & Spach	sm-Sb	P	Cham	4	–	3				4		3
Conyza stricta Willd.	sm-Sb	P	Cham	1	–	–	1					
Fagonia bruguieri DC.	sm-Sb	P	Cham	5	8	–	4			1		
Farsetia aegyptiaca Turra	sm-Sb	P	Cham	4	–	–				4		
Heliathemum lippii (L.) Dum.-Cours.	sm-Sb	P	Cham	5	5	1	5					
Salvia aegyptiaca L.	sm-Sb	P	Cham	4	4	3	3			1		
Teucrium mascatense Boiss.	sm-Sb	P	Cham	3	8	6	1	1		2	7	
Aristida mutabilis Trin. & Rupr.	Gr	A	Hemi	1	7	3		1			6	
Cenchrus ciliaris L.	Gr	P	Hemi	1	–	5	1		1			4
Chrysopogon plumulosus Hochst.	Gr	P	Hemi	2	–	–	2					
Cymbopogon schoenanthus (L.) Spreng.	Gr	P	Hemi	1	1	6			6			
Digitaria nodosa Parl.	Gr	A	Ther	1	–	–	1					
Enneapogon persicus Boiss.	Gr	P	Hemi	5	–	–	5					
Eragrostis papposa (Roem. & Schultes) Steud.	Gr	P	Hemi	4	4	3	3			1		
Fingerhuthia africana Lehm.	Gr	P	Hemi	5	–	–	5					
Heteropogon contortus (L.) Roem. & Schultes	Gr	P		5	–	–	5					
Tetrapogon villosus Desf.	Gr	P	Hemi	2	8	6	1	2	1	1	6	5
Andrachne telephinoides L.	Di	P	Hemi	3	6	–	1			2		
Atractylis cancellata L.	Di	A	Ther	1	–	–	1					
Cymbolaena griffithii (A. Gray) Wagenitz	Di	A	Ther	–	1	1					1	1
Helichrysum glumaceum DC.	Di	A	Hemi	5	6	2	5					
Lappula spinocarpus (Forsskal) Aschers.	Di	A	Ther	5	–	–	4			1		
Linum corymbulosum Reichenb.	Di	A	Ther	5	1	–	5					
Plantago amplexicaules Cav.	Di	A	Ther	4	–	–				4		
Pseudogalliona hymenostephana (Jaub. & Spach) Lincz.	Di	P		–	2	1					2	1
Solanum incanum L.	Di	P	Cham	1	1	1				1	1	1
Viola cinerea supsp. cinerea Boiss.	Di	A	Ther	2	–	–	1			1		
Zoegea purpurea Fresen.	Di	A	Ther	2	–	–	1			1		

Life form: Tr Tree; Sb shrub; sm-Sb semi-shrub; Gr grass; Di dicotyledon.
Life span: P perennial; A annual.
Raunkiar life form: Cham chamaephyte; Hemi hemicryptophyte; Phan phanerophyte; Ther therophyte.
Not mentioned in the table are 10 additional species with low abundance (r, +) on the Ras al Kabul plateau: *Blumea bovei* (DC.) Vatke, *Diplotaxis kohlaanensis* A.G. Mill. & J. Nyberg, *Ebenus stellata* Boiss., *Ephedra pachyclada* Boiss., *Filago pyramidata* L., *Grewia erythraea* Schweinf., *Ogastemma pusillum* Brummitt, *Plectranthus rugosus* Wall. ex Benth., *Pulicaria glutinosa* (boiss.) Jaub. & Spach subsp. *glutinosa*, *Trichodesma africanum* (L.) Lehm.
Likewise, 4 additional species with low abundance were recorded for the Sayq plateau and Sayq wadi area: *Cynodon dactylon* (L.) Pers., *Daphne mucronata* Royle, *Endostemon tenuifolis* (Benth.) Ashby, *Helichrysum macranicum* (Rech. f. & Esfand.) Rech. f.

