Journal of Threatened Taxa

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ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

Communication

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26 February 2018 | Vol. 10 | No. 2 | Pages: 11271–11284
10.11609/jott.3611.10.2.11271-11284

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 February 2018 | 10(2): 11271–11284

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Vascular plant assemblage of cliffs in northern Western Ghats, India

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ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

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Abstract: Vertical rocky cliffs, which consist of various types of rock, are widespread all over the world. India's northern Western Ghats consisting of basaltic rocks form probably the largest cliff ecosystem globally, however, almost no studies are available concerning their floristic richness. In an attempt to understand the vascular plant assemblage of this habitat, cliffs of the northern Western Ghats were surveyed for their microhabitats, species diversity, distribution of endemics, occurrence of particular adaptive traits and potential threats. A total of 102 species of vascular plants were documented from the cliff habitats of which 55 are endemic. Flowering of the species on cliffs is triggered by the advent of the south-west monsoon and peak flowering is seen between August and October. Of the total species, 27 grow exclusively on cliffs. Owing to habitat specificity, cliffs show a greater number of narrow endemic and threatened species when compared with other habitats like deciduous, evergreen and semi-evergreen forests, which are widespread in the northern Western Ghats. Unfortunately, this habitat faces threats in the form of landslides, periodic burning and habitat loss due to road-widening.

Keywords: Cliff ecology, endemic species, vertical cliffs, Western Ghats.

DOI: http://doi.org/10.11609/jott.3611.10.2.11271–11284

Editor: N.P. Balakrishnan, Coimbatore, India. **Date of publication:** 26 February 2018 (online & print)

Manuscript details: Ms # 3611 | Received 30 June 2017 | Final received 15 February 2018 | Finally accepted 18 February 2018

Citation: Datar, M.N. & A.V. Watve (2018). Vascular plant assemblage of cliffs in northern Western Ghats, India. *Journal of Threatened Taxa* 10(2): 11271–11284; http://doi.org/10.11609/jott.3611.10.2.11271-11284

Funding: Agharkar Research Institute In-house grant BOT 15 for MND and self-funded by AW.

Competing interests: The authors declare no competing interests.

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Author Contribution: MD and AW did field work and wrote the manuscript.

Acknowledgements: We are thankful to the Director Agharkar Research Institute, Pune for facilities and encouragement. We are also thankful to the authorities of BSI and GU for granting us permission to check herbarium specimens. We thank Dr. Karthick Balasubramanian and Dr. Sanjay Molur for their critical suggestions on the manuscript and Dr. Stefan Porembski, Rostock University, Germany for fruitful discussions.

INTRODUCTION

The Western Ghats form a mountain range that runs parallel to the western coast of India from 8.318889^{0}N to 21.27333^{0}N for more than 1,600km. Together with Sri Lanka it is one of the 34 biodiversity hotspots designated based on high species endemism and also high degree of threat due to habitat loss (Myers et al. 2000). The region has diverse habitats ranging from dense tropical forests to sholas, swamps and rocky outcrops supporting endemic flora and fauna. The entire range is an important watershed area with many hill streams and river valleys formed by deep weathering. The weathering has given rise to hills with steep slopes, tall cliffs and flat or conical mountain tops (Images 1 & 2).

The Western Ghats are of igneous origin and geomorphologically the range is actually the western escarpment of the Deccan Plateau formed by volcanic eruption between 60 and 68 million years ago. The Western Ghats go down steeply to the coastal plains on the western side, but towards the east, they merge gently through a series of hills or spurs with the Deccan Plateau (Gunnell & Radhakrishna 2001).

Based on the parent rock, the Western Ghats can be separated into two sections. The south of the river Kali in Karnataka (15^{o}N), is the region of Precambrian archean crystalline rocks. The hills have rounded tops and they rise to 2,000m or more. This section, known as the southern Western Ghats is rich in arboreal diversity sheltered by dense evergreen forests. North of the Kali River is the Deccan trap country having relatively fragile rocks with hills not rising beyond 1,650m and having flat hill tops showing outcroppings of laterite and basalt (Gunnell & Radhakrishna 2001). Pascal (1988) describes this section as the northern Western Ghats (henceforth referred to as NWG), which has a high annual rainfall (3,000–4,000 mm) but a longer dry period (almost 8 months) as compared to the southern and central Western Ghats (rainfall above 5,000mm and almost 4 dry months). Strong seasonality together with typical geological and geomorphological features of this region have influenced the plant and animal ecology with regards to diversity of life-forms. Monsoon herbs are abundant and show higher endemism as compared to the woody endemics. The NWG comprise a large number of habitat types including forests, grasslands, and rocky outcrops. In addition to these, cliffs are also a very prominent habitat in the NWG and are seen throughout the escarpment and on the major eastern and western spurs of the NWG (Fig. 1).

Across the world, cliffs are considered as distinct habitats and studied for their biodiversity, environment, social, cultural and anthropological aspects. But little attention has been paid to the cliffs of the Western Ghats and they have not been studied in detail. The present paper addresses this gap in knowledge and attempts to give an overview of existing studies, floristic aspects and the ecological features of cliff vegetation.

Cliffs have attracted the attention of biologists, geologists and geomorphologists throughout the world. IUCN's (2014) habitat classification of the world recognizes inland cliffs as part of the general category of "rocky areas" which are generally defined as high, steep or overhanging face of rock. Though they are very distinct land forms, their spatial extension is difficult to quantify on geographical maps because of vertical surfaces. Larson et al. (2000) state that cliffs are a type of rock outcrop, having three essential elements: a level or sloping platform or plateau at the top; a pediment consisting of base-rock at the bottom; and a vertical or near-vertical part, called the cliff face or free-face in between. Cliffs usually do not form smooth walls but show crevices, caves and ledges. Talus or scree is the accumulated matter at the bottom consisting of loose rock fragments derived from the weathering of cliff. A toe is the point where the talus slope meets the pediment. Ledges are the section of cliff faces that are more or less horizontal and may have undercuts forming overhangs (Larson et al. 2000). Figure 2 shows a representative diagram of cliffs in NWG.

