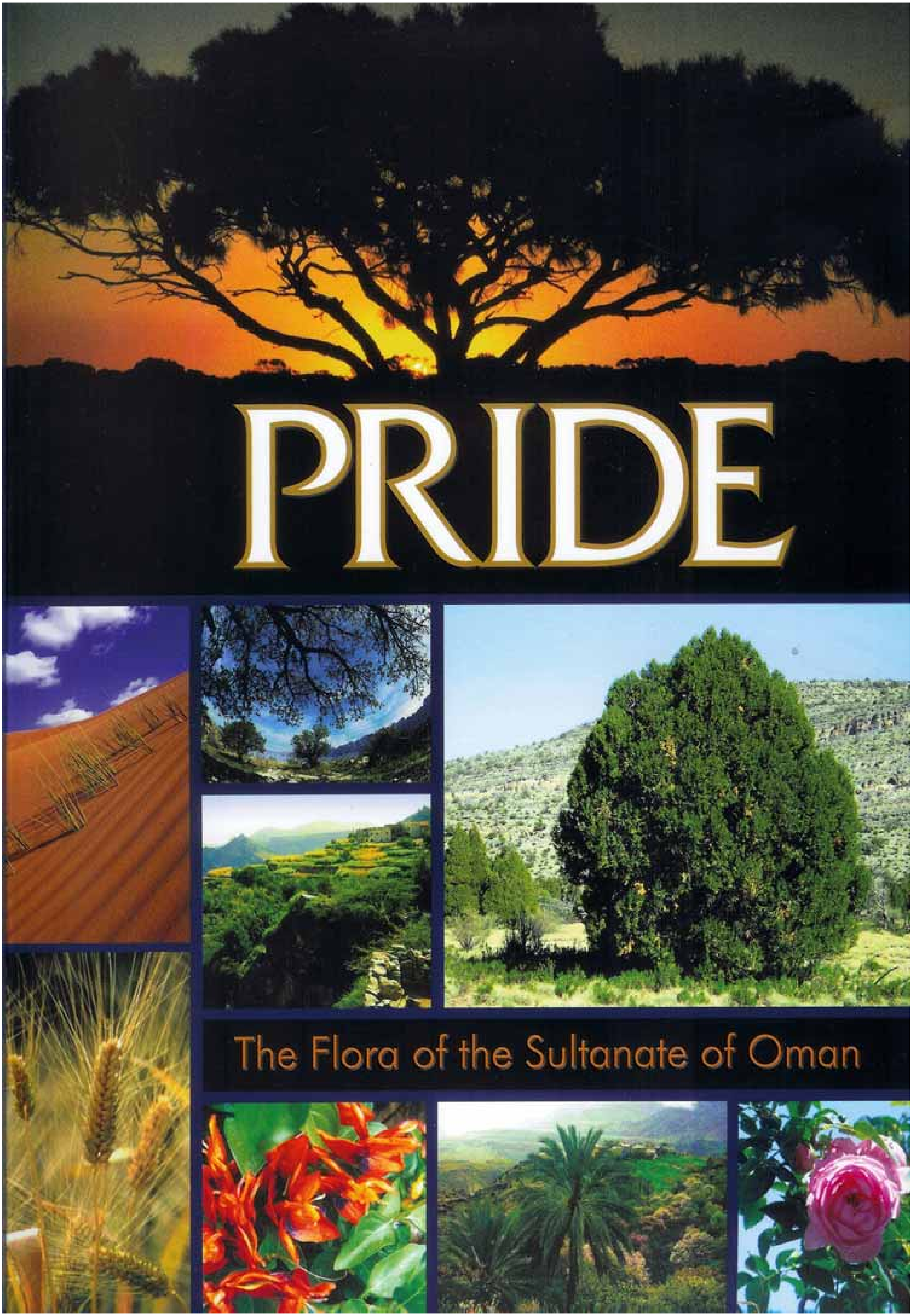
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Classification of Oases in Northern Oman

Example of a spring-fed oasis: Qasha' in Al Jebel Al Akhdar (photograph taken from the gardens of Al 'Ayn).

