



SAGA OF DISTRIBUTION AND CONSERVATION OF *CYCAS*, "A LIVING FOSSIL"

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Abstract

Cycas, the sole extant genus of Cycadaceae, represents one of the world's most evolutionarily significant plant lineages, and is among the most threatened. Using a comprehensive global dataset synthesizing species distributions, threat categories, and regional pressures, this study evaluated worldwide and Indian patterns of diversity and vulnerability. The results revealed strong biogeographic structuring, with Australia, China, Vietnam, India, and the Philippines forming the principal centres of species richness. However, these same regions also display the highest concentrations of threatened taxa, with nearly two-thirds of all species falling into the Critically Endangered, Endangered, or Vulnerable categories. Threat incidence is strongly associated with rapid land-use change, illegal horticultural harvest, restricted range, and the inherently slow life-history traits of cycads. Indian species, several of which occupy basal phylogenetic positions, exhibit acute vulnerability driven by mining, habitat conversion, demographic aging, and limited regeneration. Island taxa in the Pacific and Andaman–Nicobar regions face additional risks linked to small population sizes and micro endemism. The global synthesis highlights the convergence of evolutionary significance and contemporary threat, indicating that regions with the greatest phylogenetic value are also those undergoing the most rapid ecological degradation. These findings underscore the urgent need for habitat-level protection, long-term demographic monitoring, and ex-situ conservation programs targeting genetically and evolutionarily distinct lineages. The integrated global–Indian dataset presented here provides a critical foundation for future taxonomic, biogeographic, and conservation planning of this ancient and rapidly declining genus.

Keywords: *Cycas*, Biodiversity and Biogeography, Threatened Plant Species, Conservation Biology, Phylogenetic Significance

Introduction

Cycads, particularly those of the genus *Cycas* L., represent one of the most ancient surviving lineages of seed plants and retain a suite of primitive characteristics that illuminate early gymnosperm evolution. As the sole extant genus of the family Cycadaceae, *Cycas* is widely recognized as a group of "living fossils," reflecting their persistence with relatively unchanged morphological features over millions of years. These include pachycaulous stems, pinnate and leathery foliage, large seeds with thick sarcotesta, coralloid roots containing nitrogen-fixing cyanobacteria, extremely slow growth, and a strictly dioecious reproductive system (Khuraijam & Goel, 2015). Their reproductive attributes, such as motile sperm and spirally arranged megasporophylls, provide crucial insights into early seed plant development and the evolutionary transition from pteridophytes to gymnosperms.

Despite their evolutionary resilience, *Cycas* species are ecologically sensitive to environmental changes. Most occur in highly restricted habitats characterized by nutrient-poor substrates, low rainfall, and minimal anthropogenic disturbance. These narrow ecological tolerances make them vulnerable to rapid

environmental changes, especially habitat fragmentation, deforestation, land-use alteration, and illegal harvesting for ornamental and horticultural purposes. Global taxonomic and bio geographic assessments (Hill, 1994; Osborne et al., 2012) have identified *Cycas* as the most widely distributed cycad genus, extending from Madagascar and eastern Africa through South, Southeast, and East Asia to northern Australia and the Pacific islands. However, these assessments indicate that more than 70% of the recognized species are threatened, placing *Cycas* among the most imperiled plant groups globally.

India is a critical component of this wider bio geographic pattern. Species such as *C. beddomei*, *C. circinalis*, *C. annaikalensis*, and *C. nayagarhensis* occur in small, isolated, or fragmented populations, many of which lie within landscapes undergoing rapid ecological transformation. Their specialized habitat requirements, combined with increasing anthropogenic pressures, have resulted in severe population decline. Several Indian species are listed on the IUCN Red List and are regulated under CITES, underscoring the need for accurate distributional data to guide conservation and management efforts. Climate change projections further highlight the vulnerability of these slow-growing tax a, as shifts in temperature and precipitation patterns may exceed their capacity for ecological adaptation or migration.