thea dominated the vegetation of the Sayq plateau. The herbaceous vegetation included *Cymbopogon* spp., *Helochrysum glumaceum*, *Teucrium* spp. and *Tetrapogon villosum*. These species are characteristic for the *Reptonia–Olea* woodlands described by Mandaville (1977) for the Al Jabal al Akhdar Mountains at 1350–2300 m (*Oleetum–Reptonietum*; Kuerschner, 1998). Additionally, *Juniperus excelsa* ssp. *polycarpos*, *Euryops arabicus*, *Daphne mucronata* and *Salvia aegyptiaca* indicate the transition to the *Juniperus* woodlands, which represent the natural vegetation of the mountain ranges in Saudi Arabia and Oman above 2300 m (*Juniperueto–Euryopsietum;* Kuerschner, 1998). *Acacia gerrardii*, in contrast, is typical for the shrublands at elevations below 2200 m. Since this tree prefers deeper, alluvial soils (Miller et al., 1988), it was found in the Sayq wadi as well as on the pastures surrounding Qasha' and Masayrat. In the valleys below 1350 m, the *Euphorbia larica* shrubland (Mandaville, 1977) with *E. larica, Dyerophytum indicum*, *Capparis spinosa* and *Ficus cordata* ssp. *salicifolia* as well as the *Pteropyrum–Nerium* shrubland with *P. scoparium, Nerium mascatense* and *Moringa peregrina* dominate the vegetation (*Acacieto–Euphorbietum*; Kuerschner, 1998).

Table 3
Canopy cover of the tree and shrub stratum and the herbaceous vegetation on the heavily grazed Sayq plateau and Sayq wadi area and on the ungrazed Ras al Kabul plateau as determined in October 2005 on the Al Jabal al Akhdar mountain range, Oman.

Parameter	Sayq plateau, 8 plots of 10×10 m^2		Sayq wadi, 6 plots of 20×20 m^2		Kabul plateau, 5 plots of 8×8 m^2	
	Mean	SD	Mean	SD	Mean	SD
Canopy cover, total (%)	3.5	1.83	45.8	14.84	18.8	8.98
Canopy cover, trees & shrubs (%)	1.9	1.35	41.7	17.22	6.5	3.20
Canopy cover, herbaceous vegetation (%)	1.5	0.88	4.2	3.04	13.6	6.88
Number of plant species (*n*)	10.3	1.91	12.3	1.86	21.8	6.83

The low proportion of bare rocky surface, high canopy cover, species richness and herbaceous biomass on the Kabul plateau demonstrate the potential production of ungrazed herbaceous vegetation under the local rainfall conditions. This is opposed to large unvegetated and stone covered areas, low herbaceous biomass, reduced number of species and absence of grazing-sensitive herbaceous grasses (*Fingerhuthia africana*, *Heteropogon*

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Table 4
Spatial extent, air-dry herbaceous mass (DM), nitrogen, phosphorous and neutral detergent fibre concentration as well as organic matter (OM) digestibility of the herbaceous vegetation on the heavily grazed Sayq plateau and Sayq wadi area and on the ungrazed Ras al Kabul plateau as determined in October 2005 on the Al Jabal al Akhdar mountain range, Oman.

Parameter	Sayq plateau				Sayq wadi				Kabul plateau			
	Extent (%)[a]	*n*	Mean	SD	Extent (%)	*n*	Mean	SD	Extent (%)	*n*	Mean	SD
DM yield, sparsely vegetated patches (kg ha^{-1})	47.2	8	4.3a	3.30	59.0	8	39.4a	13.35	40.0	3	378.2b	93.62
DM yield moderately vegetated patches (kg ha^{-1})	28.0	19	23.3a	9.53	27.9	9	68.4b	14.15	44.0	5	732.6c	104.32
DM yield highly vegetated patches (kg ha^{-1})	24.8	4	107.6a	66.80	13.0	6	151.4a	53.98	15.5	3	1657.3b	518.77
DM yield extremely high vegetated patches (kg ha^{-1})	0				0				0.5	1	4505.2	
Nitrogen (g kg^{-1} DM)			8.2	0.39							5.8	0.01
Phosphorus (mg kg^{-1} DM)			504	7.9							255	23.8
Neutral detergent fibre (g kg^{-1} DM)			570	11.5							751	19.5
Organic matter digestibility (g kg^{-1} OM)[b]			543	13.7							479	10.7

