

TAPROBANICA, ISSN 1800–427X. Vol. 14, No. 02 (2025): pp. 206–213, pls. 23–24.
Published by Research Center for Climate Change & Faculty of Mathematics & Natural
Sciences, Universitas Indonesia, Depok 16424, INDONESIA.
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<http://www.taprobanica.org>
<https://doi.org/10.47605/tapro.v14i2.373>



OPEN ACCESS

DIVERSITY, SEASONALITY, AND HERBIVORE PALATABILITY OF THE GRASSES OF KAVALEDURGA FORT, WESTERN GHATS, INDIA

Submitted: 30 September 2024, Accepted: 22 September 2025, Published: 30 October 2025
Subject Editor: Jess Rickenback

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Abstract

The Western Ghats, a biodiversity hotspot in India, face environmental changes from human activities. While various species have been studied, grass ecology remains underexplored in this region. This study reports on the diversity, seasonality, and herbivore palatability of grass species at Kavaledurga Fort in Karnataka, a tourist spot where wild small mammals and livestock graze. From 2019 to 2022, we documented 51 grass species from 33 genera, 9 tribes, and 6 subfamilies across various microhabitats. Over 80% of the grasses flower and fruit between August and December, coinciding with the late monsoon to early winter period. The dominant subfamilies were Panicoideae and Chloridoideae, accounting for 88% of species. About 47% of the species were palatable to herbivores, while 35% were not. Our study highlights the ecological importance of grass flora in the historical forts of Western Ghats, emphasizing the need for continued documentation and monitoring, as these often-neglected habitats face growing pressures.

Keywords: Floristic survey, Grazing, Habitat degradation, Poaceae

Introduction

The Western Ghats of India are one of the hottest biodiversity hotspots. They are well-known as the second most speciose center for endemism in India, with 1,500 endemic flora species (Nair & Daniel 1986, Joseph *et al.* 2012). The region of the Western Ghats in Karnataka is referred to as the Central Western Ghats and comprises 27% of

India's total plant diversity (Nayar 1980). In plant science, diversity and complexity are two major subjects of research, and many taxonomists have explored plant diversity in the last five decades (Ghate *et al.* 1998). Among angiosperms, grasses (family: Poaceae) are morphologically diverse, complex, and distinct (Shantz 1954). Grasses are a major source of food, fodder, fuel, and

medicine globally, and they contribute to ecosystem services and the economy (Joshi & Rao 2011). They form approximately 24% of Earth's tropical and temperate vegetation (Jain 1986). Globally, approximately 11,000–12,000 grass species belonging to 750–770 genera have been estimated (Hodkinson 2018). In India, a total of 1506 grass species have been reported (Kellogg *et al.* 2020). Karnataka state hosts 402 species and 17 varieties of 124 genera (Lakshminarasimhan *et al.* 2019).

In recent years, anthropogenic activities and environmental changes have been reported to affect the landscape, species diversity, and vegetation of Western Ghats (Dinakaran & Anbalagan 2007, Potdar *et al.* 2012, Jones *et al.* 2021). Anthropogenic threats to various taxa, such as orchids, insects, and amphibians, have been well reported (Krishnamurthy 2003, Dinakaran & Anbalagan 2007, Jalal & Singh 2015, Kumara *et al.* 2023). Among these reports, anthropogenic activities such as habitat fragmentation, change in land use, environmental pollution, and overgrazing are reported to be affecting various taxa (Baskaran *et al.* 2012). However, the effects of anthropogenic activities and environmental changes on grass diversity in the Western Ghats are not well reported.

There are hundreds of forts and historical monuments dispersed throughout the hills of the Western Ghats. The structures represent considerable cultural, historical, and ecological significance. Over time, the structures have developed into unique ecosystems, thus providing habitats to diverse flora and fauna, some of which are endemic to the location. However, there is a lack of information on the distribution of species in these unique habitats (Jangam & Pawar 2023). Such information would help prioritize important areas for conservation, manage culturally important sites sustainably, and develop strategies to minimize the effects of climate change in vulnerable ecosystems.

