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Diversity, Endemism, and Future Research Needs: A Meta-Analysis on the Orchids of Andaman and Nicobar Archipelago, India

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ABSTRACT
Tropical Islands are among the important hotspots of orchid diversity and endemism. The peculiar requirements of orchids, their distribution, and population status in remote Islands like Andaman and Nicobar are largely unknown. Therefore, their conservation and management remain a major challenge. Here, we attempted to analyse the trend in orchid-related research published in the past two decades (2001-2023) pertaining to the orchid diversity, endemism, and population status in the Andaman and Nicobar (hereinafter ANI) archipelago through systematic meta-analysis. A total of 55 orchid-related studies (~2.5 per year) were found in the past two decades, showing an overall modestly decreasing trend (– 0.084x + 3.39) with erratic increases and decreases across the study period. Our findings also compiled a total of 161 orchid species (18% endemic) reported from the islands, representing approximately ~12% of the total orchid species found in India (~1300). Furthermore, a total of 47 new orchids were described in the previous two decades, indicating the high potential for the presence of many such undescribed orchid species in the archipelago. Despite the high endemism, only nine orchids have their population status evaluated according to IUCN Red List criteria. Island biogeography theory fits well in the ANI system where the orchid species richness (R^2 – 0.76, P-value – 0.004) and endemism (R^2 – 0.72, P-value – 0.0077) show a high correlation with the size of the island. Among the literature, only four publications concerning the ecology of orchids have been published since 2001, which is far too less considering the high species richness, impact of century-old logging practices, and fragility of the island ecosystem to natural disasters, including the 2004 tsunami. Additionally, increasing human population and the resultant land-use land cover change in ANI are likely to further impact the orchid populations. Therefore, immediate attention is required to understand the population status and to map critical hotspots so that the impact of ever-increasing anthropogenic pressure on the orchids can be minimized.

Key words: Island biogeography theory, Orchid conservation, Orchid checklist, Orchid endemism, Selective logging, 2004 Tsunami

INTRODUCTION

Orchids are highly diverse flowering plants with a cosmopolitan distribution, inhabiting a wide range of habitats - swamps, forests, deserts, and grasslands (Barman and Devadas 2013, Karthigeyan et al. 2014). Orchidaceae is the second-largest flowering plant family, with around 30,000 species belonging to 700 genera, contributing to around 10% of all the reported flowering plants in the world (Dressler 1981, Mabberley 2008). Though orchids are distributed globally; a large proportion occurs in the tropics, from Central and South America to India, Sri Lanka, Myanmar, South China, Thailand, Malaysia, Philippines, New Guinea, and Australia (Cribb et al. 2003). Orchids generally grow as lithophyte, terrestrial, and epiphytic or climbing herbs, with high dominance of epiphytic orchids (Weston et al. 2005). Epiphytic orchids exhibit commensal interaction (+ , 0) with trees, merely establishing themselves on the branches while deriving nutrients and water from the ambient environment (Weston et al. 2005). The exponential increase in human population over the last century - from 1.6 billion at the start of the 20th century to 7.7 billion today - especially in Asia and Africa (Roser et al. 2013), has resulted in increased rates of deforestation, and conversion of land for other purposes (Pahari and Murai 1999). The impacts of deforestation are numerous, but the removal of large canopy trees, which principally influences

orchid species diversity and habitats, is particularly detrimental (Hietz 1999, Hundera et al. 2013).

