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ARABIA'S LAST FORESTS UNDER THREAT: PLANT BIODIVERSITY AND CONSERVATION IN THE VALLEY FOREST OF JABAL BURA (YEMEN)

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The isolated massif Jabal Bura (Yemen) is home to the largest area of 'valley forest' in southwest Arabia's western escarpment mountains. This study surveys the composition of this very rare forest and records the diversity of vascular plant species. It notes the valley forest as the home of several regionally rare species and records new locations for these taxa. A brief analysis of the canopy layer is provided, enabling comparisons with similar vegetation in northeast Africa. The paper discusses the importance of this regionally rare vegetation as well as threats to its conservation.

Keywords. Arabia, conservation, evergreen forest, rare species, valley forest, Yemen.

INTRODUCTION

Located in the southwest corner of the Arabian Peninsula, the western escarpment mountains of Yemen are home to forests – a rare habitat in the Arabian Peninsula. The valley forest (Wood, 1997) of the western escarpment mountains in Yemen is dominated by a dense evergreen canopy of mature trees reaching 30 m. Scholte *et al.* (1991) and Wood (1997) described the vegetation as a dense forest type, dominated by *Combretum molle* and *Terminalia brownii* (plant name authors are given in Appendix 1) and with a characteristic Sudano-Zambezian distribution pattern. It is significant, however, that several other large tree species are present in the valley forest, including *Acacia johnwoodii* and *Commiphora kataf*, both Yemeni endemics, and *Mimusops laurifolia*, a species restricted to the transition zone between the East African Afromontane and Somalia-Masai regions (Friis, 1992).

Patches of valley forest are found in isolated valleys between 500 and 1000 m on Jabal Raymah, Jabal Melhan (Milhan) and Jabal Bura (Bura'a/Bura'), in Wadi

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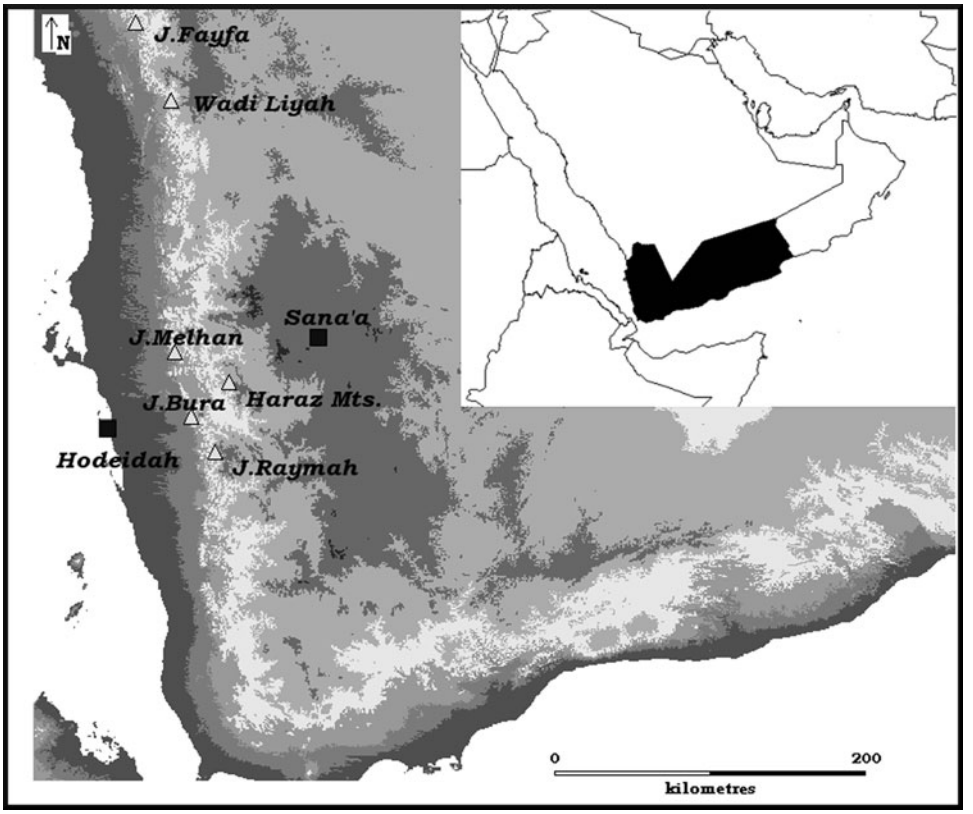

FIG. 1. The valley forest sites in Yemen and the valley forest site on Jabal Fayfa, Saudi Arabia.

Liyah in Khawlan Ash Sham and in the Haraz mountains (Wood, 1997) (Fig. 1). A much degraded site on Jabal Fayfa, on the Yemen–Saudi Arabian border, was studied by Al-Turki (2004). These valleys are characterised by a west or southwest aspect and receive locally high levels of orographic rainfall, falling in the spring and late summer. In this paper, the definition of valley forest encompasses the vegetation that occurs alongside the wadi channel, commonly termed riparian forest, but also the vegetation that is not so strongly associated with the presence of water, occurring on the lower catchment slopes. It is presumed that occurrence of winter mists in these steep sided wadi areas contributes to the occurrence of this vegetation away from the wadi channel.

The largest area of valley forest in Yemen is found on Jabal Bura. As there is little closed forest remaining on the Arabian Peninsula the valley forest habitat on Jabal Bura has recently received protected area status under Yemeni law (EPA, 2005), some time after Scholte *et al.* (1991) pleaded for its conservation. The rationale for its conservation on a national and regional scale has been to protect the closed forest habitat, a very rare habitat type in the Arabian Peninsula. There are no species that

are entirely restricted to the valley forest habitat, but it is an important site for a number of plant species that are endemic to Yemen. Another very important feature of the valley forest is the occurrence of several species which are entirely restricted to this habitat in Arabia. The majority of these have distributions centred on tropical Africa and are from tropical families (e.g. *Anacardiaceae*, *Bignoniaceae*, *Ebenaceae*, *Moraceae*, *Sapotaceae*). These restricted species distributions were first recorded by Wood (1997).

Despite their value for conservation there have been no published botanical surveys of any of the sites of valley forest in Yemen and no floristic studies have been attempted. Before the 1970s the only botanical records of the valley forest arose from collections by Forsskål and Schweinfurth on their early expeditions to Yemen. More recent descriptions of the forest are all brief and lack species lists and thorough assessments of the forest composition (Hepper, 1977; Hepper & Wood, 1979; Al-Hubaishi & Müller-Hohenstein, 1984; Scholte *et al.*, 1991; Wood, 1997). To date the most complete record of the Yemen valley forests can be found in Hall (2005).