Grasslands in the Western Ghats, including those found on historical forts, represent unique and ecologically important open habitats that are increasingly threatened by land-use changes and neglect (Jangam & Pawar 2023). Despite their conservation value, these ecosystems are underrepresented in ecological research (Watve 2013). Two key and understudied aspects of grassland ecology are species palatability to herbivores and flowering phenology, both of which directly influence vegetation dynamics

and habitat management (Skarpe & Hester 2008). Palatable species are more likely to be selectively grazed, influencing species composition over time, while the timing of flowering affects regeneration, seed dispersal, and community structure (Little *et al.* 2015). Understanding these traits in grass species found on fort summits is particularly important, given the growing pressures of grazing, tourism, and habitat fragmentation in the Western Ghats (Gorade & Datar 2014, Jangam & Pawar 2023).

Kavaledurga Fort is an archeological site atop a hill and surrounded by a reserve forest in the Central Western Ghats. The site experiences considerable tourist traffic throughout the year. Although it is under the care of the Department of Archaeology, tourist activity currently remains largely unregulated. Furthermore, the open grassy areas of the site are used by livestock for grazing (DHNS 2016, Madhusoodhan 2018, Karnataka Tourism 2023). In this study, we report on the diversity, seasonality, and herbivore palatability of grasses in Kavaledurga Fort, thus providing insights into the status of grasses in a human-altered landscape of the Western Ghats.

Materials and Methods

Study area. The study was conducted in Kavaledurga Fort (13° 42' 49.76"–13° 43' 24.30" N and 75° 06' 54.66"–75° 07' 43.04" E; Elevation: 900–934 MSL) situated in the Central Western Ghats of Shivamogga district of Karnataka (Fig. 1).

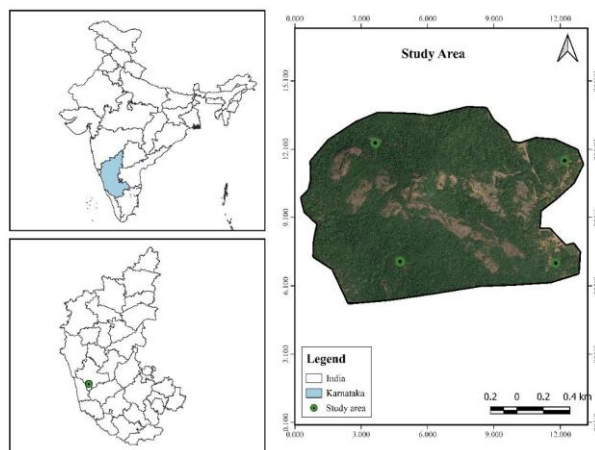


Figure 1. Study area: top left, map of India highlighting Karnataka State; bottom left, map of Karnataka State highlighting the location of Kavaledurga Fort in Shivamogga District; right, Kavaledurga Fort in the Central Western Ghats.

Kavaledurga Fort was built on a hill in the ninth century and renovated in the 14th century

Plate 23



Figure 2. Kavaledurga fort: (A) aerial view of the fort, (B) a pond in the fort complex, (C) cattle grazing in the fort area, (D) top of the hill on which the fort is situated, and (E, F) rocky habitats