Although substantial regional studies exist, there remains a lack of an integrated, up-to-date synthesis comparing the global distribution patterns of *Cycas* with those of the Indian subcontinent. Reliable baselines are essential for identifying conservation priorities, correcting taxonomic ambiguities and informing national and international policies. The present study addresses this gap by compiling and analysing verified global records of *Cycas* species, assessing their distributional ranges, and evaluating their conservation status at both the global and Indian scales. By incorporating a comprehensive species appendix and cross-referencing the published literature with regional surveys, this study provides one of the most detailed contemporary overviews of *Cycas* biogeography and identifies priority areas for conservation intervention.

Materials and method

This study was conducted entirely through computer-based compilation and evaluation of published data on *Cycas* species. All information relating to taxonomy, species distribution, locality records, and conservation status was sourced from authoritative monographs, regional floras, peer-reviewed literature, and verified assessments on the IUCN Red List. Each species entry was carefully cross-validated across multiple references to ensure consistency and reliability before being incorporated into a comprehensive dataset. Species were subsequently grouped into major bio geographic regions to facilitate a comparative analysis of richness and distributional trends across Asia, Australia, the Pacific Islands, Africa, and the Indian subcontinent. A dedicated dataset for India was developed by extracting state-level occurrences, endemic taxa, and documented threat factors from national botanical records and regional revisions. Conservation categories were assigned using the most recent IUCN assessments, and for species lacking formal evaluation, provisional status was inferred from published accounts describing population size, habitat specificity and observed anthropogenic pressures. Patterns of diversity and threat incidence were summarized descriptively, and digital maps depicting global and Indian distributions were generated from the compiled dataset. As this study relied exclusively on secondary information, no field sampling, experimental work, or specimen collection was performed.

Observation

1. Global Distribution of *Cycas*

The genus *Cycas*, comprising more than 125 species, is primarily distributed across the tropical and subtropical regions of Asia, its largest center of diversity, as well as Australia, the Pacific Islands, and parts of East Africa and Madagascar, collectively representing four major bio geographic zones in its global range (Hill, 1995; Lindström & Hill, 2007). Within the Old World, *Cycas* shows its greatest richness in equatorial and adjacent subtropical regions of Asia. The genus is particularly well represented in India, China, Japan, Thailand, Vietnam, and the Philippines, and its range extends further into Eastern Africa, Northern Australia, Polynesia, and Micronesia (Hill, 1995). The distribution of *Cycas* species reflects long-term geological processes, climatic stability, and varying degrees of geographic isolation.



Figure 1: Global distribution of Cycas species in different countries

2. Distribution of Cycas in China

The distribution of Cycas species in China is concentrated mainly in the southern and south western provinces, where complex topography and subtropical climates support high levels of endemism. Guangxi contains several narrowly restricted species, including *C. baiseensis* (Huang, 2018) and critically endangered *C. debaoensis* (Zhong & Chen, 1997). Yunnan represents another major center of diversity, with species such as *C. chenii* (Zhou et al., 2015), *C. diannanensis* (Guan & Tao, 1995), *C. hongheensis* (Wang, 1996), *C. multipinnata* (Chen & Yang, 1994), and *C. tanqingii* (Wang, 1996) being found there. Hainan supports the endangered *C. changjiangensis* (Hill, 2008), and Guizhou hosts localized populations of *C. guizhouensis* (Lan & Zou, 1983). Several species occur along China's border regions, demonstrating biogeographic links with Southeast Asia, such as *C. bifida* (Hill et al., 2004), *C. dolichophylla* (Hill et al., 2004), and *C. simplicipinna* (Hill & Yang, 1999). Eastern provinces, such as Fujian and Guangdong, harbor species with limited distributions, including *C. szechuanensis* (Cheng et al., 1975) and *C. taiwaniana* (Carruthers, 1893), whereas Taiwan contains the endemic *C. taitungensis* (Shen et al., 1994). Overall, China's Cycas flora exhibit strong regional specialization, fragmented population structures, and pronounced conservation concerns.