Eike Luedeling and Andreas Buerkert

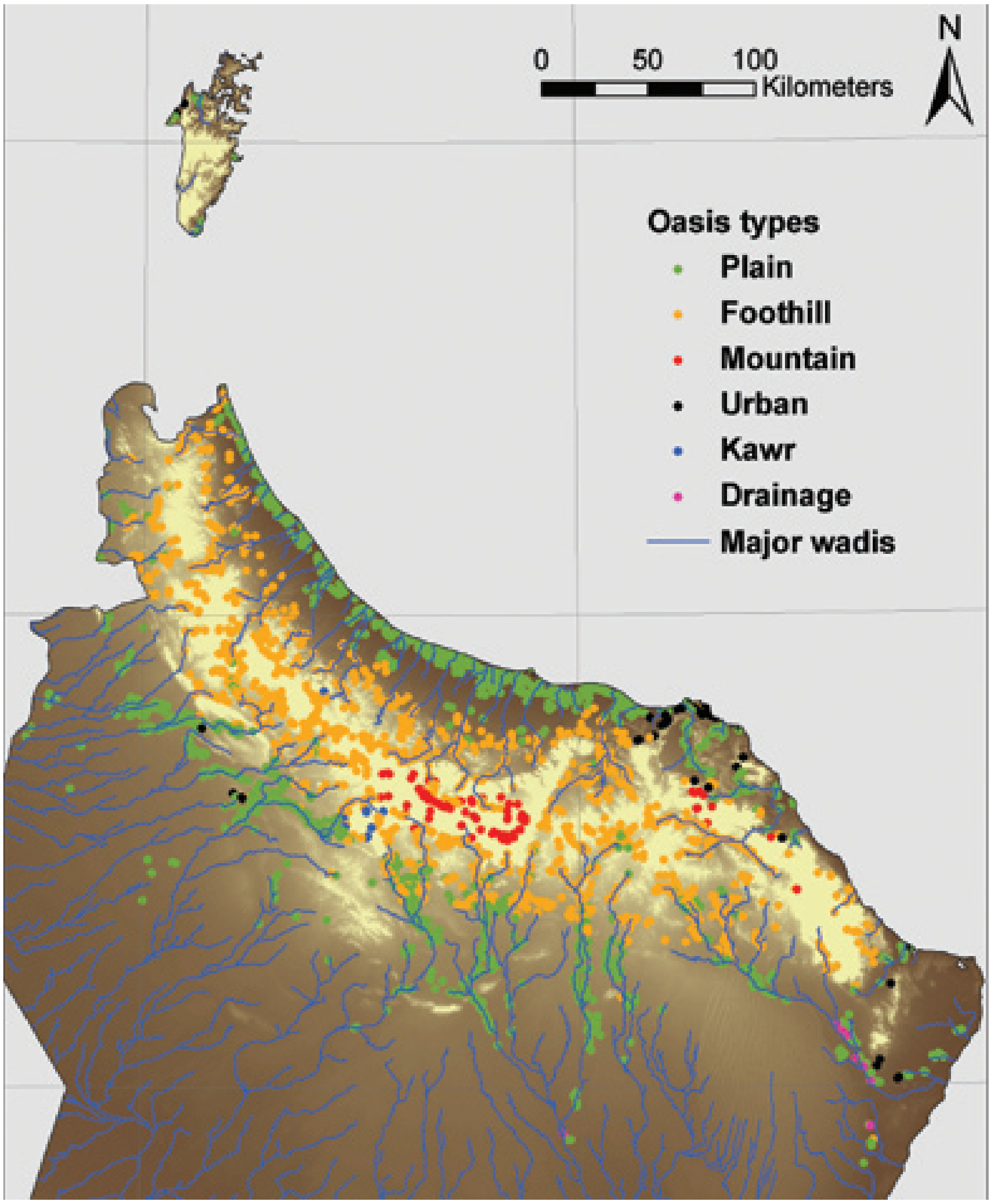
For millennia oasis agriculture has been the economic and cultural backbone of Oman (Korn et al. 2004, Nagieb et al. 2004). This is particularly remarkable as Omani oases have stood the test of time in sustainably producing food in the hyperarid desert climate of the country. In recent years, Omani oases have, therefore, aroused the interest of the international scientific community, and researchers from many parts of the world have worked in Oman to study oasis agriculture and *falaj* irrigation systems. Only a small number of these scientists have looked at more than a few oases, and it is unclear how representative their findings are for other oases. To date, it is even uncertain how many oases exist in northern Oman, and in order to better target research, it would be helpful to know how oases can be categorised so that future studies can aim at representative oases. Since the vast countryside makes it impossible to travel to every oasis in Oman, we attempted to determine the number of oases using remote sensing techniques, and after identification, classified them into distinct types to facilitate future research on oasis systems.

oasis detection

To detect oases in northern Oman, we used images taken by the Landsat 7 satellite in 2000 and 2001, which have a spatial resolution of 28.5 m. The Enhanced Thematic Mapper Plus (ETM+) instrument traveling on this satellite registers reflections by the ground surface at different wavelengths of the electromagnetic spectrum, such as visible blue, green and red light, and the invisible near infrared. In contrast to bare ground, active vegetation absorbs almost all red light through photosynthesis but reflects most radiation in the near infrared part of the spectrum, so that these two wavelengths can be used to detect vegetation on the ground. We combined them using the Normalized Difference Vegetation Index (NDVI = (Near Infrared – Red) / (Near Infrared + Red).

the whole of northern Oman. To compensate for the different light intensities between images taken during different seasons and for the generally higher intensity of mountain vegetation, we subtracted a regional average of a square of 101 by 101 pixels around each pixel of the image. One last remaining disturbance to the detection of oases was the presence of natural vegetation. Since patches of natural vegetation are normally much smaller than agricultural oases, uncultivated plants were excluded by calculating mean NDVI values of 3 by 3 pixels. The result was then classified into

Locations of oases belonging to the different types in northern Oman. Locations of the major wadis were derived from hydrological modeling.



