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The Flora of Wadi Wurayah National Park
Fujairah, United Arab Emirates

An annotated checklist and selected observations on the flora of an extensive ultrabasic bedrock environment in the northern Hajar Mountains

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Report of a baseline survey conducted for EWS−WWF and sponsored by HSBC

(December 2012 – November 2014)

by Gary R. Feulner

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Executive Summary

Wadi Wurayah National Park is situated within the mountains of the UAE's East Coast, also known as the Shimayliyah range. WNPP encompasses 221 square kilometers, including the entire watershed of Wadi Wurayah and much of Wadi Zikt, two of the largest and most remote wadi systems in the Shimayliyah range, as well as the upper reaches of several neighboring watersheds (Wadi Siji, Wadi Abadilah and Wadi Ghulayyil Khun).

The protected area, and Wadi Wurayah in particular, has more permanent surface water than any other part of the Hajar Mountains of the UAE. For that reason it is home to a high proportion of the plant and animal species that can be found in the UAE mountain environment.

More generally, the northern Hajar Mountains is an important area from the perspective of regional plant biogeography because it is situated at the boundary of three major biogeographical zones — the Afrotropical, the Palaearctic and the Oriental — and three major phytogeographical regions — the Saharo-Arabian (Saharo-Sindian), the Sudanian (Nubo-Sindian), and the Irano-Turanian.

Within WWNP, the bedrock consists almost exclusively of igneous rock called harzburgite, originally formed exceptionally deep within the earth. The harzburgite bedrock has an unusual geochemistry, described as "ultrabasic", that can present special challenges to plant physiology. Ultrabasic environments elsewhere are associated with reduced plant diversity and high levels of endemism.

The present survey recorded more than 200 species of plants from within the area of WWNP, including one species new to the UAE. This total exceeds earlier informed estimates by one-third or more, moderating although not negating the prevailing view that the flora of the ultrabasic rocks of the Hajar Mountains is limited in diversity relative to more geologically conventional environments.

Comparison of the baseline survey results with published studies of nearby mountain areas indicates that WWNP has more than 70% of the number of plant species found at comparable elevations in the carbonate environment of the Ru'us al-Jibal range (the mountains of the Musandam peninsula), and may have *ca*. 8-12% more plant species than Wadi Hiluw, which drains a watershed composed almost wholly of basic rock (gabbro). The latter finding casts doubt on the conventional wisdom that the ultrabasic environment alone is responsible for reduced floral diversity.

All eight Hajar Mountain endemic plant species found in the UAE were recorded within WWNP. WWNP is also an important site, and in some cases the only UAE site, for more than a dozen other rare or noteworthy plant species.

At the same time, a number of plant species common in other areas of the Hajar Mountains of the UAE and northernmost Oman appear to be absent within WWNP, indicating that more focused study of WWNP in comparison to neighboring mountain areas has the potential to reveal previously unrecognized biogeographical patterns and/or ecological relationships.

Introduction

Wadi Wurayah National Park

Wadi Wurayah National Park (WWNP) was created by Decree No. 2 of 2009 of the Ruler of Fujairah, H.H. Hamad bin Mohammad Al Sharqi, on 15 March 2009. It is located in the mountains of the Shimayliyah range along the East Coast of the United Arab Emirates (UAE) and constitutes the UAE's first mountain protected area.

The boundaries of WWNP are shown in Map 1. It encompasses almost the entire watershed of Wadi Wurayah (Arabic: وريعة *wu-ray-ع ah*) as well as a large portion of neighboring Wadi Zikt, to the north. These are two of the largest catchment areas in the Shimayliyah region. The National Park comprises a core protected area (the "core zone", shown in orange in Fig. 1) and a surrounding buffer zone (shown in yellow) which includes the adjacent mountain areas of upper Wadi Siji and upper Wadi Abadilah to the west, lower Wadi Zikt to the north, and Wadi Ghulayyil Khun to the east. The total area of WWNP is 221 square kilometers (equivalent to 12,700 hectares or 31,000 acres), including 129 square kilometers within the core area and 92 square kilometers in the buffer zone.

Wadi Wurayah was already well known by the early 1980s as the site of the UAE's only year-round waterfall, although it was then a full hour's drive from the coast by 4WD. It re-captured public attention again in the mid-1990s when it was proposed for protection by the Arabian Leopard Trust ("ALT") and Arabian tahr were discovered living there. More recently the protection initiative was taken up by EWS–WWF, culminating in the historic declcaration of WWNP. WWNP is currently managed by EWS-WWF.

Wadi Wurayah is justifiably acclaimed for its scenic beauty and its exceptional biodiversity. By virtue of its large size and its relative abundance of permanent water, it is home to a high proportion of the plant and animal species that can be found in the Hajar Mountains of the UAE.

More generally, the northern Hajar Mountains is an especially significant area from the perspective of regional biogeography because it is situated at the boundary of three major biogeographical zones — the Afrotropical, the Palaearctic and the Oriental — and three major phytogeographical regions — the Saharo-Arabian (Saharo-Sindian), the Sudanian (Nubo-Sindian), and the Irano-Turanian.

WWNP is also largely free of the influence of human exploitation found in other UAE mountain areas. There are no current plantations within WWNP, little evidence of abandoned cultivation, and only obscure evidence of ancient, very small scale hydro-engineering at a few locations on gravel terraces, so almost the whole of WWNP can be considered natural habitat. The silt accumulations behind the Wadi Wurayah dam are arguably an exception, but similar habitats can be created naturally, e.g., by landslides (Feulner 2004). A single farmstead used for goat husbandry, with minor associated agriculture, is located a short distance from the paved road in Wadi Wurayah, north of the dam. A few discrete sites (the Wadi Wurayah roadhead, trackhead and gorge, and waterfall picnic area) receive regular short-term human visitation.

Geography, geology and botanical implications

The Shimayliyah range, a sub-unit of the Hajar Mountains, lies between the cities of Fujairah in the south and Dibba in the north. It is bordered on the east by the Gulf of Oman coast, and on the west by the arc of wadis and roadways that connects (from south to north) the villages of Bithnah, Deftah, Masafi, Tayyibah, Uyaynah and Dibba.

The mountains of the Shimayliyah range are not especially high but they are extremely rugged. Three summits on the edge of WWNP (Jebel Masafi and its neighbor, Four Peaks, in the southwest, and Jebel Dad (a/k/a Jebel Adhn) in the northwest) exceed 1100 meters, but these are exceptional. Few other summits and ridges within the area exceed 800-900 meters. However, the slopes are steep, the ridgetops are narrow, the bedrock is heavily fractured and the surface is often friable, making ascents extremely difficult in most places.

For comparison, the Hajar Mountains to the south of WWNP, from Wadi Ham (the Masafi-Fujairah road) southwards to Wadi Hatta (the Hatta road), include a number of ridgetop plateaux at 900-1050 meters (Feulner 2014). South of Wadi Hatta the central peaks are higher still, reaching 1400 meters or more almost all the way south to the Jebel Akhdar.

Geologically, the Shimayliyah area (and most of the Hajar Mountains southwards to the Jebel Akhdar) represents a thick slice of the earth's mantle that has been detached and thrust to the surface by tectonic forces. The predominant rock type is an igneous rock called harzburgite, a chemically altered form of normal mantle rock, depleted by partial melting and fractionation at depth. Mantle rock is very low in silica (SiO_2) relative to most igneous rocks. Geologists refer to the various low-silica mantle rock types, including harzburgite, as "ultrabasic" rocks or "ultrabasics".

The term "ophiolite" has been used historically to refer to the suite of ultrabasic mantle rocks and associated rock types from the overlying oceanic crust (gabbro and pillow lavas) that is found as a minor element of many mountain belts worldwide, but a significant one, because it represents the remnants of a former ocean basin closed by subduction. The Hajar Mountains comprise the world's largest surface exposure, by far, of an association of such rocks. These have been called by various names including the Hajar Mountain ophiolite, the Semail ophiolite and the Semail nappe.

Within WWNP, the bedrock is almost exclusively harzburgite (Boeuf et al. 1974; Ball et al. 1988; British Geological Survey 2006; Goodenough et al. 2006), with the exception of a few small localities of dunite (another ultrabasic rock) and rare dikes (intrusive veins or sheets) of granite (a high-silica or "acidic" igneous rock) (British Geological Survey 2006; Goodenough et al. 2006). A number of larger granite dikes are found in the area of the divide between Wadi Zikt and the Wadi Ghayl branch of Wadi Wurayah. The granite dikes are conspicuously grey, in contrast to the reddish brown weathering harzburgite.

To the south of the Shimayliyah range, occupying roughly the southeast quadrant of the Hajar Mountains within the UAE, is an area that consists mostly of gabbro, an igneous rock with intermediate silica content (called "basic" by geologists), representing former oceanic crust. To the north of the Shimayliyah range lie the

mountains of the Musandam peninsula, the Ru'us al-Jibal range, which consists of a 2,000 metre thick sequence of mostly shallow water carbonate sediments (limestone and dolomite).

These geological and geochemical distinctions are not merely of academic interest. Ultrabasic bedrock is associated with distinctive soil chemistry (e.g., low calcium, nitrogen and phosphorus, high magnesium and heavy metals, and hyperalkaline groundwater) which is often reflected in distinctive flora, including the evolution of races or species that are confined to ultrabasic substrates (Harrison & Kruckeberg 2008). These include species that selectively accumulate heavy metals, perhaps as a deterrent to predators, as well as others that have evolved mechanisms to restrict excessive metal uptake (Ghaderian & Baker 2007; Harrison & Kruckeberg 2008). (See also the discussion in Feulner (2011), at Section 6.2, pp. 75-76.)

Within the Hajar Mountains, ultrabasic bedrock is associated with distinctive physical and physiographic properties as well as geochemical ones. Harzburgite tends to fracture readily, weathering into shards, and to form steep or vertical faces above slopes littered with talus or scree. Gabbro bedrock, by contrast, is more coherent and weathers in a blocky fashion. Among the practical differences from the point of view of field studies is that gabbro slopes are generally somewhat less steep and easier to ascend.

It has been asserted or implied that botanical diversity is lower within the ophiolite rocks of the Hajar Mountains than in the areas of carbonate bedrock, especially the Jebel Akhdar and the Jebel Bani Jabr (Munton 1985, Insall 1999). That has not been controverted, as far as the author is aware, although the difference may not be due to geochemistry alone. But no study has yet specifically examined either the influence of the ophiolite substrate on the distribution of plant species within the Hajar Mountains or the influence of the ultrabasic substrate on their distribution within the Hajar Mountain ophiolite. However, the major gabbro areas in the UAE are now recognized to host an association of plant species that differs in a number of respects from that of ultrabasic areas (Feulner 2014; see Observation 9.5 below).

The Shimayliyah region represents the northernmost extent of the Hajar Mountain ophiolite. To the north, across the Dibba plain (the alluvial fan of Wadi Basairah), lies the carbonate sedimentary massif of the Ru'us al-Jibal. To the west and southwest the ultrabasics of Shimayliyah are bordered, respectively, by the distinctive fringing metamorphic rocks of the Masafi-Tayyibah and Wadi Limarit areas. To the south, as noted above, they are bordered by extensive areas of gabbro within the ophiolite. By virtue of its location, therefore, WWNP presents botanists with an excellent opportunity to study the possible influence of geology, and in particular the influence of ultrabasic geochemistry, on plant diversity and distribution within Eastern Arabia.

Climate and rainfall

The climate and rainfall of the Shimayliyah area are briefly described in EWS–WWF (2006, at Section 3.2 at pp. 20-21) and Tourenq et al. (2009), based on data from four meteorological stations flanking the area, at Masafi, 'Asimah, Khor Fakkan and Ghayl. Temperatures are relatively high. For Masafi, a long-term mean of 26.8°C is given, with a low monthly mean of 11.4°C in January and a high monthly mean of 43.0°C in June. Winter temperatures on the East Coast (including the coastal

mountains) average about 2°C higher than in most of the rest of the UAE (UAE University 1993).

Relative humidity varies widely but the mean for the mountain regions of the UAE's East Coast is 50-60% (UAE University 1993). That figure is somewhat higher, perhaps as much as 10% higher, than for the mountain regions farther inland, to the west and to the south (UAE University 1993, EWS–WWF 2006, Tourenq et al. 2009). Relative humidity is generally greatest in autumn and wnter, and lowest in spring and summer (UAE University 1993, EWS–WWF 2006, Tourenq et al. 2009).

Rainfall is extremely variable but low overall, although the mountains of the Masafi area have long been recognized as the wettest area of the UAE. The composite 30-year (1975-2004) average for the four meteorological stations listed above is approximately 160 millimeters/year (Feulner 2011), corresponding to a "semi-arid" regime. The long-term records for Masafi show a mean of 179 millimeters annually, with a minimum of 27.6 millimeters in 1985 and a maximum of 443.8 millimeters in 1976 (UAE University 1993).

Rainfall is correlated at the above four stations and is also correlated with rainfall throughout the UAE generally (Feulner 2006b). Rainfall records appear to show a cyclical pattern (EWS–WWF 2006, Feulner 2006b, Tourenq et al. 2009) that is correlated with the El Niño phenomenon, UAE rainfall being highest in El Niño years (EWS–WWF 2006, Tourenq et al. 2009).