Plate 24

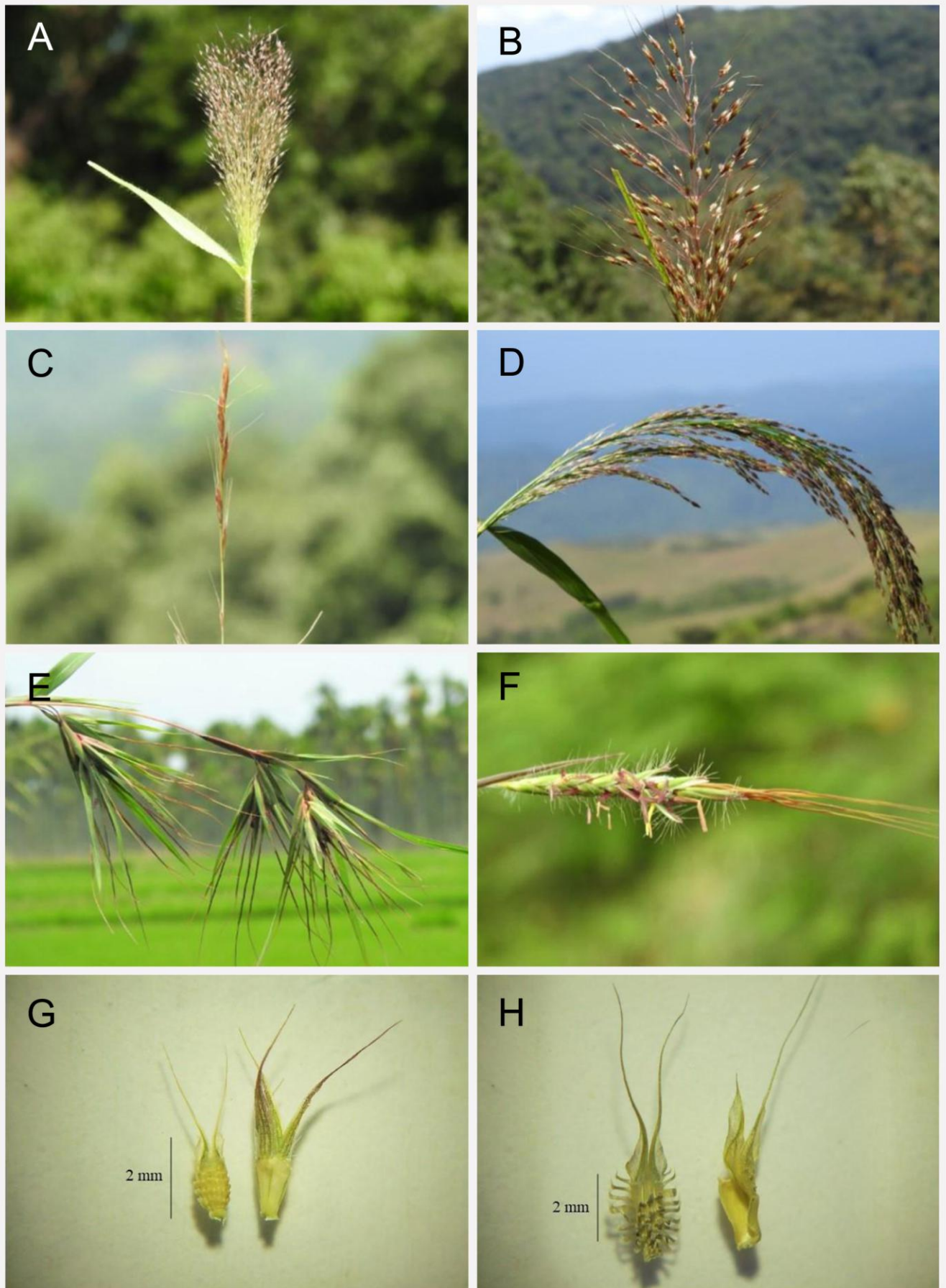


Figure 3. Grass species from Kavaledurga Fort: **(A)** *Arundinella pumila* (Hochst. Ex A. Rich.), **(B)** *Chrysopogon hackelii* (Hook.f.) C.E.C. Fisch., **(C)** *Indopoa paupercula* (Stapf) Bor., **(D)** *Garnotia arundinacea* Hook. f., **(E)** *Themeda triandra* Forssk., **(F)** *Heteropogon contortus* (L.) P. Beauv. Ex Roem. & Schult., **(G)** dissected pedicelled and sessile spikelets of *Glyphochloa divergens* (Hack.) Clayton var *divergens*, **(H)** dissected pedicelled and sessile spikelets of *Glyphochloa mysorensis* (S. K. Jain & Hemadri) Clayton