Deforestation poses a serious threat to biodiversity globally, and the Andaman and Nicobar Islands (ANI) are no exception to this global phenomenon (Giam 2017, Symes et al. 2018). In the past century, roughly 11% of forest land (616 km^2) in the archipelago was converted for human use, of which 7% is now used for agriculture (Anonymous 2003). Deforestation in ANI primarily occurred to establish new settlements on uninhabited islands. Additionally, more than 150 years of logging in the archipelago have eliminated most of the large and older canopy trees (Surendra et al. 2021). The ease of logging in the relatively flat terrain, along with accessibility and easy transportation, has resulted in high deforestation in the coastal forest (littoral and mangrove). Moreover, the 2004 tsunami and earthquake have seriously impacted the island's coastal forests (terrestrial, littoral, and mangroves) (Thakkar and Goyal 2006, Ray and Acharyya 2011, Nehru and Balasubramanian 2014). The tsunami waves physically uprooted and broke several trees (Sankaran et al. 2005), while landmass subduction (uplift and subsidence) changed the tidal water inundation pattern, ultimately resulting in permanent modification of the island coastline (Meltzner et al. 2006), and severe degradation of both inland and mangrove forest (Nehru and Balasubramanian 2014, 2018, Majumdar et al. 2019, ShivaShankar et al. 2020, Ramakrishnan et al. 2020; Singh et al. 2024). Island ecosystems are relatively more susceptible to disturbances compared to other ecosystems (Loope and Mueller-Dombois 1989, D'Antonio and Dudley 1995, Reaser et al. 2007). Consequently, century-old timber extraction practices - though presently implemented in a controlled manner - along with the 2004 mega catastrophe are likely to have adversely affected the wild and rare orchid populations in the ANI. Additionally, the recent drive for rapid development and ambitious international economic activities (Anonymous 2019, 2020, 2022) will further lead to deforestation, eventually aggravating the deterioration of the orchid population in the islands. Therefore, it is important to provide a comprehensive synthesis of orchid-related research undertaken in the island to highlight the major knowledge trends and gaps, which will strengthen the conservation and management of biodiversity in general and orchids in particular in the islands. We have attempted a systematic meta-analysis on the orchids of the Andaman and Nicobar Islands using secondary information and published literature from the past two decades (2001-2023). Specifically, we aim to (i) draw recent trends in orchid research across different subject areas (e.g. new orchid species, orchid ecology, population status assessment) (ii) document the orchid diversity, distribution, and endemism in ANI and update the orchid checklist, (iii) understand how the patterns in our study system fit into island biogeography theory, and (iv) highlight important knowledge gaps that need to be addressed through future research.

MATERIAL AND METHODS

We manually searched for orchid-related research published from the ANI from 2001 to 2023 using a widely accepted and easily accessible scientific citation database: Google Scholar (Castellanos-Galindo et al. 2021) (Fig. 1). Further, the literature search from the Google Scholar database was cross verified through the software Publish or Perish (PoP), Version 8, which automatically produces a list of published articles according to the keyword(s) for the specified time frame (Castellanos-Galindo et al. 2021). For Ph.D. and master's thesis, we explored the Sodhganga webpage, the largest repository of Indian theses. Additionally, the flora of ANI and India were reviewed to update the checklist of orchid species present in the islands. Finally, the search on Google Scholar was followed by the snowball method, where the reference section of the downloaded articles was checked diligently for the relevant article (Naderifar et al. 2017) and other grey literature (project reports) that the authors have access to from the libraries of various academic institutions.

The orchid-related literature from the ANI was obtained using the following simple keywords: "Flora," "Flowering plants," "Angiosperm," "Orchids," "Andaman and Nicobar," in combination with "Orchid," "New record," "New Report," "First," "New Distribution," "Orchidaceae," "Andaman and Nicobar Island," and "India". Further, the literature search was concurrent with the eligibility check of

articles for their inclusion or exclusion in the meta-analysis. This involved scrutinizing the titles and abstracts of the article using a straightforward criterion: whether the article addresses the orchids of ANI post-2001. Duplicate articles, including non-peer-reviewed, were removed from the qualitative and quantitative analysis, and the remaining articles were broadly categorized into eight thematic areas, namely: 1. New distribution record to the orchid flora of India, 2. New distribution record to the orchid flora of ANI, 3. New species discovery, 4. Orchid species rediscovery from the ANI, 5. Taxonomic note on orchid species, 6. Orchid ecology, 7. Review article, and 8. Orchid species checklist. The species names were verified from the Plants of the World Online (POWO) webpage (Anonymous 2024b) for validity, accepted names and synonyms. The global conservation status and threat category of each of the species in the compiled list was verified on the IUCN Red List webpage (Anonymous 2024a). Further, a linear regression model was performed in R software (version 4.3.2) to analyze the relevance of island biogeography theory on the orchid richness and endemism of the ANI system concerning island size. A graphical representation of the meta-analysis was prepared in MS-Excel (version 2019), while the study area map with species hotspots was prepared in Arc-GIS (version 10.5).