Rainfall is generally greatest in winter (December through March). Summer rain is normally associated with thunderstorm activity. The winters of 2012-13 and 2013-14 were both wetter than average. Prior to commencement of the baseline survey, rain had fallen in mountain areas in each month from September to December 2012. Heavy rain fell in mid-December 2012 and again at the end of April 2013. The latter was reportedly associated with cloud-seeding efforts. Autumn rain was limited in 2013 but rain fell on several occasions in January 2014**.** Exceptionally heavy rain fell again in mid-March 2014, filling the basin and wadi behind the Wadi Wurayah dam to within ca. 250 meters of the lower road crossing. Rain fell again in late October 2014 and a major flash flood occurred in Wadi Wurayah on 1 November, a few days before the last field visits undertaken for the baseline survey.

The baseline survey and annotated checklist of the flora of WWNP

History of botanical investigation in and around WWNP

The mountains of the Shimayliyah area were described in the first published flora of the UAE (Western 1989) as "wild and almost inaccessible . . ." and were identified as "an under-explored area as far as botany is concerned". Access has since improved but the area has remained under-explored botanically until the baseline survey reported here.

The author first visited Wadi Wurayah in the mid-1980s. Since early 1992, he has returned intermittently to explore areas now within WWNP for the express purpose of botanical and other natural history investigation. The dates and locations of those historical visits, totaling 20 field days, are shown in Table 1A.

During the winters of 1994-95 and 1995-96, naturalist consultants Chris and Tilde Stuart of South Africa conducted wildlife surveys in Wadi Wurayah on behalf of the Arabian Leopard Trust ("ALT"). Their efforts produced important zoological data (including the discovery of Blanford's Fox and Arabian tahr) but they paid only limited attention to the Hajar Mountain flora.

Based in part on the Stuarts' results, the creation of a national park in the Shimayliyah range, centered on Wadi Wurayah, was proposed by the ALT (Jongbloed 1996). A provisional management plan for the proposed park was also prepared (Hornby 1996), including checklists of fauna then known or expected to occur within the Shimayliyah range.

The provisional management plan also includes a brief discussion of the flora within the area of the proposed national park (Hornby 1996, at 7-8) [updated botanical nomenclature is shown in brackets]:

> The high temperatures, the extreme aridity for most of the year and the violence of the infrequent rain events make the mountains a difficult place for plant growth. There is therefore a great deal of bare ground. The dominant species tend to be low-growing woody perennials, obviously well adapted to surviving high temperatures and periods of drought. In shady situations or in wadis where the water table is high for most of the year, a wider range of plant species is able to grow. Many annual species appear after rain, and the mountains can be relatively green and flowery at such times.
>
> . . . . The total number of plant species growing in the proposed national park is likely to be of the order of 120 to 150.
>
> The most characteristic perennial species include:
>
> *Tephrosia apollinea*
> *Taverniera glabra* [=*T. cuneifolia*]
> *Crotalaria aegyptiaca*
> *Astragalus fasciculifolius*
> *Ochradenus aucheri*
> *Euphorbia larica*
> *Nerium mascatense* [= *N. oleander*]
> *Forsskaolea tenacissima*
> *Indigofera oblongifolia* [*sic*]
> *Fagonia indica*
> *Cassia italica* [= *Senna italica*]
> *Aerva javanica*
> *Asphodelus tenuifolius*
> *Heliotropium calrareum* [= *H. brevilimbe*]
> *Pulicaria nobilis* [= *P. edmondsonii*]
>
> and the trees:
>
> *Ziziphus spina-christi*
> *Acacia tortilis*
> *Prosopis cineraria*
> *Ficus salicifolia* [= *F. cordata salicifolia*]
> *Moringa peregrina*
>
> Two species regarded as of particular interest are the orchid *Epipactis veratrifolia* and the fern *Onychium divaricatum*. These are two of the species likely to be an attraction to future 'ecotourists'.
>
> There are probably several species of plant which are endemic to the mountains of the UAE and Oman and these would represent an important element of the biodiversity of the region. There is a great need for work to document the distribution of mountain plants, both in the UAE and Arabia as a whole. Co-

operation with the newly formed Plant Group of Arabia, convened under the auspices of IUCN, is strongly recommended.

Much of the information accumulated through the foregoing efforts was incorporated in Jongbloed et al. (2000) and Jongbloed (2003). The author was actively involved in providing information and photographs for use in for Jongbloed (2003) and reviewing and commenting on the accounts of species found in mountain areas.

In 2006, at the request of EWS–WWF, the author prepared and contributed a compilation of his records of flora and selected fauna from historical visits to Wadi Wurayah and its tributaries (Feulner 2006a), for use in connection with a study sponsored by HSBC to evaluate the prospective creation of a protected area. The list of flora was acknowledged to exclude many annuals and most grasses (Poaceae) that might potentially occur (the author was at that time still inexperienced in the identification of grasses), but it nevertheless included *ca*. 87 species.

The final study report relied more heavily on a January-March 2006 field survey of plants by EWS–WWF volunteers. It lists, in Appendix 3, 27 species said to have been "the major plants found in the area", but a number of the species listed are problematic in light of both prior and subsequent information. In particular, the records and/or accounts of *Cyperus conglomeratus*, *Cymbopogon commutatus*, *Lycium shawii* and *Fagonia indica* must be regarded skeptically, and the record of *Tamarix aphylla* is known to be erroneous – and was in any case from another wadi to the south, not Wadi Wurayah (C. Tourenq, *pers. comm.*).

Notwithstanding the foregoing criticism of botanical identifications, the HSBC-sponsored report is in many other respects one of the best sources of general information currently available about UAE mountain wadis, especially for hydrology. The results of that study were subsequently published for a broader audience, with selected additional information and commentary (Tourenq et al. 2009).

The "Flora" section of the original report (Emirates Wildlife Society–WWF 2006) was republished intact in Tourenq et al. (2009), except that it was unwisely introduced in the latter by the additional statement that "Wadi Wurayah hosts about 300 plant species." That statement was attributed only to an unpublished report and is clearly erroneous, but it has nevertheless been repeated and continues to appear in print and internet sources, including Wikipedia (Wikipedia – "Wadi Wurayah").

The author's own study of the flora of the Ru'us al-Jibal range (the mountains of the Musandam peninsula) (Feulner 2011) expanded the number of species known from the UAE and Northern Oman, facilitated the resolution of several instances of synonymy, and established a basis for comparison with the flora of other mountain areas.

The baseline survey

The current survey consisted of botanical excursions on foot within WWNP, comprising a total of 33 field days between 15 December 2012 and 4 November 2014, as detailed in Table 1B. Field work included visits during eleven different months of the year but was concentrated in December 2012, January, March and August 2013, and March 2014.

In addition to the current survey data, this report and the accompanying Checklist incorporate the botanical results of historical natural history investigations by the author, shown in Table 1A, amounting to 22 field days between March 1992 and January 2012, including several remote areas not reached by the current survey.

The geographical coverage of the current survey and those historical visits is shown in Map 2. The overall coverage is extensive but investigation of summit ridges, passes and uppermost slopes and wadis was more limited. At least eighteen excursions explored terrain lying at *ca.* 400 meters or more, but only ten excursions reached elevations exceeding *ca.* 550 meters and only five of those reached or exceeded *ca.* 700 meters (the summit of Jebel Masafi, two traverses of the pass from Wadi Siji to Wadi Murtaqam, the traverse from Wadi Abadilah to Wadi Yushemah, and the pass at the head of the SW branch of Wadi Zikt). This reflects the difficulty of the summit terrain within the ultrabasic environment of WWNP.

The Checklist also relies on information contained in selected literature sources as well as unpublished documents available to the author. Those are indicated by citations.

Almost all taxonomic determinations were made by the author, based on field experience in the UAE and Oman (see, e.g., Jongbloed (2003) and Feulner (2011)) and reference to Boulos' *Flora of Egypt* (Boulos 1999, 2000, 2002 and 2005), Ghazanfar (2003, 2007, *in press*), Cope (2007) and Karim & Fawzi (2007). Most determinations could be made with confidence. Selected details are discussed in individual Checklist entries. Marijcke Jongbloed identified *Zaleya pentandra* and Norbert Kilian identified *Launaea omanensis*, in each case from the author's photographs.

The nomenclature used in the Checklist follows Jongbloed (2003), as amended pursuant to Ghazanfar (2003, 2007, *in press, in prep.*) and Feulner (2011).

The Checklist

On the basis of survey data and historical records, an annotated checklist ("the Checklist") has been prepared in digital format using Microsoft Office Excel 2003. All species of vascular plants recorded within the area of WWNP are included. The default organization of the Checklist is by Order and Class in taxonomic order, then by family, genus and species alphabetically.

For each species, the following information is entered:

- Family
- Genus
- Species
- Authority for nomenclature
- Growth form
- Abundance
- Habitat (primary = 1, secondary = 2)
  - Wadi pools
  - Wadi bed and bank
  - Wadi slope

Gravel terrace
Gravel terrace (silt accumulations)
Gulleys
Stony slopes
Rocky slopes
Remarks

An abridged version of the Checklist is appended to the printed version off this report as Appendix 1, showing all of the above categories except the authority for nomenclature. A key to the abbreviations used is given at the end of the Checklist.

For convenience, an alphabetical list of species has also been prepared from the Checklist and is included in this report as Table 2A, showing genus, species, family and remarks.

The Checklist can be readily expanded to add, at a later stage, additional categories of data, including, e.g., global range, regional range, UAE Red Data List status, geographic coordinates of important sites, and traditional uses.

Selected Observations on the Flora of the Wadi Wurayah Protected Area

The principal purpose of the baseline survey was to produce the Checklist. Nevertheless, it is appropriate and valuable also to provide an indication of the nature and significance of the results and to highlight a number of specific facts and generalizations relevant to a better appreciation of the flora of WWNP.

To that end, a number of selected observations are set out below in summary fashion. Many of these are worthy of further investigation and/or elaboration.

1. Abundance and diversity.

Table 2A lists alphabetically, with selected annotations, 206 plant species that have been recorded within the boundaries of WWNP, including both the core zone and the surrounding buffer zone. The list includes:

- 178 species (86%) recorded from within the core zone, either by the current survey or historically.
- 28 species (14%) recorded only from within the buffer zone, either by the current survey or historically. For convenience, those records are also listed separately in Table 2B.
- 19 species (9%) represented by historical records only, i.e., species previously recorded from within the area of WWNP (core zone or buffer zone) but not recorded during the current survey. For convenience, the historical records are also listed separately in Table 2C.
- 17 species (8%) represented by records of single plants only, whether current or historical. This is indicated by annotations in Table 2A. An additional 8 species are represented by historical records from which it cannot be determined whether more than a single plant was observed.

Appendix 1, the Checklist, presents a more fully annotated tabulation of all of the above-mentioned species, by family, including an indication of growth form, a qualitative assessment of abundance and preferred habitat(s), and selected remarks.

1.1. Some quantitative data and comparisons.

1.1.1. Exclusion of four introduced exotic species. The statistics presented below are based on the list of species in Table 2A, but *excluding* the records of four introduced exotics: *Citrullus lanatus* (Cucurbitaceae, the cultivated watermelon), *Ficus religiosa* (Moraceae, the peepul tree), *Solanum lycopersicum* (Solanaceae, the cultivated tomato) and *Mangifera indica* (Anacardiaceae, the cultivated mango). None of those species have become or are likely to become established in WWNP.

1.1.2. Gross totals. So tabulated, WWNP, including its buffer zone, is home to at least 53 families, 163 genera and 202 species of native higher terrestrial plants, as detailed in the accompanying Checklist. This amounts to more than one-quarter of the ca. 720+ species of higher terrestrial plants recorded to date for the UAE and adjacent areas of Northern Oman. (For a discussion of some of the difficulties of calculating the exact number of plant species recorded in the UAE, see Feulner (2011) at Section 1.1., pp. 32-34.)

These totals exceed previous informed estimates by one-third or more, moderating although not negating the prevailing view that the flora of the ultrabasic rocks of the Hajar Mountains exhibits limited diversity relative to more geologically conventional environments. Moreover, it is inevitable that additional species, both anticipated and unanticipated, will be added to the list over the course of time.

1.1.3. Family level diversity and regional comparisons. The families best represented in WWNP, in terms of numbers of species, are Poaceae (30 spp.), Asteraceae (20 spp.) and Fabaceae (13 spp.). A small majority of the families present are represented by more than one species (29 of 53 families, or 55%); 24 of the 53 known families (45%) are represented by only a single species.

The top three families (Poaceae, Asteraceae, and Fabaceae) also hold the top three positions within the flora of the neighbouring Ru'us al-Jibal range (Feulner 2011) and the nearby Wadi Helo Protected Area (El-Keblawy 2011), as well as the florae of the UAE (Jongbloed et al. 2000) and Oman (Ghazanfar 1992b) as a whole (Table 3). Six additional families (Boraginaceae, Brassicaceae, Caryophyllaceae, Euphorbiaceae, Lamiaceae and Scrophulariaceae) appear in the top dozen in each list.

1.1.4. Genus level diversity. Only 28 of the 163 genera present in WWNP, or about 17%, are represented by multiple species; 135 genera (83%) are represented by just a single species. The best represented genera are: *Launaea* (5 spp., but none is common, one is rare, and one is a sole record); *Plantago* (4 spp., all common or occasional annuals); *Cleome* (4 spp., but none is common and one is at the limit of its range and very rare); and *Eragrostis*, *Euphorbia* and *Salvia* (each with 3 spp.). 22 genera (14%) are represented by 2 species each. At the genus level, therefore, taxonomic diversity is high and taxonomic concentration is low.