(Vidyashree & Malammanvar 2021) and covers an area of approximately 8 km². This area is characterized by a humid tropical climate with an average annual rainfall of 3870 mm and a temperature of 23.3°C. The fort has seven perennial ponds from the base to the peak with interconnected channels (Vidyashree & Malammanvar 2022). The area is dominated by rocks, and their crevices are microhabitats for many small annual endemic grass species (Porembski 2000) (Fig. 2).

Data collection. An extensive grass survey was conducted from June 2019 to June 2022, covering all seasons. Field surveys were conducted during the first week of every month except for two periods during March to June 2020 and April to May 2021 due to COVID-19 restrictions, totaling 32 sampling surveys. The entire 8 km² study area was surveyed each time using an opportunistic sampling method (Prayudi *et al.* 2019, Williams & Brown 2019). Only grass specimens that were unidentified and in flowering or fruiting stages were collected and brought to the laboratory for identification. Grasses already identified in the field were recorded but not collected. Plots were not established, as the objective was not to assess spatial diversity metrics but to develop a checklist and collect data on phenology and palatability. The collected samples were identified using standard floras and research papers (Bor 1960, Sreekumar & Nair 1991, Bhat & Nagendran 2001, Potdar *et al.* 2012), and herbaria were prepared using the standard protocol (Rao & Sharma 1990). The voucher specimens were deposited in the Herbaria, Department of Botany of the authors' University. The nomenclature and classification of grasses have been updated according to a recent valid publication (Kellogg *et al.* 2020, Soreng *et al.* 2022).

The palatability of grasses by livestock was documented by direct observation in the field. We observed cattle grazing from a distance to minimize disturbance and verify their foraging behavior. Once the cattle had moved on to other areas, we systematically surveyed the grazed sites and identified the grass species that had been consumed. Thus, palatability assessment was based on direct field observation of animal preference and consumption, following the methodology described by Gorade and Datar (2016) and Bor (1960). We did not attempt to quantify the amount of grass consumed. Moreover, our focus was on identifying which

grass species were selected and grazed by the cattle during the observation period. This qualitative approach allowed us to document species-specific grazing preferences without measuring biomass removal or grazing intensity.

Results

The assessment of grasses in the study area revealed a total of 51 species belonging to 33 genera, 9 tribes, and 6 subfamilies. The grass checklist includes valid names, subfamilies, tribes, and habitats of all documented species (Sup. Table 1). Figure 3 shows photographs of some selected species. Among the six subfamilies (Fig. 4A), Panicoideae had the most species ($n=37$), constituting 72% of the total grasses, followed by Chloridoideae ($n=8$), Pooideae and Bambusoideae ($n=2$), and one species each in Micrairoideae and Oryzoideae.

Among the documented nine tribes (Fig. 4B), Andropogoneae showed the maximum number of species (16 species), followed by Paniceae (12 species), with the remaining tribes having fewer than 10 species. The grasses were found in five different microhabitats: 33% were in open grasslands (17 species), followed by rocky areas or crevices (13 species), moist shady places (13 species), marshy areas (6 species), and forest or road margins (2 species).

