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Vegetation patterns and diversity along an altitudinal and a grazing gradient in the Jabal al Akhdar mountain range of northern Oman

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ABSTRACT

Little is known about the effects of grazing on vegetation composition on the Arabian Peninsula. The aim of this study therefore was to analyse the vegetation response to environmental conditions of open woodlands along an altitudinal and a grazing gradient in the Jabal al Akhdar mountain range of Oman. The species composition, vegetation structure, grazing damage and several environmental variables were investigated for 62 samples using a nested plot design. Classification analysis and a Canonical Variate Analysis (CVA) were used to define vegetation types and to identify underlying environmental gradients. The relationship between environmental variables and diversity was analysed using correlation coefficients and a main-effects ANOVA. The plant species richness followed a unimodal distribution along the altitudinal gradient with the highest number of species at the intermediate altitudinal belt. The cluster analysis led to five vegetation groups: The *Sideroxylon mascatense–Dodonaea viscosa* group on grazed and the *Olea europaea–Fingerhuthia africana* group on ungrazed plateau sites at 2000 m a.s.l., the *Ziziphus spina-christi–Nerium oleander* group at wadi sites and the *Moringa peregrina–Pteropyrum scoparium* group at 1200 m a.s.l, and the *Acacia gerrardii–Leucas inflata* group at 1700 m a.s.l. The CVA indicated a clear distinction of the groups obtained by the agglomerative cluster analysis. The landform, altitude and grazing intensity were found to be the most important variables distinguishing between clusters. Overgrazing of the studied rangeland is an increasing environmental problem, whereas the plant composition at ungrazed sites pointed to a relatively fast and high regeneration potential of the local vegetation.

1. Introduction

The Jabal al Akhdar massif in the Hajar mountains of northern Oman has been classified as a local centre of plant endemism (Miller and Nyberg, 1991; Ghazanfar, 2003). It belongs to the WWF's Global 200 ecoregion "Arabian Highland Woodlands and Shrublands" occurring on the Arabian Peninsula, Yemen, Oman, Saudi Arabia and the United Arab Emirates with a total area of 470,000 km^2 and has a ecologically "vulnerable" status (Olson and Dinerstein, 2002). Above 1500 m altitude, this area hosts about 33% of Oman's 1200 species of vascular plants, of which 14 taxa are endemic to Oman (Patzelt, 2008).

Prior to 1975 little was known about the flora and fauna of Oman as tribal conflicts rendered access to the rugged and inhospitable terrain very difficult for scientists. So far, only the first two volumes of the Flora of Oman (Ghazanfar, 2003, 2007) and two volumes of the Flora of Arabia have been completed (Miller and Cope, 1996; Cope, 2007). The first regional checklist of the flora of the Jabal al Akhdar range was published thirty years ago (Mandaville, 1977). This check list has recently been updated and completed (Patzelt, submitted for publication) and the first country-wide Red List of plants has been finalised (Patzelt, 2008). Several botanical studies have been conducted in different parts of the country (Radcliffe-Smith, 1980; Mandaville, 1985; Cope, 1988; Ghazanfar, 1992; Patzelt, 2004; Gebauer et al., 2007), but on the phytogeography and vegetation structure of the northern Oman Hajar mountain range only a few descriptive studies have been published (Mandaville, 1977; Sankary, 1980; Ghazanfar, 1991b; Kuerschner, 1998). Mandaville (1977) described the zoning

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of plant communities with respect to altitude for the central Jabal al Akhdar and the summit area of Jabal Aswad (eastern Hajar). Ghazanfar (1991b) analysed the altitudinal zoning, community composition and species diversity of the vegetation of Jabal Shams using multivariate analysis.

The rangelands of the Jabal al Akhdar (1580–2000 m) are characterised by semi-evergreen woodlands dominated by *Sideroxylon mascatense* (A. DC.) Penn. growing in scattered mixed stands with *Dodonaea viscosa* (L.) Jacq., *Euryops arabicus* Steud. ex Jaub. and Spach, *Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don) Ciferri and *Sageretia thea* (Osb.) M.C. Johnst. (Ghazanfar, 1991b). At these and higher altitudes, *Cymbopogon schoenanthus* (L.) Spreng. forms the dominant ground cover. From heights of 2000 m up to the summit, the vegetation is characterised by *Juniperus excelsa* M. Bieb subsp. *polycarpos* (K. Koch) Takhtajan, *Ephedra pachyclada* Boiss. subsp. *pachyclada* and *Teucrium mascatense* Boiss. (Ghazanfar, 1991b). It has been suggested that the occurrence of *Juniperus excelsa* and other plant species in the Hajar range may be due to plant migrations from southeastern Iran across the Arabian Gulf (Mandaville, 1977; Miller and Nyberg, 1991; Kuerschner, 1998).