The valley forest in Wadi Rijaf is reportedly within a disputed tribal area and until recently has been relatively inaccessible. These factors have ensured a degree of protection for the habitat and have contributed to its conservation. Unfortunately, access into the area has increased recently through the construction of a tarred road, resulting in considerable direct damage to the forest as well.

This study aimed to (i) complete the first preliminary botanical survey of the area, (ii) provide a basic description of the canopy layer, (iii) record rare or taxonomically interesting species, (iv) determine the extent of the forest and threats to its conservation, and (v) produce a checklist of the valley forest.

The overall aim of this paper is to highlight the importance of valley forest for conservation. Whilst this study is founded on the collection of field data, it will not attempt an exhaustive data analysis. This will be performed in an accompanying study to be published later.

Methods

Study site

Jabal Bura is an isolated granite massif located in Hodeidah governorate of Yemen, centred approximately on 43°26′E and 14°52′N (see Fig. 1). The most important valley forest is found between 500 and 900 m in the bottom of the Wadi Rijaf catchment, at the southern side of the mountain. Jabal Bura marks the western boundary of the western escarpment area of Yemen. The topography is mountainous and comprises a series of gorges and valleys with some of the slopes in excess of 70%. The elevation ranges from 400 m where Wadi Rijaf enters the Tihama coastal plain, up to an altitude of 2500 m.

The valley forest of Wadi Rijaf is also an important faunistic refuge. Mammal species recorded from Jabal Bura include the leopard *Panthera pardus* L. (believed to be locally extinct), the striped hyena *Hyaena hyaena* L., and the hamadryas baboon

Papio hamadryas L. An estimated 150 baboons live in the valley forest, making Jabal Bura an important site for this species in Arabia (EPA, 2005). Important reptiles include the endemic Yemen monitor lizard *Varanus yemenensis* Bohme, Joger & Schatti, the holotype of which was found a few kilometres from Wadi Rijaf (Bohme *et al.*, 1989), and the bright blue agamid lizard *Acanthocercus adramitanus* Anderson, an Arabian endemic. At least 30 resident bird species breed in the valley forest, with visiting species including the globally threatened imperial eagle *Aquila heliaca* Savigny. The designation of Wadi Rijaf as a Birdlife International Important Bird Area has formalised its value to bird conservation (Evans, 1994).

Erratic rainfall characterises the climate of the western escarpment. The general rainfall pattern is seasonal, with two rainy seasons during April–July and September–October. The high mountain causes a local build up of cloud formed from the Red Sea, resulting in orographic rainfall. On the upper slopes, low lying cloud results in a frequent fog which increases the water availability to plants at this altitude. Meteorological data in Yemen are generally of a very poor standard and there are no reliable data for the Wadi Rijaf catchment. Estimates in the field by Herzog (1998) and from our own fieldwork suggest a figure of 900–1000 mm per annum. At low elevations daytime temperatures are generally above 35°C all year round, with summer temperatures above 40°C. Night temperatures are generally above 15°C and rarely drop below 10°C. At higher altitudes corresponding temperatures are several degrees lower but frost is absent.

As the steep upper slopes of the catchment area are covered in large granite slabs, during local rainfall there is often a large amount of surface runoff towards the main wadi channels. This greatly reduces the amount of available moisture on the slopes and increases available water at the wadi side. Evidence of this can be seen by the channelling of runoff along rocks by local people for drinking water. A small stream runs steadily along the main watercourse during the rainy season, whilst only scattered pools of surface water are found in the drier parts of the year. Soils are alkaline with a pH of 8.0 and consist principally of clay and rocky debris (EPA, 2005). In the forested areas the soils are rich in humus but the topsoil depth does not exceed 30 cm.

Data collection

Field surveys were carried out between July and October 2003, April 2005 and September 2005. Short visits were also made in 1988–9, and in 2006–7. The sampling procedure took the form of 625 m^2 plots which were randomly positioned along transects through the valley forest, allowing samples to be taken within a relatively short timeframe and increasing the chances of recording all the species in an area. The vegetation relevés were concentrated on the densest area of valley forest in Wadi Rijaf, centred on 43°26′05″E, 14°52′39″N. In total, 52 relevés were conducted in the valley forest and for each it was assumed that the vegetation was uniform over the whole area.

For the purposes of this study, recording all vascular plant species in each relevé would allow a basic analysis of the tree layer in the forest and would form the basis of a checklist (Appendix 1). Each site was georeferenced and notes were taken on elevation, aspect, slope and vegetation cover. The majority of species identifications were made in the field, but in difficult cases, voucher specimens were taken and identifications took place at the Royal Botanic Garden Edinburgh. A further set of voucher specimens were deposited at the Taiz Botanic Garden, Yemen.

In addition to conducting the vegetation relevés, we collected and recorded rare species throughout the forest, with particular emphasis being placed on the species listed by Wood (1997) as being entirely restricted to the valley forest and the recording of their locations using a GPS.

Results

Valley forest in Wadi Rijaf

Upon entering the wadi catchment from the Tihama coastal plain one sees the vegetation change dramatically from a sparse covering of *Acacia* and *Commiphora* shrubs and *Indigofera* sub-shrubs to an evergreen forest dominated by tall trees. Further up the valley the canopy gradually increases in density and the trees become increasingly covered in a dense tangle of climbing species, reminiscent of a tropical rainforest. The densest area of this forest, with the tallest canopy (approximately 30 m), is found along the bottom of the wadi catchment along the general course of the wadi channel from 400 to 800 m (Fig. 2). Whilst this area of forest is clearly associated with the presence of water in the wadi, it is not restricted to a narrow band along the wadi channel. It is an area of several hectares, approximately centred on 43°26′18″E, 14°52′28″N.

Some of the largest trees to be found throughout the area are common riparian species such as *Ficus ingens*, *Ficus vasta*, *Ficus sycomorus* and *Breonadia salicina*. These reach over 25 m in height and are frequent along the wadi channel. Other common trees are *Combretum molle*, *Terminalia brownii*, *Mimusops laurifolia*, *Tamarindus indica* and *Trichilia emetica*. These form a dense canopy of trees in the valley bottom and are invariably covered in an equally dense tangle of climbing species. The parasitic climber *Cassytha filiformis* is most easily recognisable from its pale orange colour and is abundant. Other climbing species are present including *Cissus rotundifolia*, *Jasminum fluminense*, *Rhoicissus revoilii* and *Ipomoea obscura*.