1.1.5. Qualitative assessment of species abundance. The Checklist includes a qualitative assessment of the abundance of each species, on a scale of Hyperabundant

(H), Common (C), Locally Common (L), Occasional (O), Rare (R) and Exceptional (E). Only four species have been designated as Hyperabundant: the tall perennial reed *Arundo donax* and three annuals – the lily *Aphodelus tenuifolius*, the blue pimpernel *Anagallis arvensis*, and the dock *Rumex vesicarius*. Otherwise, the numerical results are distributed over a rough bell curve from Common (27 species) through Locally Common and Occasional (combined 87 species) to Rare (65 species) and Exceptional (23 species).

As used here the foregoing terms have not been assigned specific operational definitions. Rather, they are used in a common sense way to convey a reasonable expectation of the likelihood that an observer looking in a suitable habitat at a suitable time will find the species in question.

Common species can often be seen simply by glancing at a suitable habitat, or for smaller species, by a short walk across it. Examples include trees such as *Acacia tortilis*, the wadi fig *Ficus cordata salicifolia* and the *sidr* tree *Ziziphus spina-christi*, small to medium shrubs such as *Convolvulus virgatus*, *Euphorbia larica*, *Lavandula subnuda* and *Leucas inflata*, prostrate perennials such as *Fagonia brugueri*, grasses such as *Cenchrus ciliaris* and the wadi bed tussocks of *Saccharum griffithii*, and annuals such as the prostrate *Aizoon canariense* and *Argyrolobeum roseum* and the erect *Diplotaxis harra* and *Silene austroiranica*.

Locally Common species can sometimes be abundant over modest areas but are otherwise normally Occasional or Rare. Examples include the prostrate annuals *Plantago ciliaris*, *Plantago ovata* and *Tribulus terrestris*, which can proliferate on gravel terraces, the erect annuals *Cleome noeana*, *Euphorbia arabica* and *Reseda muricata*, which may multiply in gravel wadis, the small shrubs *Gymnocarpos decandrum* and *Ochradenus aucheri*, which sometimes cluster at the base of rolling slopes, and the larger, gulley-loving shrub *Dodonaea viscosa*.

Occasional species would normally be seen during the course of a day's outing, but typically only as scattered individual specimens. Examples include perennial shrubs such as the delicate but spiny *Blepharis ciliaris*, the cactus-like milkweed *Desmidorchis arabicus*, the slope shrubs *Iphiona scabra* and *Vernonia arabica*, and annuals like the erect but wispy *Gypsophila bellidifolia* and *Misopates orontium*, the diminutive, sheltering *Andrachne aspera* and *Nanorrhinum hastatum*, the sometimes gangling *Erodium neuradifolium* and *Geranium* species, and the dodder *Cuscuta planifora*.

Rare species require greater patience and effort. Most of them were not unexpected in WWNP, but they have been recorded only in very small numbers, many in remote locations. Some examples are the climbers *Ephedra foliata* and *Pentatropis nivalis*, the newly recognized *Launaea omanensis*, the spiny shrub *Astragalus fasciculifolius*, and the small grasses *Enneapogon desvauxii* and *Eragrostis ciliaris*.

Exceptional species may require luck as well as persistence, although several were recorded in an area frequented by the general public. Most were unexpected in WWNP and have been recorded only once or twice. They include the four introduced exotic species mentioned in Observation 1.1.1, none of which are likely to survive to maturity in WWNP. Other examples are the rare UAE-Oman endemic *Scrophularia*

imbricata, *Tephrosia* cf. *uniflora*, the tiny, herbaceous *Asterolinon linum-stellatum*, otherwise known only from the high Musandam, and "indigenous exotics" such as the large, errant desert shrub *Leptadenia pyrotechnica*.

1.2. Comparison with the Ru'us al-Jibal range.
In order to provide context for the WWNP survey results, they can be compared with similar data for the adjacent Ru'us al-Jibal range, which has been the subject of relatively comprehensive floristic investigation (Feulner 2011). In terms of gross figures:

- 53 families are represented in WWNP versus 68 in the Ru'us al-Jibal (78%).
- 163 genera are represented in WWNP versus 239 genera in the Ru'us al-Jibal (68%).
- 202 native species are recorded from WWNP versus 338 from the Ru'us a-Jibal (60%).

1.2.1. Adjustment for the greater elevation of the Ru'us al-Jibal. The foregoing comparisons of aggregate numbers are not entirely fair, because the Ru'us al-Jibal is considerably higher than the mountains of WWNP and Shimayliyah generally, it features relatively extensive plateau areas at elevations from 500 to 1500 meters, and it is characterized by a distinctive higher elevation vegetation zone. More specifically, the Ru'us al-Jibal is home to 75 species that, within the UAE and Oman, are found only there. Of those 75 species, 56 are found only above *ca.* 700 meters (Feulner 2011 at Section 2, pp. 49-50 and Table 3).

A further adjustment should perhaps be made in the interest of a "fair" comparison, since the WWNP figures include records from the silted basin behind Wadi Wurayah dam, whereas the Ru'us al-Jibal figures exclude records from an extensive, low elevation, silty parkland called Sal al-'Ala, where a large number of widely distributed annuals (including several grasses) were collected, many of which are neither common in nor characteristic of mountain areas (Feulner 2011, Appendix at p. 98). That adjustment is not significant, however, since only one species was found in the Wadi Wurayah dam basin that was not found at other sites within WWNP (the wild mustard *Sinapis arvensis*).

If the Ru'us al-Jibal figures are adjusted by subtracting the 56 higher elevation species, and if the WWNP figures are reduced by the one species found only in the dam basin, the species totals remain disparate but the comparison is much closer: 201 for WWNP versus 282 for the Ru'us al-Jibal (71%). By this measure, the floristic diversity of WNPP is (in round numbers) at least 70% of that of the Ru'us al-Jibal at comparable elevations.

1.2.2. The distinctive geochemistry of the ultrabasic environment. That is not an unexpected result, for reasons briefly introduced earlier. Although the ophiolite mountains are relatively rich in surface water compared to the carbonate massifs of the Jebel Akhdar and the Ru'us al-Jibal, the distinctive geochemistry of the ophiolite environment poses special difficulties for plant life:

> "The weathering of ultrabasic rocks such as the ophiolite of the Hajar Mountains creates soils that generally have distinctive chemical characteristics. They are

> deficient in calcium and other essential nutrients, such as nitrogen and phosphorus; they are rich in magnesium, which interferes with the uptake of calcium; and they usually have high levels of heavy metals such as chromium, nickel and cobalt. The slow percolation of groundwater through ultrabasic rock in an arid climate also produces exceptionally alkaline groundwater, with pH as high as 11.9." [Feulner (2011) at Section 6.2, citations omitted.]

The ophiolite of the Hajar Mountains has generally been considered to exhibit low botanical diversity (e.g., Insall 1999), although Munton (1985) was judicious in accounting for his early observations (in the area northwest of the Jebel Akhdar), allowing that they might reflect in part the combination of drought (at the time of his observations) and relatively extensive human inhabitation of the area, with concomitant exploitation by agriculturalists and pastoralists.

When examined in detail, however, there exist certain floral differences between WWNP and the Ru'us al-Jibal which are not necessarily explained by ultrabasic geochemistry. In some cases alternative explanations suggest themselves; in other cases the reasons remain speculative. These are discussed briefly in Observation 1.2.4 below, and in more detail in Observation 9.

1.2.3. Family level comparisons.

- As noted above, the same three families (Poaceae, Asteraceae, and Fabaceae) hold the top three positions in the lists for both WWNP and the Ru'us al-Jibal, and six additional families (Boraginaceae, Brassicaceae, Caryophyllaceae, Euphorbiaceae, Lamiaceae and Scrophulariaceae) appear in the top dozen positions in both lists (Table 3).
- Grass species (Poaceae) are slightly over-represented in WWNP (as a proportion of total species) relative to the Ru'us al-Jibal. The number of grass species in WWNP is 67% of the number of grasses in the Ru'us al-Jibal, whereas the total number of WWNP species is only 59% of the Ru'us al-Jibal total (Table 3). Grass species represent 15% of the recorded flora of WWNP versus only 13% of the Ru'us al-Jibal flora. That comparison is unchanged if the Ru'us al-Jibal data is adjusted by subtracting the exclusively higher elevation species, as described above. The percentage of grass species in the flora as a whole is 17% for both the UAE and Oman, so from that perspective, grasses are slightly under-represented in both mountain areas.
- Most plant families other than grasses (Poaceae) are under-represented in WWNP, relative to the Ru'us al-Jibal, having only half or less the number of species. Some exceptions are noted in the following paragraphs.
- Asclepiadaceae is considerably over-represented in WWNP, having 7 species present, versus only 5 in the Ru'us al-Jibal. However, 2 Asclepiadaceae species are so far known in WWNP only from only one or two specimens, and one of those species is considered exceptional.
- Scrophulariaceae is also over-represented in WNNP, having an equal number of species (10) in both WWNP and the Ru'us al-Jibal. However, three Scrophulariaceae species from WWNP have so far been found only in the buffer zone and another is known from only two specimens.
- Cyperaceae is greatly over-represented in WWNP, being only a minor family in the Ru'us al-Jibal and in the UAE and Oman lists. The relatively high count for Cyperaceae reflects the concentration of hygrophilous species at the Wadi Wurayah waterfall area.

- 3 species of Solanaceae were recorded in WWNP, but two are single historical records and the third is found only in the waterfall picnic area where introduction by human activity is possible. This contrasts with 3 species of Solanaceae that are occasional in the Ru'us al-Jibal.
- No Apiaceae spp. were recorded from WWNP, whereas at least 6 species are found in the Ru'us al-Jibal. At least three of the UAE representatives of this family, most of which are annuals, are restricted to the carbonate rocks of the Ru'us al-Jibal; the distribution of two other species, the perennials *Ducrosia anethifolia* and *Pycnocycla caespitosa*, suggests that they may preferentially colonize carbonate rocks and avoid ophiolite. Jongbloed (2003) says that the annual *Ammi majus* is "locally common and widespread in the Hajar Mountains" and maps it accordingly, but Karim & Fawzi (2007) give its habitat as "[c]ultivated places or roadsides" and El-Keblawy (2011) did not record it from Wadi Hiluw.
- Several families comprising primarily annual species (e.g., Geraniaceae, Plantaginaceae and Primulaceae) show little difference in species numbers between WWNP and the Ru'us al-Jibal.

1.2.4. Species level comparisons.

- Ru'us al-Jibal species not found in the Hajar Mountains. Of the 75 Ru'us al-Jibal species previously considered to be absent or nearly so in the Hajar Mountains (Feulner 2011, Table 3), five have in fact been found within WWNP. *Asterolinon linum-stellatum* and *Astragalus fasciculifolius* appear to be genuinely rare. *Bromus danthoniae* and *Gastridium phleoides* are grasses of higher elevations and could possibly be under-recorded in WWNP, where higher elevations are very rugged and access is difficult; *B. danthoniae* is distinctive, but *G. phleoides* is not. In contrast to prior understanding, however, *Geranium biuncinatum* appears to be the most common *Geranium* species in WWNP, although the several *Geranium* species can only be distinguished confidently when they are in seed.

- Hajar Mountain species not found in the Ru'us al-Jibal. Looked at from the opposite perspective, three dozen (36) species have been described as "[c]ommon Hajar Mountain species that are absent or very rare in the Ru'us al-Jibal" (Feulner 2011, Table 5). Possible explanations for those discrepancies include not only (i) ultrabasic geochemistry, but also (ii) differential hydrology between the karst environment of the Ru'us al-Jibal carbonates and the ophiolite of the Hajar Mountains (specifically, the absence of significant surface or near-surface water in the Ru'us al-Jibal to support hygrophilic species); (iii) edaphic differences, i.e., differences in the development and character of the soil and substrate; and (iv) regional biogeographical gradients.

  Of that subset of three dozen "common Hajar Mountain species that are absent or very rare in the Ru'us al-Jibal", 21 species are in fact common, locally common or at least occasional within WWNP. Most of those species can rightly be called characteristic of the Hajar Mountains:

  Aizoon canariense
  Arundo donax
  Boerhavia elegans
  Chrozophora oblongifolia
  Cleome noeana
  Cleome rupicola

Cometes surattensis
Convolvulus virgatus
Crotalaria aegyptiaca
Haplophyllum tuberculatum
Hibiscus micranthus
Iphiona scabra
Morettia parviflora
Nerium oleander
Physorrhynchus chamaerapistrum
Pulicaria glutinosa
Reseda aucheri
Saccharum griffithii
Taverniera cuneifolia
Tribulus terrestris
Trichodesma enetotrichum

On the other hand, fifteen (15) of the "common Hajar Mountain species" are absent or very rare in WWNP as well as the Ru'us al-Jibal. This signals the importance of factors other than carbonate versus ultrabasic geochemistry alone, and highlights the existence of biogeographical differentiation *within* the Hajar Mountains. In fact, five of the "common" Hajar Mountain species that are absent or rare in both the Ru'us al-Jibal and in WWNP, are absent in WWNP because it is situated beyond the northern extent of their regional biogeographic range. The other ten (10) species require more individualized explanations.

Observation 9 below deals more generally with plant biogeography *within* the ophiolite rocks of the Hajar Mountains, and specifically with the phenomenon of "common" Hajar Mountain species that are absent or very rare in WNPP, whether or not they are also present in the Ru'us al-Jibal.

1.3. Comparison with Wadi Hiluw – a gabbro environment in the Hajar Mountains.

A further instructive comparison of the WWNP survey results can be made with the Wadi Helo Protected Area in Sharjah Emirate. Wadi Hiluw (a/k/a Wadi Helo) drains a large area of the mountains of the East Coast hinterland, some 50 km south of WWNP. The bedrock of the Wadi Hiluw watershed consists almost entirely of gabbro, which has a chemical composition essentially the same as basalt. Compared to harzburgite, gabbro has a higher content of silica (SiO_2) and a more normal geochemistry. In geological terms it is considered a "basic" rock, in contrast to the "ultrabasic" harzburgite.