RESULTS AND DISCUSSION

A total of 55 orchid-related studies from the Andaman and Nicobar archipelago were published in the last two decades (2001–2023). The number of publications over this period shows a modestly negative trend (– 0.084x + 3.39) with erratic increases and decreases across the study period (R^2 – 0.078) (Fig. 2). On average, 2.39 ± 0.42 (mean ± standard error) articles are published annually on the orchids of ANI, with the highest number of publications observed during 2013–2014 (n = 14) (Fig. 2). All eight thematic areas have an average of seven publications each, with four thematic areas having fewer than the average number of publications (in descending order: "taxonomic note," "ecology article," "species rediscovery," and "review articles") (Fig. 3). More than 80% (n=42) of publications fall within the "new species," "new distribution," and "rediscovery" thematic areas. Under the "new species discovery" theme, 47 new orchid species were reported, emphasizing the importance of the island ecosystem and the unknown biodiversity it holds. However, a recent study estimated that two-thirds of total extinct species reported globally are from island ecosystems (Kier et al. 2009, Fernández-Palacios 2021) indicating that several species, including orchids from the ANI, may be extinct even before documented. Further, "new distributional records" are reported for 33 orchid species, of which 15 species are also reported from mainland India, demonstrating the biogeographical affinities between the two landmasses (Ganeshaiah et al. 2019). The remaining 18 species are new reports to both India and the islands, illustrating the linkage of the ANI biodiversity with other Southeast Asian countries (Kier et al. 2009). The ecology and whereabouts of the species are fundamental information required for planning conservation strategies and preparing policy frameworks (Ludwig et al. 2001). Therefore, one orchid ecology publication every five years from the islands is far too few, considering the current rate of biodiversity loss (Anonymous 2024c) due to increased intensity of threats from climate change, natural hazards, and anthropogenic pressure (Tilman et al. 2017).

A total of 161 orchid species belonging to 70 genera are present in the Andaman and Nicobar archipelago, which accounts for approximately 12% of total orchid species found in India (~1300) and 17 more orchid species than previously reported (Karthigeyan et al. 2014). Among the reported orchid species, 68% (n=110) are epiphytic, 29% (n=46) are terrestrial, and the remaining 3% (n=5) are common to both categories (Authors personal record - https://doi.org/10.13140/RG.2.2.23929.48487). The terrestrial forest of the archipelago (including hill forest) constitutes 153 (95%) orchid species. Therefore, the continuous selective logging of large trees may have severely affected the orchid populations. It is noteworthy that the post-tsunami geomorphological changes across the archipelago have considerably impacted the coastal forests and mangroves in ANI (Nehru and Balasubramanian 2018, Ramakrishnan et al. 2020, ShivaShankar et al. 2020). For example, the land uplift caused a loss of approximately 65 km^2 (70%) of mangroves in North