Walking in the densest forest on the wadi bottom is difficult due to an almost impenetrable shrub layer in many parts. The most common shrubs include *Carissa spinarum* (syn. *C. edulis* Vahl), several *Grewia* species including *G. schweinfurthii*, *G. tembensis* and *G. villosa*, several species of *Maytenus*, *Premna resinosa* and *Teclea nobilis*. Under the densest tree and shrub cover above there is an inconspicuous ground flora. However, along the wadi channel and in forest gaps there is an abundant herbaceous layer. The most common ground species is *Selaginella imbricata*, which is a local species in Yemen. Other national rarities include

FIG. 2. The densest area of valley forest in Wadi Rijaf. At this site, along the wadi bed the closed canopy reaches 30 m and is covered in a dense tangle of climbing species.

Actiniopteris radiata, *Aneilema forskalei* and *Commelina erecta*. These most often occur in damp, sheltered micro-habitats. Nationally widespread species such as *Hibiscus deflersii*, *Indigofera spinosa* and *Ruellia patula* are also common in the valley forest understorey. Grasses such as *Dactyloctenium aegyptium*, *Digitaria nodosa* and *Aristida adscensionis* occur under gaps in the canopy. Local patches of *Phoenix caespitosa* occur in previously disturbed areas, often on abandoned terraces.

From basic observations during the fieldwork it was clear that there is not always a sharp distinction between the valley forest vegetation at the bottom of the wadi (or riverine forest) and the forest on the slopes of the catchment. This contradicts the findings of Al-Hubaishi & Müller-Hohenstein (1984). Along the first two kilometres of the track into Wadi Rijaf (from the Tihama) the slopes of the catchment are covered in an open *Acacia–Commiphora* scrub up to 5 m in height. This area is dominated by *Acacia asak*, *Acacia mellifera* and *Commiphora myrrha*. *Berchemia discolor* and *Adenium obesum* are also common. A dense shrub layer is dominated by *Grewia schweinfurthii*, *Grewia trichocarpa*, various species of *Maytenus*, *Acalypha fruticosa* and to a lesser extent *Anisotes trisulcus*. Scrambling over this scrub is the common climber *Cissus rotundifolia*. On the slopes the ground flora is relatively sparse and the most common species are *Selaginella imbricata* and *Indigofera*

spinosa. Where this vegetation extends into the valley bottom the ground flora is richer and includes *Ocimum filamentosum*, *Boerhavia repens*, as well as various grass species, for example *Tetrapogon* spp.

However, beyond two kilometres into the wadi, it is clear from basic observations that the valley forest type extends several hundred metres up the slopes. Although *Acacia johnwoodii* is common it is far from the dominant tree species as suggested by Al-Hubaishi & Müller-Hohenstein (1984). *Mimusops laurifolia*, regarded by Wood (1997) as an indicator of the valley forest, occurs here and can be locally dominant up to about 900 m. *Terminalia brownii* is one of the most common trees along with *Combretum molle*, *Euclea racemosa*, *Ficus vasta*, *Ficus sycomorus*, *Phoenix caespitosa*, *Rhus natalensis*, *Rhus retinorrhaea*, *Teclea nobilis* and *Ziziphus mucronata*. *Barbeya oleoides* and *Olea europaea* are present at higher altitudes. The shrub layer is again dominated by *Acalypha fruticosa*, *Carissa spinarum*, and several species of *Maytenus* and *Grewia*. In addition, *Dichrostachys cinerea*, *Clitoria ternata* and *Oncoba spinosa* are also important constituents of the vegetation, together with the ubiquitous climbing species *Cassytha filiformis* and *Cissus rotundifolia*. However, as altitude increases, we clearly observed that the canopy is much reduced. With increasing altitude the incidence of tall trees also falls and the shrubs become much more prominent. The vegetation cover is still very dense and varied. This is not a drought deciduous *Acacia–Commiphora* forest as suggested by Al-Hubaishi & Müller-Hohenstein (1984), but should be regarded as an extension of the valley forest (Wood, 1997).

The remaining valley forest area was estimated by plotting the 52 relevé sites into a GIS package (Globalmapper v.6) and then calculating the minimum area needed to enclose these sites. Using this basic technique we calculated that a possible 180 ha of valley forest remain in Wadi Rijaf. However, as this area includes large rocky slopes, cultivated terraces and the new road, a more realistic estimate is that (including the slopes of the catchment and the less dense areas of forest) only 80 ha remain.

Basic floristics

The 52 survey plots in Wadi Rijaf contained 159 vascular plant species, of which 24 (15%) were recorded from only one relevé[1]. A total of 129 genera and 55 families (angiosperm family delimitation follows Angiosperm Phylogeny Group, 2003) were recorded from the 52 vegetation relevés. A high number of genera are monospecific (105, or 81%) and 25 families are represented by only a single species. Only 11 families contain four or more species and only one family, *Leguminosae*, has more than 10 species. The most prominent 10 families together contribute 88 species, or 55% of the overall species total. The six most species rich families are *Leguminosae* (17 spp.), *Apocynaceae* (9 spp.), *Compositae* (9 spp.), *Euphorbiaceae* (9 spp.),

[1] The checklist of the valley forest in Wadi Rijaf contains 167 species as eight species known from the forest were not recorded.

Gramineae (9 spp.) and *Malvaceae* (9 spp.). The most frequent genera are *Ficus* (5 spp.), *Grewia* (5 spp.), *Acacia* (4 spp.) and *Indigofera* (3 spp.).

Fifty-three species (33%) were found at more than 10 relevé sites. The most prominent species are *Cissus rotundifolia* (*Vitaceae*), *Mimusops laurifolia* (*Sapotaceae*), *Acalypha fruticosa* (*Euphorbiaceae*), *Phoenix caespitosa* (*Arecaceae*), *Tamarindus indica* (*Leguminosae*), *Pavetta longiflora* (*Rubiaceae*), *Acacia asak* (*Leguminosae*), *Terminalia brownii* (*Combretaceae*) and *Cissus quadrangularis* (*Vitaceae*), *Grewia schweinfurthii* (*Malvaceae*), *Ruellia patula* (*Acanthaceae*), *Combretum molle* (*Combretaceae*) and *Carissa spinarum* (*Apocynaceae*), all of which were found in over half of the relevé sites. No species were found in all 52 relevés.

Exhaustive analysis of species richness is not the focus of this study, but basic data show that species richness in the valley forest is relatively low. The mean species richness was 28 species per plot and the range was from 11 to 48 species. The most species rich plots were located in the densest patches of valley forest and are the areas most at risk from the construction of the new road.