Within rows, DM yields with different alphabets (a,b,c) differ at $P < 0.01$ (moderately vegetated patches) and at $P < 0.001$ (sparsely and highly vegetated patches), respectively.
[a] Percentage of the vegetated area covered by the respective density class; patches of bare soil are not taken into account.
[b] Organic matter concentration in dry matter from Sayq plateau: 872 g kg^{-1} DM, from Kabul plateau: 920 g kg^{-1} DM.

contortus) and dicotyledons (*Helianthemum lippii*, *Linum corymbosulum*) on the Sayq plateau. These observations are in line with those of Mandaville's (1977) published three decades ago. Based on the similar climatic, geological and topographic conditions, the strongly reduced canopy cover and low biomass of the herbaceous vegetation on the Sayq plateau – and in the Sayq wadi – are ascribed to the continuous grazing pressure exerted by the large number of goats in Sharayjah ($n = 440$), Al Ayn ($n = 135$) and Sayh Qatanah ($n = 386$; MAF, 2001). This grazing pressure is even enhanced by some 2000 feral donkeys (numbers estimated by the Ministry of Agriculture and Fisheries, Nizwa) whose ancestors were released 10–20 years ago by farmers and military and are now roaming around in the area. However, the herbaceous biomass was only determined six months after the last significant rainfall and data from exlosures on the Sayq plateau and in the Sayq wadi were not available at the time of this study. It is therefore evident that our data do not account for the herbaceous DM ingested by grazing animals during the respective period. From the calculations presented in Section 4.3 and from the high proportion of bare surface it can, however, be assumed that the total herbaceous DM yield on the Sayq plateau as well as in the Sayq wadi during the 6 months in question was considerably lower than on the ungrazed Kabul plateau. Other indicators supporting this assumption are the lower concentration of N, P and DOM and the higher concentration of NDF in the herbaceous samples collected on the Kabul plateau, which point to the mature stage of these grasses and dicotyledons. This stage was seemingly not reached by the plants on the Sayq plateau, which may be due to repeated defoliation-induced regrowth of the photosynthetic and reproductive organs.

As indicated by a recent study of an exclosure established on the Sayq plateau in 1993, plant species diversity in this continuously grazed area re-established after >10 years elimination of grazing pressure (Brinkmann et al., submitted for publication). However, any stringent large-scale and long-term protection of the communal Al Jabal al Akhdar pastures from grazing is unrealistic at present, given their continued importance for the local goat husbandry system (Zaibet et al., 2004; Al Harthi et al., 2008).

4.2. Plant species selection of goats on pasture

While in autumn the goats in Masayrat mostly fed on herbaceous plants as well as on dry tree leaves and tree fruits on the

Table 5
Average feeding time of goats per stratum (% of observed feeding time) and individual plant species (% of feeding time per stratum) on pastures of three villages in the Al Jabal al Akhdar Mountains, Oman, as observed in spring and autumn 2005. Data show means ± one standard deviation.

Stratum	Plant	Masayrat		Qasha'		Sharayjah	
		Spring	Autumn	Spring	Autumn	Spring	Autumn
Vegetation	*Caralluma flava*	0.8					
	Chrozophora oblongifolia			4.3		0.1	
	Cymbopogon sp.	7.3		0.2	2.7	0.5	2.7
	Taverniera glabra	6.1	2.1	0.7	1.3	0.6	
	Grasses, herbs, litter, seeds[a]	85.7	97.9	94.8	96.0	98.7	97.3
	Total	28.6 ± 14.96	61.2 ± 8.85	74.3 ± 12.10	52.6 ± 13.58	57.0 ± 5.17	25.9 ± 6.33
Trees and shrubs	*Acacia gerrardii*	8.5	11.7	6.2	48.8	0.2	5.1
	Acridocarpus orientalis	3.4		0.8	0.5		
	Capparis sp.	4.8	20.6	0.9		3.0	
	Dodonaea viscosa			16.2	2.0	30.9	2.1
	Euphorbia larica	3.4		4.2	2.6		
	Ficus cordata ssp. *salicifolia*	1.8	6.6			0.1	
	Moringa peregrina	8.5	2.8	1.7	1.0		
	Pteropyrum scoparium	40.8	47.5	0.2			
	Sideroxylon mascatense	16.7	0.9	66.6	39.6	63.2	87.1
	Ziziphus sp.	6.2	9.8	3.3	3.6	2.6	1.4
	other shrubs[b]	5.7			2.0		4.3
	Total	71.4 ± 14.96	38.8 ± 8.85	25.6 ± 12.10	47.4 ± 13.58	43.0 ± 5.17	74.1 ± 5.33