3. Distribution of Cycas in Vietnam

Vietnam supports a rich and geographically complex distribution of Cycas species, with populations ranging from the northern mountainous regions to the southern coastal and island ecosystems of the country. The northern and north-central provinces host several narrowly distributed taxa, including *C. brachycantha* in Bac Kan (Hill et al., 2004) and *C. chevalieri* in Nghe An (Leandri 1931). *C. fugax* persists in highly restricted and vulnerable populations in Phu Tho Province (Hill et al., 2004). Central Vietnam contains multiple species adapted to diverse habitats, such as *C. aculeata* in Thua Thien-Hue (Hill et al., 2004), *C. collina* in Son La (Hill et al., 2004), and the endangered *C. elongata*, which occurs across Binh Dinh, Khanh Hoa, Ninh Thuan, and Phu Yen (Wang 1996). Southern Vietnam harbors distinctive and often critically threatened species, including *C. pachypoda* in Binh Thuan and Ninh Thuan (Hill et al., 2004) and the coastal endemic *C. lindstromii* in Binh Thuan (Hill et al., 2004).

Several species are shared with neighboring countries, illustrating strong regional and biogeographic connectivity. For example, *C. inermis* extends from Laos to central and southern Vietnam (de Loureiro, 1790), and *C. micholitzii* occurs across Dac Lak, Gia Lai, and Kon Tum (Thiselton-Dyer, 1905). Additional species, such as *C. tropophylla* in Hai Phong and Quang Ninh, represent the northern coastal elements (Hill et al., 2004). Overall, Vietnam's *Cycas* flora spans a broad ecological gradient; however, many species occur in narrow ranges and face elevated conservation risks.

4. Distribution of *Cycas* in Philippines

The Philippines hosts a highly diverse assemblage of *Cycas* species, many of which have narrow geographic ranges and elevated conservation concerns. Species such as *Cycas aenigma*, *C. flabellata*, *C. mindanaensis*, and *C. vespertilio* occur primarily across Mindanao, the Visayas, and selected provinces of Luzon, but most remain unevaluated in global assessments (Agoo et al., 2019; Lindström et al., 2008). Several species, including *C. riuminiana* and *C. lacrimans*, display wider yet fragmented distributions and are currently categorized as endangered due to habitat loss and population decline (Lindström et al., 2008; Regel, 1863). The most threatened taxa, *C. curranii*, *C. sancti-lasallei*, *C. wadei*, and *C. zambalensis*, are listed as Critically Endangered, reflecting their extremely restricted ranges in Palawan, Misamis Oriental, and Zambales and continued pressures from land conversion and disturbance (Agoo & Madulid, 2012; Hill, 1995; Madulid & Agoo, 2005; Merrill, 1936). Overall, the Philippine *Cycas* flora demonstrates high endemism and significant vulnerability, underscoring the urgent need for targeted conservation management.

5. Distribution of *Cycas* in Indonesia

Indonesia supports a diverse representation of *Cycas* species, many of which are concentrated in the archipelago's eastern and western regions. *Cycas apoa* is native to Irian Jaya, occurring near the southern coast of Lake Sentani, and is currently assessed as Near Threatened due to its restricted distribution (Hill, 1994). The widely distributed *C. edentata* extends across numerous Indonesian provinces, from Bali and Java to Sumatra and the Riau archipelago, and also spans neighbouring countries of Southeast Asia, indicating its ecological tolerance and broad biogeographic range (de Laubenfels, as cited in Indonesia dataset). In contrast, species such as *C. glauca* in Nusa Tenggara Timur remain Data Deficient, reflecting limited field information on population status (Miquel, 1840). Endemism is notable in *C. javana*, which is confined to Java and classified as endangered due to ongoing habitat pressures (Wang, 1996). Additional species, including *C. montana* and *C. sunaica* from the Nusa Tenggara region, have yet to be evaluated, emphasizing the need for comprehensive assessments to guide conservation planning (Lindström et al., 2009). Collectively, Indonesia's *Cycas* flora demonstrates broad geographic diversity and significant conservation gaps, underscoring the importance of targeted research and management.

