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REVIEW ARTICLE

Floristic Diversity, Vegetation Heterogeneity, and Conservation Significance of Odisha Flora: A Comprehensive Review

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ABSTRACT

Odisha, located in eastern India and forming a major component of the Eastern Ghats biogeographic region, represents one of the ecologically significant yet comparatively under-synthesized floristic regions of the Indian subcontinent. The state supports remarkable vegetation heterogeneity encompassing coastal ecosystems, mangrove formations, riverine habitats, tropical dry deciduous forests, moist deciduous forests, semi-evergreen hill vegetation, and plateau ecosystems, collectively contributing to substantial vascular plant diversity and phytogeographical complexity. The present review provides a comprehensive and integrated synthesis of floristic diversity, vegetation structure, ecological gradients, distributional patterns, and conservation significance of Odisha flora based on available botanical and ecological literature. The floristic composition of the state reflects a transitional phytogeographic interface between peninsular and coastal ecosystems, supporting diverse tropical taxa along with ecologically sensitive and regionally restricted plant species. Forest ecosystems of Odisha further contribute significantly to ecosystem functioning through carbon sequestration, hydrological regulation, soil stabilization, climate moderation, and maintenance of ethnobotanical resources associated with indigenous communities. The review identifies major gaps in floristic exploration, taxonomic standardization, geospatial documentation, and long-term biodiversity monitoring, particularly within remote Eastern Ghats landscapes. Increasing anthropogenic disturbances, including habitat fragmentation, mining activities, deforestation, land-use conversion, invasive species expansion, and climate variability, are emerging as major drivers of floristic degradation across the region. This review highlights the urgent necessity for integrated floristic inventories, modern taxonomic reassessment, Geographic Information Systems-based biodiversity mapping, and landscape-level conservation planning for sustainable management of Odisha flora. The study represents one of the few statewide syntheses integrating vegetation heterogeneity, floristic composition, ecological significance, and conservation perspectives of Odisha within the broader Eastern Ghats biodiversity framework.

Key words: Biodiversity conservation, Eastern Ghats, Endemic flora, Floristic diversity, Odisha flora, Phytogeography, Tropical forest ecosystems, Vascular plant diversity, Vegetation ecology

INTRODUCTION

India is recognized as one of the world's megadiverse countries due to its remarkable ecological heterogeneity, varied climatic conditions, and complex biogeographical history. The country supports extensive floristic diversity distributed across diverse ecosystems ranging from alpine regions and tropical forests to coastal habitats and arid landscapes. Within this broader framework, the state of Odisha occupies a strategically important phytogeographical position in eastern India, representing a transitional zone between the Eastern Ghats mountain system and the coastal

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plains adjoining the Bay of Bengal. This unique geographical setting has contributed significantly to the development of diverse vegetation formations and heterogeneous plant communities across the state.

Odisha encompasses a broad range of ecological habitats, including coastal ecosystems, mangrove vegetation, riverine habitats, dry and moist deciduous forests, semi-evergreen hill forests, and plateau landscapes. Variations in altitude, rainfall distribution, soil characteristics, and climatic conditions across these ecosystems have resulted in considerable floristic richness and structural vegetation complexity. The Eastern Ghats region, in particular, is recognized for its ecological sensitivity and biodiversity significance due to the presence of relatively undisturbed forest patches, endemic taxa, and diverse vegetation assemblages.

The floristic composition of Odisha reflects the coexistence of multiple phytogeographical elements originating from both peninsular and coastal ecosystems. Forest ecosystems of the state not only contribute substantially to regional biodiversity conservation but also provide important ecological services, including soil stabilization, hydrological regulation, carbon sequestration, and climate moderation. In addition, plant resources of Odisha possess considerable ethnobotanical importance, especially among indigenous and tribal communities that rely extensively on forest biodiversity for traditional healthcare systems, food resources, and cultural practices.

Despite the recognized ecological significance of Odisha flora, a comprehensive statewide synthesis of floristic diversity remains limited. Most available botanical investigations are localized and fragmented, focusing primarily on specific protected areas, forest divisions, or isolated ecological regions. Consequently, an integrated understanding of vegetation heterogeneity, distributional patterns, conservation challenges, and floristic relationships across the state remains incomplete. Furthermore, increasing anthropogenic disturbances such as deforestation, mining activities, agricultural expansion, habitat fragmentation, and climate variability are exerting significant pressure on natural vegetation and plant diversity.

In this context, the present review aims to provide a comprehensive synthesis of the floristic diversity, vegetation heterogeneity, ecological significance, and conservation status of Odisha flora. The review integrates available information from floristic surveys, ecological studies, vegetation analyses, and biodiversity assessments to highlight the phytogeographical importance of the region and identify major research gaps and future priorities for biodiversity conservation and sustainable ecosystem management.

Although several localized floristic investigations and ecological studies have been conducted across different regions of Odisha, a comprehensive statewide synthesis integrating vegetation heterogeneity, floristic distribution, ecological significance, and conservation challenges remains limited. Existing information is often fragmented across district-level surveys and isolated ecological assessments, resulting in an inadequate understanding of regional floristic patterns within the broader Eastern Ghats biodiversity framework. Therefore, the present review aims to critically synthesize available scientific literature related to Odisha flora and provide an integrated perspective on vegetation diversity, phytogeographical significance, ecological functions, conservation threats, and future research priorities. This synthesis is expected to contribute toward improved biodiversity documentation, conservation planning, and sustainable ecosystem management in eastern India.

METHODOLOGY OF LITERATURE REVIEW

The present review was developed through a comprehensive synthesis of published scientific literature related to floristic diversity, vegetation ecology, phytogeography, vascular plant resources, and biodiversity conservation of Odisha and the Eastern Ghats region of India. Relevant literature was collected from multiple scientific databases, including Google Scholar, Scopus, Web of Science, ResearchGate, and institutional repositories. Peer-reviewed journal articles, floristic surveys, ecological assessments, biodiversity reports, monographs, books, and regional vegetation studies published between 2000 and 2025 were critically evaluated for inclusion in the review.

The literature search was conducted using combinations of keywords such as “Odisha flora,”

"Eastern Ghats vegetation," "vascular plant diversity," "forest ecology," "floristic composition," "plant wealth of Odisha," "phytogeography," "vegetation heterogeneity," and "biodiversity conservation." Particular emphasis was placed on studies addressing floristic inventories, vegetation structure, species distribution patterns, endemic taxa, ecological gradients, conservation challenges, and the ethnobotanical significance of plant resources within Odisha.

Available information obtained from floristic and ecological studies was systematically categorized and synthesized to develop an integrated understanding of vegetation heterogeneity, floristic composition, ecological significance, and conservation perspectives of Odisha flora. Classical approaches of vegetation ecology and biodiversity assessment, described by Aims and Methods of Vegetation Ecology, Measuring Biological Diversity, and Vegetation Description and Data Analysis, were considered while interpreting vegetation structure and floristic diversity patterns. The review further integrates recent ecological and conservation-oriented studies to identify major research gaps and future priorities for biodiversity documentation and sustainable management of plant resources in Odisha.

VEGETATION HETEROGENEITY AND ECOSYSTEM DIVERSITY

Odisha exhibits remarkable vegetation heterogeneity due to substantial variations in climate, topography, altitude, edaphic conditions, hydrology, and anthropogenic influences operating across the Eastern Ghats landscape. The state supports diverse vegetation types ranging from tropical moist deciduous forests and semi-evergreen hill vegetation to dry deciduous forests, coastal ecosystems, mangrove habitats, grasslands, wetlands, and riverine vegetation. This environmental complexity contributes significantly to regional floristic diversity, habitat specialization, ecosystem functioning, and biodiversity conservation within eastern India (Dash *et al*., 2022; Behera *et al*., 2021). The heterogeneous vegetation structure of Odisha is strongly influenced by altitudinal gradients, rainfall distribution, temperature variability, and soil characteristics across different ecological regions. Variations in environmental conditions create diverse habitat niches capable of supporting numerous vascular plant species, including endemic, medicinal, and ecologically specialized taxa. Vegetation heterogeneity additionally promotes species coexistence, community diversification, and landscape-level biodiversity stability within the Eastern Ghats biodiversity corridor.

Tropical Deciduous Forest Vegetation

Tropical deciduous forests constitute the dominant vegetation type in Odisha and occupy substantial portions of the Eastern Ghats region. These forests are primarily classified into moist deciduous and dry deciduous formations depending upon rainfall intensity, moisture availability, soil conditions, and topographical characteristics. Moist deciduous forests generally occur in high rainfall regions and are characterized by relatively dense canopy cover, greater species richness, and higher biomass productivity. Dominant tree species commonly include *Shorea robusta*, *Terminalia alata*, *Pterocarpus marsupium*, *Madhuca longifolia*, *Lagerstroemia parviflora*, *Diospyros melanoxylon*, and *Syzygium cumini*.

Dry deciduous forests are comparatively more open in structure and occur in regions experiencing lower rainfall and prolonged dry periods. These forests support drought-tolerant plant communities adapted to seasonal climatic variability and edaphic stress conditions. Characteristic species frequently observed within dry deciduous vegetation include *Anogeissus latifolia*, *Butea monosperma*, *Boswellia serrata*, *Acacia catechu*, and *Hardwickia binata*. Dry deciduous vegetation additionally contributes significantly to regional ecosystem stability, nutrient cycling, and livelihood support for forest-dependent communities. Similar vegetation characteristics have been documented in tropical forest ecosystems across eastern and central India (Jhariya and Bargali, 2021).