[a] Other herbaceous plants that were infrequently grazed by goats: In Masayrat: *Astragalus corrugatus* and *Withania somnifera;* In Qasha': *Indigofera* sp. and *Myosotis arvensis*; In Sharayjah: *Cymbopogon commutatis*, *Fagonia bruguerii*, *Helichrysum makranicum* and *Teucrium stocksianum*.
[b] Other shrubs that were infrequently grazed by goats: In Masayrat: *Commiphora hajarensis*, *Nerium mascatense*; *Prunus amygdalus* and one unidentified shrub; In Qasha': *Dyerophytum indicum* and *Sageretia thea*; In Sharayjah: *Juniperus excelsa* ssp. *polycarpos*, *Olea europaea* ssp. *cuspidata*, *Phoenix dactilyfera* and *Sageretia thea*.

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Table 6
Characteristics of goats' grazing itineraries on the Al Jabal al Akhdar mountain range, Oman, as determined from GPS recordings in spring and autumn 2005. Data show means ± one standard deviation.

Village	Period	Tracks (n)	Duration ($h\,d^{-1}$)	Distance, total (km)	Distance, horizontal (km)	Uphill movements (sum, km)	Speed of movement ($m\,s^{-1}$)
Sharayjah	Spring	6	9.6 ± 0.76	19.5 ± 4.37	16.7 ± 2.54	3.2 ± 1.7	0.60 ± 0.165
	Autumn	6	9.4 ± 1.45	13.0 ± 2.82	11.6 ± 2.85	1.5 ± 0.43	0.39 ± 0.052
Qasha'	Spring	7	10.2 ± 0.78	15.54 ± 6.49	12.1 ± 3.88	3.4 ± 2.24	0.52 ± 0.211
	Autumn	3	9.7 ± 0.32	11.9 ± 0.27	10.5 ± 0.45	1.8 ± 0.08	0.34 ± 0.009
Masayrat	Autumn	5	8.9 ± 3.11	14.7 ± 7.77	11.8 ± 6.91	2.8 ± 1.33	0.34 ± 0.118
Parameter	df[a]	$Pr > F$[b]					
Village	2		0.689	0.495	0.301	0.409	0.553
Season	1		0.645	0.046	0.078	0.030	0.007
Village × Season	1		0.832	0.565	0.361	0.935	0.784

[a] Degrees of freedom.
[b] Probability of a parameter effect.

ground, *P. scoparium*, *C. spinosa* and the young leaves of *F. cordata* ssp. *salicifolia* were important sources of forage especially in spring. In contrast, shrubs and trees, and in particular *S. mascatense,* were the main autumn forage resources for goats on the pastures of Sharayjah and Qasha', which agrees with the findings of Al Harthi et al. (2008). These differences between the low-altitude village of Masayrat and the two high-altitude pastures of Qasha' and Sharayjah are partly explained by their affiliation to two different plant communities: while *S. mascatense* is rarely encountered in the valleys and on the slopes near Masayrat, *P. scoparium* and *E. larica* are limited to altitudes below 1350 m (Section 4.1).