The degree of slope for defining the cliffs has been debatable, but is generally taken as more than 45°. Distinctness of abiotic conditions from other habitats is a characteristic of cliffs; however, similar to other rock outcrops, the microclimate of the cliffs is more extreme in terms of moisture, humidity, radiation and soil nutrient availability as compared to the surrounding landscape. According to Larson et al. (2000), vertical exposed cliffs are very dry, hot, have little or no humus and support a very limited group of species adapted to a harsh environment. The vertical nature of cliffs, however, also leads to vegetation being strongly influenced by wind and difficulty in formation and retention of soil. Coates & Kirkpatrick (1992) describe cliffs as extreme environments where plant growth is limited by the combined effects of moisture availability, light, and gravity. Light may not be a limiting factor in the case of tropical regions such as the NWG, but availability of moisture, in the cliff environments certainly varies drastically with seasonal changes. In the wet period (June–October), most cliffs in the NWG have waterfalls and hill streams that support the lush growth of seasonal

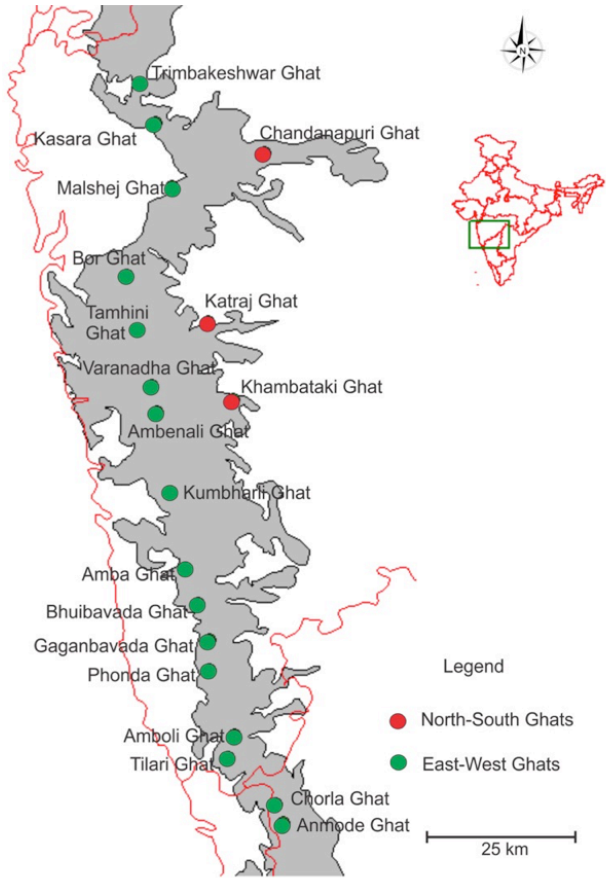

Figure 1. Locations of mountain passes in Northern Western Ghats which show predominance of cliff habitats (Map prepared using QGIS 2.16.1)

chasmophytes.

As seen from Fig. 2, cliffs include a variety of microhabitats and hence can have a diversity of plant life forms. Perennial shrubs and tree species are well established wherever humus or soil is present. The ephemeral vegetation seen during and post monsoon, however, is abundant on the cliff face, ledges and crevices. The habitat is not easily accessible, but secondary vertical cliffs faces seen along roads in mountain passes, known as "ghats" in vernacular (Marathi) also support a majority of typical elements of cliff flora. Many floristic exploratory works on various district floras of the Indian state of Maharashtra have studied vegetation of the ghats. These studies mention ghats as a habitat or location of certain species but do not give detailed information regarding microhabitat preference or adaptive features of ghat flora. Also none of them discussed the presence of specific features generally reported as life strategies for cliff species or mentioned the general floristic composition. A detailed compilation of ghat flora from the entire Western Ghats is a much-needed one.

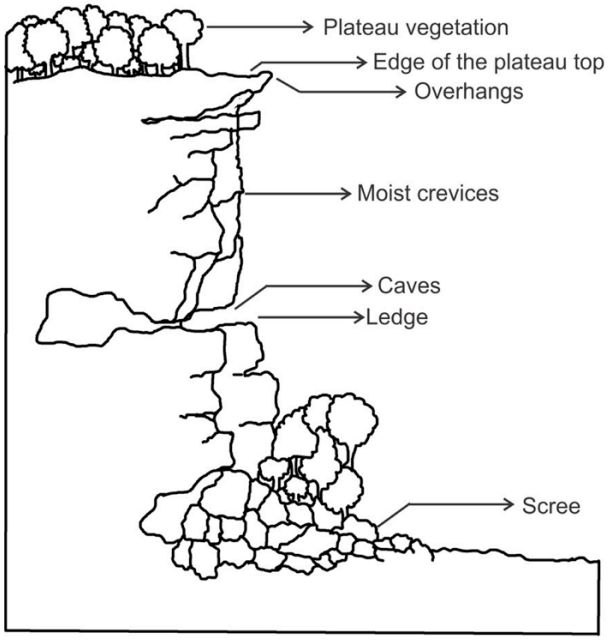

Figure 2. Microhabitats on cliffs

Ecological studies of cliff habitats in the NWG are also scarce. Bharucha & Ansari (1963) published plant associations on slopes and screes in the NWG, and included specific communities seen on steep slopes. Chasmophytic grasses of southern Western Ghats were reported by Thomas et al. (2012). Work on lithophytic grasses of Maharashtra was carried out by Gosavi (2010), which included certain cliff grasses (Image 5). These were only sporadic efforts and any exclusive review of cliff flora or vegetation ecology or autecological accounts of endemic species of this special habitat have not been published till now. Similar is the situation in the rest of India as well, where floristic literature takes cognizance of cliff as a habitat but ecological studies of cliffs have not been undertaken. Lack of baseline information on the floral composition and detailed studies on the diversity patterns on this habitat and effects of degradation are hampering the conservation efforts in the Western Ghats.

Cliffs are well studied in other parts of the world. Several researchers have contributed to our knowledge of cliff vegetation (Escudero 1996; Cooper 1997; Dimitrov & Vutov 2015; Bogges et al. 2017). Studies by Davis (1951), Wilson & Cullen (1986), Lavergne et al. (2004) are focused exclusively on cliffs, and try to bring out patterns of endemism in flora, fauna, niche requirements, habitat preferences and adaptive features. Impacts of human activities such as trekking and mountaineering on cliffs have also been studied by Nuzzo (1996). Most notable among cliff research is the review by Larson et al.