Semi-evergreen and Hill Forest Ecosystems

Semi-evergreen and hill forest ecosystems are mainly distributed across elevated regions of the Eastern Ghats and represent biologically important centers of floristic diversity and endemism within Odisha. These forests are generally associated with

comparatively humid microclimatic conditions, complex topography, and high habitat heterogeneity. Semi-evergreen vegetation supports multilayered forest structure, diverse understory communities, epiphytes, climbers, shrubs, and shade-tolerant herbaceous species.

Several ecologically important plant species, including *Michelia champaca*, *Ficus benghalensis*, *Artocarpus heterophyllus*, *Caryota urens*, and *Bambusa bambos,* are commonly associated with semi-evergreen and hill forest ecosystems. Hill landscapes additionally function as important refugia for endemic and ecologically sensitive taxa. Variations in altitude, slope orientation, soil depth, and moisture availability create localized habitat niches supporting distinct vegetation assemblages and phytogeographical differentiation within the Eastern Ghats region (Sahu *et al*., 2022).

Coastal, Wetland, and Mangrove Vegetation

The coastal region of Odisha supports highly specialized vegetation systems, including mangroves, littoral vegetation, estuarine ecosystems, marshlands, wetlands, and coastal grasslands. Mangrove ecosystems occurring along the coastal belt represent ecologically significant habitats characterized by salt-tolerant vegetation adapted to tidal fluctuations, saline conditions, and dynamic sedimentary environments. Dominant mangrove species include *Rhizophora mucronata*, *Avicennia marina*, *Sonneratia apetala*, *Bruguiera gymnorhiza*, and *Excoecaria agallocha*.

Wetland and riverine ecosystems additionally support diverse hydrophytic and semi-aquatic plant communities, contributing significantly to regional ecosystem productivity and habitat diversity. Species such as *Typha angustifolia*, *Phragmites karka*, *Nelumbo nucifera*, and *Nymphaea nouchali* are frequently associated with freshwater wetland ecosystems of Odisha. Seasonal flooding patterns, hydrological fluctuations, and sediment deposition influence species composition and vegetation dynamics within these ecosystems. Coastal vegetation systems further provide important breeding and feeding habitats for diverse faunal communities and contribute substantially to environmental resilience within coastal landscapes.

Grasslands, Scrublands, and Secondary Vegetation

Grasslands, scrublands, and secondary vegetation communities occur extensively within disturbed landscapes, degraded forest regions, shifting cultivation areas, and ecotonal zones throughout Odisha. These vegetation systems are generally dominated by herbaceous species, grasses, shrubs, climbers, and pioneer plant communities adapted to open environmental conditions and recurrent disturbances.

Secondary vegetation often develops following deforestation, anthropogenic disturbance, fire events, mining activities, or agricultural abandonment. Common species associated with secondary vegetation include *Imperata cylindrica*, *Chromolaena odorata*, *Lantana camara*, *Cassia tora*, and *Cynodon dactylon*. Such ecosystems play important roles in soil stabilization, nutrient accumulation, ecological succession, and habitat restoration processes. Disturbed landscapes may additionally support invasive alien plant species capable of altering native vegetation structure and ecosystem functioning. Vegetation succession within secondary ecosystems significantly influences long-term habitat recovery and biodiversity dynamics across disturbed regions.

Environmental Gradients and Vegetation Dynamics

Vegetation heterogeneity within Odisha is strongly regulated by environmental gradients, including rainfall variability, temperature fluctuations, altitude, edaphic conditions, hydrological processes, and anthropogenic disturbances. Spatial variation in these environmental factors influences species distribution, community composition, productivity, regeneration behavior, and ecosystem resilience across different vegetation zones.

Climate variability and land-use transformation increasingly affect vegetation dynamics within the Eastern Ghats landscape. Alterations in rainfall regimes, increasing temperature stress, habitat fragmentation, mining activities, and deforestation may substantially modify species composition, biological interactions, and vegetation stability in several forest ecosystems (Behera *et al*.,

2021). Geospatial technologies, remote sensing approaches, Geographic Information Systems (GIS), and ecological modeling therefore, provide valuable tools for monitoring vegetation change, habitat fragmentation, and biodiversity dynamics across Odisha (Dash *et al*., 2022).

The interaction among climatic variability, topographical complexity, hydrological conditions, and anthropogenic disturbances collectively regulates vegetation heterogeneity and ecosystem functioning throughout Odisha. These interacting environmental drivers significantly influence habitat diversification, floristic composition, regeneration processes, and long-term ecosystem resilience within the Eastern Ghats biodiversity corridor.

Overall, the remarkable vegetation heterogeneity of Odisha reflects the environmental complexity and phytogeographical significance of the Eastern Ghats region. The coexistence of diverse forest types, coastal ecosystems, hill vegetation, wetlands, and secondary vegetation systems contributes substantially to regional floristic diversity, ecosystem stability, and biodiversity conservation within eastern India.

FLORISTIC COMPOSITION, VEGETATION STRUCTURE, AND ECOLOGICAL HETEROGENEITY

The floristic composition of Odisha reflects a complex integration of multiple ecological, climatic, and phytogeographical influences, resulting in considerable vascular plant diversity across the state. The interaction of diverse ecological gradients and heterogeneous habitat conditions has resulted in the development of structurally complex and compositionally diverse plant communities throughout the state. The vegetation is predominantly represented by angiospermic taxa, which form the major structural and functional component of forest and non-forest ecosystems. Diverse habitat conditions ranging from coastal ecosystems and riverine vegetation to tropical deciduous forests and Eastern Ghats hill landscapes collectively contribute to substantial floristic heterogeneity and ecological complexity within the region.

The distribution and composition of plant communities in Odisha are strongly influenced by variations in rainfall patterns, altitude, soil characteristics, temperature regimes, hydrological conditions, and levels of anthropogenic disturbance. Ecologically stable forest ecosystems, particularly within the Eastern Ghats region, support comparatively higher species richness and structural complexity owing to favorable microclimatic conditions and relatively lower habitat disturbance. Previous studies have reported significant diversity of tree, shrub, herbaceous, climber, and medicinal plant species across the tropical forest ecosystems of Odisha and the Eastern Ghats landscape (Sahu *et al*., 2020; Mohapatra and Panda, 2021). Variations in vegetation composition across ecological zones indicate strong relationships between habitat conditions and species assemblage patterns, reflecting the adaptive response of plant communities to environmental gradients and disturbance regimes.

Tropical dry deciduous forests constitute the dominant vegetation type across large parts of Odisha and are characterized by seasonally adapted plant communities capable of tolerating periodic moisture stress and climatic variability. Moist deciduous and semi-evergreen forests occurring within hill ecosystems exhibit comparatively greater floristic richness and multilayered vegetation structure due to enhanced moisture availability and habitat heterogeneity. Moist deciduous and semi-evergreen forests additionally exhibit greater canopy stratification, regeneration potential, and ecological stability compared to degraded dry forest systems. Mangrove and littoral vegetation along coastal regions represent ecologically specialized plant assemblages adapted to saline and tidal environmental conditions. The major vegetation formations and ecological gradients of Odisha are illustrated in Figure 1.

The floristic structure of Odisha forests demonstrates considerable spatial variation associated with ecological gradients and habitat diversity. Forested landscapes within protected areas and relatively undisturbed hill regions maintain higher native species composition and ecological integrity compared to heavily modified landscapes experiencing deforestation, mining activities, agricultural expansion, and urbanization. Such anthropogenic disturbances have resulted in habitat fragmentation, ecological simplification, and alteration of natural vegetation structure in several regions of the state. Remote sensing

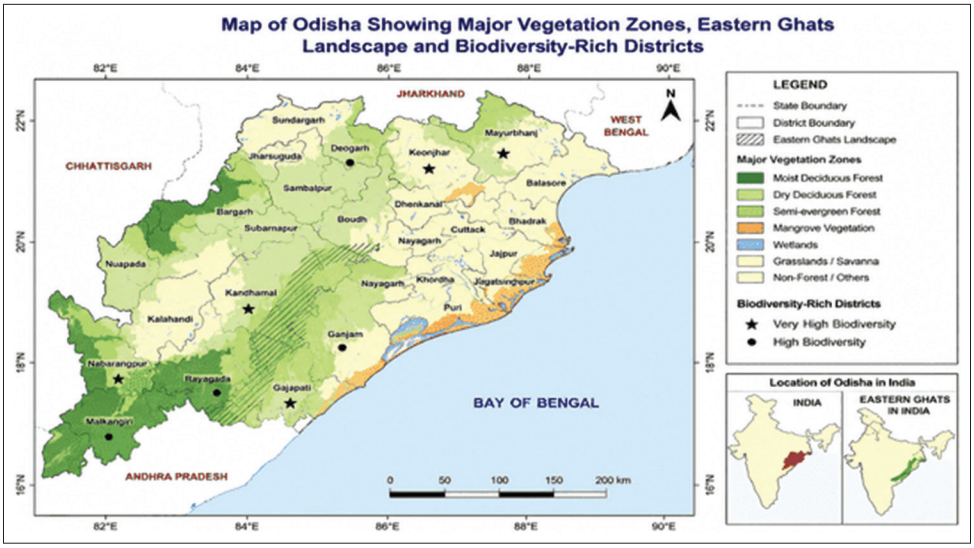

Figure 1: The map illustrates the heterogeneous distribution of moist deciduous forests, dry deciduous forests, semi-evergreen vegetation, mangrove ecosystems, wetlands, and grassland ecosystems across different ecological regions of the state

investigations have further indicated increasing forest fragmentation and landscape-level vegetation changes across portions of the Eastern Ghats region (Dash *et al*., 2022).