Among the herbaceous species, the dicotyledonous *T. mascatense* and *T. stocksianum*, and the perennial grasses *C. ciliaris*, *Cymbopogon spp., C. dactylon* and *T. villosus* were the most important forage plants. Since these species were often growing in-between rocks, the goats could not easily access them. Moreover, the small size of *C. ciliaris* and *C. dactylon* prevented the goats from defoliating the entire plant, which allowed them to persist in highly vegetated patches. The broad-leaved perennial grass *H. contortus* and the tender leaves of the annual dicot *L. corymbosulum* were also preferably grazed and were therefore less abundant or even missing on the Sayq plateau and in the Sayq wadi. In contrast, the shrub *D. mucronata* was not encountered on the Kabul plateau and the shrubs *D. viscosa* and *E. arabicus* were much less abundant there than on the Sayq plateau. While just the young leaves and flowers of *D. viscosa* are foraged by the goats, *E. arabicus* and *D. mucronata* contain poisonous secondary compounds (Katayoun et al., 2003; Mothana and Lindequist, 2005) and are therefore avoided by animals. Consequently, these evergreen perennials can easily spread when grazing reduces the abundance of the mostly annual herbaceous species, and they gradually dominate the natural vegetation of the *Reptonia–Olea* woodlands in heavily grazed areas (Brinkmann et al., submitted for publication). In Masayrat, goats sometimes nibbled on the flower buds of *E. larica* during springtime; other parts of this shrub were, however, not ingested. Of the shrub *F. cordata* ssp. *salicifolia,* only the leaves of young plants were frequently browsed, while the poisonous shrubs *Acridocarpus orientalis* and *N. mascatense* (Jongbloed et al., 2003) were not touched. The leguminous tree *A. gerrardii*, typical for the Al Jabal al Akhdar Mountains, occurs in Masayrat as well as in the wadis at higher elevations and was browsed whenever present. In October, the herders would hit the *Acacia* branches with sticks so that their pods fell on the ground and seeds became available to the goats. The fact that fallen leaves and pods could often not be identified as such by the distant observer may at least partly explain why the proportion of feeding time spent on the herbaceous stratum was >50% in autumn, despite a 6-month drought spell.

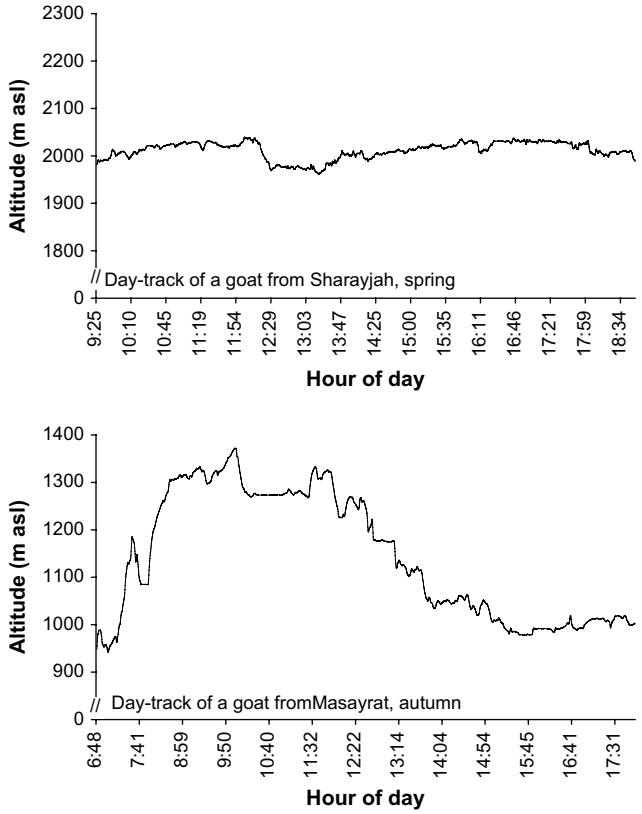

Fig. 2. Daily vertical movements of two grazing goats as recorded by GPS collars at the level pastures of Sharayjah and the steep hillslopes around Masayrat, Al Jabal al Akhdar range, Oman. The line represents the moving average of altitude at one minute intervals; the initial and final altitudes indicate the location of the homestead. Both ordinates cover a range of 500 m.