(2000), which documents biological, environmental as well as social and cultural aspects of cliff ecology. The review indicates that cliffs harbor a multitude of rare, endemic and endangered plant species and contribute substantially to regional biodiversity.

The scope of this paper, as a preliminary report is mainly to compile a list of species that primarily use cliffs as habitat in the NWG. It also discusses the microhabitats and particular plant adaptive traits, endemism, conservation significance and future research needs.

MATERIALS AND METHODS

Study area

The study was carried out in the NWG between 15° and 21°N latitudes, one-third of the total length of the Western Ghats. To understand the distribution of species in NWG, the region was divided into three parts: northern, (between 19° and 21° N), central (between 17° and 19° N), and southern (between 15° and 17° N) parts of the northern Western Ghats.

Data collection and analysis

Primary information for this paper has been collected during field studies between 2008 and 2016 in various parts of the NWG. During field work observations related to species distribution, details of microhabitats, phenology of the species and particular plant adaptive traits were made. Based on these observations a checklist of vascular plants growing on primary as well as secondary cliffs was prepared (Table 1). Primary cliffs are the natural cliffs seen in the Western Ghats while secondary ones are the man-made cliffs during construction of roads in the ghat sections. Available literature on floristic studies of the NWG especially district floras for ghats like Trimbakeshwar and Kasara (Billore 1972; Lakshminarasimhan & Sharma 1991); Malshej (Billore 1972); Bor (Santapau 1953); Tamhini & Varandha (Kothari & Moorthy 1993); Ambenali & Kumbharli (Almeida 1983–1986; Deshpande et al. 1993–95); Amba, Bhuibavda, Gaganbavda and Phonda (Kulkarni 1988; Yadav & Sardesai 2002); Amboli and Tilari (Kulkarni 1988; Almeida 1990); Sattari (Rao 1985–1986) and Anmode (Rao 1985–1986; Datar & Lakshminarasimhan 2013a&b) was consulted. Additional ecological information was collected from the specimens and field notes in the herbaria of Botanical Survey of India, Western Regional Center (BSI), Agharkar Research Institute Herbarium (AHMA) and Goa University herbarium (GU). The microhabitats of cliff plants were categorized into six major microhabitat groups (Table 1). The species were categorized as generalist (GN) and restricted (RI). Their specific adaptations for survival in cliffs were also recorded. In the checklist all the names are as per the Plant List (2013).

RESULTS

Our studies yielded a total of 102 species of vascular plants belonging to 35 families and 69 genera for the cliff flora of the main range of the NWG which pass through Sindhudurg, Ratnagiri, Kolhapur, Sangli, Satara, Pune, Nashik, Ahmednagar, Palghar and Thane districts of Maharashtra state and north and south Goa districts of Goa State. Of the total species 91 are angiosperms and 11 are pteridophytes. Although pteridophytes are less in the number of species, they can be seen as dominant members with respect to percentage cover on some cliffs. In case of some species there was not enough or accurate ecological information available from earlier floristic works to assign them conclusively to a life form category. We have categorized them based upon field observations and habit, however further research on these aspects is necessary. In the list, therophytes are represented by 54 species followed by 27 geophytes, 12 phanerophytes and nine hemicryptophytes (Fig. 3) based on Raunkiaer's classification (Cain 1950) of life forms. This is consistent with the seasonal climate of the region, which is more favorable for the growth of therophytes and geophytes.

As far as distribution of cliff species is concerned, 61 species are spread throughout the NWG while five are exclusively in the northern part of NWG, 13 in the central part of NWG and 16 in the southern part of NWG. Five species are distributed in the southern and central parts of NWG while two species in the northern and central part of NWG. Five species viz. *Kalanchoe bhidei*

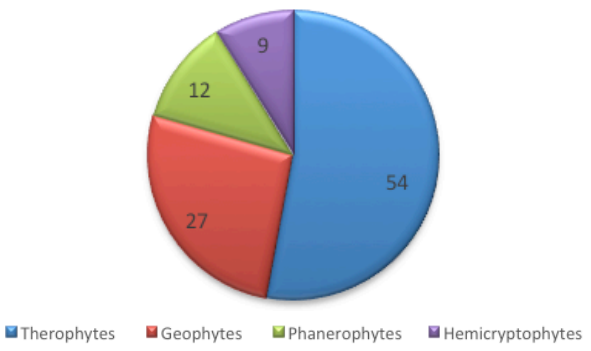

Figure 3. Distribution of various life forms in cliff flora

Cooke, *Kalanchoe olivacea* Dalzell, *Senecio edgeworthii* Hook.f., *Dyerophytum indicum* (Gibs. ex Wt.) O. Ktze. And *Chlorophytum bharuchae* Ansari et al. were found to grow exclusively on cliffs of ghats connecting north and south which are comparatively drier than the east-west ghats (Fig. 1). These hill passes are located at about 40km towards east of the main crest of the Western Ghats.

DISCUSSION

Cliffs are known to support ecologically specialized taxa. Extreme climatic conditions have made species growing on cliffs flower for a limited duration. From the phenology of the species it can be seen that flowering is triggered by the advent of the monsoon. The maximum flowering is seen between August and December when the monsoon is settled. During the monsoon mostly therophytes and geophytes flower, while post monsoon flowering is observed in phanerophytes (Fig. 4).

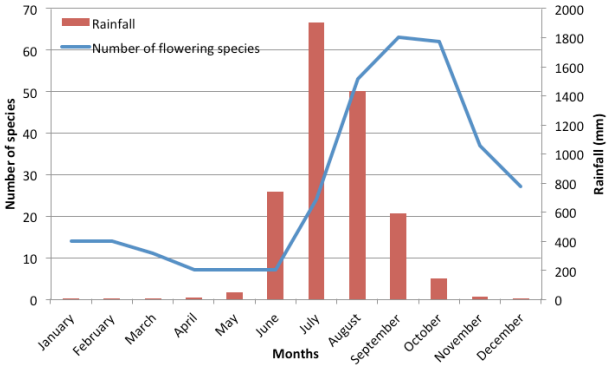

Figure 4. Seasonal changes in precipitation and flowering of cliff dwelling species (Precipitation data based on India meteorological department, Climate of Maharashtra report 2005).