Pastoral livestock husbandry is the prevalent form of land use in arid or semi-arid rangelands. During the last decades the grazing pressure on the desert rangelands has increased steadily across the entire Arabian Peninsula (Khan, 1982; Oatham et al., 1995) and overgrazing is now considered to be a serious environmental problem (CBD, 1997; Ghazanfar, 2003; Kharbotly et al., 2003; Patzelt, 2008). Goats are the most numerous livestock species in northern Oman, followed by sheep, cattle and camels. It is known that goat browsing results in changes of plant species composition whereby some species decline, whereas those avoided by goats increase (Riggs and Urness, 1989). The relationship between herbivory and plant species diversity can not be generalised. It varies across environmental gradients (Olff and Ritchie, 1998; Curtin, 2002) and often depends on the palatability of particular species (Pacala and Crawley, 1992).

A complex of various factors determines the botanical composition and the related species richness and functional trait variation among the species (=functional diversity; Petchey and Gaston, 2006) of the rangeland vegetation. One important factor is altitude, which has a strong influence on the structure of the vegetation of the Arabian Peninsula, with species richness reported to be greatest from 1000 to 1480 m (Deil and Al Gifri, 1998). Changes in species richness along altitudinal gradients have been the subject of numerous studies (Lomolino, 2001) and most of them found a "humped" distribution showing peak species richness near the middle of the gradient (Rahbek, 1995, 2005).

To better understand and manage rangeland ecosystems, it is important to study the relationships between environmental factors and vegetation. Despite some earlier work, data are lacking about the effects of (over-) grazing by domestic livestock, including feral donkeys, on plant composition and local diversity (CBD, 1997) on the Arabian Peninsula and particularly in the Sultanate of Oman. Equally lacking are quantitative data about the distribution and ecology of different plant species, and also the vegetation response to environmental conditions. The aim of this study therefore was to analyse the species composition, floristic diversity and stand structure of communal pastures within open woodlands of the Jabal al Akhdar along an environmental gradient. We hypothesise that the environmental factors "altitude" and "grazing intensity" discriminate best between the vegetation types identified by a cluster analysis and explain also a high proportion in the variability of plant species richness and stand structure.

2. Materials and methods

2.1. Study area

The Hajar-al-Gharbi mountain range is the highest in eastern Arabia, forming a spectacular rise from the surrounding deserts. The highest part of the Hajar is the limestone massif of Al Jabal al Akhdar ("The Green Mountain"), lying between the western and eastern parts of the range within which the Jabal al Akhdar (23.07 N, 57.66 E) reaches an elevation of almost 3000 m. The climatic conditions across the entire range are arid to semi-arid, with a potential evapotranspiration of more than 2000 mm per annum (Siebert et al., 2007).

The study was carried out at the three villages Masayrat ar Ruwajah (1030 m a.s.l.), Qasha' (1640 m a.s.l.) and Ash Sharayjah (1900 m a.s.l.), which are located within 10 km of Sayh Qatanah, the central settlement of the Jabal al Akhdar mountains (Fig. 1). The total annual precipitation at Sayh Qatanah ranges between 100 and 340 mm with a higher probability of rainfall in February–March and July–October (Luedeling and Buerkert, 2008). Fisher (1994) calculated a mean annual precipitation in this region of 312 mm.

The geology of the study area consists mainly of highly permeable carbonates (black limestones and brownish dolomites of the Saiq Formation) resting on rocks of the pre-Late Permian Sedimentary Basement, conformably overlain by the Mahil Formation (Béchennec et al., 1992). Masayrat ar Ruwajah and its surroundings are characterised by the Muaydin Formation with siltstone and shale with carbonate beds. The Mistal Formation with diamicite, greywacke, basalt and basaltic andesite occurs between the settlements Ash Sharayjah and Salut.

The rocks are largely exposed, steep, with almost no soil cover and sparsely covered with vegetation that is primarily limited to runnels or small depressions where some sediments have accumulated in pockets. Large boulders, small stones and gravel are found in the steep runnels. The wadi fans consist mainly of gravel and sandy soil. Occasional rainfalls in winter can lead to flash floods that rush through the barren wadis.

2.2. Data collection

The common pastures sampled were selected to comprise a wide range of sites with differing grazing intensities within a study area of 50 km^2. Site selection was based on a map highlighting the pasture area of the study area and the main grazing zone associated with the three selected villages Masayrat ar Ruwajah, Qasha' and Ash Sharayjah. The latter was determined by Schlecht et al. (2009) using a GIS-based analysis of GPS-tracked livestock grazing itineraries and animals' activity patterns classified as "resting", "grazing" and "walking" along the route. Further pasture areas of the surrounding settlements were defined by Dickhoefer et al. (submitted) based on farmer interviews. The resulting maps were subsequently classified into four grazing intensities (Fig. 1): ungrazed rangelands (exclosures or areas with poor accessibility, class 0), pastures with low grazing pressure outside the main grazing zone (class 1), pastures with a medium grazing pressure within the main grazing zone (class 2) and pastures with a high grazing pressure within the grazing area along the goat tracks (Pressure zone, class 3).

The sampling of the vegetation was based on a nested plot design, whereby the plots were randomly distributed within a relatively homogeneous area in terms of topography, landform and present vegetation. Each plot measured 20 × 30 m and contained nested subplots of two different sizes. All shrubs and trees (>50 cm) within the whole plot area were sampled. To ascertain