The growth forms exhibited by the 159 species of the valley forest in Wadi Rijaf can be split generally into the categories of trees, shrubs, herbs and grasses, climbers, succulents and ferns (including clubmosses)[2]. The forest canopy itself is made up of 35 tree species (22%), whilst 50 shrub species (31%), 52 herbs and grasses (33%), 13 climbing species (8%), five succulents (3%) and four species of fern and clubmoss (3%) make up the forest understorey. Of the 35 tree species which make up the tree layer, only 14 species (38%) were found in more than 10 of the relevé sites. In addition 11 of the tree species (31%) in the valley forest were found in fewer than five relevé sites (see Table 1).

Table 1 illustrates the mixed floristic nature of the forest trees in Wadi Rijaf. Two of the valley forest species, *Commiphora kataf* and *Acacia johnwoodii*, are Yemeni endemics. These species are widespread along the escarpment mountains in areas of high rainfall. One species, *Annona squamosa*, is an introduced species which has become naturalised along the escarpment in Yemen. Of the remaining 33 species, 18 species are widespread across tropical and southern Africa and occur predominantly in the Sudano-Zambezian 'super region' (White, 1983), across a variety of habitats, whilst five are species which have principally Somalia-Masai distributions. There are three species which are part of a small restricted element between the Afromontane and Somalia-Masai regions of northeast tropical Africa. The most prominent of these trees is *Mimusops laurifolia*, which was found in the largest number of survey plots. There are also two species in the valley forest that occur across the Sudanian and Sahelian regions of Africa.

The species-accumulation curve for Wadi Rijaf shows that the majority of species were recorded ($y = 33.7 \ln x + 30.3$, $R^2 = 0.988$). However, it must be noted that for several known reasons, the observed number of species is less than the actual number of species present. Firstly, as the vegetation relevés were conducted at

[2] Trees were defined as those plants predominantly found occupying a canopy position. Shrubs formed the woody understorey, herbs and grasses the non-woody understorey.

TABLE 1. The 35 tree species which comprise the canopy layer in the valley forest of Wadi Rijaf. A comparison of the varied distribution patterns of these species (White, 1983) indicates the mixed floristic nature of the forest

Species	Family	Plots	Distribution
Mimusops laurifolia (Forssk.) Friis	*Sapotaceae*	34	Afromontane forest and East African bushland, forming part of the transition element between Afromontane and Somalia-Masai centres of endemism
Phoenix caespitosa Chiov.	*Arecaceae*	33	Restricted to Somalia and southwest Arabia
Tamarindus indica L.	*Leguminosae*	32	Widespread in tropical and southern Africa
Terminalia brownii Fresen.	*Combretaceae*	31	Sudanian region 'Ethiopian undifferentiated woodland' and Jabal Marra woodland, Sudan
Acacia asak (Forssk.) Willd.	*Leguminosae*	31	Somalia-Masai bushland and thicket
Combretum molle R.Br. ex G.Don	*Combretaceae*	26	Sudano-Zambezian riparian woodland
Berchemia discolor (Klotzsch) Hemsl.	*Rhamnaceae*	23	Widespread in riparian woodland and dry scrub forest across Sudano-Zambezian region and Somalia-Masai centre of endemism
Ziziphus mucronata Willd.	*Rhamnaceae*	22	Riparian woodland and savannah woodland across Sudano-Zambezian region
Trichilia emetica Vahl	*Meliaceae*	18	Widespread throughout tropical and southern Africa
Commiphora kataf (Forssk.) Engl.	*Burseraceae*	18	Yemeni endemic
Ficus sycomorus L.	*Moraceae*	15	Widespread in riparian woodland across tropical and southern Africa
Ficus ingens (Miq.) Miq.	*Moraceae*	15	Guineo-Congolian East African forest belt linking species, extending into Sudano-Zambezian region
Breonadia salicina (Vahl) Hepper & J.R.I.Wood	*Rubiaceae*	12	Widespread in tropical and southern Africa in riparian woodland
Ficus exasperata Vahl	*Moraceae*	11	Guineo-Congolian East African forest belt linking species, extending into Sudano-Zambezian region
Ozoroa insignis (Del.) O.Kuntze	*Anacardiaceae*	9	High rainfall deciduous woodland and bushland throughout the Sudano-Zambezian region
Acacia mellifera (Vahl) Benth.	*Leguminosae*	9	Bushland and thicket across the Sudano-Zambezian region, Somalia-Masai bushland and Sahel region bushland and thicket
Rhus retinorrhaea Oliv.	*Anacardiaceae*	8	Evergreen bushland in Somalia-Masai region

TABLE 1. (*Cont'd*)

Species	Family	Plots	Distribution
Pistacia falcata Becc. ex Martelli	*Anacardiaceae*	8	Afromontane forest and East African bushland, forming part of the transition element between Afromontane and Somalia-Masai centres of endemism
Ficus vasta Forssk.	*Moraceae*	8	Riverine forest across the Somalia-Masai centre of endemism
Acacia johnwoodii Boulos	*Leguminosae*	8	Afromontane woodland and forest, considered an Afromontane endemic by Friis (1992)
Olea europaea L.	*Oleaceae*	7	Widespread across Africa, Arabia and Mediterranean
Annona squamosa L.	*Annonaceae*	7	Naturalised species with origins in Central America
Barbeya oleoides Schweinf.	*Barbeyaceae*	5	Afromontane forest and East African bushland, forming part of the transition element between Afromontane and Somalia-Masai regions
Balanites aegyptiaca (L.) Del.	*Zygophyllacea*e	5	Across the dry habitats of the Sudano-Zambezian region and Somalia-Masai centre of endemism
Rhus natalensis Bernh. ex Krauss.	*Anacardiaceae*	4	Somalia-Masai bushland and thicket
Celtis toka (Forssk.) Hepper & J.R.I.Wood	*Cannabaceae*	4	Widespread across tropical Africa (north of the equator) in riparian woodland
Antiaris toxicaria Lesch.	*Moraceae*	3	Widespread in African and Asian tropics to Australia
Stereospermum kunthianum Cham.	*Bignoniaceae*	2	Predominantly in Sudano-Zambezian woodland but extends into Guineo-Congolian transition woodland
Nuxia oppositifolia (Hochst.) Benth.	*Stilbaceae*	2	Sudano-Zambezian woodland and riparian woodland
Piliostigma thonningii (Schumach.) Milne-Redh.	*Leguminosae*	1	Widespread in tropical and southern Africa, mainly in woodland and wooded grassland
Maerua triphylla A.Rich.	*Capparaceae*	1	Somalia-Masai evergreen bushland and thicket
Ficus populifolia Vahl	*Moraceae*	1	Widespread across tropical Africa in riparian woodland and wooded grassland
Commiphora schimperi (Berg.) Engl.	*Burseraceae*	1	Somalia-Masai bushland and thicket
Allophylus rubifolius (Hochst.) Engl.	*Sapindaceae*	1	Woodland and bushland throughout Sudano-Zambezian region
Acacia ehrenbergiana Hayne	*Leguminosae*	1	Sahelian region grassland and Sahara regional transition zone woodland

different times of year, undoubtedly some annual herbaceous species will not have been recorded. Furthermore, the taxon recorded as *Maytenus* sp. is a species complex which is most likely made up of several species. Although there is a relatively recent revision of *Maytenus* (Sebsebe, 1985), much more work is needed in Arabia to render this complex into satisfactory species.