Microhabitats on cliffs

All 102 plant species growing on cliffs grow in 6 major microhabitats. All these microhabitats are present on most of the cliffs, but their relative area on each cliff in various regions may differ. A brief description of the prominent microhabitats is given below:

a. Edge of the plateau tops: plateau top edges are often marked by deep crevices and fissures in the rock due to natural erosion processes. Many small or large waterfalls can be seen along the plateau edges during monsoon.

Most of the species found in this microhabitat have also been noted on plateau tops and boulders as well but they are abundant on plateau edges. Although ecological research on their habitat preference has not been carried out, these observations have been made during fieldwork and are supported by literature data. In most areas, plateau tops are heavily grazed and trampled by people as well as livestock. Some monsoon agriculture is also practiced and very often they are subject to burning during the summer for increasing the grass flush. It is possible that one or more of these processes have heavily impacted populations of these species on the plateau tops and they are thus restricted or abundant only along the edge of the plateaus.

b. Hill slopes: Slope varies between 30–60 degrees along the hill ranges of NWG. They are mostly covered with soil of varying depth formed by weathering. The vegetation cover may vary from scrub grassland to forest depending on the local land use. Very often hill slopes are burnt as part of developing secondary grasslands for cultivation where they are easily accessible to people.

c. Seasonally moist vertical rock face (MVR): exposed vertical rock with almost 90 degree inclination and devoid of soil is a classic feature of most cliffs. Geomorphologically it is termed as free face or cliff face (Image 7). In the rainy season waterfalls are present and in general water seepage is common. Here a biofilm made up by cyanobacteria, diatoms and lichens occurs. In the monsoon they are moist due to continuous trickling of water even during the gap in rain owing to the availability of water from the plateau. If a waterfall is large, the cliff face has a spray zone near waterfalls, which is also moist. Moist crevices on vertical faces can be treated under this microhabitat. Narrow cracks are often seen on vertical rock faces. These crevices have some amount of humus accumulated over the years. Water trickles continuously during the wet period (Image 3).

d. Ledges: They are sections of cliff face that are more or less horizontal and may be undercut, thus forming overhangs (Larson et al. 2000). These are step like formations due to weathering of cliff faces and look like small terraces with accumulation of soil and humus. These ledges can support phanerophytes and geophytes. Caves and overhangs are often seen and can be of varying depth. Vascular plants, however, hardly ever occur in caves.

e. Dry vertical rock (DVR): exposed vertical rock with almost 90 degree inclination and devoid of soil. DVR can be distinguished from MVR in having no trickling of water on the rocks. These rock faces are moist during the rains, but in the absence of trickling water these rocks dry up very quickly as compared to the MVR. As seen from the description, MVR and DVR are both moist

in heavy rainfall period, but the moisture lasts longer on MVR due to waterfalls or streams thus influencing the vegetation.

f. Scree: This is a well-defined habitat consisting of accumulation of large rock fragments derived from weathering of the cliff face (Larson et al. 2000). Soil of varying depth can be seen and in the absence of intensive biotic pressures, scree has dense shrub or low tree growth.

Ecological amplitude of species

For the sake of understanding we have classified plants into generalist (GN) and restricted (RI) here. Recently Kypriotakis & Tzanoudakis (2001) have categorized plant taxa occurring on cliffs into three categories (a) obligate chasmophytes, which exclusively occur on cliffs and in crevices; (b) plants that are mainly chasmophytes, occurring mostly on vertical cliffs, but occur in other habitats with lower frequency; and (c) plants that are partially or occasionally occurring on cliffs and mostly occur in other habitats.

The term generalist (GN) is used as a descriptor in Table 1 indicating that these species were also seen in habitats other than cliffs, e. g. *Delphinium malabaricum* is also seen on high altitude plateaus while *Begonia crenata* is seen on boulders in exposed or shaded areas and it grows as an epiphyte in dense forest as well. The same is the case with other species marked GN in Table 1. But our observations suggest that these species do have a greater abundance on cliffs as compared to the rest of the habitats in which they occur. The reasons of this could be many ranging from environmental parameters to biotic pressures.

Many species, which are facultative or opportunistic cliff dwellers, were excluded from this list, for the reason that they do not show more abundance on the cliffs as compared to the other habitats, e.g., *Senecio bombayensis* grows on cliffs but is much more abundant on plateaus.

The term RI (Restricted) is used in Table 1 instead of specialist. It indicates that these species are observed or reported so far only from the cluster of microhabitats identified under the broad category of cliff. Some of them such as *Utricularia striatula* (Image 9) or *Rhynchoglossum notonianum* can be called specialists considering the fact that their pattern of growth and root system appeared to be adapted to vertical cliffs.

About 62 species are noted as generalists while 40 are restricted to cliffs. More detailed ecological and autecological studies are needed for a more reliable categorization into generalists and specialists. In the case of species such as *Silentvalleya chandwadensis*, which are known from a limited number of specimens it is not possible to ascertain whether they are specialists or not.

Adaptations

Some of the species recorded in cliffs in the NWG showed characteristic adaptations to grow under harsh environmental conditions. They are explained below:

a. Poikilohydry: Poikilohydry is a highly specialized adaptation shown by plants growing under conditions of periodic water stress. These species are more commonly known as desiccation tolerant or resurrection plants owing to the unique adaptation for sustaining during the dry period. At the beginning of a dry spell the tissues of these plants lose water and become dry and shriveled. But if a small amount of water becomes available from rainfall or streams, these plants absorb water and resume normal growth even during the dry period. Eight poikilohydric species were listed on cliffs, viz. *Tripogon lisboae, T. capillatus, T. filiformis* (Image 4)*, Didyimocarpus pygmaea, Microchirita hamosa, Actinopteris sp., Cheilanthes sp.,* etc. Poikilohydry has not been studied for Indian plants with the exception of a paper by Gaff & Bole (1986). It is quite possible that more such species can be found on cliffs and other outcrop habitats in future.

b. Carnivory: Carnivory is an adaptation by plants to overcome the scarcity of nutrients like nitrogen, phosphorus and potassium (Ellison 2006). Carnivorous plants are abundant and diverse in the ephemeral flush vegetation on rock outcrops (Porembski & Watve 2005) such as ferricretes, mesas and inselbergs in India. But only two species of bladderworts were recorded on cliff microhabitats in this study. *Utricularia striatula* is a specialist that often covers large MVR, and many individuals are seen on wide, open faces with trickling water. *U. graminaefolia* is another generalist carnivorous species seen on cliffs.