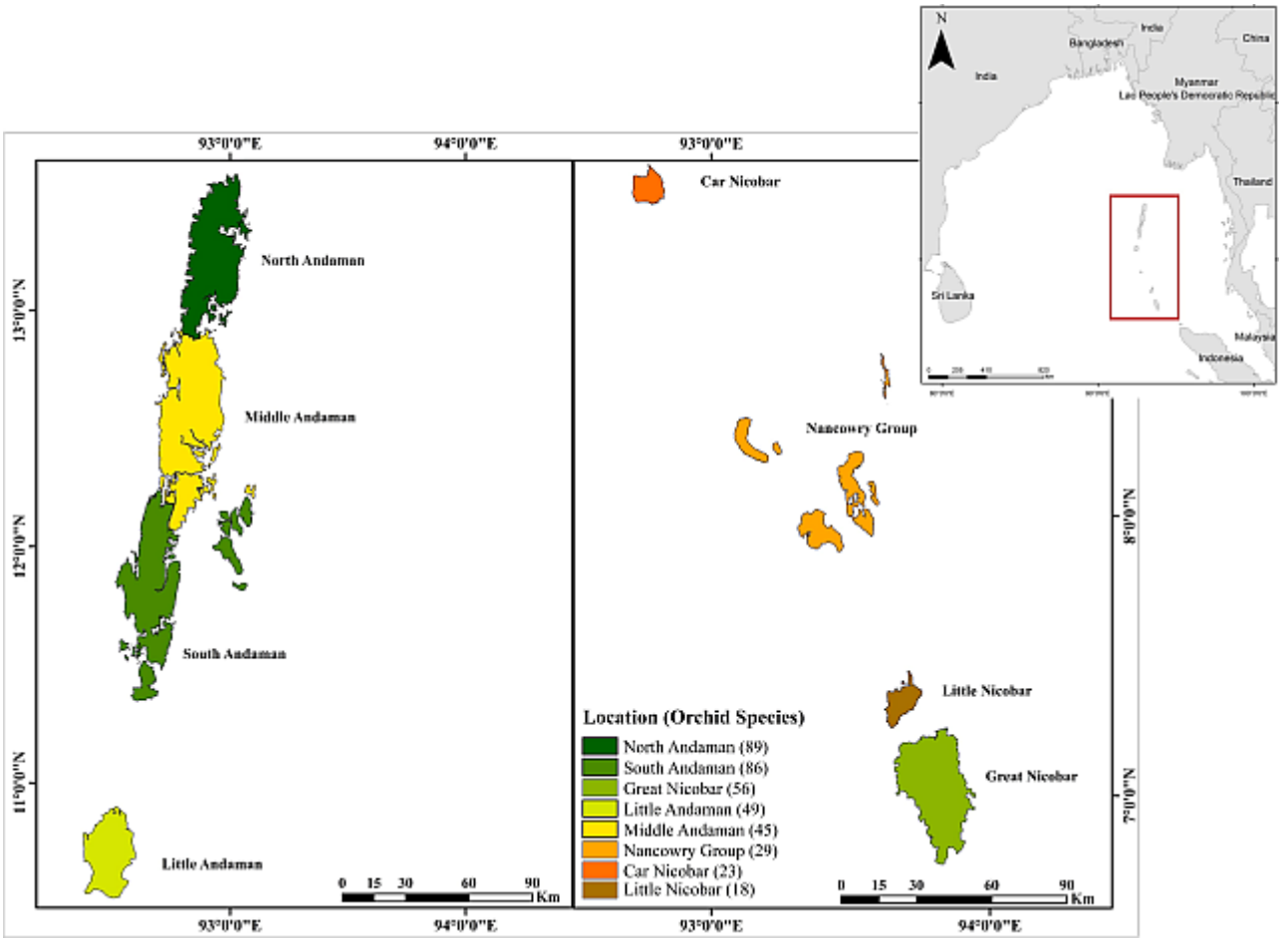

Figure 1. Showcasing study area with a heat map of orchid species richness across the Andaman and Nicobar Islands

Andaman (Ramakrishnan et al. 2020), and the land subsidence led to 35 km^2 (97%) mangroves degradation and more than 60% loss of coastal terrestrial forests in the Nicobar group of Islands (Nehru and Balasubramanian 2018). Additionally, ANI has 36 (22%) orchid species whose distribution is limited to the coastal forests and around 38 common orchid host trees (Karthigeyan et al. 2014) that are particular to the coastal forests. Therefore, it is likely that these orchid species specific to coastal forest must have sustained a serious population decline, and habitat loss, or may have gone locally extinct from the islands after the 2004 tsunami.

The equilibrium theory of island biogeography states that larger islands will have higher species richness compared to smaller islands (Mayr 1940, Macarthur and Wilson 1963, 1967). Thus, in general, the number of species present in the island would be strongly correlated with island-area (Mayr 1940, Preston 1962). In our island-wise distribution of orchid species analysis, we found that the island area and the number of species show a high correlation (R^2 – 0.76, P-value – 0.004). For instance, North Andaman and South Andaman, which have the largest landmass among all the islands, possess the highest number of orchid species 89 (55%) and 86 (53%), respectively (Fig. 1). Also, these two islands have a high intensity of human habitation and developed road networks, making them easily accessible for exploratory research and scientific excursions. In contrast, Middle Andaman records a relatively lower number of orchid species (n=45) despite having a similar landmass size to North Andaman and South Andaman. This discrepancy could be due to a major portion of Middle Andaman being protected as a tribal reserve (*Jarawa* reserve)