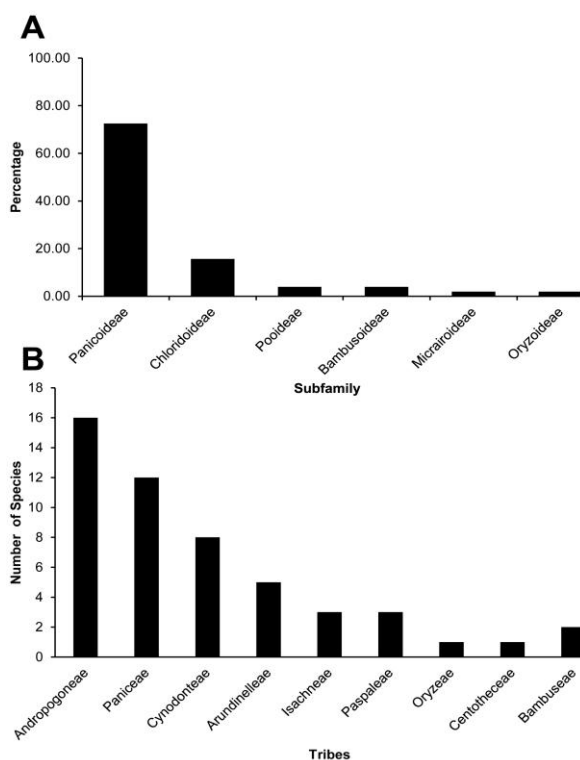


Figure 4. (A) Percentage of grass species in Kavaledurga Fort belonging to each subfamily; (B) Number of grass species by tribe

Among the documented genera, *Digitaria*, *Ischaemum*, *Paspalum*, and *Tripogon* had the maximum number of species (three each), followed by *Arthraxon*, *Arundinella*, *Chrysopogon*, *Cyrtococcum*, *Eragrostis*, *Garnotia*, *Glyphochloa*, *Isachne*, *Panicum*, and *Themida* (two species each). The remaining 19 genera had one species each.

The flowering and fruiting periods of grasses in Kavaledurga Fort varied widely, with most species exhibiting seasonal reproductive activity. The majority (approximately 70%) flowered and fruited during the monsoon and post monsoon periods, from August to January, with peak activity between September and December (Sup. Table 1). A few species, such as *Alloteropsis cimicina*, *Chrysopogon aciculatus*, *Digitaria ciliaris*, *Eleusine indica*, *Heteropogon contortus*, *Isachne globosa*, *Oplismenus compositus*, and *Panicum repens*, showed year-round reproductive activity, indicating adaptation to stable microhabitats. Notably, the bamboo species *Bambusa arundinacea* and *Ochlandra scriptoria* exhibited extremely rare flowering events, occurring only once every 20–30 years. These phenological patterns indicate that the reproductive timing of grasses is closely aligned with local climatic patterns, particularly the southwest monsoon.

Of the 51 species, 47% were palatable (24 species), 18% were palatable only in the vegetative phase (9 species), and 35% were nonpalatable (18 species). The distribution of species across five microhabitats is shown in Figure 5.

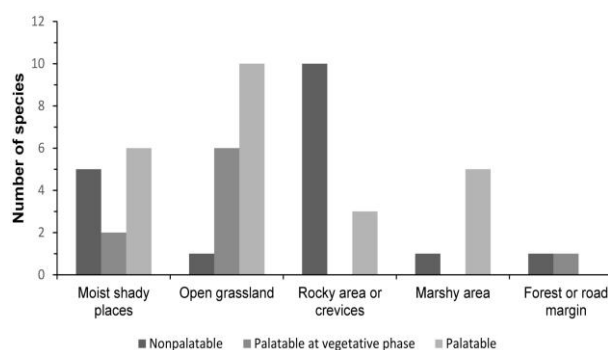


Figure 5. Distribution of grass species by palatability category across five microhabitats at Kavaledurga Fort, Western Ghats. Species were classified as fully palatable, palatable during the vegetative phase only, or nonpalatable.

Open grasslands supported the highest number of palatable species (10) and had the largest number of vegetative-phase palatable

species (6), with only one nonpalatable species. Moist shady places exhibited a relatively even distribution, with six nonpalatable species, two palatable at the vegetative stage, and five palatable species. Rocky crevices were dominated by nonpalatable grasses (10), with only three palatable species and no seasonally palatable species. Marshy areas contained four nonpalatable and two palatable species. Forest or road margins had one species each in the nonpalatable and vegetative-palatable categories but no palatable species.