c. Succulence: *Frerea indica* and *Sarcostemma intermedium* (Apocynaceae) are the only two succulent species growing on cliffs. *Frerea indica grows* on hills of the main NWG, while *Sarcostemma intermedium* grows on offshoots of Ghats, in drier areas as compared to the former. *Frerea indica* was considered as one of the most threatened species of the region, but it is now reported from six localities on plateau edges (Misra & Singh 2001). *Frerea indica* is also found to show C4 pathway of photosynthesis (Lange & Zuber 1977), which is one of the adaptations for surviving in harsh environment on cliffs.

d. Geophytes: Presence of tubers, bulbs and rhizomes is a classic adaptation to seasonal climate, where growing period is limited to only a certain part of the year. This is by far the most common adaptation shown by cliff species. A total of 2 bulbous, 22 tuberous and 2 rhizomatous species are included in table 1. The reproductive phase of these plants is over after the monsoon and the plant remains in the form of underground organs until the next monsoon. This group includes species like *Ceropegia huberi* (Image 8)*, C. mahabalei,* and *C. santapaui* which generally grow on moist vertical rocks or hill slopes with some amount of soil accumulation.

In addition to these well documented adaptations, certain species show perennating organs in the form of dry cottony balls produced next to the soil surface at the base of the stem. This understudied adaptation is observed in species belonging to genera like *Blumea* and *Senecio*. These species are treated here under hemicryptophytes. As seen from above, the adaptations recorded so far seem to be more for the seasonal dryness and nutrient scarcity experienced by the flora in this habitat. More research is necessary to understand if adaptations related to wind velocity, radiation or any other factors are also present.

Endemism and rarity

Numerous endemic (Image 6) species are found on cliffs owing to their geographical isolation and selective pressure towards evolution of adaptive features (Larson et al. 2000). Cliffs of the NWG also support many endemic species. The list (Table 1) includes 55 species reported as endemic in previous studies of which 35 are endemic to the NWG (Singh & Karthikeyan 2000; Datar & Lakshminarasimhan 2013a). The number of endemics shows a fairly large percentage (50%+) of the cliff flora. Many of these are restricted (RI) as per our observations and 19 species are reported as Critically Endangered (CR), Endangered(EN) and Vulnerable (VU) as per the Botanical Survey of India (Mishra & Singh 2001) and IUCN indicating high conservation significance of cliff habitats.

The species growing on cliffs also show microhabitat preference, for example species like *Hubbardia diandra, Eria reticosa*, *Ceropegia huberi, C. santapauii* are restricted to moist vertical rocks while species like *Begonia concanensis*, *B. phrixophylla* prefer to grow in moist areas on edges of plateau tops. Species like *Frerea indica* always prefer dry vertical rocks while *Trachyspermum roxburghianum* and *Ceropegia noorjahanae* grow on hill slopes where some amount of soil is accumulated.

Cliffs shelter six narrow endemic species viz. *Hubbardia diandra* (Image 10)*, Silentvalleya chandwadensis, Ceropegia mahabalei, C. santapaui, C. noorjahanae* and *Begonia concanensis*. It was found that narrow endemic species showed a clear pattern of ecological differentiation from their widespread congeners as they occurred in steeper habitats, higher bedrock and sparser vegetation. This is consistent with observations of Baskin & Baskin (1988) that rocky areas have a higher number of narrow endemic species.

Endemism and the presence of threatened plants on cliffs is also reported by Shmida (1984) and Aronne et al. (2014). They have documented 7% endemic plants from coastal vertical cliffs of the national park of Cilento. But compared to this region cliffs of the NWG have a much higher percentage of endemic plants emphasizing again its high conservation value.

Threats to the habitat and vegetation

During this first study, the focus was on floristics, however, notes were recorded on pressures and threats to the habitat. As compared to the plateau tops, valleys, forests and other more accessible habitats near human habitations, cliffs are less intensively used by humans and livestock. Hill slopes are used for grazing by sheep and cattle, but the vertical cliffs faces (MVR, DVR) and edges, ledges or overhangs are rarely accessed by people, making these safe sites for some species. A major threat for cliff vegetation appears to be from manmade fires, which are lit for developing scrub grasslands, or hill slope cultivation. These are mostly seen during hot months (January to April) and often fire escapes and burns many habitats. Widening of roads and railway track expansion is another threat to established vegetation on the cliffs. This can be seen in Anmode Ghat (Datar & Lakshminarasimhan 2013a). The vegetation of cliffs is heavily dependent on accumulated humus and intense burning can affect it severely. Landslides are also a threat to vegetation, but in the absence of any specific data on frequency or intensity of landslides, their actual effect at species level cannot be predicted. This is more evidenced in secondary cliffs. Nuzzo (1996), Camp & Knight (1998) and McMillan & Larson (2002) have addressed effect of rock climbing on cliff vegetation and their effect on endemic flora. So far this does not appear to be a threat to cliff flora of this region as rock climbing or mountaineering is not common. It may be a local factor of importance in case of some localities such as forts and peaks such as Raigad, Sinhagad, Kalsubai and others popular for these sports.

Table 1. Vascular plant species growing on cliffs in the northern Western Ghats.