El-Keblawy (2011) is a report of a survey of the flora of Wadi Hiluw. That survey recorded a total of 216 plant species in 35 families, of which 147 species were said to have been recorded in natural habitats, versus the balance of 69 species which were recorded only in "ruined [abandoned] and cultivated farms". It is somewhat frustrating that the recorded species are not actually listed in full in the report, and although the photographic Appendix appears to be largely complete, it omits at least a few species mentioned in the text and tables. However, the photographs are in most cases very good and include multiple views in support of the species identifications. In addition, the photographic Appendix includes a number of rare species centered on the highlands to the north of Wadi Hiluw, indicating that the field work was diligently conducted. The Wadi Hiluw report is therefore taken here as the starting point for a rough comparison of floral diversity. (However, see also the note at the end of this Section, which discusses some important limitations of that report.*)

For the purpose of comparison with WWNP, the Wadi Hiluw report's stated total of 147 species recorded from natural areas sets a baseline. Most of the identifications

appear from the published photographs to be sound; a few are considered likely to be erroneous, but without affecting the total number of species. However, the photos include five species that are repeated under different (and unlikely) labels, leading to a probable overcount; the adjusted total would be 142 species.

To that adjusted total must be added a further 12 species recorded by the present author in the course of field excursions over the years throughout natural areas of Wadi Hiluw, plus one congener depicted but not separately identified in the photographic Appendix. The resulting total of 154 species is still substantially lower than the total of 202 native species recorded within WWNP (76%). That comparison is extremely significant because it casts the seed of doubt on the conventional wisdom that the ultrabasic environment is characterized by reduced floral diversity.

The gap between the WWNP and Wadi Hiluw survey totals would be narrowed if, as is likely, some of the 69 Wadi Hiluw species said to have been recorded only from ruined or cultivated farms prove to be species that can be found in natural areas as well. Unfortunately the Wadi Hiluw report does not include data on the environment of collection for all species, but only for approximately 135 species considered "common" in the UAE (El-Keblawy 2011, Table 6). The basis for designating those species as "common" is not specified but seems most likely to be derived from the categorizations in Jongbloed (2003) and Karim & Fawzi (2007).

A measure of the possible skewing created by differences in survey coverage and methodology is illustrated by consideration of the grass species reported from Wadi Hiluw. Of the 30 grass species depicted in the photographic Appendix to the Wadi Hiluw report, 13 are species not recorded from WWNP. At least 5 of those are typically associated with cultivation and at least 2 others (possibly 3) may represent alternative identifications of similar congeners also recorded from Wadi Hiluw. The Wadi Hiluw report does not indicate when or in what season(s) the underlying field work was conducted, so it is difficult to assess the significance of negative records, i.e., species not recorded, especially small annuals and grasses.

From the data tabulated in the Wadi Hiluw report, it is possible to estimate that at least 8-10 "farm" species are likely to be found in natural environments in Wadi Hiluw (e.g., widespread mountain grasses such as *Rostraria pumila* and *Hyparrhenia hirta* and annuals such as *Launaea capitata* and *Polygala erioptera*). Another 8-10 species could potentially be found in natural environments in isolated circumstances (as some of them are, within WWNP). In addition, at least a few species not yet recorded are likely to be present, e.g., *Misopates orontium* and *Centaureum pulchellum*, both known from nearby Wadi Mayy. So on the basis of present knowledge, the total for natural environments in Wadi Hiluw could reasonably be *ca.* 175 species.

No comparable adjustment needs to be made for "farms" within WWNP, where only a single small agricultural field exists, in the buffer zone in upper Wadi Siji. That field was fallow when visited in March 2013 and March 2014 but it produced the sole WWNP records of *Cynodon dactylon* and *Echinochloa crusgalli*. The Adder's tongue fern *Ophioglossum polyphyllum* is the only other WWNP species that is suspected of association with former human cultivation. All survey records of *O. polyphyllum* were from a single locality, centered atop a thick gravel terrace where a small, shallow

gulley appears to have been serially dammed for very localized agriculture, evidently well before the modern era.

It could be argued that a proper comparison of "natural areas" should also exclude species found in WWNP only in anthropogenic areas such as the silted basin and wadi behind Wadi Wurayah dam, or in synanthropic areas such as the picnicking area below the Wadi Wurayah waterfall. Only one species has been recorded exclusively from the silt accumulations behind the dam (the wild mustard *Sinapis arvensis*); exclusion of the waterfall picnic area would reduce the WWNP totals by only a further six species (*Launaea procumbens*, *Lotus schimperi*, *Physalis minima*, *Sonchus oleraceus*, *Schweinfurthia imbricata* and *Sporobolus spicatus*). However, exclusion of the latter might require parallel exclusion of postulated exceptional occurrences in Wadi Hiluw.

All of the above potential adjustments taken together would still leave a quantitative gap of *ca.* 8-12% in favor of WWNP, so that even a fairly optimistic forecast for future flora records from Wadi Hiluw would result in no more than rough parity with WWNP for natural environments.

[**NB: Notwithstanding the evidently conscientious collection and compilation of floristic data by the Wadi Hiluw survey, it is imperative to caution that many of the conclusory judgments contained in the Wadi Hiluw report are seriously flawed and should not be relied on either as factually accurate information or as well-informed or appropriate guidance for future environmental management. This includes much of what appears in the "Executive Summary" and "Results" sections, and most of what is presented as "Conclusions and Practical Recommendations".*

Such a blanket criticism demands a measure of elaboration. The fundamental problem is that most of the conclusions and recommendations complained of go well beyond the information gathered by the Wadi Hiluw survey itself, and that, in formulating them, the report author, in default of personal experience with the UAE's mountain flora outside of Wadi Hiluw, has placed poorly-informed, highly selective and idiosyncratic reliance on information contained in (or sometimes erroneously inferred from) the several available and otherwise authoritative general references.]

2. All eight of the UAE's mountain endemics are found in WWNP, including one endemic newly recorded by the baseline survey.

The UAE has no nationally endemic plant species, but eight species considered endemic to the mountains of the UAE and Northern Oman have been recorded within the UAE. All of those species are found in WWNP. One was recorded in the UAE for the first time during the course of the baseline survey:

- *Desmidorchis arabicus* (formerly *Caralluma arabica*) (Asclepiadaceae): a cactus-like succulent milkweed that is widespread but seldom encountered, probably because it favors rocky slopes that are difficult to access. It was recorded at numerous sites throughout WWNP.
- *Echinops erinaceus* (Asteraceae): A tall, spiny thistle, locally common on rubble and scree. This species is listed in Jongbloed (2003) only as *Echinops* sp.

Feulner (2011) updated the nomenclature based on information from N. Kilian (pers. comm.).

- *Launaea omanensis* (Asteraceae): A semi-erect daisy with rubbery, leafless, greyish blue-green stems spreading from a basal rosette of thin, dissected and finely toothed leaves. The baseline survey produced the first record of this plant from the UAE. Single specimens have been found at four widespread and varied sites within WWNP. It has also been recorded subsequently from a rocky ridge on the slopes of Jebel Qitab in Fujairah Emirate, southwest of Fujairah city. The UAE records were identified, from photographs, by Dr. Norbert Kilian of the Botanic Garden and Botanical Museum Berlin-Dahlem, who first distinguished and named the species in 1997.
- *Lindenbergia arabica* (Scrophulariaceae): Usually a sparse, erect, opposite-leafed shrub, typically found on the vertical wadi walls of coarse gravel terraces; rare in WWNP.
- *Pteropyrum scoparium* (Polygonaceae): A medium-sized woody shrub with villous leaves, occasional along wadi banks and adjacent slopes; reportedly very similar to *P. aucheri* of Iran, Pakistan and Afghanistan.
- *Pulicaria edmondsonii* (Asteraceae): A slope-dwelling dwarf shrub that is locally common along gulleys at elevations above ca. 400 meters. It is also locally common in the Ru'us al-Jibal but uncommon in the mountains to the south of WWNP.
- *Rumex limoniastrum* (Polygonaceae): An erect to semi-pendant small shrub with fleshy, yellow-green, pointed oval leaves, resembling a caper plant but without spines, typically found on ledges, walls or other sites protected from browsing; widespread but very rare. After its collection by Aucher-Eloy in the Jebel Akhdar in 1837, it was not recorded again until the 1990s, when it was photographed at several sites in the UAE and northernmost Oman. Two specimens have been found within WWNP. The first was a historical record from upper Wadi Siji, in the WWNP buffer zone, but in the course of the survey a specimen was found in upper Wadi Zikt, anomalously situated in the gravel wadi bed.
- *Schweinfurthia imbricata* (Scrophulariaceae): A prostrate, spreading annual with round, dark green, overlapping leaves. A rare and limited range species, it has been found mostly on gravel in the areas to the north and south of the Hatta road. It was not expected in WWNP, where two specimens have now been found, one in silt behind the Wadi Wurayah dam and one on gravel along the distal portion of the surface water outflow below the Wadi Wurayah waterfall. These are the northernmost UAE records, *ca*. 25 km from the closest other record, near Siji.

3. WWNP is an important site for many rare species. For some, it is one of the only UAE sites.

WNPP is an important site, and in some cases one of the only known UAE sites, for a number of rare or otherwise noteworthy UAE plant species. A few of those are associated with the mesic environment of the permanent waterfall. The following list is indicative, not exhaustive.

- *Asterolinon linum-stellatum* (Primulaceae): The Wadi Ghayl branch of Wadi Wurayah is the only known UAE site outside the Ru'us al-Jibal for this delicate annual herb.
- *Bromus danthoniae* (Poaceae): This coarse-headed grass, apparently limited to high elevations, has previously been recorded in the UAE only from the Ru'us al-Jibal. It was found on a ridgetop in the southwest of WWNP.
- *Castellia tuberculosa* (Poaceae): The survey produced a photo record of this species from Wadi Ghayl. It was previously known in the UAE only from a single collection in upper Wadi Siji, within the WWNP buffer zone. A number of specimens have subsequently been recorded from the bed of a major ravine on the slopes of Jebel Qitab, southwest of Fujairah city.
- *Cladium mariscus* (Cyperaceae): The Wadi Wurayah waterfall area is the only known UAE site for this large, water-loving sedge. It is found in small bedrock pools at the base of the permanent waterfall, where it was first recorded in 2009 by Valerie Chalmers, Vice Chairman and Plant Recorder of the Dubai Natural History Group. When not in seed, it is difficult to distinguish from the other large hygrophilous monocots present.
- *Dianthus crinitus* (Caryophyllaceae): This is a Palearctic species and in the UAE and Northern Oman it is generally restricted to higher elevations. It is locally common in the Ru'us al-Jibal above 1000 meters; to the south, it is rare but has been found in the Jebel Akhdar and the Eastern Hajar Mountains above 1200 meters. The WWNP record (*ca.* 550 meters) is anomalously low. This species has one of the largest flowers of any UAE mountain plant.
- *Desmidorchis arabicus* (Asclepiadaceae): A UAE/Oman endemic. See discussion under Observation 3 above.
- *Enneapogon persicum* (Poaceae): This tall, silvery-green grass has been recorded in the UAE only rarely, from scattered locations in the Ru'us al-Jibal (Feulner 2011), from Khor Fakkan (Jongbloed 2003) and from cultivation in Wadi Hiluw (El-Keblawy 2011).
- *Epipactis veratrifolia* (Orchidaceae): The UAE's only orchid depends on water from seeps. Although the orchid is rare within WWNP, Wadi Wurayah has more permanent water than other UAE wadis, making it important as a potential refuge for this species.
- *Nanorrhinum acerbianum* (Scrophulariaceae): A straggling species which apparently favors damp, shaded places. Three of the very few UAE records are from WWNP.
- *Ophioglossum polyphyllum* (Ophioglossaceae): An edible fern, the Adder's Tongue, that is threatened in its coastal habitat in the UAE, but that can also be found in silt accumulations in the mountains (Jongbloed 2003). The WWNP record may be related to ancient cultivation.
- *Papaver decaisnei* (Papaveraceae): A red poppy, most commonly found in the high Ru'us al-Jibal.
- *Rumex limoniastrum* (Polygonaceae): A rare UAE/Oman endemic. See discussion under Observation 2 above.
- *Saccharum kajkaiense* (Poaceae): The waterfall area of Wadi Wurayah is the only known East Coast site (and the northernmost Hajar Mountain site) for this cryptic wadi grass, rare in the UAE, which closely resembles the much more common *S. griffithii* (Feulner & Karki 2009, but NB: *S. griffithii* is discussed therein as *S. ravennae*).

- *Schweinfurthia imbricata* (Scrophulariaceae): An uncommon UAE/Oman endemic. See discussion under Observation 2 above.