Eight species are endemic to India, which are *Chrysopogon hackelii* (Hook.f.) C.E.C. Fisch., *Garnotia arundinacea* Hook.f., *Glyphochloa divergens* (Hack.) Clayton var. *divergens*, *Glyphochloa mysorensis* (S.K. Jain & Hemadri) Clayton, *Indopoa paupercula* (Stapf) Bor, *Isachne gracilis* C.E. Hubb., *Ochlandra scriptoria* (Dennst.) C.E.C. Fisch., and *Tripogon lisboae* Stapf. One species, *Cyrtococcum deccanense* Bor, is endemic to India and Sri Lanka.

Discussion

Although a comparison of grass diversity with other forest ecosystems is limited because of a lack of similar studies, our findings align with other reports from the Western Ghats, where Panicoideae was the dominant subfamily (Vasanthakumari *et al.* 2010, Abhijit & Krishnamurthy 2020). The documentation of 51 grass species highlights the floral richness of Kavaledurga Fort, and future studies comparing grass communities across forts in the Western Ghats can enhance our understanding of the biogeographic patterns of these ecosystems.

Most grasses in the study area flowered and fruited from August to January, with peak activity between September and December. This late monsoon to early winter seasonality likely coincides with a period of favorable temperature and moisture conditions for seed production and dispersal. Our finding aligns with the general flowering patterns observed in tropical grasses (Parihar & Pathak 2006). This seasonality might influence herbivore preference; however, this requires further investigation.

The distribution of palatability classes across microhabitats indicates that open grasslands within the fort support the highest number of forage-relevant species, including both palatable and vegetative-stage palatable grasses. In contrast, rocky crevices and marshy areas were dominated by nonpalatable species, whereas

moist shady places exhibited a more even distribution of all three types. Forest or road margins supported very few species overall, none of which were fully palatable. Although palatability data alone do not enable the inference of actual grazing pressure or its ecological effects, this pattern highlights the variation in potential forage availability across microhabitats. Future studies incorporating grazing intensity, species abundance, and herbivore preferences would be necessary to evaluate how these differences may influence plant community dynamics.

Forts of the Western Ghats, particularly those in the northern region, provide diverse microhabitats and support unique grass and herbaceous flora. The region is characterized by rocky plateaus and stony outcrops that are home to endemic plant species, many with highly restricted distributions (Jangam & Pawar 2023). Several new species have been described from these forts, including grasses and other angiosperms; for example, the first collections of *Eriocaulon tuberiferum* and other taxa were made at forts such as Panhala and Harishchandragad in the northern Western Ghats. Floristic studies have documented significant diversity; Santapau (1958) reported 683 species from Purandar Fort in the northern Western Ghats. Kulkarni *et al.* (2015) recorded 194 tree species on Lohgad and Visapur Forts in the northern Western Ghats. Nandikar *et al.* (2018) reported 399 angiosperm species on Torana Fort in the northern Western Ghats. However, comprehensive studies focusing on grass species across multiple forts remain limited, and the available data indicate that each fort may host a distinct assemblage of grass species because of their unique topography and microclimates. This highlights the need for further comparative studies to contextualize the grass diversity of individual forts within the wider landscape of the Western Ghats.

Although we did not quantify livestock densities or vegetation cover in this study, we noted signs of tourism and livestock grazing during fieldwork. There was no clear evidence of severe floristic degradation. Nevertheless, previous reports (Madhusoodhan 2018) have indicated that tourism and livestock grazing may pose threats to the floristics of the fort. As the study site is a popular tourist spot, activities such as fire, plucking, and trampling may affect the vegetation. Livestock grazing currently occurs at low intensity in the study area. However, the