	Name of the species	Family	Life form	Specificity	Adaptation	Microhabitats	Distribution in NWG	Endemicity -range	Voucher specimen*
1	*Delphinium malabaricum* (Huth) Munz	Ranunculaceae	TH	GN		HS	Northern and central parts of NWG	NWG	15929
2	*Thalictrum dalzellii* Hook.	Ranunculaceae	TH	GN		DVR, L	Throughout NWG	NWG	78
3	*Reinwardtia indica* Dumort.	Linaceae	TH	GN		DVR, L	Throughout NWG		2159
4	*Impatiens acaulis* Arn.	Balsaminaceae	GE	RI	UPO	MVR	Throughout NWG		2289
5	*Rhamnus virgata* var. *hirsuta* (Wight & Arn.) Y.L. Chen & P.K. Chou	Rhamnaceae	PH	GN		HS	Throughout NWG	PI	25386
6	*Kalanchoe bhidei* Cooke	Crassulaceae	TH	RI		EP	Central part of NWG	NWG	
7	*Kalanchoe olivacea* Dalzell	Crassulaceae	TH	RI		EP	Central part of NWG	NWG	899
8	*Sonerila scapigera* Dalzell	Melastomataceae	GE	RI	UPO	MVR	Throughout NWG	NWG	20880
9	*Rotala floribunda* (Wt.) Arn.	Lythraceae	TH	RI		MVR	Central part of NWG	NWG	1981
10	*Begonia concanensis* DC.	Begoniaceae	GE	RI	UPO	EP	Throughout NWG	NWG	8149
11	*Begonia crenata* Dryand	Begoniaceae	GE	GN	UPO	MVR	Throughout NWG		8155
12	*Begonia phrixophylla* Blatt. & McCann	Begoniaceae	GE	RI	UPO	EP	Central part of NWG	NWG	
13	*Begonia trichocarpa* Dalzell	Begoniaceae	GE	RI	UPO	MVR	Central and Southern parts of NWG	WG	21028
14	*Heracleum grande* (Dalzell & A. Gibson) Mukhop.	Apiaceae	GE	GN	UPO	EP	Throughout NWG	WG	1023
15	*Pinda concanensis* (Dalzell) P.K. Mukh. & Constance	Apiaceae	GE	GN	UPO	EP	Throughout NWG	NWG	8174
16	*Scandix stellata* Banks & Soland	Apiaceae	TH	GN		HS	Central part of NWG		
17	*Trachyspermum roxburghianum* (DC.) Craib.	Apiaceae	GE	RI	UPO	HS	Throughout NWG	PI	8295
18	*Argostemma verticillatum* Wall.	Rubiaceae	GE	RI	UPO	MVR	Southern part of NWG		186753 (BSI)
19	*Argostemma courtallense* Arn.	Rubiaceae	GE	RI	UPO	MVR	Southern part of NWG		186777 (BSI)
20	*Hymenodictyon obovatum* Wall.	Rubiaceae	PH	GN		EP	Throughout NWG	India	
21	*Hymenodictyon orixensis* (Roxb.) Mabb.	Rubiaceae	PH	GN		EP	Throughout NWG		15522
22	*Neanotis lancifolia* (Hook.f.) W. H. Lewis	Rubiaceae	TH	GN		MVR	Throughout NWG	WG	5443
23	*Neanotis monthlonii* (Hook.f.) W. H. Lewis	Rubiaceae	TH	GN		MVR	Throughout NWG	PI	6093
24	*Spermadictyon suaveolens* Roxb.	Rubiaceae	PH	GN		HS	Throughout NWG		26272
25	*Artemisia japonica* Thunb.	Asteraceae	PH	GN		HS	Central part of NWG		7468
26	*Artemisia nilagirica* (C.B.Clarke) Pamp.	Asteraceae	PH	GN		HS	Throughout NWG		
27	*Blumea membranacea* DC.	Asteraceae	TH	GN		HS	Throughout NWG		7533
28	*Kleinia grandiflora* (wallich ex DC.) N.Rani	Asteraceae	TH	GN		EP	Throughout NWG		1177
29	*Senecio edgeworthii* Hook.f.	Asteraceae	HE	RI	DCB	DVR, HS	Throughout NWG	PI	7895

	Name of the species	Family	Life form	Specificity	Adaptation	Microhabitats	Distribution in NWG	Endemicity -range	Voucher specimen*
30	*Gynura bicolor* (Roxb. ex Willd.) DC.	Asteraceae	TH	GN		S	Throughout NWG		7818
31	*Campanula alphonsii* Wall. ex A.DC.	Campanulaceae	GE	RI	UPO	DVR	Central part of NWG	NWG	8823
32	*Dyerophytum indicum* (Gibbs ex Wight) Kuntze	Plumbaginaceae	PH	RI		DVR	Northern part of NWG		8894
33	*Ceropegia huberi* Ansari	Apocynaceae	GE	RI	UPO	MVR	Southern and Central part of NWG	NWG	26636
34	*Ceropegia mahabalei* Hemadri & Ansari	Apocynaceae	GE	RI	UPO	HS	Northern part of NWG	NWG	17548
35	*Ceropegia noorjahanae* Ansari	Apocynaceae	GE	RI	UPO	HS	Central part of NWG	NWG	175465 (BSI)
36	*Ceropegia sahyadrica* Ansari & Kulkarni	Apocynaceae	GE	RI	UPO	EP,HS	Throughout NWG	NWG	17713
37	*Ceropegia santapaui* Wadhwa & Ansari	Apocynaceae	GE	RI	UPO	MVR	Southern part of NWG	NWG	26091
38	*Frerea indica* Dalzell	Apocynaceae	HE	RI	SUC	DVR	Northern and central parts of NWG	NWG	17540
39	*Sarcostemma intermedium* Decne.	Apocynaceae	HE	GN	SUC	DVR	Central part of NWG	NWG	17824
40	*Canscora concanensis* C.B.Clarke	Gentianaceae	TH	GN		EP	Throughout NWG	NWG	20139
41	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	Gentianaceae	TH	GN		EP	Throughout NWG		14145
42	*Kickxia incana* (Wall.) Pennell	Scrophulariaceae	TH	RI		HS	Southern part of NWG		11886
43	*Kickxia ramosissima* (Wall.) Janchen	Scrophulariaceae	TH	GN		DVR	Throughout NWG		11855
44	*Utricularia striatula* Sm.	Lentibulariaceae	TH	RI	CAR	MVR	Throughout NWG		26941
45	*Utricularia graminifolia* Vahl	Lentibulariaceae	TH	GN	CAR	MVR	Southern part of NWG		12903
46	*Microchirita hamosa* (R.Br.) Yin Z.Wang	Gesneriaceae	TH	RI	POIK	MVR	Southern part of NWG		
47	*Didymocarpus pygmaeus* C.B.Clarke	Gesneriaceae	TH	RI	POIK	DVR	Central part of NWG		12936
48	*Epithema carnosum* Benth.	Gesneriaceae	TH	RI		MVR	Southern part of NWG		
49	*Rhynchoglossum notonianum* (Wall.) Burtt.	Gesneriaceae	TH	RI		MVR	Southern part of NWG		12941
50	*Rhynchoglossum obliquum* Blume	Gesneriaceae	TH	RI		MVR	Central part of NWG		12947
51	*Strobilanthes callosa* Nees	Acanthaceae	PH	GN		HS	Throughout NWG	NWG	13083
52	*Eranthemum capense* L. var. *concanense* (T. Anders.) Santapau	Acanthaceae	TH	GN		HS	Southern part of NWG	WG	186720 (BSI)
53	*Haplanthodes neilgherryensis* (Wight) Majumdar	Acanthaceae	TH	GN		HS	Throughout NWG	NWG	13078
54	*Haplanthodes plumosa* (T. Anders.) Panigr. & G. C. Das	Acanthaceae	TH	GN		EP	Throughout NWG	WG	
55	*Haplanthodes verticillatus* (Roxb.) R.B.Majumdar	Acanthaceae	TH	GN		HS	Throughout NWG	WG	13388
56	*Justicia wynaadensis* B.Heyne	Acanthaceae	TH	GN		HS	Southern part of NWG	NWG	187501 (BSI)
57	*Strobilanthes scrobiculatus* Dalzell ex C.B.Clarke	Acanthaceae	PH	RI		HS	Southern part of NWG	NWG	1786
58	*Anisochilus carnosus* (L.f.) Wall.	Lamiaceae	TH	GN		S	Throughout NWG		13559