The vegetation heterogeneity observed across Odisha also reflects the transitional biogeographic nature of the state, where floristic elements originating from peninsular India, Indo-Malayan regions, and coastal ecosystems coexist within overlapping ecological zones. This coexistence of multiple phytogeographical components contributes significantly to regional species diversification and ecological resilience. Several forest ecosystems additionally support endemic, rare, medicinal, and ecologically sensitive plant taxa that enhance the conservation importance of Odisha flora within the broader Eastern Ghats biodiversity framework. Similar vegetation diversity patterns have also been reported in tropical forest ecosystems across eastern India (Sahoo *et al*., 2022; Sahu and Mishra, 2023).

Recent floristic and ecological studies have emphasized the importance of systematic vegetation assessment, biodiversity documentation, and long-term ecological monitoring for understanding temporal changes in species composition and ecosystem stability (Mishra and Upadhyay, 2020; Behera *et al*., 2021). Strengthening floristic inventories and integrating ecological, taxonomic, and geospatial approaches will therefore be essential for improving scientific understanding and sustainable conservation of vegetation diversity in Odisha.

Overall, the floristic composition and vegetation heterogeneity of Odisha reflect the ecological complexity and transitional phytogeographical nature of the Eastern Ghats landscape. The coexistence of diverse vegetation formations, ecological gradients, and regionally significant plant taxa highlights the importance of Odisha as a critical center for biodiversity conservation and ecological research in eastern India.

FLORISTIC DIVERSITY, ENDEMISM, AND BIODIVERSITY SIGNIFICANCE

Odisha represents one of the biologically important floristic regions of eastern India due to its remarkable species richness, vegetation heterogeneity, and phytogeographical complexity associated with the Eastern Ghats landscape. The diverse environmental conditions prevailing across the state support a wide range of vascular plant species, including trees, shrubs, climbers, herbs, grasses, pteridophytes, bryophytes, and economically important medicinal taxa. Variations in climate, altitude, soil characteristics, hydrology, and habitat structure collectively contribute to the development of highly diversified plant communities within different ecological regions of Odisha (Behera *et al*., 2021; Dash *et al*., 2022).

The Eastern Ghats are recognized as one of the important biodiversity-rich regions of India due to their high habitat heterogeneity, endemic plant

diversity, and ecological sensitivity. The floristic richness of Odisha is strongly associated with the environmental complexity of the Eastern Ghats, which functions as an important center of species diversification and habitat specialization. Forest ecosystems, coastal landscapes, wetlands, grasslands, and hill vegetation collectively support numerous native and ecologically significant plant taxa. The coexistence of tropical deciduous forests, semi-evergreen vegetation, mangrove ecosystems, and secondary habitats contributes substantially to regional biodiversity stability and ecosystem functioning.

Species Richness and Floristic Composition

The floristic composition of Odisha includes diverse angiosperms, gymnosperms, pteridophytes, bryophytes, and economically important plant taxa distributed across multiple habitat types. Dominant tree species commonly recorded from different forest ecosystems include *S. robusta*, *T. alata*, *P. marsupium*, *M. longifolia*, *D. melanoxylon*, *S. cumini*, and *A. latifolia*. Several climbers, shrubs, and herbaceous species additionally contribute to understory diversity and ecosystem productivity within forested landscapes.

Wetland ecosystems support diverse hydrophytic vegetation, including *N. nucifera*, *N. nouchali*, *T. angustifolia*, and *P. karka*, whereas coastal and mangrove ecosystems are characterized by salt-tolerant species such as *R. mucronata*, *A. marina*, *S. apetala*, and *B. gymnorhiza*. Grasslands and secondary vegetation systems additionally support numerous herbaceous and pioneer species adapted to disturbed environmental conditions. Such floristic variability reflects the environmental complexity and adaptive potential of plant communities occurring across Odisha.

Endemic and Rare Plant Species

The Eastern Ghats region of Odisha supports several endemic, rare, and geographically restricted plant taxa due to its ecological isolation, topographical heterogeneity, and diverse habitat conditions. Hill ecosystems and relatively undisturbed forest landscapes function as important refugia for endemic flora and habitat-specialized species. Endemism within the region is influenced by altitudinal variation, climatic stability, habitat fragmentation, and localized environmental adaptation processes.

Several endemic and threatened taxa occurring within the Eastern Ghats require immediate conservation attention due to habitat degradation, mining activities, deforestation, and anthropogenic disturbances. Restricted distribution patterns and low population density increase the vulnerability of many endemic species to environmental change and habitat fragmentation (Sahu *et al*., 2022). Conservation of endemic-rich landscapes is therefore essential for maintaining regional biodiversity integrity and long-term ecosystem resilience.

Rare medicinal and economically valuable plant species additionally contribute substantially to the conservation importance of Odisha flora. Many of these taxa possess considerable ethnobotanical and pharmaceutical significance but continue to face threats from overharvesting, habitat degradation, and unsustainable resource utilization. Strengthening scientific documentation and habitat protection measures will therefore be necessary for safeguarding endemic and threatened plant diversity within the Eastern Ghats region.

Phytogeographical Significance

Odisha occupies an important phytogeographical position within the Indian subcontinent due to the convergence of floristic elements derived from peninsular India, Indo-Malayan regions, and coastal ecosystems. The Eastern Ghats landscape functions as a transitional biogeographical zone supporting species assemblages adapted to diverse climatic and environmental conditions. Such phytogeographical complexity contributes considerably to regional species richness, habitat specialization, and vegetation heterogeneity.

Altitudinal gradients, climatic variability, and habitat fragmentation further influence species distribution patterns and floristic differentiation across the region. Hill forests often exhibit distinct vegetation assemblages compared with coastal plains and plateau ecosystems. Environmental isolation and habitat heterogeneity within the Eastern Ghats may additionally promote localized speciation and habitat-specific diversification processes. Similar

phytogeographical patterns have been reported in several tropical biodiversity hotspots of India (Pattanaik *et al*., 2022).

Ecological and Conservation Importance

The floristic diversity of Odisha plays a fundamental role in maintaining ecosystem productivity, nutrient cycling, hydrological regulation, carbon sequestration, and habitat stability within the Eastern Ghats landscape. Diverse plant communities support complex trophic interactions and provide food, shelter, and breeding habitats for numerous faunal species. Forest vegetation additionally contributes to soil conservation, microclimatic regulation, watershed protection, and long-term environmental resilience across different habitat types.

Biodiversity-rich ecosystems of Odisha also possess considerable socio-economic and ethnobotanical significance. Forest-dependent and tribal communities rely extensively on plant resources for food, medicine, fodder, fuelwood, construction materials, and livelihood support. Traditional ecological knowledge associated with medicinal plants and sustainable resource utilization further highlights the cultural and economic importance of regional floristic diversity (Panda *et al*., 2021).

Despite their ecological significance, several floristically important habitats remain vulnerable to anthropogenic disturbances, including deforestation, mining activities, invasive species expansion, land-use transformation, and climate variability. Habitat fragmentation and environmental degradation may substantially reduce species diversity, regeneration potential, and ecosystem functionality. Long-term biodiversity conservation therefore, requires integrated habitat management, ecosystem restoration, scientific monitoring, and community participation approaches.

Biodiversity Assessment and Future Conservation Priorities

Recent advances in biodiversity assessment, remote sensing, GIS, ecological modeling, and molecular taxonomy have considerably improved the understanding of floristic diversity and vegetation dynamics within Odisha. Integration of geospatial technologies with field-based floristic investigations provides valuable information regarding species distribution patterns, habitat fragmentation, ecological connectivity, and conservation prioritization (Dash *et al*., 2022).

Long-term biodiversity monitoring programs are necessary for assessing vegetation change, species vulnerability, ecosystem resilience, and climate-induced environmental impacts across different landscapes of Odisha. Future conservation strategies should particularly emphasize endemic-rich habitats, ecologically sensitive hill ecosystems, underexplored forest landscapes, and climate-vulnerable vegetation zones. Conservation planning should additionally integrate ecosystem restoration, sustainable land-use management, invasive species control, and participatory biodiversity management approaches.

Integrative biodiversity informatics and artificial intelligence (AI)-assisted ecological assessment may further enhance large-scale floristic monitoring and conservation prioritization within Odisha. The interaction among climatic variability, environmental gradients, habitat heterogeneity, and anthropogenic pressures collectively regulates floristic diversity and ecosystem functioning throughout the state. Understanding these complex ecological relationships is therefore essential for developing scientifically informed biodiversity conservation strategies within the Eastern Ghats biodiversity corridor.

Overall, the floristic diversity and phytogeographical significance of Odisha highlight the environmental importance of the Eastern Ghats as a major center of tropical biodiversity and ecosystem sustainability in eastern India. Protection of these biologically rich ecosystems will be critical for maintaining long-term ecological stability, environmental resilience, and sustainable utilization of plant resources for future generations.

ECOLOGICAL FUNCTIONS AND ETHNOBOTANICAL SIGNIFICANCE OF ODISHA FLORA

The floristic diversity of Odisha plays a critical role in maintaining ecological stability, ecosystem functioning, and environmental sustainability across the Eastern Ghats landscape. The ecological functionality of vegetation systems in Odisha is

closely associated with the structural complexity and biological diversity of forest ecosystems distributed across the Eastern Ghats landscape. Diverse vegetation formations distributed throughout the state contribute significantly to essential ecological processes, including carbon sequestration, nutrient cycling, soil conservation, hydrological regulation, climate moderation, and maintenance of habitat connectivity. Forest ecosystems of Odisha further function as important reservoirs of biodiversity supporting numerous plant, animal, and microbial communities within tropical forest environments.