Endemic and rare species

During the field surveys, six Yemeni endemics were recorded from the valley forest of Wadi Rijaf. These were *Abrus bottae*, *Barleria bispinosa*, *Centaurothamnus maximus*, *Commiphora kataf*, *Euphorbia inarticulata* and *Ormocarpum yemenense*.

Wood (1997) also lists 18 species which are principally restricted in their Arabian distribution to the Yemeni valley forest habitat. Nine of these species had previously been recorded in the valley forest of Wadi Rijaf. During the survey, new records were made for three species previously unknown from the catchment: *Allophylus rubifolius*, *Nuxia oppositifolia* and *Ozoroa insignis*. Two mature trees of each species were found. Table 2 lists the distribution of the 12 regionally rare species from Wadi Rijaf. It is important to note that three of these species – *Antiaris toxicaria*, *Piliostigma thonningii* and *Stereospermum kunthianum* – are each found in only one other location. This makes Wadi Rijaf a very important site for the continuance of these species in Arabia.

Of the 12 species in Table 2, only four other rare species were recorded during this field study. Sixteen mature trees of *Antiaris toxicaria* were found throughout the densest area of valley forest, from 425 to 600 m. This was previously known in Wadi Rijaf from two collections by Wood (*Wood* 2175, K & 3288, BM). Good regeneration of *Antiaris toxicaria* was also observed. Approximately 40 trees of *Mimusops laurifolia* were found within 34 relevé sites in the densest areas of valley forest. Previously this species was known in Wadi Rijaf from only one collection by Wood (*Wood* 3291, K).

Eight trees of *Piliostigma thonningii* were noted between 567 and 774 m, in both dense and more open patches of forest. This was previously only known on Jabal Bura from a collection by Wood. Fifteen individuals (mainly juvenile) of *Stereospermum kunthianum* were found between 577 and 680 m close to the new road. Sadly, on a short visit to Wadi Rijaf in April–May 2007 we found that one of these extremely rare trees had been killed by the construction process. Although the current study is the most comprehensive survey of Wadi Rijaf to date, it failed to find two of the regionally rare species listed by Wood (1997). The absence of *Croton macrostachyus* and *Gymnema sylvestre* is notable because it may indicate a decline in habitat quality in the valley forest.

Discussion

Importance of valley forest for conservation

This study is a preliminary floristic assessment of the valley forest in Yemen's western escarpment mountains and will act as a baseline study for further work on

TABLE 2. The Arabian distribution of the 12 species found in Wadi Rijaf which are restricted to the valley forest habitat in Arabia. The paucity of remaining sites highlights the importance of both Wadi Rijaf and the other valley forest locations for the conservation of these species in the region (adapted from Wood, 1997)

Species	Family	Habit	Haraz Mts.	J. Melhan	Wadi Rijaf, J. Bura	J. Raymah	Wadi Liyah	Hujaraya	Other sites in Arabia
Antiaris toxicaria	*Moraceae*	Tree	X		X				
Triumfetta pentandra	*Malvaceae*	Herb			X	X			
Mimusops laurifolia	*Sapotaceae*	Tree	X	X	X	X			X
Piliostigma thonningii	*Leguminosae*	Tree			X	X			
Meineckia phyllanthoides	*Phyllanthaceae*	Shrub	X	X	X	X			
Croton macrostachyus	*Euphorbiaceae*	Tree			X				
Ozoroa insignis	*Anacardiaceae*	Shrub		X	X	X			
Gymnema sylvestre	*Apocynaceae*	Climber			X				
Stereospermum kunthianum	*Bignoniaceae*	Tree	X		X				
Endostemon gracilis	*Labiatae*	Herb		X	X	X			
Nuxia oppositifolia	*Stilbaceae*	Tree	X	X	X			X	X
Allophylus rubifolius	*Sapindaceae*	Tree	X	X	X	X			X

Jabal Bura. Fieldwork is needed in the other remaining areas of valley forest to allow comparative studies of all the sites of valley forest in Yemen. Surveys are also required in prospective valley forest areas on Jabal Fayfa and in the Lejib Gorge in Saudi Arabia. In the same way, survey data are needed for similar vegetation in northeast tropical Africa before floristic studies can properly assess the status of the Yemeni valley forests.

In conservation practice, endemism and species richness are considered two of the most important criteria in conservation assessment (Myers *et al.*, 2000). At a global level, the Yemeni valley forest is not particularly remarkable in either respect. The valley forest in Wadi Rijaf contains only six Yemeni endemic species and an average of 28 species per 625 m^2. However, on a national and regional level, the valley forest is an important habitat for the conservation of these six plant species that are endemic to Yemen. There are few areas of the country that are as protected, both by legislation and by topography.

Physiognomically the valley forest of the western escarpment mountains is an extremely rare habitat type, one of only two closed forests in Arabia, the other being the 'fog oasis' of Hawf/Dhofar (Miller & Morris, 1988). In Wadi Rijaf, the largest known site of valley forest in Yemen, we estimate that only 80 ha of forest remains. One of the principal features of the Yemeni valley forest is the occurrence of 12 species which are restricted in their distribution to this habitat (Wood, 1997). The majority are known from fewer than five locations, making the remaining 80 ha of forest in Wadi Rijaf vital for their persistence in Arabia. On both a national and regional level, the valley forest is important for plant conservation. It is home to both rare and endemic species and should be regarded as an Important Plant Area for Arabia (Plantlife International, 2004).