4. A list of the most biodiverse environments within WWNP includes both wild and synanthropic habitats.

A qualitative assessment of the most biodiverse habitats includes the following:

- Third-order tributary wadis with a low to moderate gradient. These wadis typically feature a close association of diverse small-scale habitats, which facilitates overall biodiversity, and they are not swept clean by flood waters to the same extent as lower order streams. Examples include Wadi Dhahir (a/k/a Jacky's Wadi), about a kilometer below the Wadi Wurayah waterfall; the Blue Water (*May'a-t-al-Azraq*) Fork of Wadi Ghayl; and the Ghalil al-Haban Fork of upper Wadi Wurayah (Wadi Murtaqam).
  Among the species that were noticeably more common in these environments are: *Convolvulus glomeratus*, *Dodonaea viscosa*, *Lavandula subnuda*, *Leucas inflata*, *Galium decaisnei*, *Parietaria alsinifolia*, *Plocama hymenostephana*, *Pulicaria edmondsonii*, *Salvia macilenta*, and *Taverniera cuneifolia*.
  The middle reaches of Wadi Ghayl and its tributaries were especially noteworthy in terms of plant species diversity. That is probably due mostly to their geographic circumstances. Wadi Ghayl is the lowest of the major tributaries of the Wadi Wurayah watershed, and in addition, from its junction with Wadi Wurayah it initially trends north for several kilometers, through foothills and gravel plains, before turning west into higher peaks. Thus, in its middle reaches it flows through somewhat gentler (but still highly varied) mountain terrain than the steeper upper tributaries, effectively behaving like a higher order stream, with corresponding opportunities for greater numbers of species.
  The Powerline Fork of Wadi Ghayl is a special case, having a very shallow gradient and flowing for several kilometers through low, rolling terraces and very low hills. Two species all but absent elsewhere in WWNP were found there in small numbers: *Pergularia tomentosa* (Asclepiadaceae), a ruderal milkweed shrub, and *Teucrium stocksianum* (Lamiaceae), an edible aromatic species found elsewhere in the Hajar Mountains mostly at higher elevations but present in the Powerline Fork at low elevation beside shallow wadis in an area subject to browsing by goats and sheep. Also found there is the newly recognized UAE/Oman endemic *Launaea omanensis*.
- North-facing rubble slopes, shaded by a cliff. These provide a relatively mesic environment for plant life, especially annuals. Among the species associated with this environment are: *Anagallis arvensis*, *Asterolinon linum-stellatum*, *Ephedra foliata*, *Erodium neuradifolium*, *Forsskaolea tenacissima*, *Geranium biuncinatum*, *Geranium trilophum* and *Sisymbrium erysimoides*.
- The Wadi Wurayah dam basin. In the gravel wadi above the Wadi Wurayah dam, alluvial silt has accumulated in various places and to varying thicknesses for *ca.* 2 kilometers upstream, as a result of intermittent flooding. The Wadi Wurayah dam is a man-made feature but similar silt accumulations can be created naturally, e.g., by landslides (Feulner 2004). Among the plant species recorded in the silty alluvium, but only seldom recorded elsewhere within WWNP are: *Chrozophora oblongifolia*, *Citrullus colicynthis*, *Cleome noeana*,

Cyperus conglomeratus, *Monsonia* cf. *heliotropioides*, *Pennisetum divisum* and *Spergula fallax*. One species, *Sinapis arvensis* (wild mustard), was found only in this habitat, and one of the two specimens of each of *Schweinfurthia imbricata* and *Tephrosia* cf. *uniflora* were also found there. There is a price to be paid, however, for seeking out the alluvial silt, and that is the threat of inundation or burial by subsequent floods. An exceptional flood in mid-March 2014 filled the basin and wadi behind the dam to within *ca*. 250 meters of the lower road crossing, wiping out all of the pre-existing basin vegetation and leaving a veneer of clean silt over a much greater area than previously observed.

- The outflow pools and rivulet at the base of the Wadi Wurayah waterfall, an area that has been heavily used by picnickers. A number of species were recorded here that have not been found elsewhere within WWNP. They represent a mix of water-loving and synanthropic species, plus opportunistic specimens of mountain species not typically found in this environment (see also Observation 14 below). Among the rare, limited range and restricted habitat species and indigenous exotics that have been found there are:
  Adiantum capillus-veneris, *Bolboschoenus maritimus*, *Campanula erinus*, *Centaurium pulchellum*, *Cladium mariscus*, *Citrullus lanatus* (watermelon), *Cyperus rotundus*, *Epipactis veratrifolia*, *Euphorbia granulata*, *Filago desertorum*, *Launaea procumbens*, *Lotus schimperi*, *Solanum lycopersicum* (tomato), *Ochradenus arabicus*, *Parietaria alsinifolia*, *Physalis minima*, *Sonchus oleraceus*, *Spergula fallax*, *Sporobolus spicatus* and *Typha domingensis*.
  All environments within the main wadis are subject to significant disruption and reorganization by flash floods, but this area at the base of the falls is particularly vulnerable. During a visit made on 4 November 2014, several days after heavy rain, no more than a third of the above listed species could be found. The apparent absentees included *C. erinus*, *C. pulchellum*, *C. mariscus* (a surprising absence for such a large species), *C. lanatus*, *C. rotundus*, *E. veratrifolia*, *E. granulata*, *F. desertorum*, *L. procumbens*, *L. schimperi*, *S. lycopersicum*, *O. arabicus*, *P. alsinifolia*, *S. oleraceus*, *S. fallax*, and *S. spicatus*. On the other hand, the tall reed *Arundo donax* had extended its dominion below the falls, both immediately below the waterfall pool and along the outflow downstream from the pipeline area. An interesting question is whether closure of the park to the general public (since mid-January 2014), may have eliminated some of the disruption (and inadvertent introductions) that allowed some of the foregoing opportunistic species to establish themselves. Several, however, are annual species that would not necessarily have been expected to persist into the fall season.
- The parking area on the gravel terrace at the end of the paved road. *Aristida abnormis*, *Cyperus conglomeratus*, *Dichanthium foveolatum*, *Galium decaisnei*, *Gymnocarpos decandrus* and *Monsonia* cf. *heliotropioides* were all recorded on the waste ground and gravel terrace adjacent to the parking area. All are native UAE species and *A. abnormis*, *G. decaisnei* and *G. decandrum* are mountain denizens, but none of them would have been expected in this location. This suggests that their introduction may have been inadvertently facilitated by humans and/or their associated vehicles (e.g., visitors, municipal sanitation workers et al.). (See also Observation 14 below).

5. 14% of the recorded species (n = 28) were found only in the buffer zones of WWNP, signaling the importance of these marginal mountain and foothills areas for biodiversity.

Twenty-four (24) species, or 12% of the total, were found only in the mountainous buffer zones of upper Wadi Siji and upper Wadi Abadilah in the west and lower Wadi Zikt in the north (Table 2B). This confirms the wisdom of incorporating those areas into the WWNP scheme in order to capture and protect the biodiversity of the mountain environment as a whole.

There is no single explanation for the presence of the buffer zone species. The majority (16) are species found in mountain habitats elsewhere in the UAE that could reasonably be expected within the core zone. One is a plains species that represents an outlier from more extensive populations on the coastal plain (*Haloxylon salicornicum*). Four are associated with agriculture within or at the margin of the Wadi Siji and Wadi Abadilah buffer zones (*Anchusa aegyptiaca, Cynodon dactylon, Echinochloa crusgalli* and *Medicago laciniata*). Two are outliers of populations that seem to be localized in the Masafi area (*Chaenorrhinum rubrifolium* and *Hyoscyamus muticus*). One is a gravel plains and gravel terrace species which is much more common southwards and for which the WWNP record is among the northernmost known (*Cleome scaposa*).

It is worth noting specifically that the buffer zones in question (upper Wadi Siji, upper Wadi Abadilah and lower Wadi Zikt) do not generally constitute significantly altered or degraded environments. Rather, they appear to be relatively undisturbed mountain environments, at least in UAE terms.

In contrast, Wadi Ghulayyil Khun, which constitutes most of the buffer zone along the eastern edge of WWNP, shows many scars of human contact. It flows through relatively low but still steep and rocky ridges of harzburgite, but those were not sufficient to insulate it from the march of progress. It has a waste dump and a modest dam at its mouth, another dam *ca*. 2 km upstream, and it bears throughout its length the aesthetic indignity of the high voltage power lines that adorn the East Coast skyline, along with the service road used to construct and maintain them. The vegetation does not at first appear to have been much altered by these activities, or by agriculture or human use generally, but the upper part of the wadi shows evidence of grazing. A herd of 30 sheep was observed there during the survey visit, evidently having crossed a low pass from the hinterland of Bidiyah.

For those reasons, it was anticipated that Wadi Ghulayyil Khan might host several anthropophilic plant species not found elsewhere in WWNP (including possible invasive species), but that was not the case.

It was therefore a surprise to find four additional native species (2% of the total) within the newly fenced area of the WWNP headquarters compound, during a serendipitous late-stage reconnaissance in January 2014. The headquarters area is located at the southern extremity of the eastern buffer zone of WWNP, in an environment of rolling gravel pediment traversed by shallow wadis, all in medium to fine gravel.

Despite the coincidence of their presence at WWNP headquarters, there is no suggestion that any of the four species are other than naturally occurring. Two of them, *Eragrostis barrelieri*, an inconspicuous grass, and *Acacia ehrenbergiana*, a large shrub, are locally common in mountain front environments elsewhere in the UAE, and *E. barrelieri* was subsequently found in the WWNP buffer zone in upper Wadi Siji. *A. ehrenbergiana* certainly predates erection of the headquarters fence and buildings. A second small grass, the congener *Eragrostis ciliaris*, is less well known but has been recorded from disused wadi bank fields at low elevation in the Ru'us al-Jibal. The fourth headquarters species is the erect but diminutive, spreading *Zaleya pentandra*, a ruderal species found in UAE coastal regions and farms and along the Batinah coast of Oman.

6. 4.0% of the recorded species (n = 8) were found only in Wadi Zikt.

Eight (8) species, or 4% of the total, were found only within the watershed of Wadi Zikt, including one species found only within the buffer zone in Wadi Zikt (Table 2D). Again, this confirms the wisdom of including most of the Wadi Zikt watershed within WWNP. Nevertheless, most of the species in question could reasonably be expected throughout WWNP in suitable habitats, including silt and gravel wadi beds, gravel terraces, wadi walls and gulleys. One exception is *Haloxylon salicornicum*, a sand and gravel plains species which is relatively unlikely to be found within the core zone.

A second possible exception is *Astragalus fasciculifolius*. The most recently recorded shrubs of this species were several found in a (relatively) low pass formed within one of the large parallel granitic dikes on the divide between Wadi Zikt and the Wadi Ghayl branch of Wadi Wurayah, and a single specimen in an upper tributary of Wadi Zikt. Only a tiny seedling was recorded elsewhere, from harzburgite at another remote site in Wadi Zikt. This suggests the possibility that *A. fasciculifolius* may be intolerant of the ultrabasic rock (harzburgite) that comprises most of WWNP. However, the author's notes from an excursion in March 1997, in the middle of several exceptionally wet years (Feulner 2006b) describe flowering specimens from "slopes in upper wadi" in the area of the granitic dikes, but without reference to geology.

A. fasciculifolius is common in the Ru'us al-Jibal to the north, in carbonate rock, but the author has encountered it only once south of Wadi Zikt. Since it is normally found at elevations of greater than *ca*. 400 meters, elevation could be an alternative explanation for why it was not more commonly recorded by the baseline survey. It was recorded by the Wadi Hiluw survey (El-Keblawy 2011), but without habitat or elevation data. *A. fasciculifolius* is believed to be absent regionally between Wadi Hiluw and the Eastern Hajar Mountains, southeast of Muscat, including the intervening Western Hajar Mountains and the extensive carbonate massif of Jebel Akhdar. It was recorded by Mandaville from higher elevations (>1000 meters) at Jebel Aswad, a carbonate area in the Eastern Hajar (Mandaville 1977).

7. The tree flora of WWNP consists of only 7 species, but is typical of the northernmost Hajar Mountains.

Only seven tree species (3.5% of the total naturally occurring species) are found within WWNP:

Acacia ehrenbergiana, typically a large shrub with multiple stems, not a single trunk, known only from the headquarters area of WWNP
Acacia tortilis, the common acacia or *samr* tree
Ficus cordata salicifolia, the wadi fig
Ficus johannis, the mountain fig
Moringa peregrina, known by various local names
Prosopis cineraria, the *ghaf* tree, rare within the mountain environment
Ziziphus spina-christi, the large, fruit-bearing *sidr* tree

This situation is typical of the Hajar Mountains of the UAE and northernmost Oman. Additional tree species and large shrubs can be found in the mountains further south, especially from Wadi Jizzi southwards, both at wadi level and at higher elevations (e.g., *Acridocarpus orientalis*, *Maerua crassifolia*, *Olea europaea*, *Rhus aucheri*, *Sageretia thea*, and *Tamarix aphylla*).

Among larger shrubs, *Dodonaea viscosa* is present in WWNP; it can grow to a height of two meters or more, but very few large specimens were seen during the survey. Likewise only one large specimen of the woody shrub *Grewia erythraea* was seen; where browsing pressure is heavy, this plant may be browsed to a dense cushion, but that phenomenon was also not seen in WWNP. A few relatively large *Calotropis procera* can be found in the lower wadis within WWNP, but that species is more an opportunist than a mountain species.

Another large shrub, the Desert Thorn *Lycium shawii*, was expected in WWNP but has been recorded only once, historically. Elsewhere it is a species of wadi banks, lower slopes and terraces, and is highly susceptible to browsing. (See also Observation 9.4 below.)

8. Vegetation zones: a lower "wadi zone" can be distinguished from a higher "montane zone".

Additional species appear in the WWNP flora with increasing elevation, although at the relatively modest elevations of most of WWNP (*ca.* 50-900 metres) this normally occurs without significant loss of low elevation species other than those that are tied to the mesic conditions of the main wadi bed. There may be some value in distinguishing, from a floristic point of view, between a "wadi zone" and a "montane zone".

The montane zone is characterized by the regular appearance of species such as *Desmidorchis arabicus*, *Ficus johannis*, *Launaea bornmuelleri*, *Linum corymbulosum*, *Orobanche cernua* and *Pulicaria edmondsonii* and rarer species such as *Bromus danthoniae*. Other species recorded in small numbers at low elevation in WWNP, but generally characteristic of higher elevations elsewhere, are *Helichrysum glumaceum* and *Teucrium stocksianum*.