The ecological significance of Odisha flora is strongly associated with the heterogeneity of forest ecosystems and their capacity to sustain diverse ecological interactions. Tropical deciduous and semi-evergreen forests provide suitable habitats for pollinators, seed dispersers, decomposers, and other ecologically important organisms that collectively contribute to ecosystem productivity and resilience. Vegetation cover within hill ecosystems additionally plays a major role in reducing soil erosion, stabilizing slopes, conserving watershed systems, and regulating regional hydrological processes. Ecologically stable forest landscapes also contribute substantially to long-term carbon storage and the mitigation of climate change impacts within eastern India. These forest ecosystems additionally function as ecological buffers that enhance landscape resilience against climatic fluctuations and environmental disturbances.

The plant wealth of Odisha possesses considerable ethnobotanical significance, particularly among indigenous and tribal communities inhabiting forested regions of the state. Traditional knowledge systems associated with medicinal plants, wild edible species, fiber-yielding plants, timber resources, and ethnoveterinary applications represent an important component of regional socio-ecological heritage. Several tribal communities of Odisha continue to depend extensively on forest plant resources for primary healthcare, food security, household requirements, and cultural practices. Previous ethnobotanical investigations have documented the utilization of numerous medicinal and economically important plant species across tribal-dominated landscapes of the Eastern Ghats region (Sahu *et al*., 2020; Panda *et al*., 2021). Indigenous communities also possess traditional ecological knowledge associated with sustainable harvesting, seasonal resource utilization, and conservation-oriented management of plant resources.

Medicinal plants constitute a particularly valuable component of Odisha flora due to their extensive application in traditional healthcare systems and indigenous therapeutic practices. Forest ecosystems of the state support diverse medicinal taxa possessing antimicrobial, anti-inflammatory, antioxidant, and pharmacologically important properties. Wild relatives of cultivated species and economically important non-timber forest products additionally contribute to local livelihoods and regional bioresource sustainability. Several medicinal and aromatic plant species occurring within Odisha forests also possess potential pharmaceutical, nutraceutical, and biotechnological importance requiring further scientific investigation and conservation prioritization. The conservation of ethnobotanically important plant species is therefore closely linked with the preservation of indigenous knowledge systems and sustainable resource management practices.

Despite their ecological and socio-economic importance, plant resources of Odisha are increasingly threatened by anthropogenic pressures, including deforestation, habitat fragmentation, overexploitation of forest products, mining activities, urban expansion, and unsustainable harvesting practices. Degradation of natural habitats not only affects plant diversity and ecosystem functioning but also threatens the continuity of traditional ethnobotanical knowledge associated with forest-dependent communities. Climate variability and ecological disturbances may further alter species availability and ecosystem stability within ecologically sensitive regions of the Eastern Ghats landscape. Loss of traditional ethnobotanical knowledge due to socio-economic transformation and modernization may further reduce the long-term sustainability of indigenous plant resource management systems.

Recent ecological studies have emphasized the importance of integrating biodiversity conservation with community-based resource management and sustainable utilization strategies for long-term protection of floristic diversity (Behera *et al*., 2021; Mishra and Upadhyay, 2020). Strengthening ethnobotanical documentation,

conservation awareness, habitat restoration, and participatory forest management approaches will therefore be essential for safeguarding both plant diversity and associated traditional knowledge systems in Odisha.

Overall, the ecological and ethnobotanical significance of Odisha flora extends beyond biodiversity conservation and contributes substantially to ecosystem sustainability, climate resilience, socio-economic stability, and preservation of indigenous cultural heritage. Conservation of ecologically and ethnobotanically important plant species will therefore require integrated strategies combining biodiversity protection, habitat restoration, sustainable utilization, and preservation of indigenous knowledge systems. The integration of ecological conservation with sustainable utilization of plant resources will be critical for ensuring long-term protection and management of floristic diversity within the Eastern Ghats region.

CONSERVATION CHALLENGES, ANTHROPOGENIC PRESSURE, AND ECOLOGICAL THREATS

The floristic diversity and vegetation heterogeneity of Odisha are increasingly threatened by multiple anthropogenic and environmental pressures affecting ecosystem stability, habitat continuity, and long-term biodiversity conservation across the Eastern Ghats landscape. Rapid land-use transformation, deforestation, mining activities, industrialization, agricultural expansion, urbanization, and climate variability have collectively accelerated ecological degradation within several floristically important regions of the state (Behera *et al*., 2021; Dash *et al*., 2022). These disturbances significantly influence vegetation structure, species composition, regeneration dynamics, and ecosystem resilience throughout Odisha.

The interaction among environmental degradation, habitat fragmentation, climate stress, and unsustainable resource utilization has intensified biodiversity vulnerability across ecologically sensitive landscapes. Several forest ecosystems and endemic-rich habitats continue to experience increasing anthropogenic disturbances that may adversely affect long-term conservation of native flora and ecosystem functioning within the Eastern Ghats biodiversity corridor [Figure 3].

Deforestation and Habitat Fragmentation

Deforestation and habitat fragmentation represent major drivers of biodiversity decline in Odisha. Conversion of natural forest landscapes into agricultural fields, mining zones, transportation corridors, and human settlements has resulted in substantial loss of native vegetation and disruption of ecological connectivity. Fragmented habitats often exhibit reduced species richness, altered vegetation structure, impaired regeneration potential, and increased vulnerability of ecologically sensitive taxa.

Forest fragmentation additionally isolates plant populations and may reduce genetic diversity, reproductive success, and ecological stability within disturbed landscapes. Habitat discontinuity also affects ecological interactions among species, modifies microclimatic conditions, and disrupts ecosystem processes such as nutrient cycling and natural regeneration. Similar patterns of vegetation degradation and biodiversity decline have been reported in several tropical forest ecosystems of eastern India (Jhariya and Bargali, 2021).

Remote sensing investigations have further indicated progressive structural alteration and fragmentation of Eastern Ghats forests due to expanding anthropogenic pressures and changing land-use dynamics (Dash *et al*., 2022). Such environmental disturbances substantially threaten the long-term sustainability of biologically important forest ecosystems within Odisha.

Mining Activities and Land-use Transformation

Mining activities constitute one of the most severe ecological threats to biodiversity-rich regions of Odisha, particularly within mineral-rich hill ecosystems of the Eastern Ghats. Extraction of bauxite, iron ore, coal, chromite, and other mineral resources has caused extensive habitat destruction, soil degradation, hydrological alteration, and vegetation loss in several ecologically sensitive landscapes.

Mining-associated infrastructure development further intensifies environmental disturbances through

road construction, human encroachment, industrial expansion, and secondary habitat degradation. Open-cast mining operations may significantly alter topography, soil structure, groundwater availability, and local microclimatic conditions, thereby affecting vegetation dynamics and ecosystem functioning within surrounding forest ecosystems.

Ecologically sensitive hill landscapes supporting endemic and medicinal plant species are particularly vulnerable to mining-induced habitat degradation (Sahu *et al*., 2022). Long-term land-use transformation associated with industrial and developmental activities may additionally reduce habitat continuity and compromise ecosystem resilience within the Eastern Ghats region.

Overexploitation of Forest Resources

Unsustainable extraction of forest resources and overharvesting of medicinal and economically important plant species further contribute to floristic degradation within Odisha. Forest-dependent and tribal communities rely extensively on plant resources for fuelwood, timber, fodder, food, medicine, and non-timber forest products. Increasing anthropogenic pressure on forest ecosystems may therefore reduce population stability of several ecologically and economically important plant taxa. Unregulated harvesting practices often disrupt natural regeneration processes and reduce the reproductive potential of medicinal and endemic species. Overexploitation of commercially valuable plants may additionally threaten habitat stability and ecological sustainability within sensitive forest ecosystems. Anthropogenic disturbances associated with shifting cultivation, uncontrolled grazing, fuelwood collection, and forest fires further intensify vegetation degradation in several regions of Odisha.

Climate Change and Environmental Stress

Climate variability and changing environmental conditions are emerging as additional threats influencing vegetation structure, species distribution, and ecosystem functioning across Odisha. Alterations in rainfall regimes, increasing temperature fluctuations, prolonged drought periods, cyclonic disturbances, and extreme climatic events may substantially affect forest productivity, regeneration capacity, hydrological balance, and species composition (Behera *et al*., 2021).

Ecologically sensitive and geographically restricted plant taxa occurring within hill ecosystems are particularly vulnerable to climatic disturbances and habitat instability. Climate-induced alterations in flowering phenology, seed germination, regeneration behavior, and species migration patterns may further influence long-term floristic stability throughout the Eastern Ghats landscape.

Coastal vegetation systems and mangrove ecosystems are also highly susceptible to sea-level rise, salinity intrusion, coastal erosion, and recurrent cyclonic disturbances. Environmental stress associated with climate variability may therefore accelerate habitat degradation and biodiversity vulnerability within several ecologically fragile landscapes of Odisha.

Invasive Alien Species and Biodiversity Loss

Invasive alien plant species represent an increasing environmental concern within several forest ecosystems and disturbed landscapes of Odisha. Species such as *L. camara*, *C. odorata*, *Parthenium hysterophorus*, and *Prosopis juliflora* frequently invade degraded habitats and suppress the regeneration of indigenous flora. Biological invasions may alter species composition, reduce habitat quality, modify nutrient cycling, and affect ecosystem functioning.