	Name of the species	Family	Life form	Specificity	Adaptation	Microhabitats	Distribution in NWG	Endemicity -range	Voucher specimen*
59	*Anisochilus adenanthus* Dalzell & A.Gibson	Lamiaceae	TH	RI		HS	Southern part of NWG	WG	13563
60	*Leucas montana* (Roth) Spreng.	Lamiaceae	PH	GN		HS	Central part of NWG		14628
61	*Lecanthus peduncularis* (Wall. ex Royle) Wedd.	Urticaceae	TH	GN		MVR	Throughout NWG		11109
62	*Ficus arnottiana* (Miq.) Miq.	Moraceae	PH	GN		EP	Throughout NWG		11263
63	*Eria reticosa* Wt.	Orchidaceae	HE	RI		MVR	Throughout NWG	India	21009
64	*Habenaria brachyphylla* (Lindl.) Aitch.	Orchidaceae	GE	GN	UPO	MVR	throughout NWG	NWG	21092
65	*Habenaria rariflora* A. Rich.	Orchidaceae	GE	GN	UPO	MVR	Throughout NWG	WG	6271
66	*Crinum brachynema* Herb.	Amaryllidaceae	GE	RI	UPO	HS	Throughout NWG	NWG	6640
67	*Crinum woodrowii* Baker	Amaryllidaceae	GE	GN	UPO	HS	Throughout NWG	NWG	17557
68	*Chlorophytum arundinaceum* Baker	Asparagaceae	GE	GN	UPO	L	Southern part of NWG		
69	*Chlorophytum bharuchae* Ansari, Sundararagh. & Hemadri	Asparagaceae	GE	GN	UPO	HS	Central and Southern parts of NWG	NWG	20490
70	*Chlorophytum glaucum* Dalzell	Asparagaceae	GE	GN	UPO	EP	Throughout NWG	NWG	24500
71	*Chlorophytum glaucoides* Blatt.	Asparagaceae	GE	GN	UPO	EP	Northern and central parts of NWG	PI	165260 (BSI)
72	*Chlorophytum nimmonii* Dalzell	Asparagaceae	GE	GN	UPO	L	Southern part of NWG		25048
73	*Phoenix loureiroi* var. *pedunculata* (Griff.) Govaerts .	Arecaceae	PH	GN		HS	Northern part of NWG	PI	12367
74	*Ariopsis peltata* Nimmo	Araceae	GE	GN	UPO	MVR	Throughout NWG		187924 (BSI)
75	*Eriophorum comosum* (Wall.) Nees	Cyperaceae	TH	RI		DVR	Northern and central parts of NWG		19985
76	*Arthraxon jubatus* Hack.	Poaceae	TH	RI		MVR	Throughout NWG	WG	13665
77	*Arthraxon hispidus* (Thunb.) Makino	Poaceae	TH	RI		MVR	Throughout NWG		13657
78	*Arthraxon meeboldii* Stapf	Poaceae	TH	RI		MVR	Throughout NWG	NWG	13704
79	*Garnotia arborum* Stapf. ex T. Cooke	Poaceae	TH	GN		MVR	Throughout NWG	NWG	204 (GU)
80	*Hubbardia diandra* Chandore , Gosavi & S.R.Yadav	Poaceae	TH	RI		MVR	Southern part of NWG	NWG	182304 (BSI)
81	*Isachne gracilis* C.E. Hubb.	Poaceae	TH	RI		MVR	Throughout NWG	NWG	20284
82	*Ischaemum raizadae* Hemadri & Billore	Poaceae	TH	GN		MVR	Throughout NWG	NWG	25817
83	*Ischaemum diplopogon* Hook. f.	Poaceae	TH	GN		MVR	Throughout NWG	NWG	15614
84	*Lakshmia venusta* (Thwaites) Veldkamp	Poaceae	TH	RI		MVR	Southern part of NWG	NWG	
85	*Silentvalleya chandwadensis* Gosavi, B.R. Pawar & S.R. Yadav	Poaceae	TH	RI		DVR	Northern part of NWG	NWG	
86	*Pseudodichanthium serrafalcoides* (Cooke & Stapf) Bor	Poaceae	TH	GN		EP	Throughout NWG	India	17757
87	*Tripogon bromoides* Roth	Poaceae	HE	GN	POIK	MVR	Throughout NWG		21266
88	*Tripogon capillatus* Jaub. & Spach	Poaceae	HE	GN	POIK	MVR	Throughout NWG	WG	21501