Because the elevation changes involved are modest, the transition between the wadi zone and the montane zone probably reflects changes in physiography and drainage as much as temperature, rainfall or elevation *per se*. For this reason the elevation of the montane zone is not entirely independent from the overall wadi profile. The base level of the main wadis rises from *ca.* 200 metres at the Wadi Wurayah waterfall to more

than 500 metres at the heads of the main branches (Wadi Murtaqam, Wadi Yashimah, Wadi Ghayl et al.), with the result that the boundary between the two vegetation zones may vary accordingly, from *ca.* 300-400 metres in the lower and middle reaches of the wadis to *ca*. 500 metres in the upper wadis,

Some of the typical montane species can also occur, atypically, at lower elevations. For example, during the baseline survey occasional seedlings of *P. edmondsonii* were recorded in gravel wadi beds, and two specimens of *F. johannis* are known from wadi level at and below the Wadi Wurayah waterfall.

9. A number of "common" Hajar Mountain species are not common in WWNP, some for reasons that remain to be investigated.

A number of species generally considered to be common in the Hajar Mountains of the UAE were recorded only extremely rarely or not at all during the baseline survey, nor is their presence in WWNP reflected in historical data.

That is a reminder that the Hajar Mountain flora has never been the subject of a fine scale biogeographical study and that a more focused study of WWNP in comparison to other mountain areas has the potential to reveal previously unrecognized biogeographical patterns and insights about ecological relationships and the factors that control plant diversity and distribution in this area.

Most of the absent or rare species were absent unexpectedly. In some cases, upon closer consideration, those absences can be explained in terms of many of the same factors discussed above in the comparison of WWNP with the Ru'us al-Jibal, including: (i) regional biogeographical gradients; (ii) edaphic differences, i.e., differences in the development and character of the soil or substrate; and (iii) geochemical differences – now, *within* the ophiolite – and specifically the difference between ultrabasic (harzburgite) and basic (gabbro) bedrock). In other cases an explanation remains speculative.

9.1. Common Hajar Mountain species that are absent from WWNP without explanation.

Some of the most striking examples of unexpectedly (and so far mostly inexplicably) "absent" species within WWNP are:

- *Erucaria hispanica* (Brassicaceae). This often hyperabundant pink annual can dominate whole flats, fields, terraces and gravel plains in the Ru'us al-Jibal, along the west flank of the Hajar Mountains, and in the mountains of the Hatta and Masafi areas. It was demonstrably abundant in many such areas on several occasions during the course of the baseline survey, while remaining absent in WWNP. A review of the author's historical records from the Hajar Mountains indicates that this species is absent or rare in most other wadis of Shimayliyah and the East Coast generally.
- *Fagonia indica* (Zygophyllaceae). This distinctive yellow-green, erect, spiny dwarf shrub is common and conspicuous in many Hajar Mountain areas, favoring silty wadi banks, stony lower slopes and silt accumulations on terraces. In WWNP, however, it was all but absent. A single small specimen of probable *F. indica* was found at a low pass in the WWNP buffer zone in the Nimriyah area of Wadi Zikt. An unequivocal specimen and another enigmatic

one were recorded in upper Wadi Siji, again in the WWNP buffer zone. During the period of the baseline survey, *F. indica* was observed elsewhere along the East Coast as a perianthropic ruderal species in the mouth of Wadi Safad, *ca.* 20 km from WWNP, and along a storm drainage channel at the mountain front in nearby Khor Fakkan. Both of those sites are in gabbro environments. That fact raises the initial suspicion that *F. indica* may be among the plant species that are intolerant of ultrabasic bedrock (discussed below), but in fact it is common at many sites along the west flank of the Hajar Mountains, especially south of the Hatta road in Wilayat Mahdhah, Oman, where ultrabasic bedrock prevails.

- *Juncus rigidus* (Juncaceae). The UAE's only mountain bulrush species is occasional, and locally common, in a number of wadis draining the west flank of the Hajar Mountains, especially in Wilayat Mahdhah, Oman, in locations where the water table is close to the surface. However, a review of the author's historical records from the Hajar Mountains indicates that *J. rigidus* is absent or rare in most wadis of Shimayliyah and the East Coast generally, although it can be found north of the Masafi area and as far north as tributaries of Wadi Fa'y, on the south edge of the Ru'us al-Jibal, in each case in ultrabasic bedrock.
- *Lycium shawii* (Solanaceae). This medium to large sized woody shrub is edible and is often limited elsewhere to sites where it is (or was) protected as a sapling, whether by rocks or other plants. On the East Coast of the UAE it is common as a browsed shrub along wadi banks in Wadi Safad and on hillsides along Wadi Mayy, on the lower slopes of Jebel Qitab, south of Fujairah, both gabbro environments some 20 km and 40 km distant, respectively, from WWNP. But only a single record exists from WWNP, in upper Wadi Yashimah, of a scraggly specimen growing up in a mountain fig *Ficus johannis*. A review of the author's historical records from the Hajar Mountains makes it clear that *L. shawii* is among the species that are intolerant of ultrabasic bedrock (see Observations 9.1 and 9.4 below).
- *Rhazya stricta* (Apocynaceae). This toxic species is most common in the UAE and Northern Oman on gravel plains, but it is not unusual to encounter it in Hajar Mountain wadis, especially in or alongside the beds of broader, flatter wadis. The prevalence of *R. stricta* is an indicator of overgrazing. It is present on the East Coast in at least lower Wadi Safad and lower Wadi Mayy, both gabbro environments. Within WWNP, however, it was recorded only at a single, atypical site in the buffer zone, in a steep rubble gulley in upper Wadi Abadilah.
- *Sclerocephalus arabicus* (Caryophyllaceae). This is a small species of gravel plains and terraces. In February and early March 2013, during the period of the baseline survey, it was locally common on the west flank of the Hajar Mountains in the UAE, but the only record from WWNP is a historical record (based on the author's written description) from the buffer zone in upper Wadi Siji.
- *Teucrium stocksianum* (Lamiaceae). This edible aromatic is a species of rocky mountain slopes. It is occasional in the Hajar Mountains generally and in the Ru'us al-Jibal, where it is more common at higher elevations (although in many of the more accessible areas it has been reduced in abundance in recent years due to increased browsing by domestic goats). During the period of the baseline survey *T. stocksianum* was readily observed on hillsides in Wadi

Mayy, along the slopes of Jebel Qitab, southwest of Fujairah, a gabbro environment where it has been recorded historically from *ca.* 200 meters to the summits at *ca.* 1000 meters. In WWNP, however, it escaped notice until two small plants were recorded in a single gulley along the eastern edge of the core zone, in the Powerline Fork of Wadi Ghayl, in March 2014. Another plant was found in May 2014 near the head of a broad scree gulley leading up to a massive granitic dike at the head of Dam Wadi. Two more scattered plants, healthy and in late flower, were found, anomalously, along the banks of a shallow tributary in the open reaches of upper Powerline Fork.

Additional field work and a more detailed review of historical records and relevant botanical literature may help to explain more conclusively the factors that control the presence or absence of the above species, and others, within the Hajar Mountains. As indicated in the descriptions of several of the 'missing' species, the nature of the surrounding bedrock, and specifically the distinction between ultrabasic versus gabbroic (basic) rocks, must be considered as a potentially important element. Nevertheless, ultrabasic geochemistry alone is not a sufficient explanation in all cases. And even if bedrock composition is a determinant of distribution for a particular species, it should not be expected in most cases that the species will be entirely excluded from the disfavored environment.

It is possible, among other things, that the geochemistry of certain habitats, e.g., wadi pools, wadi beds with thick gravel, silt accumulations, and perhaps even gravel plains (and the subsurface weathering beneath them), can effectively mitigate the adverse effects of the ultrabasic environment and permit the growth of species that would otherwise be intolerant of it. Climatic factors, particularly rainfall, may also attenuate at least some of the rigors of the ultrabasic environment. For example, the development of the most extremely alkaline groundwater depends on the slow percolation of relatively small amounts of groundwater through relatively large amounts of ultrabasic bedrock, so a higher rainfall regime is associated with lower groundwater alkalinity (Clark & Fontes 1990). This has, potentially, both short-term and long-term effects on the local flora. In the short-term, above average seasonal rainfall could insulate many annual species from what would otherwise be difficult or prohibitive chemical parameters of the ultrabasic environment. From a long-term perspective, it could mean that the Hajar Mountains were a somewhat more geochemically hospitable place for perennial species during past intervals of increased rainfall.

The three sections immediately below give examples of some Hajar Mountain plant species whose UAE distribution can be assigned with reasonable confidence to: (i) regional biogeographic gradients; (ii) edaphic factors; or (iii) the presence or absence of ultrabasic bedrock.

All of these examples suggest that a more detailed study of Hajar Mountain plant distribution, taking careful account of geology, geography and biogeographical history, as well as microhabitats, has the potential to result in enlightening generalizations. Conversely, they indicate that it is dangerous to generalize without an examination of individualized circumstances.

9.2. Species whose biogeographical range does not extend to WNPP.

Five of the common Hajar Mountain species highlighted in Table 5 of Feulner (2011) ("Common Hajar Mountain species that are absent or very rare in the Ru'us al-Jibal) are absent in WWNP as well as the Ru'us al-Jibal, because both of those areas are situated beyond their regional biogeographical range in Eastern Arabia.

All of these species, as it happens, are relatively large and/or conspicuous species. They include the trees *Olea europaea* (the wild olive) and *Maerua crassifolia*, the large shrub *Acridocarpus orientalis*, and the dwarf palm *Nanorrhops ritchieana*, all of which are more common to the south, in the mountains of Northern Oman (and, in the case of *N. ritchieana*, on the plains of Central Oman). Nevertheless, all of the foregoing species except *A. orientalis* are also found in the Makran region, i.e., the coast and hills of southern Iran and southwestern Pakistan.

The toxic perennial composite *Iphiona aucheri* is perhaps a recently arrived species; it is centered in the foothills south of the Hatta road in Wilayat Mahdhah and has not been found further north, although it has been recorded as far south as Jebel Hafit (A.R. Western, *pers. comm.*).

9.3 Species that are absent or rare in WWNP for edaphic reasons.

The ghaf tree *Prosopis cineraria* is primarily a species of sand and gravel plains, but it is not unusual to encounter it in or adjacent to broader, flatter gravel wadis within the Hajar Mountains. Yet although it is reasonably common on the plains of the East Coast, it is rare in WWNP, where anthropogenic influence is suspected for the trees at the three recorded sites. Edaphic (soil/substrate) and hydrologic factors are the most likely explanations for its absence in the more rugged wadis of the Hajar Mountains, including WWNP. *P. cineraria* is a notoriously deep rooted species and it may be unable to penetrate the relatively shallow ophiolite bedrock.

In some cases, drainage characteristics of the substrate may be the principal determinant of distribution. Among the best examples are the two *Lindenbergia* species (*L. arabica*, which is endemic to the UAE and Oman, and *L. indica*). Both are typically found on, or at the base of, the vertical wadi walls of coarse gravel terraces – an extremely common habitat in the Hajar Mountains. The gravel terraces serve, among other things, as reservoirs for the slow downward percolation of groundwater. However, both *L. arabica* and *L. indica* have proved to be rare in WWNP relative to their abundance in the Hajar mountains to the south. One possible explanation for this is lower rainfall in the northernmost Hajar Mountains (see Feulner (2011) at Sections 8.4, pp. 80-81, and 9.1, pp. 91-92), and therefore less percolating water. Another possibility is that the large size of the Wadi Wurayah watershed channels higher floodwaters into the main wadis, dislodging the typically low-growing *Lindenbergia* species and restricting them to tributary wadis, where gravel terraces are often less well-developed.

9.4. Species whose distribution may be controlled by the presence or absence of ultrabasic bedrock.

The results of the baseline survey suggested to the author a number of plant species whose distribution within the Hajar Mountains appeared to be sensitive to the presence or absence of ultrabasic bedrock, including both species recorded in WWNP and species absent from it. In order to make a preliminary assessment of that possibility, reference was made to the author's field records from selected excursions

throughout the Hajar Mountains and surrounding areas. This was supplemented by contemporaneous investigation of two non-ultrabasic locations within the Hajar Mountains – Jebel Qitab and Wadi Sfai, both situated in areas of gabbro bedrock.

That effort confirmed some hypotheses, eliminated some others, and left still others for additional targeted field and literature investigation and future elaboration. In the case of a few rare species, the total number of records is insufficient to support firm generalizations. Some preliminary conclusions are presented in summary fashion below.

(i) Species that strongly 'favor' ultrabasic bedrock environments
Diplotaxis harra (Brassicaceae)
Gypsophila bellidifolia (Caryophyllaceae)
Pteropyrum scoparium (Polygonaceae)
Salvia macilenta (Lamiaceae)

(ii) Species that weakly 'favor' ultrabasic bedrock environments
Cleome rupicola (Capparaceae)
Haplophyllum tuberculatum (Rutaceae)
Pulicaria edmondsonii (Asteraceae) [also limited to high elevation]

(iii) Species that strongly 'avoid' ultrabasic bedrock environments
Convolvulus acanthocladus (Convolvulaceae) [also limited to high elevation]
Dicoma schimperi (Asteraceae)
Echiochilon persicum (Boraginaceae)
Lycium shawii (Solanaceae)

(iv) Species that weakly 'avoid' ultrabasic bedrock environments
Phagnalon schweinfurthii (Asteraceae) [also limited to high elevation]
Vernonia arabica (Asteraceae) [also limited to high elevation]

It is also possible that the unexpected distribution of certain congeneric species in WWNP (see Observation 11 below) may be influenced by the presence or absence of ultrabasic bedrock, but this has not yet been investigated.