observed presence of several palatable grasses in their vegetative stage may require attention, as even modest increases in grazing pressure—potentially driven by future land-use or management changes—could affect community composition. Studies from other ecosystems have shown that preferential grazing can reduce the abundance of palatable species and lead to shifts in plant communities (Sankaran 2005). This concern is particularly relevant in plateau ecosystems of the Western Ghats, where vegetation is dominated by herbaceous life-forms that are sensitive to disturbance (Joshi & Janarthnam 2004), and where increasing anthropogenic pressures, including grazing, have been associated with ecological degradation (Watve 2013). Although low grazing densities are often associated with higher plant diversity, higher densities may reduce diversity through the selective removal of species (Olff & Ritchie 1998). Because of the lack of comparative data on species abundance and cover across forts, we cannot determine whether herbivore preferences shape floristic patterns here in the same way as observed elsewhere. Given the ecological uniqueness and vulnerability of these habitats, monitoring grazing effects remains important despite the current low pressure. Hence, we recommend a social awareness program for cleanliness and conservation of flora and monuments.

Although we did not evaluate management strategies, certain approaches may be worth exploring in future efforts to protect grass diversity in similar habitats. These include promoting responsible tourism through designated walking paths, encouraging local community engagement in conservation (Dai *et al.* 2024, Maghsoodi *et al.* 2024), and monitoring tourist activities.

Among the strengths of this study is the comprehensive documentation of grass diversity across various microhabitats within Kavaledurga Fort. Additionally, data on herbivore preference through field observations provides valuable insights into potential threats to the grasslands.

Among the limitations, the study duration of 3 years limits the ability to assess long-term trends in grass populations. The study was conducted in a single historical fort in the region. Furthermore, the lack of quantitative data on grazing intensity hinders a more precise understanding of its impact.

In conclusion, we documented the grass diversity within Kavaledurga Fort, Western

Ghats of Karnataka, identifying 51 species across 33 genera, 9 tribes, and 6 subfamilies. Panicoideae was the dominant subfamily, comprising 72% of the documented species, underscoring its importance in the fort's ecosystem within the Western Ghats. Panicoideae has diverse taxa, which are highly adaptive to various habitats (Vasanthakumari *et al.* 2010, Abhijit & Krishnamurthy 2020). The timing of late monsoon–early winter flowering aligns with optimal conditions for seed production and dispersal. Furthermore, nearly half of the grass species we observed are palatable to herbivores, which indicates that, should grazing pressure increase in the future—due to changes in land use, tourism expansion, or management practices—these species may be disproportionately affected.

Although current livestock density is low, the dominance of palatable species in early growth stages may make the community structure susceptible to future shifts if grazing intensity rises. Our findings lay a crucial foundation for future conservation efforts, emphasizing the necessity of a comprehensive management plan. Given the ecological sensitivity of grasslands on fort sites in the Western Ghats, proactive measures—such as regulating tourist access, designating controlled grazing areas, and community engagement initiatives—may help safeguard these habitats from future degradation and are important strategies for maintaining a balanced ecosystem (Mohandass *et al.* 2016, Punjabi & Rao 2017). Although current disturbance levels appear limited, increased visitor numbers or changes in land use practices could lead to emerging ecological pressures. Further studies into grass communities across different forts and regions within the Western Ghats, population ecology of dominant species, grazing effects, and habitat restoration potential can guide future management decisions.

Author contributions

All the authors contributed equally.

Acknowledgments

We thank E.S.K. Udupa (Sri JCBM College) for the support; Kuvempu University for providing facilities; Vagner Zanzarini (University of São Paulo, Brazil), Jess Rickenback (University of Edinburgh, UK), Vinayaka Ks (Shri Venkataramana Swamy College, India), and Shravan Kumar (Indian Institute of Science, India) for reviewing the manuscript.

Research permits

Permits issued by the Karnataka Forest Department to conduct field work (No. APCCF-RU-A1-RAC-CR-37/2014-15)

Supplemental data

<https://doi.org/10.47605/tapro.v14i2.373>

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