Floristically, the valley forest canopy is composed of taxa with varying distributions, with Yemeni endemic, Sudano-Zambezian, Somalia-Masai, Afromontane, widespread Afrotropical and transitional species present. There is a large number of families and genera, relative to the observed number of species, suggesting that the vegetation is principally a 'relict forest', where little evolutionary diversification has occurred since the available migration pathways between Africa and Arabia were cut (Fernandez *et al.*, 2006). Of particular interest is the occurrence of *Barbeya oleoides* and *Pistacia falcata*. In Africa these are principally Afromontane species which are found between 1200 and 2900 m, yet in Wadi Rijaf these species occur at altitudes between 500 and 900 m (Friis, 1992). *Mimusops laurifolia* is also an Afromontane forest species, which occurs between 750 and 1850 m in northeast Africa, and was found in the greatest number of valley forest survey plots between 500 and 900 m.

In the past, the valley forest of Yemen has been compared with the Sudanian woodland of White (1983), a very broad and coarsely defined vegetation type with a wide geographical range. Although Sudanian woodland contains some of the prevalent species of the Yemeni valley forests (e.g. *Terminalia brownii*, *Combretum molle*) and characteristic species (e.g. *Stereospermum kunthianum*), it lacks many other species found in the valley forests, such as *Mimusops laurifolia*, *Phoenix caespitosa*, *Acacia johnwoodii* and *Commiphora kataf*. The southwest Arabian valley forests are

also comparable with the Eritrean 'xerophilous open woodland' (Pichi-Sermolli, 1957). Whilst they contain characteristic valley forest species, such as *Combretum molle* and *Piliostigma thonningii* (Hepper & Wood, 1979), they lack *Mimusops laurifolia* and have a generally open canopy. The 'gallery forest' of Jabal Marra in the Darfur region of Sudan is also similar, particularly the gallery forest of Mortagello gorge. However, although it contains *Combretum molle*, Wickens (1976) notes that this forest is dominated by *Syzygium guineense*, *Diospyros mespiliformis* and *Phoenix reclinata*. Yemen's valley forests are also comparable with the 'riverine' forest of Friis (1992), which is another large, widespread, and very variable community. Several species found alongside the wadi channel in Wadi Rijaf also occur across areas of 'riverine forest' in northeast Africa. These include *Ficus sycomorus*, *Ficus vasta*, *Trichilia emetica*, *Tamarindus indica*, *Ziziphus mucronata* and *Breonadia salicina.*

The floristic composition of the Yemeni valley forest requires a comprehensive analytical study, which will be a future output from the data collected during the current field surveys. However, until further field surveys are completed in northeast Africa, more accurate comparisons between the Yemeni valley forest and northeast African vegetation will not be possible. Currently these different patches of African forest do not concur with the description and composition of the valley forest vegetation in Arabia. One of the most obvious differences between the Yemeni valley forest vegetation and Sudanian woodland is the strong presence of *Mimusops laurifolia* in Wadi Rijaf. At present the valley forest is best considered as a 'relict forest' which has acted as a refuge for a number of tropical African families and species, with different regional centres of endemism (White, 1983).

Threats to conservation

The most immediate threat to the preservation of this relict forest is the construction of a new tarred road through the wadi catchment. Previously access had only been possible along a rough track which was constructed into Wadi Rijaf in the 1980s. This rough and rocky road ran eastward into Wadi Rijaf for 5 km from the entrance to the Tihama at 300 m up to the hamlet of Al Maham (14°52′07″N, 43°27′06″E). Although the track was built adjacent to the watercourse and cut through the densest and richest area of forest, the narrow, difficult access ensured that visitors were partly deterred and in turn the forest was protected. In August 2004, despite the protests of the Yemeni protected area management project for Jabal Bura, construction work began to widen, upgrade and eventually asphalt the track along its entire length. The actual impact of the road is over 30 m wide in places and is generally over 15 m. With the road an estimated 5 km long, the destroyed area of this special habitat is approximately 10 ha or 13% of the remaining vegetation (Fig. 3). Sadly, this unusual Arabian habitat has been unalterably damaged by this insensitive road building process. If similar case histories in Arabia can be used as a yardstick, unless immediate action is taken the new road could signal a rapid decline and destruction of the forest along its length.

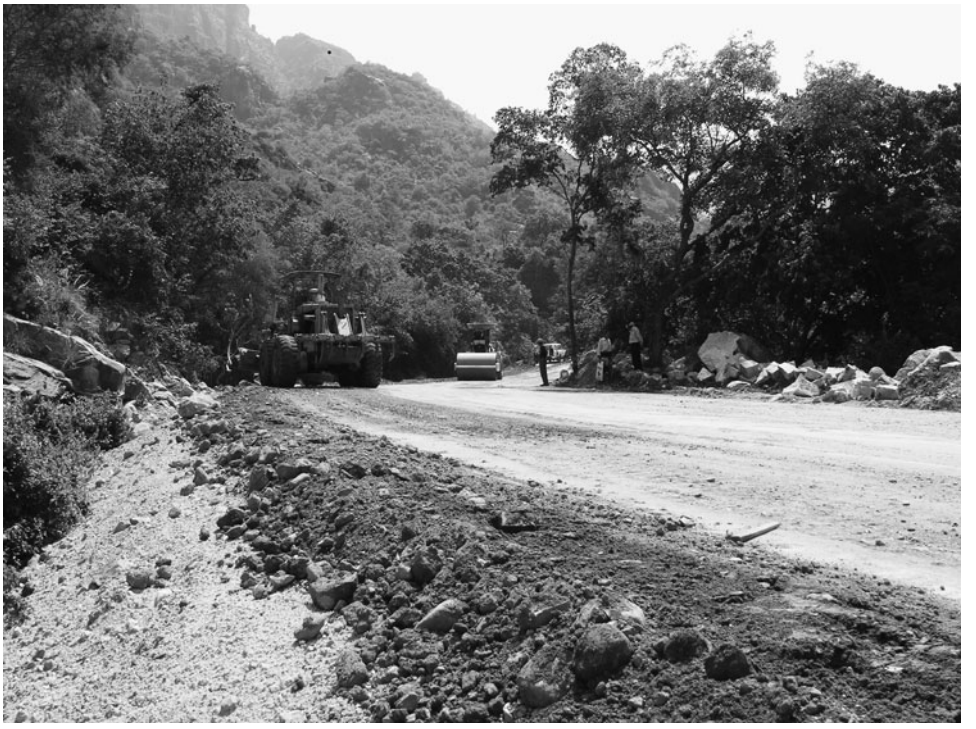

FIG. 3. The impact of the construction of a new road through the richest area of valley forest in Wadi Rijaf, Jabal Bura. It is estimated that the construction of the road has destroyed over 10% of the remaining vegetation.