Disturbed and fragmented ecosystems are generally more susceptible to invasion by alien plant species due to reduced ecological resistance and altered habitat conditions. Expansion of invasive species may therefore accelerate environmental degradation and reduce biodiversity stability within affected ecosystems. Effective management of invasive taxa is consequently essential for maintaining native vegetation structure and long-term ecosystem resilience.

Conservation Limitations and Ecological Vulnerability

Despite the presence of protected areas, wildlife sanctuaries, reserve forests, and biodiversity

conservation programs, several ecologically important regions of Odisha remain inadequately protected and insufficiently documented. Many floristically significant habitats occur outside formally protected landscapes and continue to experience increasing anthropogenic pressure. Limited floristic inventories, inadequate ecological monitoring, insufficient geospatial assessment, and lack of long-term biodiversity databases further constrain effective conservation planning within the region.

Environmental degradation resulting from cumulative anthropogenic disturbances may substantially reduce ecosystem resilience and adaptive capacity under future climate change scenarios. Ecologically fragile hill ecosystems, endemic-rich habitats, coastal vegetation systems, and fragmented forest landscapes, therefore, require immediate scientific assessment and conservation prioritization.

Recent ecological investigations have emphasized the necessity for integrated conservation strategies incorporating habitat restoration, sustainable land-use management, ecological monitoring, geospatial biodiversity assessment, climate-resilient planning, and community participation for long-term protection of floristic diversity (Mishra and Upadhyay, 2020; Dash *et al*., 2022).

Overall, the conservation challenges affecting Odisha flora highlight the urgent need for scientifically informed and landscape-level conservation approaches capable of balancing biodiversity protection with sustainable socio-economic development. Long-term conservation of the region's floristic diversity will depend on effective habitat management, restoration of degraded ecosystems, climate-resilient conservation planning, invasive species control, and preservation of ecologically sensitive forest landscapes within the Eastern Ghats biodiversity corridor.

CONSERVATION STRATEGIES AND SUSTAINABLE MANAGEMENT APPROACHES

The increasing ecological degradation and biodiversity vulnerability observed across the Eastern Ghats region of Odisha necessitate comprehensive and scientifically informed conservation strategies for long-term protection of floristic diversity and ecosystem stability. Effective biodiversity conservation within the state requires integration of habitat protection, ecological restoration, climate-resilient management, sustainable resource utilization, geospatial monitoring, and community participation approaches. Considering the complex interaction among anthropogenic disturbances, climate variability, habitat fragmentation, and ecological vulnerability, multidimensional conservation frameworks are essential for ensuring long-term sustainability of Odisha flora (Behera *et al*., 2021; Dash *et al*., 2022).

Conservation planning should particularly emphasize ecosystem-level management rather than isolated species protection because vegetation heterogeneity and ecological connectivity play fundamental roles in maintaining biodiversity resilience within the Eastern Ghats landscape. Integrated conservation approaches combining scientific research, technological innovation, policy implementation, and indigenous ecological knowledge may therefore considerably strengthen regional biodiversity governance and environmental sustainability [Figure 4].

In situ Conservation and Protected Area Management

In situ conservation remains one of the most effective approaches for protecting native flora, endemic species, and ecologically sensitive habitats within Odisha. Protected forests, wildlife sanctuaries, biosphere reserves, community forests, and ecologically important landscapes provide essential refugia for maintaining natural vegetation structure, species interactions, and ecosystem functioning.

Strengthening the management effectiveness of existing protected areas is therefore necessary for minimizing habitat degradation, illegal resource extraction, and biodiversity loss. Conservation strategies should additionally prioritize the expansion of ecologically important corridors connecting fragmented forest landscapes to improve habitat continuity, genetic exchange, and species migration. Ecological restoration of degraded buffer zones surrounding protected areas may further enhance biodiversity resilience and landscape stability.

Special conservation attention should be directed toward endemic-rich hill ecosystems, mangrove

habitats, wetlands, riverine vegetation, and climatically vulnerable landscapes due to their high ecological sensitivity and conservation significance. Long-term habitat protection is essential for sustaining floristic diversity and ecosystem functionality within the Eastern Ghats biodiversity corridor.

Ex situ Conservation and Germplasm Preservation

Ex situ conservation strategies provide important complementary approaches for safeguarding threatened, endemic, medicinal, and economically valuable plant species facing increasing habitat degradation and ecological vulnerability. Botanical gardens, seed banks, tissue culture repositories, arboreta, and germplasm conservation centers play critical roles in preserving plant genetic resources and supporting species recovery programs.

Conservation of rare medicinal and endemic plant taxa through seed storage, micropropagation, cryopreservation, and nursery development may substantially improve long-term species survival and restoration potential. Establishment of regional biodiversity repositories and digital herbarium databases could additionally strengthen taxonomic documentation and conservation planning within Odisha.

Ex situ conservation programs should further support scientific research on species propagation, genetic diversity, ecological adaptability, and climate resilience to facilitate future habitat restoration and biodiversity rehabilitation initiatives.

Ecological Restoration and Habitat Rehabilitation

Ecological restoration of degraded forest ecosystems, mining-affected landscapes, fragmented habitats, and invasive species-dominated regions is essential for improving biodiversity stability and environmental resilience across Odisha. Restoration programs should emphasize rehabilitation of native vegetation, soil recovery, watershed stabilization, and enhancement of ecological connectivity within disturbed landscapes.

Native species reintroduction and assisted natural regeneration approaches may significantly accelerate vegetation recovery and improve ecosystem functioning in degraded habitats. Restoration planning should additionally incorporate ecological succession dynamics, habitat suitability assessment, hydrological regulation, and climate-adaptive management strategies for long-term sustainability.

Mining-affected ecosystems particularly require scientifically guided restoration interventions because extensive soil degradation, vegetation removal, and topographical alteration often reduce natural regeneration capacity. Integration of restoration ecology with geospatial monitoring and biodiversity assessment may therefore improve ecological rehabilitation outcomes within disturbed regions.

Community-based Conservation and Indigenous Knowledge

Local communities and tribal populations possess extensive traditional ecological knowledge associated with medicinal plants, sustainable harvesting practices, biodiversity conservation, and forest resource management. Community participation, therefore, represents an essential component of effective biodiversity governance and sustainable ecosystem management within Odisha.

Participatory conservation programs involving local stakeholders may substantially improve habitat protection, resource sustainability, ecological monitoring, and restoration effectiveness across forest-dependent regions. Integration of indigenous ecological knowledge with scientific conservation strategies may additionally strengthen adaptive biodiversity management and promote sustainable utilization of plant resources.

Awareness programs, biodiversity education, capacity-building initiatives, and livelihood diversification strategies are also necessary for reducing anthropogenic pressure on forest ecosystems and encouraging long-term conservation participation among local communities.

Climate-resilient Conservation Planning

Climate variability and increasing environmental stress require the development of climate-resilient conservation frameworks capable of improving ecosystem adaptability and biodiversity stability under future climatic scenarios. Conservation

Table 1: Major vegetation types and representative floristic composition of Odisha

Vegetation type	Major ecological regions	Dominant/representative plant species	Ecological characteristics	Conservation significance
Tropical Moist Deciduous Forests	Eastern Ghats hill ranges, high rainfall forest zones	*Shorea robusta, Terminalia alata, Pterocarpus marsupium, Madhuca longifolia, Syzygium cumini*	Dense canopy, high biomass productivity, multilayered vegetation	Important carbon sink and biodiversity reservoir
Tropical Dry Deciduous Forests	Interior plateau and low rainfall regions	*Anogeissus latifolia, Butea monosperma, Boswellia serrata, Acacia catechu, Hardwickia binata*	Open canopy, drought-adapted vegetation, seasonal leaf shedding	Supports ecosystem stability and tribal livelihoods
Semi-evergreen and Hill Forests	Elevated Eastern Ghats landscapes	*Michelia champaca, Ficus benghalensis, Artocarpus heterophyllus, Caryota urens, Bambusa bambos*	High habitat heterogeneity and humidity	Refugia for endemic and sensitive taxa
Mangrove Ecosystems	Coastal Odisha and estuarine regions	*Rhizophora mucronata, Avicennia marina, Sonneratia apetala, Bruguiera gymnorhiza*	Salt-tolerant vegetation adapted to tidal influence	Coastal protection and nursery grounds for fauna
Wetland and Riverine Vegetation	Freshwater wetlands and floodplain ecosystems	*Nelumbo nucifera, Nymphaea nouchali, Typha angustifolia, Phragmites karka*	Hydrophytic and semi-aquatic vegetation	Maintains hydrological balance and aquatic biodiversity
Grasslands and Scrublands	Disturbed and ecotonal landscapes	*Imperata cylindrica, Cynodon dactylon, Cassia tora*	Herbaceous dominance and pioneer communities	Soil stabilization and ecological succession
Secondary Vegetation	Mining areas, degraded forests, abandoned agricultural lands	*Chromolaena odorata, Lantana camara, Parthenium hysterophorus*	Disturbance-driven vegetation communities	Indicates ecological degradation and invasion risk