It bears noting that, somewhat counterintuitively, the above allocation of species does not bear a straightforward relationship to their presence or absence in the carbonate rocks of the Ru'us al-Jibal range. Five of the six species that appear to 'avoid' ultrabasic rock are common or occasional in the Ru'us al-Jibal (the sixth is absent), but three of the seven species that 'favor' ultrabasic bedrock are also locally common in the Ru'us al-Jibal (three others are rare and one is absent) (Feulner 2011).

9.5. Elevation as an additional control on distribution.
In a few cases, elevation (which is in part a surrogate for temperature and moisture) may be an equally or more important factor than geochemistry in determining the distribution of sensitive species. *Ephedra pachyclada* and *Phagnalon schweinfurthii* are two higher elevation species that, outside the Ru'us al-Jibal, are found in the UAE almost exclusively in the Olive Highlands (Feulner 2014), an extensive area of gabbroic rock, on ridges and plateaux at elevations of ca. 800 to 1050 metres. With the exception of a single *P. schweinfurthii*, neither species has been found within

WWNP, but this may be primarily because the total area in WWNP at elevations of 800 metres and above is small, and consists of steep, narrow and inhospitable ridges. Both species have been found within ultrabasic rocks to the south, in the mountains southeast of Jebel Hatta, although only at much higher elevations (ca. 1400 meters).

10. Additional species are certain to be found in WWNP. Some likely candidates are suggested.

No survey can claim to have revealed all plant species present in such a large and difficult area as WWNP. The many sole records, historical records, and records of rare or short-lived annuals emphasize the importance of contingency and of being in the right place at the right time. For these reasons, it is inevitable that additional species will be added to the Checklist over the course of time.

That said, some species are more likely than others to be found in WWNP in the future. Any of the "missing" species discussed above in Observation 9 is possible, at least in small numbers; the expectation that they should be present is what makes their absence noteworthy. They would be precluded only if some parameter of the WWNP environment proves to be an absolute bar to their presence.

It is also reasonable, as a general matter, to expect that several additional grass species (Poaceae) will be recorded over time. Many grasses are both inconspicuous and seasonal, and some could have been overlooked. Several of those that are more likely to occur are included in the list below.

For a few genera of UAE mountain plants, closely similar congeners have been recorded in the literature. With that in mind, the author made the effort to distinguish between them and to ascertain whether multiple congeners might be present in WWNP, with results as follows:

- For *Andrachne*, only *A. aspera* (not *A. telephioides*) was recorded.
- For *Cymbopogon*, only *C. schoenanthus* (not *C. commutatus*) was recorded.
- For *Digitaria*, only *D. nodosa* (not *D. ciliaris* or *D. sanguinalis*) was recorded.
- For *Erodium*, only *E. neuradifolium* (and none of several similar congeners) was recorded.
- For *Geranium*, of three similar congeners, two species (*G. biuncinatum* and *G. trilophum*) were recorded during the survey; *G. mascatense* was not.
- For *Nanorrhinum*, only *N. hastatum* (not *N. ramosissimum*) was recorded.
- For *Stipagrostis*, only *S. hirtigluma* (and none of several similar congeners) was recorded.

These results are briefly discussed in the relevant entries in the Checklist. *Digitaria*, *Erodium*, *Geranium* and *Stipagrostis* are also discussed separately below in Observation 11, because the species recorded in WWNP are not the ones generally considered to be the most common. It is possible, however, that some or all of the unrecorded congeners could also be present in WWNP.

Below is a short list of additional species which, in the author's opinion, are among the most reasonable candidates to be found in WWNP, at least in small numbers. The list attempts to take account of the author's experience in neighboring mountain areas

including the Ru'us al-Jibal (Feulner 2011), the highlands of Jebel Qitab and the surrounding watersheds of Wadi Hayl, Wadi Hiluw, Wadi al-Iyeli and Wadi Sfai (El-Keblawy 2011, Feulner 2014), and the ultrabasic mountains in the Hatta area and southwards, as well as general floral accounts for the UAE and Northern Oman. However, any such list is inevitably somewhat arbitrary, and other prospective species could also be suggested.

- *Cenchrus* spp. (Poaceae): *Cenchrus* spp. were collected intermittently during the course of the survey, and the spikelets were examined in the field or laboratory, but all proved to be *C. ciliaris*. However, *C. pennisetiformis* and *C. setigerus* have been recorded by others, including from the mountains of the East Coast (Jongbloed 2003, El-Keblawy 2011), and could therefore be present in WWNP.
- *Cleome brachycarpa* (Capparaceae): This species is locally common along the plains of the East Coast, as shown in Jongbloed (2003) (although contrary to what is stated in Jongbloed (2003), it does not favor limestone outcrops, which are not found on the East Coast). In January 2013, during the course of the survey, *C. brachycarpa* was common on the irrigated gabbro hillside above Suwaifah Park on the northern outskirts of Khor Fakkan town, only *ca.* 5 km from the mouth of Wadi Wurayah. It is possible that this species may depend on relatively mesic conditions, including above average rainall. *C. brachycarpa* is also found locally among ultrabasic rocks (harzburgite) in the mountain foothills of Al-Fay, Oman, near Hatta, UAE (as also shown in Jongbloed (2003)), but there it is associated with freshwater springs and outcrops of tufa, a carbonate rock precipitated by the reaction between the highly alkaline groundwater in the ultrabasic rock and atmospheric CO_2.
- *Convolvulus prostratus* (Convolvulaceae): This spreading ruderal species is found in waste ground on the East Coast and could occur within WWNP, especially in or near the buffer zone on the eastern margin.
- *Cosentinia vellea* (= *Cheilanthes vellea*) (Pteridaceae): Elsewhere in the UAE and Northern Oman, this fern species is more or less sympatric with *Cheilanthes acrostica*, which has already been recorded in WWNP. If *C. vellea* is not found within WWNP, then the chemistry of the ultrabasic rocks could be the explanation.
- *Dichanthium annulatum* (Poaceae): This species, which the author has never knowingly encountered, is nevertheless mapped by Jongbloed (2003) as widespread but not common over most of the northern UAE, including mountain areas, and it was recorded by El-Keblawy (2011) in Wadi Hiluw.
- *Eliocharis geniculata* (Cyperaceae): This delicate sedge is typically found at the margins of shallow pools and on adjacent damp ground. It would be reasonable to expect it in the area of the Wadi Wurayah waterfall and perhaps at selected pools in upstream areas.
- *Erodium laciniatum* (Geraniaceae): Consistent with the baseline survey results, Western (1989) found *E. neuradifolium* to be the most common mountain *Erodium*. However, Jongbloed (2003) has mapped *E. laciniatum* in mountain areas in the UAE. Patzelt, in Ghazanfar (2007), reports *E. laciniatum* from lower elevations (20-500 meters) in Northern Oman and the Musandam region, and considers it more commonly collected than other *Erodium* spp. If it proves not to be present in WWNP, the ultrabasic environment may be the most likely explanation. (See also Observation 11 below.)

- *Geranium mascatense* (Geraniaceae): This species has generally been reckoned the most common of the *Geranium* species in the Hajar Mountains (Western 1989, Jongbloed 2003, Karim & Fawzi 2007), so it would be curious if (as so far appears) it is absent in WWNP, given that its two local congeners (*G. biuncinatum* and *G. trilophum*) are present. However, during the period of the baseline survey, *G. mascatense* was collected in a wadi on the slopes of Jebel Qitab, in gabbro bedrock southwest of Fujairah city, where it was the only *Geranium* species identified. This suggests that it could prove to be another species that is intolerant of the ultrabasic environment of WWNP. (See also Observation 11 below.)
- *Linaria* spp. (Scrophulariaceae): *L. simplex* and *L. tenuis* have both been recorded from mountain areas of the UAE (Jongbloed 2003, Karim & Fawzi 2007, El-Keblawy 2011, Feulner 2011), but both are diminutive annuals that could easliy escape notice.
- *Nanorrhinum ramosissimum* (Scrophulariaceae): This species is very similar to *N. hastatum* and could have been overlooked. Both have similar flowers but both are otherwise variable in appearance and habit. Geographically, *N. hastatum* is a species of northeast Africa and Arabia (Boulos 2002), whereas the principal range of *N. ramosissimum* is in Iran, Afghanistan and Pakistan (Nasir & Rafiq 1995). This raises at least the possibility that the two species may yet be synonymized, based on investigations from the area where they "meet", in the Hajar Mountains of the UAE. There is precedent for this result in the recent synonymization by Norbert Kilian of two Asteraceae pairs having analogous distribution patterns, *Helichrysum glumaceum* and *H. makranicum*, and *Phagnalon schweinfurthii* and *P. viridifolium* (Feulner 2011).
- *Pulicaria arabica* (Asteraceae): This spreading species is typically found on damp ground at the margins of shallow pools. It would be reasonable to expect it in the area of the Wadi Wurayah waterfall and at pools in upstream areas.
- *Sisymbrium irio* (Brassicaceae): This species is very similar to *S. erysimoides*, which is occasional within WWNP, usually at shaded or sheltered sites among other annuals. *S. irio* was mapped by Jongbloed (2003) throughout the Hajar Mountains of the UAE, but as "uncommon". In the course of the baseline survey, in most instances no attempt was made to distinguish between the two *Sisymbrium* spp., but the occasional fruits that were examined all appeared to be *S. erysimoides*. However, both species were recorded from Wadi Hiluw by El-Keblawy (2011). *S. erysimoides* was found there in both natural habitats and plantations; no habitat information is given for *S. irio*.
- *Stipagrostis* spp. (Poaceae): Western (1989) and Jongbloed (2003) both mapped *Stipagrostis plumosa* throughout the mountains of the East Coast, including the Ru'us al-Jibal, and El-Keblawy (2011) has recorded it from Wadi Hiluw. Feulner (2011) recorded *S. raddiana* (= *S. paradisea*) from higher elevations in the Ru'us al-Jibal, based on determinations by the late Prof. Hildemar Scholz. The field appearances of *S. hirtigluma* and *S. raddiana* are very similar. *S. ciliata* is distinctive in appearance and is locally common in the Hajar Mountains in the Mahdhah area of Northern Oman. The author is aware of no actual determinations of material collected from WWNP other than the multiple determinations of *S. hirtigluma* made in the course of the baseline survey, but any of the above-mentioned *Stipagrostis* spp. could possibly occur. (See also Observation 11 below.)

- *Tribulus* spp. (Zygophyllaceae): Both *T. parvispinus* and *T. pentandrus* are prostrate or spreading species similar in appearance to *T. terrestris*, and are difficult to distinguish when not in fruit (Western 1991, Jongbloed 2003). *T. parvispinus* has been recorded from the East Coast of the UAE and *T. pentandrus* has been recorded from the UAE mountains generally. Prostrate *Tribulus* plants found during the course of the baseline survey were regularly examined. All plants found in fruit were determined to be *T. terrestris* and no plants were found which appeared inconsistent with *T. terrestris*.

Finally, the silt accumulations found for *ca.* 1-2 kilometers in the basin and wadi bed above the Wadi Wurayah dam constitute an environment that could be colonized by a number of species not normally found in the mountain environment, especially ruderal ones. Similar but less extensive silt accumulations on gravel banks at Tennis Club Dam, on the outskirts of Fujairah, host, e.g., *Amaranthus viridis*, *Portulaca oleracea* and *Tephrosia nubica* (for the latter, this is believed to be the northernmost record in the region). *Amaranthus albus* and *Emex spinosa* are additional examples of species that might occur opportunistically in the alluvial silt environment, although both appear to be rare on the East Coast. *Corchorus depressus* is another such species, and was recorded from a single silted, bulldozed terrace site in lower Wadi Ghayl.

11. The relative abundance of certain congeneric species must be reassessed, at least within the ultrabasic mountain environment.

For several plant genera represented in the UAE by multiple species, the species found to be the most common within WWNP were previously considered to be uncommon:

- *Digitaria* (Poaceae): All of the widespread, scattered specimens of *Digitaria* collected within WWNP are believed to be *D. nodosa*, consistent with the historical record of that species from Wadi Wurayah (by Curtis, 03/1998), which, however, remains the only prior UAE record. *D. nodosa* is an extremely variable species and specimens collected during the baseline survey exhibit the full range of variation, but with a few consistent features. Spikelets of *D. nodosa* and other potentially relevant *Digitaria* species (*D. ciliaris*, *D. sanguinalis* and *D. velutina*) are depicted rather differently in illustrations in Boulos (2004) and Cope (2007), but keys in both of those references encourage primary reliance on the gross form of the plant, *D. nodosa* being distinguished as an erect, tufted perennial without rhizomes. Cope (2007) is expressly skeptical of UAE and other Arabian records of *D. sanguinalis* but he also maps the only published record of *D. ciliaris* from the UAE's East Coast.
- *Erodium* (Geraniaceae): All collected specimens of *Erodium* spp., determined by examination of the fruiting parts, proved to be *Erodium neuradifolium*, not *E. laciniatum*, although the latter is considered by recent authors to be the most common *Erodium* species (Jongbloed 2003, Patzelt writing on Geraniaceae in Ghazanfar 2007). However, Western (1989) regarded *E. neuradifolium* as "Common in mountains at all elevations; occasional along east coast slopes".
- *Geranium* (Geraniaceae): Field identifications and collected specimens of *Geranium* spp., likewise determined by examination of the fruiting parts, proved to be predominantly *Geranium biuncinatum*, with two collections of *G. trilophum*. *G. muscatense*, which has heretofore been treated as the most common *Geranium* species in the UAE (Jongbloed 2003, Karim & Fawzi

2007) was not recognized within WWNP, although it was collected during the period of the survey on the slopes of Jebel Qitab, in gabbro bedrock, southwest of Fujairah city.