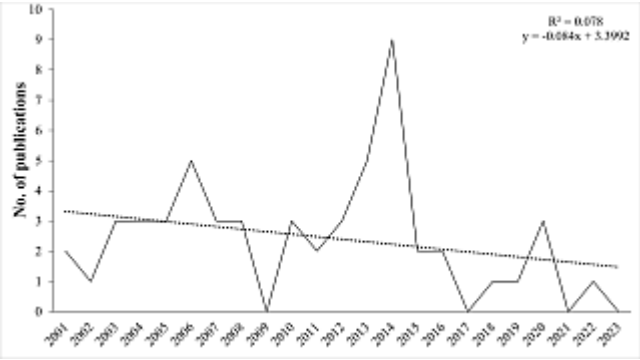

Figure 2. Trends and number of orchid-related studies published each year in the past two decades (2001-2023) from the Andaman and Nicobar Islands

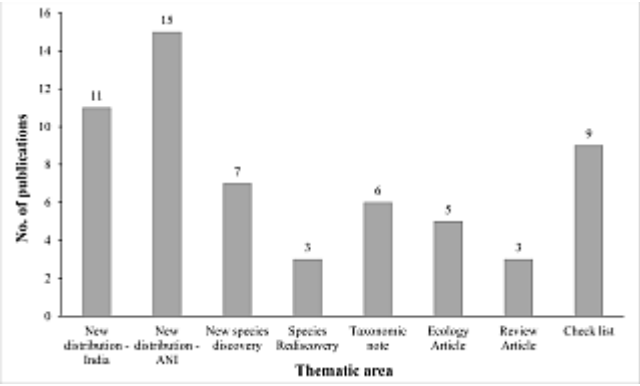

Figure 3. Number of orchid-related publications in various thematic areas from the Andaman and Nicobar Islands during 2001 to 2023

where research activity is highly restricted (Chakrabarty et al. 2012). Similarly, the Nancowry group (n=29), Car Nicobar (n=23), and Little Nicobar (n=18) reported fewer orchid species, as these islands are relatively smaller in size and less explored due to accessibility and logistical constraints (Fig. 1). The island biogeography theory is also evident when correlating the size of the island with the number of endemic orchid species it holds. A similar trend was observed, where the larger sized island (North Andaman and South Andaman) has higher endemic species (n=14 and 13 respectively) (R^2 – 0.72, and P-value – 0.0077). However, considering the limited number of orchid related publication/year, and lack of island-wide extensive studies suggest that these islands may be possessing higher numbers of orchid species than currently presented. Therefore, upon more extensive studies and exploration on orchids of the islands in future would alter the corelation pattern and might show different trends.

The literature search suggests that ANI contains in total of 29 (18%) endemic orchid species, seven more than the previous report (Karthigeyan et al. 2014) (Table 1). The seven new endemic species are mostly reported from the highly accessible part of the archipelago, indicating a high potentiality for discovering new orchid species in the remote and least explored areas of the islands. Among the 29 endemic orchids, 10 of them have unapproved names according to POWO (Anonymous 2024b) (Authors personal record - https://doi.org/10.13140/RG.2.2.23929.48487), possibly due to recent reporting of these endemic orchids from the archipelago. Also, population status is available for only one species, *Zeuxine rolfeana* King & Pantl., which is critically endangered according to the IUCN Red List (Anonymous 2024a), but specific ecological data for ANI is currently unknown. As per the global database POWO (Anonymous 2024b), 149 orchid species names are valid, which is 92.5% of the species reported from ANI, whereas the remaining 7% (n=12) orchid species names are currently unavailable at the global database (Authors personal record - https://doi.org/10.13140/RG.2.2.23929.48487). Out of these 12 orchids, 10 are reported as novel orchids from the island (endemic) (Table 1), and the population status of these ten species is yet to be evaluated according to the IUCN Red List categories (Anonymous 2024a). Furthermore, we found that only nine (5%) orchids have been evaluated by the IUCN, while the population status of the remaining 152 (95%) species is yet to be assessed. Notably, out of nine evaluated species, seven are categorized as least concerned, while two are critically endangered (Table 2). The population status of these evaluated orchids is a global estimate, and the local status in ANI is still unknown. Therefore, conserving and improving orchid habitat will not only protect the threatened orchids but also benefit the wide range of other taxa (Dressler 1993, Phillips et al. 2020).