Table 2: Ecological functions and ethnobotanical significance of Odisha flora

Ecological/ ethnobotanical component	Major functions	Representative plant species/ vegetation	Ecological or socio-economic importance
Carbon Sequestration	Storage of atmospheric carbon in forest biomass and soils	*Shorea robusta, Terminalia alata*, semi-evergreen forests	Climate change mitigation and ecosystem stability
Soil Conservation	Prevention of soil erosion and maintenance of soil fertility	Grasslands, hill vegetation, bamboo stands	Watershed protection and slope stabilization
Hydrological Regulation	Maintenance of groundwater recharge and water cycles	Wetlands, riverine vegetation, mangroves	Flood regulation and water security
Nutrient Cycling	Recycling of organic matter and maintenance of ecosystem productivity	Deciduous forests and microbial-rich forest litter	Supports long-term ecosystem functioning
Habitat and Biodiversity Support	Provision of food, shelter, and breeding habitats for fauna	Forest ecosystems, mangroves, wetlands	Maintains biodiversity and ecological interactions
Pollination and Seed Dispersal	Support of reproductive processes in plant communities	Flowering forest species and climber vegetation	Enhances vegetation regeneration and species continuity
Traditional Medicinal Uses	Utilization of plants in indigenous healthcare systems	*Madhuca longifolia, Azadirachta indica, Tinospora cordifolia*	Ethnomedicinal and pharmaceutical importance
Food and Nutritional Resources	Supply of edible fruits, leaves, tubers, and seeds	*Artocarpus heterophyllus, Syzygium cumini,* wild edible flora	Tribal food security and nutritional sustainability
Non-timber Forest Products (NTFPs)	Collection of gums, fibers, oils, resins, and medicinal products	*Boswellia serrata,* bamboo species, medicinal herbs	Livelihood support and rural economy
Cultural and Indigenous Knowledge	Preservation of traditional ecological practices and rituals	Sacred groves and ethnobotanical plant species	Conservation of socio-cultural heritage

planning should therefore integrate climate vulnerability assessment, ecological resilience analysis, species distribution modeling, and adaptive habitat management approaches.

Protection of climate-sensitive habitats, including mangroves, wetlands, hill ecosystems, and endemic-rich forests, is particularly important for maintaining ecological stability and reducing biodiversity vulnerability. Assisted species migration, climate-adaptive restoration strategies, and long-term ecological monitoring may additionally enhance ecosystem resilience against future climatic disturbances.

Carbon sequestration potential of forest ecosystems should also be incorporated into biodiversity

conservation frameworks because sustainable forest management can simultaneously support climate mitigation and ecological restoration objectives.

Geospatial Technologies and Modern Conservation Approaches

Recent advances in remote sensing, GIS, AI, ecological modeling, drone-based vegetation assessment, and biodiversity informatics provide valuable tools for improving habitat monitoring and conservation prioritization across Odisha. High-resolution geospatial technologies enable large-scale assessment of vegetation dynamics, habitat fragmentation, land-use change, invasive species expansion, and ecological degradation.

Integration of machine learning algorithms and AI-assisted ecological assessment may substantially improve predictive conservation planning and biodiversity risk evaluation within the Eastern Ghats region. Real-time ecological monitoring using satellite imagery and spatial biodiversity databases can further strengthen conservation decision-making and environmental governance.

Future conservation programs should therefore increasingly adopt interdisciplinary and technology-driven approaches capable of integrating floristic inventories, climate datasets, geospatial analysis, and ecological modeling for landscape-level biodiversity management.

Policy Integration and Sustainable Biodiversity Governance

Effective conservation of Odisha flora requires strong policy implementation, institutional coordination, scientific research support, and sustainable land-use governance. Biodiversity conservation policies should integrate ecological sustainability with socio-economic development to minimize conflicts between environmental protection and resource utilization.

Strengthening forest governance, environmental regulations, ecological impact assessment frameworks, and biodiversity management committees may substantially improve conservation outcomes across ecologically sensitive landscapes. Sustainable mining practices, regulated developmental activities, and scientifically guided land-use planning are additionally essential for reducing long-term habitat degradation and biodiversity loss.

Collaborative partnerships among governmental agencies, research institutions, universities, conservation organizations, and local communities are crucial for implementing integrated conservation strategies and ensuring long-term ecological sustainability within Odisha.

Overall, conservation of the floristic diversity and vegetation heterogeneity of Odisha requires multidimensional, climate-resilient, and scientifically integrated management approaches capable of addressing current ecological challenges and future environmental uncertainties. Strengthening habitat protection, ecological restoration, geospatial biodiversity assessment, participatory conservation, and sustainable policy frameworks will therefore be critical for safeguarding the ecological integrity and biodiversity significance of the Eastern Ghats landscape in eastern India.

RESEARCH GAP, EMERGING PERSPECTIVES, AND FUTURE DIRECTIONS

Despite considerable progress in floristic exploration and biodiversity assessment within Odisha, several ecological, taxonomic, phytogeographical, and conservation-related aspects of the Eastern Ghats flora remain insufficiently investigated. Existing studies are often fragmented, geographically restricted, or focused primarily on localized vegetation surveys, thereby limiting a comprehensive understanding of ecosystem dynamics, species interactions, habitat vulnerability, and long-term vegetation change across the region. The increasing influence of anthropogenic disturbances and climate variability further necessitates integrated and multidisciplinary research approaches for effective biodiversity conservation and sustainable ecosystem management.

Recent advances in ecological modeling, biodiversity informatics, remote sensing, molecular taxonomy, climate science, and geospatial technologies provide new opportunities for improving floristic documentation, habitat monitoring, and conservation prioritization within Odisha. Integrating traditional floristic investigations with modern analytical approaches may substantially

enhance understanding of vegetation heterogeneity, ecological resilience, and conservation significance of the Eastern Ghats landscape.

Incomplete Floristic Inventories and Taxonomic Limitations

Several forest ecosystems, hill landscapes, riverine habitats, wetlands, and ecologically sensitive regions of Odisha remain inadequately explored from floristic and taxonomic perspectives. Existing vegetation surveys are frequently localized and may not fully represent regional species diversity, endemic taxa distribution, or ecological variability across the Eastern Ghats. Inadequate herbarium documentation, limited taxonomic revision, and insufficient long-term floristic databases additionally constrain accurate biodiversity assessment within the state.

Many rare, endemic, medicinal, and habitat-specialized plant species continue to remain poorly documented, particularly in remote hill ecosystems and fragmented forest landscapes. Comprehensive floristic inventories integrating field exploration, herbarium validation, molecular taxonomy, and digital biodiversity databases are therefore essential for improving scientific understanding of regional plant diversity and conservation status.

Future taxonomic investigations should additionally focus on cryptic species identification, phylogenetic relationships, population genetics, and species distribution modeling to improve conservation planning and biodiversity prioritization within ecologically sensitive habitats.

Limited Long-term Ecological Monitoring

Long-term ecological monitoring programs evaluating vegetation dynamics, ecosystem resilience, regeneration behavior, and climate-induced biodiversity change remain limited within Odisha. Most existing studies are short-term and may inadequately capture temporal fluctuations in species composition, habitat structure, ecological succession, and environmental responses across diverse ecosystems.

Sustained monitoring of forest ecosystems, mangrove habitats, wetlands, and hill vegetation is necessary for understanding long-term ecological processes and biodiversity trends under changing climatic and anthropogenic conditions. Permanent vegetation plots, ecological observatories, and landscape-level biodiversity monitoring frameworks may therefore provide valuable insights into ecosystem functioning, habitat degradation, and conservation effectiveness.

Integration of field-based ecological observations with geospatial analysis and climate datasets could substantially improve predictive understanding of future vegetation shifts and ecological vulnerability within the Eastern Ghats biodiversity corridor.

Climate Change Vulnerability and Ecosystem Resilience

The ecological consequences of climate variability on floristic diversity, species migration, regeneration potential, phenological behavior, and ecosystem functioning within Odisha remain insufficiently investigated. Increasing temperature fluctuations, altered rainfall patterns, prolonged drought periods, cyclonic disturbances, and extreme weather events may substantially influence vegetation dynamics and biodiversity stability across ecologically sensitive landscapes.

Endemic and geographically restricted species are likely to exhibit higher vulnerability to climate-induced habitat alteration due to narrow ecological adaptability and fragmented distribution patterns. However, limited climate-resilience studies currently exist for many forest ecosystems and endemic-rich habitats within the Eastern Ghats region.

Future research should therefore emphasize climate-resilient biodiversity assessment, species vulnerability modeling, ecological niche analysis, carbon sequestration potential, and adaptive conservation planning. Integrating climate science with vegetation ecology may significantly improve long-term conservation preparedness and ecosystem sustainability within Odisha.

Geospatial Technologies and Biodiversity Informatics

Advanced geospatial technologies, including remote sensing, GIS, unmanned aerial vehicles, spatial ecology, and satellite-based vegetation analysis, remain underutilized in floristic and ecological

studies across Odisha. Although several recent investigations have employed geospatial tools for habitat mapping and vegetation assessment, comprehensive landscape-level biodiversity analysis remains limited.

Future biodiversity research should increasingly integrate high-resolution satellite imagery, machine learning algorithms, ecological modeling, and spatial biodiversity informatics for real-time monitoring of vegetation dynamics, habitat fragmentation, invasive species spread, and ecosystem degradation. AI-assisted ecological assessment may additionally improve predictive conservation planning and biodiversity prioritization within large and ecologically complex landscapes.

Development of integrated digital biodiversity databases linking floristic inventories, herbarium records, climate datasets, and geospatial information could substantially strengthen regional conservation strategies and scientific decision-making processes.

Ethnobotanical Knowledge and Community-based Conservation

Traditional ecological knowledge associated with medicinal plants, forest resource utilization, and indigenous conservation practices remains inadequately documented in several tribal-dominated regions of Odisha. Rapid socio-economic transformation, cultural erosion, habitat degradation, and unsustainable resource extraction may gradually reduce traditional knowledge systems associated with biodiversity conservation.