- *Stipagrostis* (Poaceae): All collected specimens of *Stipagrostis* spp. from WWNP, and all of the many *Stipagrostis* specimens that were examined in the field, proved to be *Stipagrostis hirtigluma*. Previously *S. plumosa* had been reckoned to be the predominant *Stipagrostis* species and was mapped as present in the UAE mountains by Western (1989) and Jongbloed (2003). Jongbloed (2003) mentioned records by others of *S. hirtigluma* "from the southern Hajar Mountains".

It is possible that the distribution of some of the above congeners may be influenced by the presence or absence of ultrabasic bedrock (see Observation 9.4 above), but this has not yet been investigated in detail.

12. A number of species flowered in winter in response to fall rains, ignoring low temperatures.

A number of species, both annuals and perennials, flowered in winter, evidently in response to fall rains, ignoring relatively low temperatures. This phenomenon was observed both in Wadi Zikt in mid-January 2012 and in Wadi Wurayah in January 2013. In most cases this meant that flowering occurred somewhat earlier than the generally recognized flowering period for the concerned species, as set out in Jongbloed (2003), Ghazanfar (2003, 2007) and Karim & Fawzi (2007).

Among the species recorded in flower in January 2013 and January 2014 were the following:

Annuals

Anagallis arvensis
Arnebia hispidissima
Asphodelus tenuifolius
Cleome rupicola
Cuscuta planifora
Eragrostis cilianensis
Erodium neuradifolium
Euphorbia arabica
Lotononis platycarpa
Nanorrhinum hastatum
Ophioglossum polyphyllum
Plantago spp.
Polygala erioptera
Rumex vesicarius
Sisymbrium erysimoides
Tribulus terrestris

Perennials

Aerva javanica
Aizoon canariense
Andrachne aspera
Boerhavia elegans
Cenchrus ciliaris
Convolvulus virgatus
Desmidorchis arabicus
Haplophyllum tuberculatum
Heliotropium brevilimbe
Leucas inflata
Periploca aphylla
Salvia macilenta
Tricholaena teneriffae

13. The survey emphasizes the ephemeral nature of even some very common annual species, with implications for floral assessments.

Timing is everything, especially for many annual species. This is a simple but very important statement that is emphasized by the survey results. A few examples will illustrate the point.

The dock *Rumex vesicarius* (Polygonaceae) was hyperabundant in January through March 2012. In many places it dominated the overall impression of the wadis and wadi slopes, in terms of color and vegetative cover. But by June, only occasional dried plants were seen, and it was possible to overlook it.

Silene austro-iranica (Caryophyllaceae) is an erect but wispy annual that rolls up its petals during the heat of the day. It is not conspicuous at a distance but was common underfoot in many habitats by early March 2013 and a few were still in flower through early June 2013. Yet it would be possible to walk the wadis for most of the rest of the year without seeing it at all.

Finally, the compact Adder's Tongue fern *Ophioglossum polyphyllum* (Ophioglossaceae) was seen only in December 2012, dotting small silted plots on a gravel terrace above the waterfall area, where it may reflect ancient cultivation. In more than twenty years, the author had never before seen this species, and when the site was re-visited in March 2013, there was no trace of it.

14. No invasive plant species were recorded within WWNP.

No exotic species, invasive or otherwise, were encountered at wild sites within WWNP, notwithstanding the large scale introduction of dry-adapted exotic plants for landscaping in the UAE as a whole over the past 40 years, including the East Coast. This may be an oblique tribute to the rigors of the local environment.

In particular, the introduced mesquite tree, *Prosopis juliflora*, the only UAE plant species generally regarded as invasive in natural environments, was not recorded within WWNP, although it has spread extensively on the sand and gravel plains and waste ground of the East Coast, bordering the mountains. *P. juliflora* is now considered a pest species in many countries where it has been introduced, including Oman, but eradication efforts have generally not proven successful. With respect to its status in the UAE, the view has been expressed that, at this point, *P. juliflora* has already spread to all places where it can thrive (A. El-Keblawy, *pers. comm.*). If so, then only significant disturbance of the environment within WWNP would pose a threat from this invader.

Four exotic species have been recorded as isolated specimens in the area of the Wadi Wurayah waterfall. Three of them are edible fruit or vegetable species – watermelon *Citrullus lanatus*, tomato *Solanum lycopersicum* and mango *Mangifera indica* – and one is an Asian landscaping or amenity species (the 'peepul' tree *Ficus religiosa*) found only rarely in older urban areas of the UAE. The mango and peepul are both large trees when mature, but in WWNP they were seen only as seedlings, both growing on the edge of a cemented channel just above the waterfall, and in almost exactly the same place, although several years apart. *M. indica* was encountered only in summer 2009; two large glossy leaves had sprouted from a mango pit that had been scraped clean and discarded by picnickers. The *F. religiosa* was present throughout most of the baseline survey; it had a substantial woody rootstock but did not appear to

have increased in size. However, it was not seen following a flash flood in early November 2014.

A few additional watermelon plants were found on fine gravel beside the lower road crossing in Wadi Ghayl. The area was used as a parking place during several baseline survey excursions and it is possible that other visitors, including picnickers, may also have made use of the same convenient location.

Several of the other species found only in the waterfall area, or at pull-off areas along the paved road leading to it, can be considered 'indigenous exotics' – i.e., native species that have somehow been transported to WWNP from their customary environments within the UAE. Most likely this has been by human agency, but most likely, too, it has been inadvertent, probably by vehicles traveling quickly and effortlessly from one environment to another. The best example is the large shrub of *Leptadenia pyrotechnica* on a visitor-friendly gravel plain along the access road; another much smaller plant was subsequently discovered in a wadi bed nearby.

Other examples of indigenous exotics include *Dichanthium foveolatum*, *Launaea procumbens*, *Physalis minima* and *Sporobolus spicatus*. *Campanula erinus* and *Lotus schimperi* are much less common and less likely to be encountered by people and vehicles. They are perhaps more likely to have arrived at the waterfall area by natural means and thrived in the anthropogenic environment. In any case, there is no evidence that any of the above species have spread or will spread within WWNP.

Two conspicuous species that have arguably proliferated to the point of inconvenience are the tall reed *Arundo donax* (in Waterfall Wadi) and the ground melon *Citrullus colocynthis* (in the area behind the dam), but these species cannot be regarded as invasive. They are simply colonizing habitat for which they are specialized, at a time when conditions are favorable. The author has visited Waterfall Wadi on several occasions since the mid-1980s and has found the reed population (*Arundo donax*) to be variable. It had not, until December 2012, proved to be a serious impediment to passage.

Wadi Ghulayyil Khun occupies most of the buffer zone along the eastern edge of WWNP and debouches directly onto the coastal plain on the outskirts of an area of mixed agriculture and the industrial fringe of modern Bidiyah. It has a waste dump and a modest dam at its mouth, and another dam ca. 2 km upstream. As noted above in Observation 5, this wadi was visited in the expectation that it would host several anthropophilic species (including possible invasives) not found elsewhere in WWNP, but that was not the case.

15. Evidence of browsing within WWNP is limited and largely restricted to tributaries of lower and mid-Wadi Ghayl.

Evidence of browsing was extremely limited throughout most of the areas surveyed, consistent with the rather small number of free-ranging browsers (mostly feral goats) observed during the course of the survey. A total of twenty (20) feral goats were sighted during the course of the baseline survey, almost all of them on slopes in the upper reaches of Wadi Wurayah and Wadi Murtaqam in the southern portion of WWNP, and goat dropping were generally rare. Similarly, only 12 feral donkeys were

observed, all within the WWNP buffer zone in upper Wadi Siji, and eight of them not far from a plantation on the border of the buffer zone. However, donkey droppings and trail were encountered in mid-Wadi Ghayl and its tributaries, and are evidently in current use by at least a small local population. A program of camera trapping is currently underway by WWNP researchers for the purpose of a more accurate assessment of the browsing population.

A goat farm, with an average of [approximately 30-50] goats in residence, is situated near the head of a small tributary wadi along the access road to the waterfall. The farm pre-dates the creation of the WWNP protected area and has been allowed to remain. The goats graze regularly in the surrounding area, including lower Wadi Ghayl, under the supervision of a shepherd.

Otherwise, evidence of browsing seemed largely confined to (1) the uppermost ridges on the divide between Wadi Murtaqam and upper Wadi Siji; (2) mid and lower Wadi Ghayl and its tributaries, including the open plains of the Aqabat al-Kharus area; and (3) upper Wadi Ghulayyil Khun. The latter two areas feature relatively gentle terrain and are relatively accessible; browsing there is at least partly by domestic livestock (see below). The first area, however, is remote and difficult for humans and larger quadrupeds.

The impression given was that browsers may enter these areas intermittently from outside the core zone and/or outside WWNP. That impression was subsequently confirmed in the case of Wadi Ghayl and Wadi Ghulayyil Khun. The low pass from the Nimriyah area of Wadi Zikt into a tributary of mid-Wadi Ghayl has a well established animal trail with occasional donkey droppings and a clump of *sidr* trees (*Ziziphus spina-christi*) evidently used as a donkey scratching post.

A loose herd of 9 domestic goats (they did not flee from close approach) was seen in the Powerline Fork of Wadi Ghayl, near Aqabat al-Kharus, in July 2014. This herd was only very lightly supervised. A shepherd, an Asian expatriate employed by an owner from Bidiyah, was encountered *ca.* 2 kilometers away. When asked how many animals he tended and where they were, he shrugged and gestured broadly to the surrounding area. He said he visited regularly, sometimes by motorcycle, but he explained that access was also possible directly from Bidiyah by a steep trail in the upper wadi.

In Wadi Ghulayyil Khun, an unaccompanied flock of *ca.* 30 sheep was observed in the uppermost wadi in mid-December 2013, heading downstream along a defined animal trail descending from a low and relatively gentle pass (ca. 200 meters) connecting to the Bidiyah area.

Historically, only feral goats and Arabian tahr, and no feral donkeys (or donkey droppings), were observed in Wadi Wurayah above the waterfall area. The absence of donkeys probably reflects the difficult access from downstream for larger vertebrates, particularly the obstacle of the gorge and pools commencing at the head of the vehicle track in the main wadi, and similar obstacles in the waterfall wadi itself. Moreover the steep slopes and difficult access to many tributary wadis of upper Wadi Wurayah (Wadi Murtaqam) and Wadi Yushemah make that area inhospitable to feral donkeys.

Among the perennial species known to be especially susceptible to browsing are:

- *Convolvulus virgatus* (Convolvulaceae), sometimes browsed to a cushion.
- *Grewia erythraea* (Tiliaceae), a woody shrub sometimes also browsed to a cushion.
- *Hibiscus micranthus* (Malvaceae), an erect shrub which in upper Wadi Ghulayyil Khun was generally observed only where it grew within the protection of larger, unpalatable shrubs, and which was seen to be selectively browsed by sheep.
- *Phagnalon schweinfurthii* (Asteraceae), recorded only from a single WWNP location at anomalously low elevation in lower Wadi Ghayl.
- *Teucrium stocksianum* (Lamiaceae), an aromatic which has been recorded at only three WWNP locations. (Paradoxically, however, one of those locations was at the head of the Powerline Fork of Wadi Ghayl, in the Aqabat al-Kharus area, which is definitely subject to grazing.)

It should be emphasized that browsing does not seem to bear a simple relationship to plant diversity. Specifically, the tributaries of mid-Wadi Ghayl, identifed here as the principal area where evidence of browsing and the presence of browers have been observed, is also one of the areas that has been identified as having the highest levels of plant diversity (see Observation 4 above).

Recommendations for future botanical research

In addition to its obvious value from the standpoint of conscientious, data-based future management of Wadi Wurayah National Park, the baseline survey provided the occasion for a far more intensive investigation and analysis of the flora of a remote area of the Hajar Mountains than has previously been conducted. So it is perhaps not surprising that it has produced many interesting results that invite further inquiry. The questions posed for future research fall into four basic categories:

- Refinement of our understanding of the distribution of various plant species within the Hajar Mountains and elucidation of the factors that control their distribution; in particular, the identification of species that may avoid, or may be specially adapted to, the extensive ultrabasic bedrock environment of the Hajar Mountains, and the physiological adaptations that ultrabasic 'specialist' species may exhibit.
- Collection and taxonomic review of material belonging to problematic genera represented in the UAE by multiple species, to ascertain which of those species are in fact represented, and in what environments. Some genera which should be targeted in this effort are *Erodium*, *Geranium* and *Stipagrostis*.
- Additional botanical collection, during propitious conditions, with special attention to (i) grasses (Poaceae), of which it is reasonable to expect that at least a small number of additional species will be added to the WWNP list, and (ii) higher elevation habitats (including possible crack-dwelling and scree-dwelling species).
- Investigation of the plant species most favored by browsing quadrupeds and the effect of browsing on those species. In the apparent absence of a significant population of feral browsers within most of WWNP, and given the extreme difficulty of observing or tracking them, an indicative proxy approach

might focus on the herds of domestic browsers occasionally found within lower Wadi Ghayl and its tributaries, particularly the Aqabat al-Kharus area.

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Gary R. Feulner
c/o Chadbourne & Parke
P.O. Box 23927

Dubai, U.A.E.
grfeulner@gmail.com