4.3. Grazing itineraries and activity patterns

The length of the daily grazing itineraries of Jabal Akhdar goats was similar to values reported for goats in the West African Sahel (Schlecht et al., 2006; Ouédraogo-Koné et al., 2006). Large directional movements from the homestead to the first grazing area and from one grazing area to the next were mainly observed in Sharayjah, where goats had to walk 4–5 km before they reached the target area. The significant seasonal differences in itinerary length were possibly due to changes in the availability of forage on the pastures after the spring rains as opposed to the situation in autumn. Thereby the data indicate that itineraries shortened – and resting periods lengthened – as the drought spell persisted,

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a phenomenon also observed in Sahelian drylands (Schlecht et al., 2006). However, in contrast to Sahelian goats, Jabal Akhdar goats experience a high energy expenditure at pasture, due to the considerable distances they move uphill. Under these conditions, the daily metabolizable energy (ME) requirements for goats of 20–60 kg live weight (LW) may raise to 745 kJ $kg^{-0.75}$ as compared to a requirement of 424 kJ $kg^{-0.75}$ under stall-feeding conditions (NRC, 1981). At a concentration of 6.1 MJ ME kg^{-1} DM of the herbaceous vegetation, which corresponds to the DOM concentration determined in the samples from the Kabul plateau, the difference of 321 kJ $kg^{-0.75}$ translates to a feed requirement of 53 g DM d^{-1} just to cover the energy costs of locomotion. With respect to this, the herbaceous mass of 640 kg DM ha^{-1} on the Kabul plateau would supply 3900 MJ ME ha^{-1} and thus cover the year-round energy requirements of 0.9 goats of 40 kg LW. Considering solely the herbaceous vegetation and assuming a DM loss of about 50% due to trampling, a stocking rate of 0.45 goats per hectare and year could be maintained under the conditions represented by the Kabul plateau. To avoid a decline in the productivity of the herbaceous stratum, a 3-months pasture rest should, however, be observed, so as to allow flowering and seed shedding of the predominant annual grasses and dicotyledons. This would lower the maximum stocking rate to 0.34 goats per hectare and year.

The herd taken out for grazing comprised about 70 out of 112 goats in Qasha', 100 out of 245 goats in Masayrat and 150 out of 190 animals in Sharayjah. Since the GPS-determined pasture areas encompassed 300 ha in Sharayjah and Qasha', these numbers translate to stocking rates of about 0.5 and 0.23 goats per hectare, respectively. With respect to the herbaceous mass available on the Sayq plateau and in the Sayq wadi, the value of 0.5 indicates considerable overstocking, even if, as discussed above (Section 4.1) the herbaceous mass consumed by the animals during 6 months preceding our measurements is taken into consideration. Since the pastures of Qasha' are also grazed by goats ($n = 140$ in 2001) of Salut (Fig. 1), and the pastures on the Sayq plateau are also exploited by goats of Al'Aqr and Sayh Qatanah (total $n = 400$ in 2001; MAF, 2001), true stocking rates may be even higher than derived from our assessments. The substantial feed supplementation of goats at the homestead with dates, dried fish and cultivated fodder (Predotova et al., 2006) certainly plays an important role for the maintenance of high animal numbers despite declining herbage resources (Vetter, 2005). In addition, the ingestion of browse plays an equally important or even more important role for the feed supply to goats (Ramirez, 1999), which is reflected by the allocation of eating time determined in the three villages. An accurate evaluation of the present stocking rates must therefore account for the overall forage availability and quality of both the herbaceous and the ligneous stratum. Although the present data does not allow for such an assessment and suffers from the mentioned lack of exclosure data (Section 4.1) we postulate that the marked differences in herbaceous mass of the ungrazed *versus* the grazed plateau are due to year-round grazing, which drastically reduces the carrying capacity of the Al Jabal al Akhdar pastures, plant species richness and increases the percentage of bare surfaces.

5. Conclusions

The year-round exploitation of the forage resources on the Al Jabal al Akhdar mountain pastures by the local goat husbandry system increased the proportion of bare surfaces and reduced plant species richness and herbaceous mass yields on grazed as compared to ungrazed sites. The continuous availability of key grazing resources in the form of additional feed offered at the homestead enhances the risk of livestock-induced degradation of these otherwise non-equilibrium pastures.

The results underline the need to develop improved grazing and feeding schemes, which reduce the pressure on the natural vegetation, especially during the vegetation period. However, this remains a difficult task as many young people move out of the area and skilful livestock management declines. Studies quantifying goats' feed intake on the natural pastures and at the homesteads should be combined with further vegetation studies to better appraise the actual grazing pressure against the carrying capacity of the fragile pastures in this arid high-altitude environment.

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