	Name of the species	Family	Life form	Specificity	Adaptation	Microhabitats	Distribution in NWG	Endemicity -range	Voucher specimen*
89	*Tripogon filiformis* Nees ex Steud.	Poaceae	HE	GN	POIK	MVR	Central part of NWG		
90	*Tripogon lisboae* Stapf	Poaceae	HE	RI	POIK	MVR	Throughout NWG	PI	21030
91	*Tripogon trifidus* Munro ex Stapf	Poaceae	HE	GN		MVR	Northern part of NWG		
92	*Selaginella tenera* Spring	Selaginellaceae	TH	GN	POIK	HS	Throughout NWG		
93	*Adiantum capillus-veneris* L.	Pteridaceae	TH	GN		HS	Throughout NWG		
94	*Cheilosoria tenuifolia* (Burm. f.) Trevis.	Pteridaceae	TH	GN		HS,EP	Throughout NWG		
95	*Cheilanthes albomarginata* C.B. Clarke	Pteridaceae	TH	GN	POIK	HS,EP	Throughout NWG		
96	*Cyclosorus interruptus* (Willd.) H. Itô	Thelypteridaceae	TH	GN		HS	Throughout NWG		
97	*Thelypteris parasitica* (L.) Farwell	Thelypteridaceae	TH	GN		HS	Throughout NWG		
98	*Ampelopteris prolifera* (Retz.) Copel.	Thelypteridaceae	TH	GN		HS	Throughout NWG		
99	*Macrothelypteris torresiana* (Gaudich.) Ching	Thelypteridaceae	TH	GN		HS	Throughout NWG		
100	*Athyrium hohenackerianum* (Kunze) T. Moore	Athyriaceae	TH	GN		HS	Throughout NWG		
101	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	TH	GN		MVR	Throughout NWG		
102	*Leptochilus decurrens* Blume	Polypodiaceae	TH	GN		MVR	Throughout NWG		

Abbreviations: Adaptations: UPO - Underground Protecting or storage organ; POIK - Poikilohydrous; CAR - carnivorous plants; DCB - Dry cottony balls; SUC - Succulent. Life forms: TH - Therophyte; PH - Phanerophyte; GE-Geophyte; HE - Hemicryptophyte. Habitat specificity: GN - Generalist; RI- Restricted. Habitats: DVR- Dry vertical rocks; EP - Edge of the plateau top; HS - Hill slopes; L - Ledges; MVR- Moist vertical rocks; S - Scree. Endemism: NWG - northern Western Ghats; WG - Western Ghats; PI - Peninsular India.
Acronyms and short name of herbaria to which voucher specimens are referred: AHMA - Herbarium of Agharkar Research Institute, Pune, India; GU - Goa University herbarium, Goa, India; BSI - Botanical Survey of India, Western Circle Herbarium, Pune, India.
* All specimens without any acronym in bracket are referred to AHMA.

CONCLUSION

The cliff ecosystem of the Western Ghats is among the largest worldwide, but botanically it is still rather neglected. This review of species, vegetation and microhabitats of cliffs in the NWG is a preliminary documentation of existing information and field studies. As seen above, this cliff ecosystem has many environmental peculiarities, which are reflected in the species adaptations and life forms. Particularly outstanding is the fact that desiccation tolerant grasses (*Tripogon* spp.) are dominant colonizers of steep vertical cliffs throughout the NWG. The cliffs of this mountain range seem to form the largest rocky surface area on Earth, which is colonized by resurrection plants. The high number of endemic and threatened species, special ecological features, and specific threats due to biotic activities indicates need for conservation and protection measures. The habitat is also important from the watershed point of view and more research is needed on floristic, ecological and ecosystem processes and services to take the necessary steps for conservation. It is hoped that this paper will provide baseline information for future detailed studies on this unique habitat in the northern Western Ghats and other parts of India as well.

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Image 1. Typical basaltic cliff of the northern Western Ghats

Image 2. Cliffs with alternate lava layers at Arthur's Seat, Mahabaleshwar

Image 3. Dense mats of *Rotala floribunda* Koehne on cliffs

Image 4. Typical habitat of poikilohydrous *Tripogon* sp. on cliffs

Image 5. Dense growth of a grass *Arthraxon jubatus* Hack. on cliffs

Image 6. Endemic *Begonia concanensis* A.DC. growing on cliffs

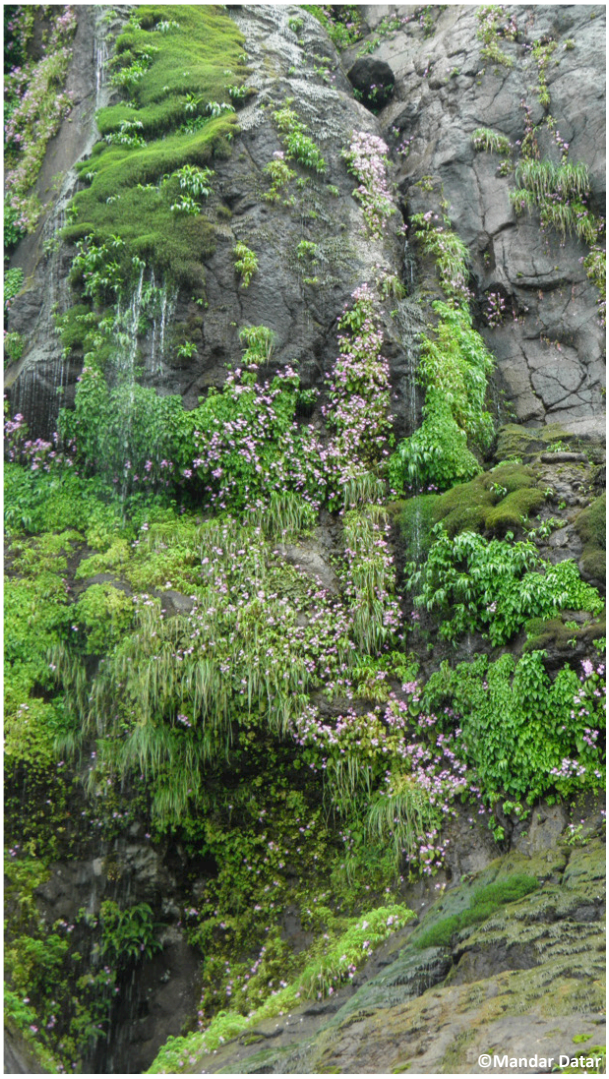

Image 7. Growth of *Impatiens acaulis* Arn. and *Tripogon* sp. on cliffs

Image 9. Insectivorous *Utricularia striatula* Sm.

Image 8. A cliff specialist endemic and threatened *Ceropegia huberi* Ansari

Image 10. Newly described grass species *Hubbardia diandra* Chandore, Gosavi & S.R. Yadav restricted only to cliffs

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Journal of Threatened Taxa

www.threatenedtaxa.org

OPEN ACCESS

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

February 2018 | Vol. 10 | No. 2 | Pages: 11245–11360
Date of Publication: 26 February 2018 (Online & Print)
DOI: 10.11609/jott.2018.10.2.11245-11360

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