6. Distribution of *Cycas* in Laos, Myanmar and Cambodia

The distribution of *Cycas* species in mainland Southeast Asia reflects a pattern of localized endemism, particularly within Laos and Cambodia, whereas Myanmar remains poorly represented in the current records. In Laos, several narrowly distributed taxa have been documented, including *Cycas laotica*, which has been recorded from Khammouan Province at low elevations and currently lacks a formal conservation assessment (Averyanov et al., 2014). Additional Laotian species, such as *C. macrocarpa*, *C. nongnoochiae*, and *C. petraea*, are primarily found in the Vientiane region, and their conservation status ranges from Vulnerable to Near Threatened due to habitat alteration and limited population sizes (Hill & Yang, 1999; Lindström & Hill, 2003).

Cambodia hosts *Cycas clivicola*, a species with a relatively broad distribution extending across several Southeast Asian countries and assessed as Least Concern, although regional habitat pressures remain a persistent challenge (Hill & Yang 1999). Despite Myanmar being included in broader biogeographic discussions of *Cycadaceae*, no specific species occurrences from Myanmar were present in the dataset, suggesting either historical data gaps or the need for updated field surveys to fill these gaps. Together, these patterns highlight the uneven documentation of *Cycas* diversity across the region and emphasize the urgency of targeted conservation work in Laos and Cambodia.

7. Distribution of Cycas in Australia

Australia contains one of the most extensive and diverse assemblages of *Cycas* species worldwide, with taxa distributed across Queensland, Northern Territory, and Western Australia. Early records, such as *Cycas angulata* from the northern coast of “New Holland,” highlight the long-recognized presence of cycads in this region (Brown, 1810). Several species show broad or stable distributions and are classified as Least Concern, including *C. arnhemica*, *C. basaltica*, *C. calcicola*, and *C. media*, which occupy a variety of habitats across northern Australia (Gardner, 1923; Hill, 1994; Maconochie, 1978). In contrast, restricted-range taxa, such as *C. arenicola* in the East Alligator River region and *C. armstrongii* near Port Essington, are listed as near-threatened or vulnerable due to habitat pressures and population decline (Hill, 1993; Miquel, 1868). Queensland harbors many species of conservation concern, including *C. cairnsiana*, *C. cupida*, *C. distans*, *C. platyphylla*, and *C. semota*, all of which are assessed as Vulnerable or Endangered because of their narrow distributions and ongoing environmental threats (Forster, 2001; Forster & Gray, 2017; Hill, 1992). Additionally, island populations, such as *C. badensis* on Badu and Moa Islands and *C. papuana* on Prince of Wales Island, show varying levels of risk, reflecting their geographic isolation and limited occurrence (Hill, 1996; Mueller, 1876). Overall, the Australian *Cycas* flora demonstrates exceptional diversity but also substantial conservation challenges, emphasizing the need for targeted monitoring and habitat management across multiple states and territories.

8. Distribution of Cycas in Indonesia

Indonesia harbors a rich diversity of *Cycas* species distributed across its major island groups, reflecting extensive biogeographic continuity and localized endemism. *Cycas apoa* is restricted to Irian Jaya, particularly around the southern coast of Lake Sentani, and is assessed as Near Threatened because of its limited geographic range (Hill, 1994). In contrast, *C. edentata* exhibits one of the widest distributions among Asian cycads, occurring across numerous Indonesian provinces—including Bali, Java, Sumatra, Lampung, and the Riau archipelago—and extending into multiple neighboring countries, indicating its broad ecological tolerance (de Laubenfels, as cited in Indonesia dataset). Several species in the Nusa Tenggara region, such as *C. glauca*, *C. montana*, and *C. sundaica*, remain poorly evaluated. *C. glauca* is listed as Data Deficient owing to insufficient population data (Miquel, 1840), whereas *C. montana* and *C. sundaica* lack formal assessments despite their geographically confined distributions (Lindström et al., 2009). Notably, *C. javana*, endemic to Java, is classified as endangered due to persistent habitat pressures within its limited range (Wang, 1996). Overall, Indonesia’s *Cycas* flora demonstrates a combination of widespread species and narrowly distributed endemics, underscoring the need for enhanced conservation assessments and region-specific management strategies.