Future ethnobotanical investigations should therefore emphasize systematic documentation of indigenous plant knowledge, sustainable harvesting practices, medicinal plant conservation, and community-driven biodiversity management strategies. Integrating local ecological knowledge with scientific conservation approaches may substantially enhance sustainable resource utilization and habitat protection within forest-dependent communities.

Participatory conservation frameworks involving tribal populations, local stakeholders, research institutions, and governmental agencies may additionally improve long-term biodiversity governance and ecological sustainability throughout the Eastern Ghats region.

Restoration Ecology and Sustainable Conservation Planning

Ecological restoration studies evaluating degraded forest recovery, soil rehabilitation, native species regeneration, and ecosystem resilience remain insufficiently developed across many disturbed landscapes of Odisha. Mining-affected regions, fragmented forests, invasive species-dominated habitats, and degraded hill ecosystems particularly require scientifically guided restoration strategies for improving ecological stability and biodiversity recovery.

Future restoration ecology programs should prioritize native species reintroduction, habitat connectivity enhancement, watershed restoration, invasive species management, and climate-adaptive ecosystem rehabilitation approaches. Restoration planning should additionally incorporate ecological carrying capacity, species interactions, landscape connectivity, and ecosystem service valuation for long-term sustainability.

Interdisciplinary integration of restoration ecology, climate science, biodiversity informatics, molecular ecology, and socio-economic assessment may therefore provide more comprehensive conservation solutions for the Eastern Ghats biodiversity hotspot.

Emerging Perspectives and Future Scientific Priorities

Future biodiversity research within Odisha should increasingly adopt multidisciplinary and technology-driven approaches capable of integrating floristics, ecology, climatology, molecular biology, geospatial science, AI, and conservation policy frameworks. Such integrative scientific strategies may significantly improve understanding of ecosystem dynamics, species vulnerability, habitat resilience, and sustainable conservation management.

Emerging fields, including environmental DNA analysis, ecological genomics, AI-assisted biodiversity prediction, drone-based vegetation assessment, and climate-resilient ecological modeling, possess substantial potential for transforming biodiversity research and conservation planning within tropical ecosystems. These modern approaches could considerably strengthen early detection of ecological degradation, invasive species

Table 3: Major anthropogenic threats and ecological impacts on Odisha flora

Anthropogenic threat	Major causes	Affected ecosystems	Ecological impacts	Conservation concerns
Deforestation	Agricultural expansion, fuelwood extraction, urbanization	Tropical deciduous forests, hill forests	Loss of vegetation cover, decline in species richness, habitat degradation	Reduction of native flora and ecosystem stability
Habitat Fragmentation	Road construction, industrial development, settlement expansion	Eastern Ghats forest landscapes	Isolation of plant populations, reduced ecological connectivity	Increased vulnerability of endemic and rare taxa
Mining Activities	Extraction of bauxite, iron ore, coal, chromite	Hill ecosystems and mineral-rich forests	Soil degradation, vegetation loss, hydrological alteration	Severe disturbance of ecologically sensitive habitats
Overexploitation of Forest Resources	Unsustainable harvesting of timber, medicinal plants, and NTFPs	Forest ecosystems and tribal resource zones	Decline in regeneration capacity and population density	Threat to economically and medicinally important species
Invasive Alien Species	Ecological disturbance and land degradation	Grasslands, degraded forests, secondary vegetation	Suppression of native flora and alteration of ecosystem processes	Biodiversity loss and reduced habitat quality
Climate Change and Environmental Stress	Temperature rise, altered rainfall, cyclones, drought	Forests, wetlands, mangroves, hill ecosystems	Changes in species distribution and vegetation dynamics	Increased ecosystem vulnerability and habitat instability
Forest Fires	Anthropogenic fire events and climatic stress	Dry deciduous forests and scrublands	Destruction of seedlings and alteration of succession patterns	Reduced regeneration and ecological resilience
Urbanization and Infrastructure Development	Expansion of roads, industries, and settlements	Coastal and peri-urban ecosystems	Habitat simplification and ecological fragmentation	Long-term biodiversity decline
Wetland Degradation	Drainage, pollution, land-use conversion	Wetlands and riverine habitats	Loss of hydrophytic vegetation and aquatic biodiversity	Decline in ecosystem productivity and hydrological balance
Coastal Erosion and Salinity Intrusion	Cyclonic disturbances and sea-level rise	Mangrove and coastal ecosystems	Habitat instability and vegetation stress	Threat to mangrove sustainability and coastal protection

Table 4: Conservation strategies and future research priorities for sustainable management of Odisha flora

Conservation/research component	Major approaches	Expected ecological outcomes	Future priorities
In situ Conservation	Protected areas, wildlife sanctuaries, biosphere reserves, habitat corridors	Preservation of native vegetation and ecosystem integrity	Expansion of ecologically sensitive protected landscapes
Ex situ Conservation	Seed banks, botanical gardens, tissue culture, germplasm repositories	Long-term conservation of threatened and endemic taxa	Development of regional biodiversity repositories
Ecological Restoration	Native species plantation, assisted regeneration, watershed rehabilitation	Recovery of degraded ecosystems and biodiversity stability	Restoration of mining-affected and fragmented habitats
Climate-resilient Conservation Planning	Climate vulnerability assessment and adaptive ecosystem management	Improved ecosystem resilience under climate variability	Climate-adaptive conservation frameworks
Geographic Information Systems and Remote Sensing-based Monitoring	Satellite mapping, habitat fragmentation analysis, vegetation monitoring	Real-time ecological assessment and conservation prioritization	High-resolution biodiversity mapping
Biodiversity Informatics and Artificial Intelligence (AI) Applications	Digital herbarium databases, ecological modeling, AI-assisted monitoring	Improved predictive biodiversity assessment	Integration of AI and geospatial ecology
Long-term Ecological Monitoring	Permanent vegetation plots and ecological observatories	Understanding vegetation dynamics and ecosystem change	Statewide biodiversity monitoring networks
Invasive Species Management	Removal and control of alien invasive plants	Restoration of native vegetation structure	Early detection and rapid response systems
Community-based Conservation	Participation of tribal and local communities in resource management	Sustainable biodiversity governance and habitat protection	Strengthening participatory conservation models
Ethnobotanical Documentation	Recording indigenous knowledge and medicinal plant use	Preservation of traditional ecological knowledge	Integration of traditional knowledge with modern conservation
Sustainable Land-use Management	Regulated developmental activities and ecological planning	Reduced habitat degradation and ecological disturbance	Environmentally sustainable policy implementation

spread, and habitat vulnerability across the Eastern Ghats landscape.

Overall, addressing existing research gaps through integrated scientific investigation, technological innovation, long-term ecological monitoring, and participatory conservation approaches will be essential for safeguarding the floristic diversity and ecological sustainability of Odisha. Comprehensive and multidisciplinary research frameworks are therefore critical for ensuring climate-resilient biodiversity conservation and sustainable ecosystem management within the Eastern Ghats biodiversity corridor of eastern India.

CONCEPTUAL FRAMEWORK OF ODISHA FLORISTIC DIVERSITY

The floristic diversity and vegetation heterogeneity of Odisha are governed by complex interactions among climatic, topographic, edaphic, ecological, and anthropogenic factors operating across the Eastern Ghats landscape. Variations in rainfall distribution, temperature regimes, altitude, soil characteristics, hydrological conditions, and habitat connectivity collectively influence vegetation structure, species composition, ecological stability, and floristic distribution patterns throughout the state. The interaction of these environmental gradients contributes significantly to habitat diversification and the development of heterogeneous plant communities within different ecological regions of Odisha.

The Eastern Ghats hill ecosystems function as important centers of floristic diversification due to their ecological complexity, altitudinal variability, and comparatively stable microclimatic conditions. Ecological interactions among forest structure, species adaptation, habitat specialization, and phytogeographical processes further regulate patterns of species richness, endemism, and vegetation dynamics across the region. Coastal ecosystems, riverine habitats, deciduous forests, semi-evergreen vegetation, and plateau landscapes together form an interconnected ecological mosaic supporting diverse vascular plant assemblages and ecosystem functions.

Anthropogenic disturbances, including deforestation, mining activities, land-use conversion, infrastructure expansion, overexploitation of forest resources, and climate variability, increasingly influence ecosystem stability and biodiversity conservation within Odisha. Habitat fragmentation and ecological degradation may alter natural vegetation structure, reduce species resilience, and affect the long-term sustainability of ecologically sensitive forest ecosystems. Climate-induced environmental changes may further modify species distribution patterns, regeneration behavior, and ecological interactions across multiple vegetation zones.