On the satellite images, many oases were clearly visible, but the scales of the NDVI are different on each image used in the analysis. Since the size of one satellite image is approximately 184 by 172 km^2, 11 images were needed to cover

five intensity classes along natural breaks in the dataset, and the class containing the most intense vegetation was interpreted as the core of an oasis. Since most oases are larger than their core area, we investigated the intensity of vegetation, represented by the NDVI, around the cores, and extended the oases until the intensity dropped off. Each contiguous area resulting from this process was interpreted as one oasis. We evaluated our detection procedure by counting the oases that were visible on Google Earth® images in 10 test squares of 20 by 20 km^2, and compared the result with our classification of the Landsat ETM+ images. The analysis revealed a total of 2663 oases in northern Oman. The evaluation procedure indicated that oases above 0.4 ha were identified reliably, whereas some smaller oases were sometimes missed. 2428 of the detected oases had agricultural areas above this threshold. Whether or not this is the real number of oases in northern Oman depends on how an oasis is defined. Of course, our remote sensing classification cannot detect administrative boundaries, so villages that are very close together or whose gardens are connected are likely to be interpreted as one in our analysis. Likewise, gardens that are separate from the oases they belong to or plantations fed from wells are considered as separate oases. However, our analysis was well able to identify contiguous areas of cultivated vegetation in northern Oman. Areas of natural vegetation that were erroneously classified as oases appear to be restricted to a few patches of juniper on Jebel Shams and several clusters of trees in some wadis.

oasis characterisation

To investigate the characteristics of the detected oases, we analysed their geological, topographical and hydrological settings using the statistical tool of cluster analysis to group the oases into six categories. For this analysis, we described the topography of the oasis sites by calculating the mean elevation and the height difference between the mean elevation and the highest point within 2 kilometres around the oasis. The hydrological setting was assessed by calculating the contributing catchment areas and the distances to large and small wadis. Finally, we characterised the geological settings of the oases by evaluating their proximity to four hydrologically important geological units, which were identified as (a) limestones of the Hajar Supergroup, (b) limestones of the Kawr Group, belonging to the Hawasina Series, (c) Samail Ophiolites, remains of an ancient seafloor, and (d) the ancient ocean sediments of the Hawasina Series (Glennie et al. 1974).

Our analysis classified Omani oases into six distinct types. The most common oasis type in modern Oman is the 'Plain Oasis' (48.5% of the total), which lie in the Batinah or on the plains west of the mountains. They comprise most of the modern irrigation schemes, which obtain their water from wells. The second most common type is the 'Foothill Oasis' (46.2%), which lie in the foothills of the mountains, often in association with Samail Ophiolites and the Hawasina Series. In this setting, we find many traditional oases, which derive their irrigation water from wadi sediments. The rocks of

Example of an 'Urban Oasis', the Sports Complex at Nizwa (Google Earth® image).

the foothills channel underground flow in the sediment-filled wadis, where water accumulates and can easily be extracted. The other four oasis types are much less common. 'Mountain Oases' only make up 2.8% of all oases; they lie in the higher reaches of Oman's mountains and are mostly fed by springs emerging at the boundary between Hajar limestones and the underlying Basement rocks. 'Kawr Oases' (0.5%) lie in similar settings, except that the water reservoir of these oases lies in the limestones of the Kawr Group rather than the Hajar Supergroup. The largest traditional oases in Oman, with cultivated areas of up to 436 hectares at Bilad Bani Bu Hassan, are the 'Drainage Oases' (0.3%), which lie along a major wadi between the Oman mountains and the dunes of the Sharqiyah Sands. Based purely on hydrological modeling, this wadi drains the entire area west of the mountains, accumulating large amounts of water in the subsurface. One last oasis type, which has become increasingly common in recent years, is the 'Urban Oasis' (1.7%). This oasis type consists mainly of parks and sporting facilities, which have been established in Oman's rapidly evolving cities.

According to their hydrological setting, oases can be summarised into three major broad categories. 'Urban Oases' do not lie in hydrologically meaningful locations but their sites are well connected to urban water supply systems, so that local water availability is not important. Oases of the 'Plain', 'Foothill' and 'Drainage' types lie in settings where water accumulates in sediments of the wadis or the gravel plains east and west of the mountains (see above) and is made available by branching off aflaj from wadis or by digging wells and pumping the water to the surface. In some cases, such as Rustaq and Nakhl, this water also surfaces naturally. Finally, oases of the 'Mountain' and 'Kawr' types are fed from natural springs emerging from limestone storage formations that are accessed using falaj technology, and directing the water to the fields through irrigation channels, which are sometimes several kilometres in length.

Example of an oasis that relies on water accumulation in sediments: the 'Foothill Oasis' of Birkat Al Mawz (Google Earth®).

The proposed classification of oases in northern Oman might help to better understand their origin and to select those for further study and preservation that are the most representative of a specific class (Luedeling and Buerkert 2008).

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