9. Distribution of Cycas in Papua New Guinea

Papua New Guinea hosts several regionally significant *Cycas* species, many of which exhibit restricted distributions and growing conservation concerns. *Cycas bougainvilleana* occurs across Bougainville and New Britain and extends into the Solomon Islands, where it is considered Near Threatened owing to localized habitat pressures within its island environments (Hill, 1994). Another species, *C. campestris*, is confined to the Lea Lakes region of Central Province and is similarly assessed as Near Threatened, reflecting both its limited extent and the vulnerability of its wetland-associated habitats (Hill, 1994). In the eastern and northern regions of mainland Papua New Guinea, *C. schumanniana* occupies the Eastern Highlands, Madang, and Morobe provinces and is also listed as Near Threatened, underscoring the conservation challenges faced by cycads in montane and lowland tropical ecosystems (de Laubenfels & Adema, 1998). Collectively, these species highlight the biogeographic uniqueness of Papua New Guinea’s cycad flora and emphasize the need for targeted conservation measures to address habitat changes and population fragmentation.

10. Distribution of Cycas in Philippines

The Philippines harbors one of the highest concentrations of *Cycas* endemism in Southeast Asia, with species distributed across Palawan, Mindanao, Luzon, Visayas, and several smaller islands. Many taxa, including *Cycas aenigma*, *C. flabellata*, *C. mindanaensis*, *C. nitida*, and *C. vespertilio*, remain formally unevaluated but occupy geographically restricted habitats in Palawan, Bukidnon, Davao Oriental,

Northern Samar, and the central Philippine islands (Agoo et al. 2019; Lindström et al. 2008). Several species are under severe conservation threat, such as *C. curranii* and *C. wadei* from Palawan and *C. sancti-lasallei* from Misamis Oriental, all of which are classified as Critically Endangered due to their extremely limited ranges and continuing habitat disturbances (Agoo & Madulid, 2012; Hill, 1995; Merrill, 1936). Endangered taxa, such as *C. lacrimans* and *C. riuminiana* illustrates the broader decline of Philippine cycads, with populations fragmented across Davao Oriental and Luzon Island provinces (Lindström et al., 2008; Regel, 1863). Additional vulnerable species, including *C. saxatilis* from Palawan, face pressure from habitat modification within narrow ecological zones (Lindström et al., 2008). Overall, the Philippine Cycas flora is characterized by exceptional endemism and heightened extinction risk, underscoring the urgent need for focused conservation and habitat protection strategies.

11. Distribution of Cycas in India

India supports a remarkably diverse and biogeographically complex assemblage of *Cycas* species, occurring across a wide range of ecological zones, from the dry deciduous forests of the Eastern and Western Ghats to the humid, isolated island ecosystems of the Andaman and Nicobar archipelago. This heterogeneity in landscape and climate has contributed to the evolution of several narrowly endemic and highly localized taxa. Among the most threatened are *Cycas beddomei* of the Cuddapah Hills and *C. circinalis*, which occurs across peninsular states such as Kerala, Karnataka, and Tamil Nadu. Both species are listed as endangered because of extensive habitat degradation, overharvesting, and rapid population decline (Linnaeus, 1763; Thiselton-Dyer, 1883). Their restricted distributions, combined with increasing anthropogenic pressures, make these taxa priority targets for conservation interventions.