In addition, natural springs have been detonated during the road construction, the loss of which can only be detrimental in an area where the abundance of water is particularly important for the continued existence of the vegetation. The diverted springs have already begun to erode the road surface. As the road surface and surrounding spoil is washed away, the wadi channel is becoming clogged, preventing the formation of semi-permanent pools. Erosion along the roadside has already been observed (Fig. 4). Furthermore there are concerns for forest regeneration due to the dumping of construction material directly in the forest. Increased access to the forest for tourists and local herders is also a potential problem. In areas where tourists have already accessed the forest there was clearly observed trampling and disturbance of the forest floor with an almost complete removal of regenerating seedlings. Although the dumping of construction spoil in the forest has damaged the vegetation, attempts to remove the debris should be avoided as they are likely to compound this problem.

The easy access into a forest area by people living on the nearby Tihama coastal plain was also observed during our field studies. The increased pressure that this will undoubtedly put on the forest resources needs to be investigated and avoided for the future survival of the valley forest in Wadi Rijaf. In particular the effect of an

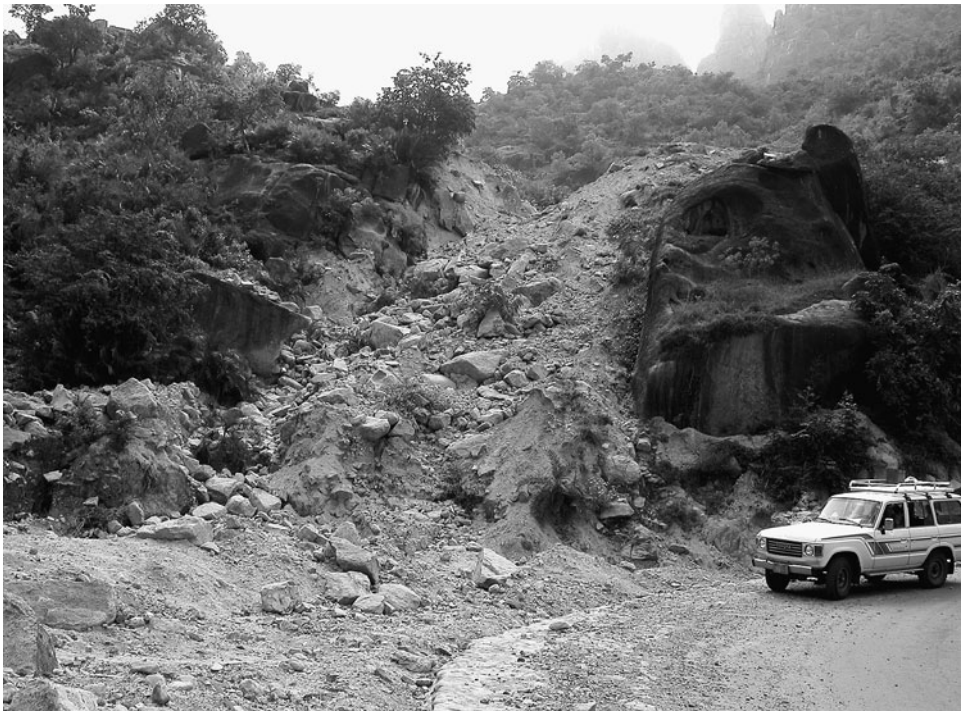

FIG. 4. An example of the erosion alongside the new road.

increased use of forest resources for fuel wood and grazing needs immediate research. New management strategies need to be devised, and these should focus on the protection of sensitive sites from disturbance, the provision of alternative resources for local people and implementing schemes which ensure that the protection of the forest has adequate local benefits. The management plan for Jabal Bura needs also to be revised to ensure adequate protection strategies are in place for this incredibly rare vegetation. From our numerous visits to Jabal Bura we suggest that field staff working in the protected area are provided with the training and resources that would enable them to physically restrict access to the densest parts of the forest. This could be simply achieved by the use of strategic natural barriers made from *Ziziphus* or *Balanites* branches, a type of barrier successfully employed by local herders. Any conservation initiatives would be greatly helped by the construction of a suitably equipped visitor centre, which could provide conservation education for the increasing number of visitors to Jabal Bura. The rarity of forest in Arabia and the occurrence of rare species need to be emphasised to ensure that all visitors understand the importance of the valley forest in Wadi Rijaf.

Of particular concern is the effect on the rare species in Table 2 of facilitating access into the valley forest. Rare species such as *Stereospermum kunthianum* are particularly at risk from the opening up of the forest by road construction and the

pressures of habitat loss, reduced regeneration and the increased use of forest resources. Any one of these factors could hasten the extinction of these species in Arabia and all need to be considered in the protection of one of Arabia's last forests.

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APPENDIX 1

Checklist of the valley forest of Wadi Rijaf

Acanthaceae
Anisotes trisulcus (Forssk.) Nees
Barleria bispinosa (Forssk.) Vahl
Barleria trispinosa (Forssk.) Vahl
Blepharis ciliaris (L.) B.L.Burtt
Ecbolium viride (Forssk.) Alston
Hypoestes forskalei (Vahl) Sol. ex Roem. & Schult.
Ruellia grandiflora (Forssk.) Blatter
Ruellia patula Jacq.

Actiniopteridaceae
Actiniopteris radiata (Swartz) Link
Actiniopteris semiflabellata Pic.-Serm.

Adiantaceae
Adiantum incisum Forssk.

Amaranthaceae
Achyranthes aspera L.
Aerva javanica (Burm.f.) Juss. ex Schult.
Amaranthus spinosus L.
Digera muricata (L.) Mart.
Pupalia grandiflora Peter

Amaryllidaceae
Pancratium maximum Forssk.
Scadoxus multiflorus (Martyn) Raf.

Anacardiaceae
Ozoroa insignis (Del.) O.Kuntze
Pistacia falcata Becc. ex Martelli

Rhus natalensis Bernh. ex Krauss
Rhus retinorrhaea Steud. ex Oliv.

Annonaceae
Annona squamosa L.

Apocynaceae
Adenium obesum (Forssk.) Roem. & Schult.
Calotropis procera (Aiton) W.T.Aiton
Caralluma penicillata (Deflers) N.E.Br.
Carissa spinarum L.
Gomphocarpus fruticosus (L.) W.T.Aiton
Gymnema sylvestre (Retz.) R.Br. ex Schult.
Kanahia laniflora (Forssk.) R.Br.
Leptadenia arborea (Forssk.) Schweinf.
Sarcostemma viminale (L.) R.Br. s.l.