CONCLUSIONS

Despite the rich diversity of orchid species in the islands, there has been a glaring absence of comprehensive studies explicitly addressing the

Table 1. List of endemic orchids in the archipelago of Andaman and Nicobar

S. No	Species	Habit	Habitat	Status	Endemism	Reference
1	*Aerides emericii*Rchb.f.	Epiphyte	Inland, Littoral Forest	Rare	South Andaman, Car Nicobar, Katchal, Great Nicobar Island	Karthigeyan et al. 2014
2	*Anoectochilus narasimhanii* Sumathi & al.	Terrestrial	Hill forest	Rare	North Andaman (Saddle Peak)	Karthigeyan et al. 2014
3	*Anoectochilus nicobaricus* N.P.Balakr. & P.Chakra.	Terrestrial	Inland forest	Rare	Great Nicobar Island	Karthigeyan et al. 2014
4	*Appendicula nicobarica* Jayanthi, Sumathi & Karthig.	Epiphyte	Inland forest	Rare	Great Nicobar Island	Karthigeyan et al. 2014
5	*Cryptostylis saddlepeakensis*	Terrestrial	Inland forest	Rare	North Andaman	Sumathi 2005
6	*Dendrobium gunnarii* P.S.N.Rao	Epiphyte	Inland forest	Rare	North Andaman	Karthigeyan et al. 2014
7	*Dendrobium shompenii* B.K.Sinha & P.S.N.Rao	Epiphyte	Inland forest	Rare	Great Nicobar Island	Karthigeyan et al. 2014
8	*Dendrobium tenuicaule* Hook.f.	Epiphyte	Inland forest	Rare	Andaman Islands	Karthigeyan et al. 2014
9	*Eria andamanica* Hook.f.	Epiphyte	Littoral, Inland Forest	Common	Andaman Islands	Karthigeyan et al. 2014
10	*Eulophia nicobarica* N.P.Balakr. & N.G.Nair	Epiphyte	Inland forest	Rare	Car Nicobar	Karthigeyan et al. 2014
11	Grosourdya appendiculata (Blume) Rchb.f.	Epiphyte	Inland forest	Rare	North Andaman, South Andaman, Little Andaman	Mishra et al. 2019
12	*Habenaria kalpongiana*	Terrestrial	Inland forest	Rare	North Andaman	Sumathi 2005
13	*Habenaria nicobarica*	Terrestrial	Inland forest	Rare	Little Nicobar, Great Nicobar Island	Karthigeyan et al. 2014
14	*Habenaria osmastonii*	Terrestrial	Inland forest	Rare	North Andaman-Kalpong, South Andaman-Rutland Island	Karthigeyan et al. 2014
15	*Habenaria rangatensis*	Epiphyte	Inland Forest	Rare	Middle Andaman	Prasad and Naik 2020
16	*Habenaria andamanica* Hook.f.	Terrestrial	Inland forest	Rare	South and Middle Andaman	Karthigeyan et al. 2014
17	*Liparis Livingstoneae*	Terrestrial/ Epiphytic	Inland forest	Rare	North Andaman	Sumathi 2005
18	*Luisia balakrishnani*	Epiphyte	Inland, Hilltop Forest	Rare	South Andaman	Karthigeyan et al. 2014
19	*Luisia diglipurensis*	Epiphyte		Rare	North Andaman	Mishra et al. 2020
20	*Luisia jarawae*	Epiphyte		Rare	North Andaman	Mishra et al. 2020
21	*Macropodanthus berkeleyi* (Rchb.f.) Seidenf. & Garay	Epiphyte	Inland forest	Rare	South Andaman, Great Nicobar Island	Karthigeyan et al. 2014
22	*Malleola andamanica* N.P.Balakr. & N.Bhargava	Epiphyte	Inland forest	Rare	Andaman Islands	Karthigeyan et al. 2014
23	*Peristylus balakrishnanii*	Terrestrial	Inland forest	Rare	South Andaman (Rutland Island)	Karthigeyan et al. 2014
24	*Taeniophyllum andamanicum* N.P.Balakr. & N.Bhargava	Epiphyte	Inland forest	Rare	South Andaman (Baratang Island)	Karthigeyan et al. 2014
25	*Trichoglottis orchidea* (J.Koenig) Garay	Epiphyte	Inland forest	Common	Car Nicobar, Katchal Island, Great Nicobar Island	Karthigeyan et al. 2014
26	*Vanilla andamanica* Rolfe.	Climber	Inland forest	Rare	Middle Andaman (Betapur)	Karthigeyan et al. 2014
27	*Vanilla sanjappae* Rasingam, R.P.Pandey, J.J.Wood & S.K.Srivast.	Climber	Inland forest	Rare	Little Andaman	Karthigeyan et al. 2014
28	*Zeuxine andamanica* King &Pantl.	Terrestrial	Inland forest	Rare	North Andaman, South Andaman	Karthigeyan et al. 2014
29	*Zeuxine rolfeana* King &Pantl.	Terrestrial	Inland forest	Rare	South Andaman (Dhanikhari)	Karthigeyan et al. 2014