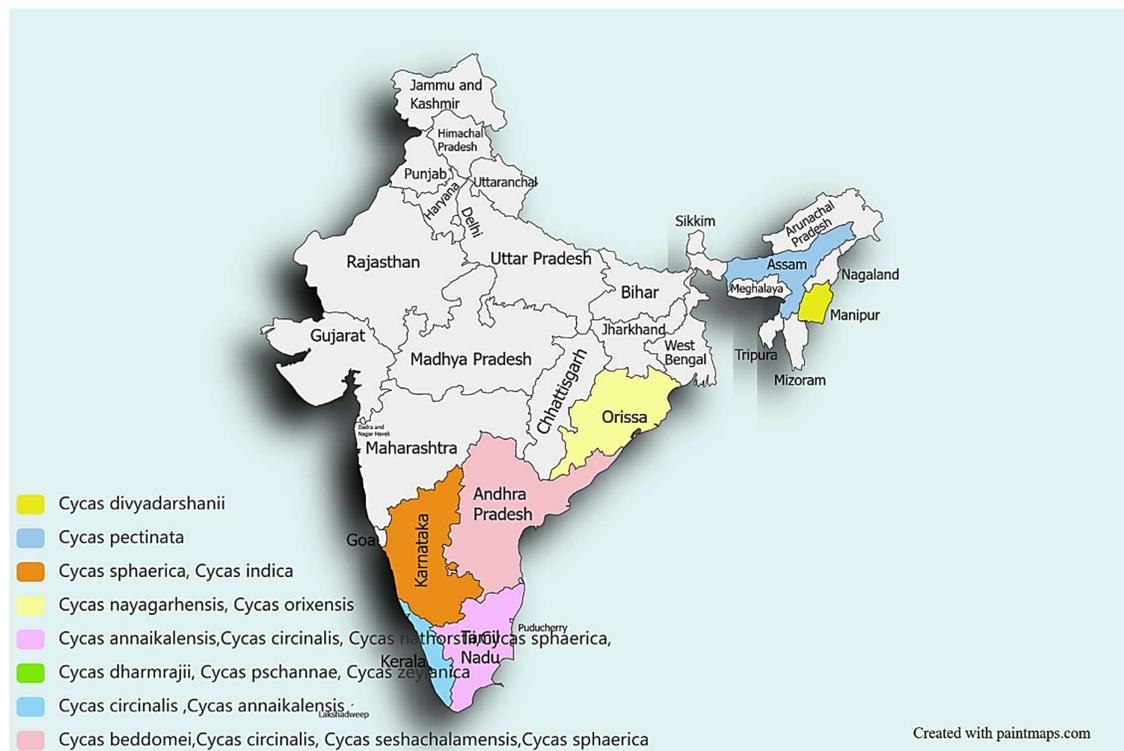


Figure 2: *Cycas* species distribution in India

The Andaman and Nicobar Islands constitute another important center of diversity, harboring several species with extremely limited distribution. *C. dharmrajii* and *C. pschannae* are notable examples. Although not yet formally assessed under the IUCN Red List, these species occupy ecologically fragile island habitats that are highly susceptible to natural disturbances, sea level rise, and land use change (Singh, 2017; Srivastava & Singh, 2015). The insular nature of these taxa increases their vulnerability, as even small-scale habitat alterations can have substantial impacts on their populations.

Within the Western Ghats, globally recognized as a biodiversity hotspot, several species are of critical conservation concern. *C. annaikalensis* and *C. nayagarhensis*, both confined to extremely limited localities in Kerala and Odisha, are categorized as Critically Endangered and face an imminent risk of extinction due to habitat fragmentation, small population sizes, and limited regenerative potential (Singh & Radha, 2006; Singh et al., 2015). Their persistence reflects a delicate balance between ecological specialization and the stability of remaining forested habitats.

Additional taxa in mainland India further illustrate the diversity and vulnerability of the cycad flora in the country. *C. nathorstii* in Tamil Nadu and *C. sphaerica* in parts of Andhra Pradesh and Karnataka demonstrate a pattern of geographically scattered but ecologically sensitive populations (Roxburgh 1832; Schuster 1932). Furthermore, species such as *C. zeylanica* and *C. indica*, which extend into island or transitional biogeographic zones, continue to face conservation challenges despite occupying slightly broader ranges (Lindström & Hill 2002, 2007). Their fragmented distributions and slow growth rates increase their susceptibility to environmental changes. The human driven actions including government development works, replacement of natural forests with commercially valuable tree plantations, agricultural expansion, forest fires, encroachment for habitation and farming, and excessive harvesting for food, medicinal, and ornamental purposes are significantly endangering cycad populations (Kushwaha et al., 2023).