Arecaceae
Phoenix caespitosa Chiov.

Asparagaceae
Asparagus africanus Lam.
Asparagus racemosus Willd.

Aspleniaceae
Asplenium sp.

Barbeyaceae
Barbeya oleoides Schweinf.

Bignoniaceae
Stereospermum kunthianum Cham.

Boraginaceae
Ehretia cymosa Thonn.
Ehretia obtusifolia Hochst. ex DC.

Burseraceae
Commiphora kataf (Forssk.) Engl.
Commiphora schimperi (Berg.) Engl.

Cactaceae
Opuntia dillenii (Ker-Gawl.) Haw.

Cannabaceae
Celtis toka (Forssk.) Hepper & J.R.I.Wood

Capparaceae
Cadaba farinosa Forssk.
Maerua triphylla A.Rich.

Celastraceae
Maytenus sp.

Combretaceae
Combretum molle R.Br. ex G.Don
Terminalia brownii Fresen.

Commelinaceae
Commelina benghalensis L.
Commelina forskalaei Vahl

Compositae
Centaurothamnus maximus (Forssk.) Wagenitz & Dittrich
Kleinia odora (Forssk.) DC.
Launaea massauensis (Fresen.) Sch.Bip. ex O.Kuntze
Psiadia punctulata (DC.) Vatke
Pulicaria jauberti E.Gamal-Eldin
Reichardia tingitana (L.) Roth
Senecio sp.
Tarconanthus camphoratus L.
Tridax procumbens L.

Convolvulaceae
Evolvulus alsinoides L.
Ipomoea obscura (L.) Ker-Gawl.
Seddera arabica (Forssk.) Choisy

Cyperaceae
Cyperus amauropus Steud.
Cyperus conglomeratus Rottb.

Ebenaceae
Euclea racemosa Murr

Euphorbiaceae
Acalypha fruticosa Forssk.
Acalypha lanceolata Willd.
Croton macrostachyus Hochst. ex Delile
Euphorbia agowensis Hochst. ex Boiss.
Euphorbia hirta L.
Euphorbia inarticulata Schweinf.
Jatropha curcas L.
Ricinus communis L.
Tragia pungens (Forrsk.) Müll.Arg.

Gramineae
Aristida adscensionis L.
Arthraxon sp.
Arundo donax L.
Brachiaria chusqueioides (Hack.) W.D.Clayton
Chloris mensensis (Schweinf.) Cufod.
Cynodon dactylon (L.) Pers.
Dactyloctenium aegyptium (L.) Willd.
Dactyloctenium scindicum Boiss.
Digitaria nodosa Parl.
Eragrostis papposa (Roem. & Schult.) Steud.
Tetrapogon sp.

Labiatae
Endostemon gracilis (Poir.) M.Ashby
Endostemon tenuiflorus (Benth.) M.Ashby

Micromeria imbricata (Forssk.) C.Chr.
Ocimum filamentosum Forssk.
Ocimum forskolei Benth.
Otostegia fruticosa (Forssk.) Briq.
Premna resinosa (Hochst.) Schauer

Lauraceae
Cassytha filiformis L.

Leguminosae
Abrus bottae Deflers
Acacia asak (Forssk.) Willd.
Acacia ehrenbergiana Hayne
Acacia johnwoodii Boulos
Acacia mellifera (Vahl) Benth.
Cadia purpurea (Picc.) Aiton
Cassia occidentalis L.
Cassia sophera L.
Clitoria ternata L.
Dichrostachys cinerea (L.) Wight & Arn.
Indigofera oblongifolia Forssk.
Indigofera spiniflora Hochst. & Steud. ex Boiss.
Indigofera spinosa Forssk.
Ormocarpum yemenense Gillett
Piliostigma thonningii (Schumach.) Milne-Redh.
Tamarindus indica L.
Tephrosia uniflora Pers.

Lythraceae
Woodfordia uniflora (A.Rich.) Koehne

Malpighiaceae
Caucanthus edulis Forssk.

Malvaceae
Corchorus triocularis L.
Grewia erythraea Schweinf.
Grewia schweinfurthii Burret
Grewia tembensis Fresen.
Grewia trichocarpa Hochst. ex A.Rich.
Grewia villosa Willd.
Hibiscus deflersii Schweinf. ex Cufod.
Hibiscus vitifolius L.
Triumfetta pentandra A.Rich.

Meliaceae
Trichilia emetica Vahl

Moraceae
Antiaris toxicaria Lesch.

Ficus exasperata Vahl
Ficus ingens (Miq.) Miq.
Ficus populifolia Vahl
Ficus sycomorus L.
Ficus vasta Forssk.

Nyctaginaceae
Boerhavia repens L.
Commicarpus helenae (J.A.Schultes) Meikle
Commicarpus plumbagineus (Cav.) Standl.

Ochnaceae
Ochna inermis (Forssk.) Schweinf.

Oleaceae
Jasminum fluminense Vell.
Jasminum grandiflorum L.
Olea europaea L.

Oxalidaceae
Oxalis corniculata L.

Passifloraceae
Adenia venenata Forssk.

Phyllanthaceae
Flueggea virosa (Roxb. ex Willd.) Voigt
Meineckia phyllanthoides Baill.
Phyllanthus tenellus Müll.Arg.

Polygalaceae
Polygala sp.

Portulacaceae
Portulaca quadrifida L.

Rhamnaceae
Berchemia discolor (Klotzsch) Hemsl.
Sageretia thea (Osbeck) Johnst.
Ziziphus mucronata Willd.

Rubiaceae
Breonadia salicina (Vahl) Hepper & J.R.I.Wood
Pavetta longiflora Vahl
Tarenna graveolens (S.Moore) Bremek.

Ruscaceae
Sansevieria forskaliana (Schult.f.) Hepper & J.R.I.Wood

Rutaceae
Teclea nobilis Delile

Salicaceae
Oncoba spinosa Forssk.

Sapindaceae
Allophylus rubifolius (Hochst.) Engl.
Dodonaea viscosa (L.) Jacq.

Sapotaceae
Mimusops laurifolia (Forssk.) Friis

Selaginellaceae
Selaginella imbricata (Forssk.) Spring
Selaginella yemensis (Swartz) Spring

Stilbaceae
Nuxia oppositifolia (Hochst.) Benth.

Verbenaceae
Priva tenax Verdc.

Vitaceae
Cissus quadrangularis L.
Cissus rotundifolia (Forssk.) Vahl
Rhoicissus revoilii Planch.

Zygophyllaceae
Balanites aegyptiaca (L.) Delile
Tribulus terrestris L.