Table2. List of orchid species reported from ANI included in IUCN Red List

S. No.	Species	IUCN Red List category	Status	Distribution	
				Global	ANI
1	*Bulbophyllum maxillare* (Lindl.) Rchb.f.	Least Concern	Rare	India, Indonesia, Malaysia, Philippines, Sulawesi, New Guinea, Solomon Island, Australia	GN
2	*Bulbophyllum restrepia* (Ridl.) Ridl.	Least Concern	Rare	India, Indonesia, Malaysia, Moluccas, Sulwesi, New Guinea	GN
3	*Dendrobium aphyllum* (Roxb.) C.E.C.Fisch.	Least Concern	Common	China, Nepal, India, Laos, Myanmar, Thailand, Vietnam, Malaysia	NA, MA, SA, LA
4	*Dendrobium incurvum*Lindl.	Least Concern	Common	India, Myanmar, Thailand, Vietnam, Malaysia	NA
5	Erythrodes blumei (Lindl.) Schltr.	Least Concern	Rare	China, Taiwan, India, Bangladesh, Myanmar, Thailand, Vietnam, Indonesia, Malaysia	GN
6	*Erythrorchis altissima*(Blume) Blume	Least Concern	Rare	China, Japan, Taiwan, India, Cambodia, Laos, Myanmar, Thailand, Vietnam, Indonesia, Malaysia, Philippines	GN
7	*Gastrochilus calceolaris* (Buch. -Ham. ex Sm.) D.Don	Critically endangered	Rare	China, Nepal, India, Bangladesh, Myanmar, Vietnam, Malaysia, Indonesia, Philippines	NA, MA, SA, LA
8	*Phreatia plantaginifolia*(J.Koenig) Ormerod	Least Concern	Rare	India, Thailand, Vietnam, Indonesia, Malaysia, Moluccas, Philippines, Sulawesi	NA
9	*Zeuxine rolfiana*King & Pantl.*	Critically endangered	Rare	India	SA

(NA-North Andaman, MA-Middle Andaman, SA-South Andaman, LA-Little Andaman, CR-Car Nicobar, NC-Nancowry Islands, LN-Little Nicobar, GN-Great Nicobar) (* endemic to ANI)

impacts of anthropogenic factors (such as selective logging and deforestation) and natural stressors (like the 2004 tsunami and earthquake) on the orchid community. Most studies have been exploratory in nature, focusing on discovering new species and documenting distribution records. However, the ecology and population status of most orchids in ANI remains unexplored. This work consolidates an updated checklist of 161 orchid species found in the islands, including 29 endemic species. The Nicobar group of islands, which has reported fewer orchids, highlights the urgent need for extensive exploration in these largely uncharted territories. A significant proportion of the islands' orchids are epiphytic, and the forests of Andaman and Nicobar have been subject to logging for over 150 years, particularly targeting large canopy trees. Surprisingly, no studies have assessed the impact of logging on the islands' orchids. Moreover, the lack of ecological information regarding the orchid population status, distribution, and ecological characteristics of over 90% of species (145) poses significant challenges in conserving and protecting these species and their habitats from extinction. The 2004 tsunami significantly impacted coastal vegetation, likely affecting orchid species specific to coastal forests. Therefore, a detailed assessment of coastal habitats and their orchid populations is necessary to understand the repercussions of natural disasters on these plants. Furthermore, regular monitoring of rare, endemic, and critically endangered orchid species is essential to ensure their long-term survival. Additionally, recent proposals for large-scale developmental projects in ANI aimed at expanding tourism and other economic activities entail clearing vast forested areas, potentially jeopardizing critical habitats of rare and endemic orchid species. Hence, an immediate detailed baseline study on the distribution of key orchid species, particularly endemics, is imperative. Moreover, identifying and delineating orchid hotspots as significant conservation areas, like Important Bird Areas, can help mitigate potential ecological damage arising from future developmental activities.

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