Collectively, the Indian Cycas flora exhibits a high degree of endemism, strong biogeographic structuring, and pronounced conservation sensitivity. Many species persist in small, isolated populations with limited dispersal capacities, making them particularly vulnerable to habitat loss, climatic fluctuations, and anthropogenic pressures. These patterns underscore the urgent need for strengthened habitat protection, targeted conservation planning, and long-term monitoring to safeguard India's unique Cycad heritage.

Result and Discussion

The global dataset assembled for this study revealed a sharply uneven distribution of Cycas diversity, with a clear biogeographic concentration that mirrors both deep evolutionary history and modern anthropogenic pressure. Australia, with 39–40 species, is the primary center of diversification, followed by China (21 species), Vietnam (20 species), India (14 species), the Philippines (12 species), and Indonesia (6 species), with 12 species scattered across Africa, Madagascar and the Pacific Islands. This gradient reflects the long evolutionary presence of the genus across climatically stable tropical and subtropical refugia. However, the same regions that sustain the greatest richness now contain the highest global threat incidences; Vietnam, the Philippines, southern China, and India's Eastern and Western Ghats collectively account for the majority of Critically Endangered and Endangered taxa.

Threat-status analysis indicates an alarming skew toward extinction risk: ~35 species are Critically Endangered, ~40 is Endangered, ~25 is Vulnerable, and fewer than 30 occupy the lower-risk categories. When mapped onto geographic patterns, this distribution suggests that nearly two-thirds of global Cycas diversity are located in socio-ecological hotspots undergoing rapid land-use transformation, making the genus highly responsive to modern disturbances. The drivers operate in reinforcing feedback loops: deforestation and mining eliminate adults, illegal horticultural collection removes reproductive stock, and inherently slow life-history traits, such as long generation time, limited dispersal, and low seedling recruitment, constrain natural recovery. These interactions are particularly severe in island systems, where Pacific and Andaman species with extremely narrow ranges face extinction from habitat loss measurable at the scale of a few hectares.

India reflects these global patterns but also provides unique insights into the evolution of risk. The 14 species of the country include several phylogenetically significant taxa occupying basal nodes in the Cycadales lineage. Critically Endangered species, such as *C. annaikalensis*, *C. nayagarhensis*, and *C. zeylanica*, persist as micro-endemics, with populations often restricted to single hillocks or forest fragments. Even historically widespread species (*C. circinalis*, *C. beddomei*) now exhibit contraction driven by limestone extraction in the Eastern Ghats, habitat conversion across Kerala and Karnataka, and coastal development in the Andaman Islands. Demographic data indicate aging and sparsely regenerating

populations, suggesting that many Indian cycads may be in an extinction debt phase, where the decline is already irreversible without intervention.

Globally, Cycas represents an evolutionary relict lineage whose persistence has depended on environmental stability over geological timescales. Current patterns of fragmentation, demographic collapse, and localized extirpation signal that the genus is undergoing a rapid, human-driven disruption that outpaces its biological capacity for adaptation or dispersal. The alignment between species richness and threat hotspots underscores a critical conservation paradox: the most evolutionarily informative and phylogenetically diverse populations are situated in regions undergoing the highest rates of ecological transformation.

The integrated dataset presented here suggests three urgent conservation priorities for this genus. First, habitat-level protection is essential, particularly in the Eastern and Western Ghats, limestone karsts of Vietnam, and ultramafic zones of the Philippines. Second, long-term demographic monitoring is required to assess regeneration bottlenecks and quantify extinction debt across fragmented populations. Third, ex situ conservation must target genetically distinct and phylogenetically basal lineages, especially those in India and southern China, to safeguard evolutionary history not represented elsewhere. The compiled global and Indian species lists, with detailed locality and status information, establish a foundational resource for future biogeographical, phylogenetic and conservation interventions.

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