The conceptual framework presented in Figure 2 illustrates the integrated relationship among

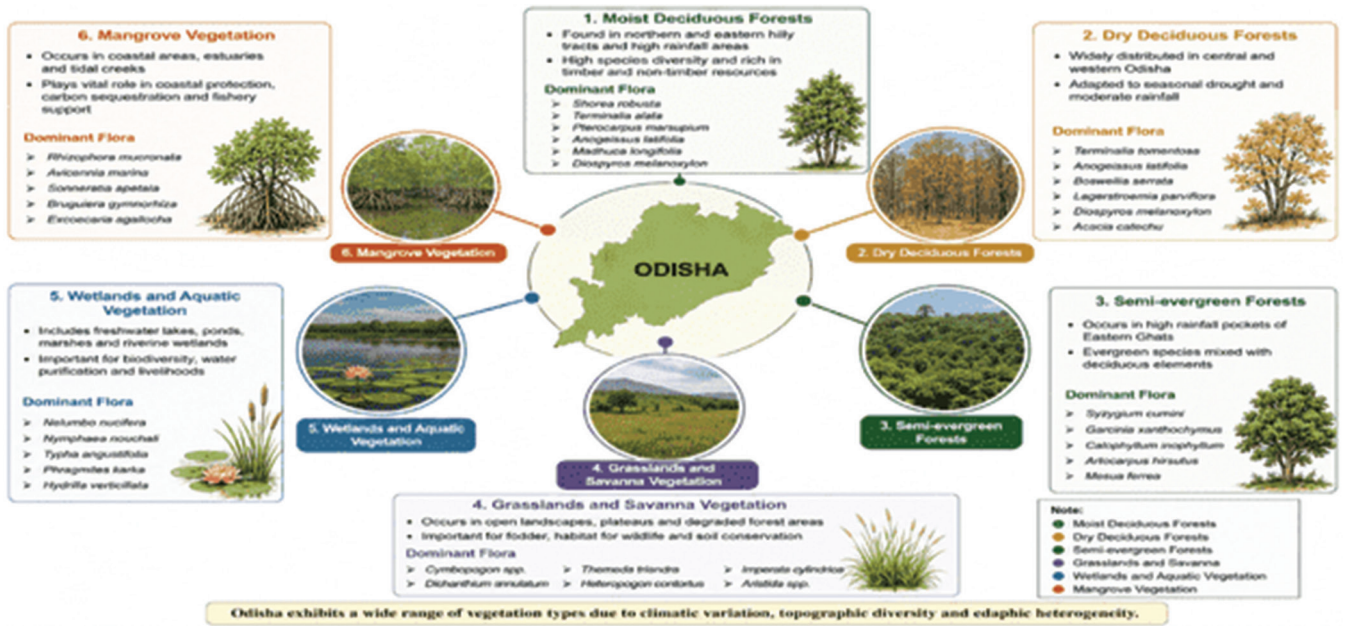

Figure 2: Major vegetation types of Odisha and their dominant flora

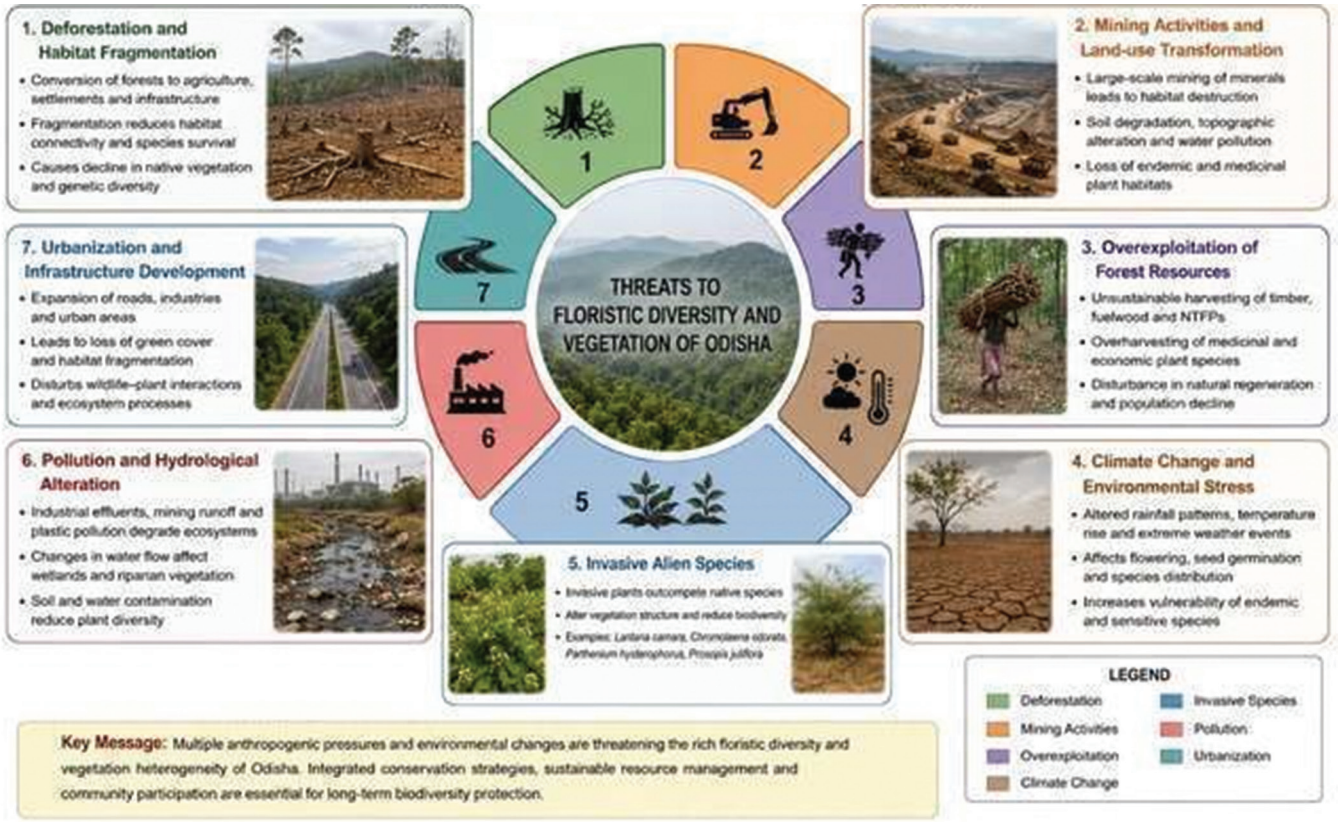

Figure 3: Major conservation threats and anthropogenic pressures affecting Odisha flora and vegetation

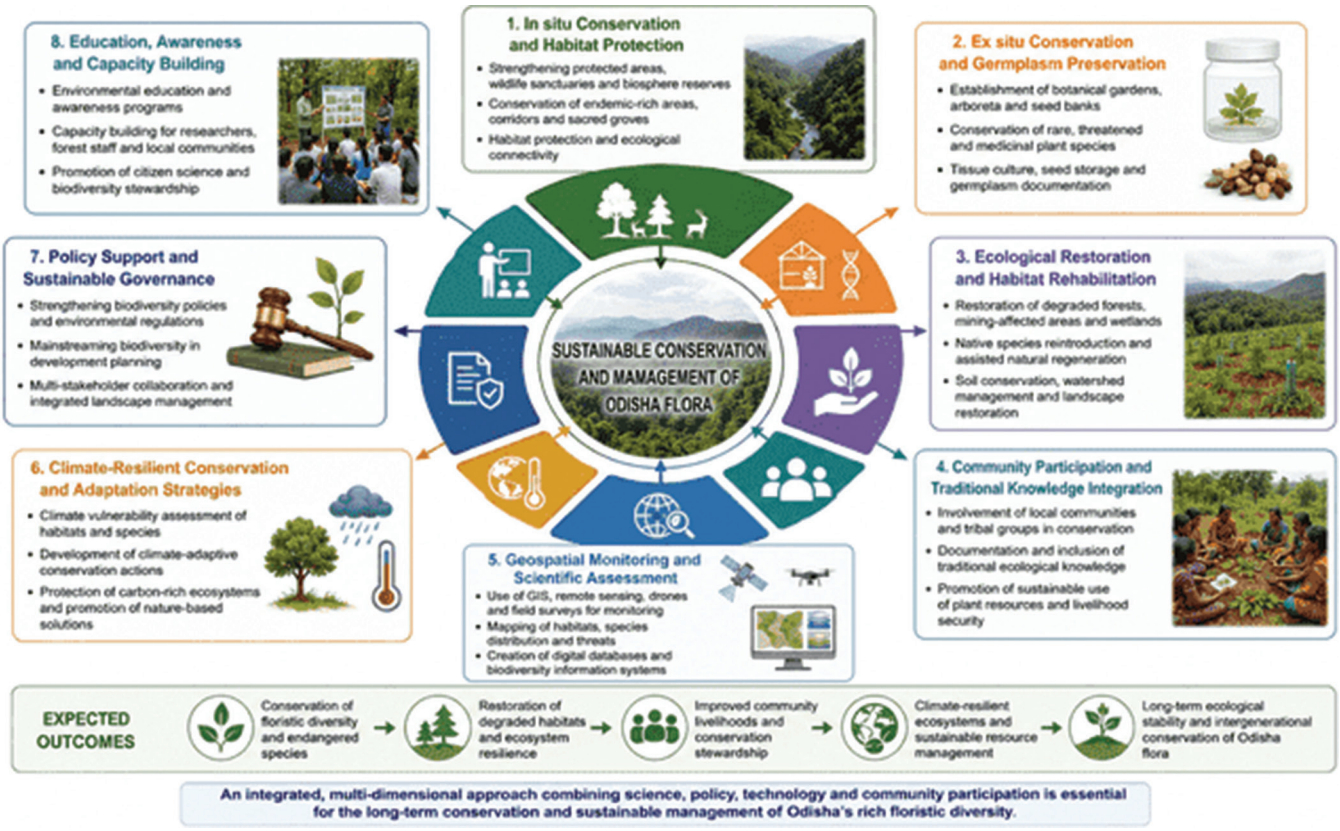

Figure 4: Integrated conservation and sustainable management framework for floristic diversity of Odisha

environmental gradients, vegetation heterogeneity, floristic diversity, ecological functions, anthropogenic pressures, and conservation strategies operating within the Odisha landscape. The framework emphasizes that sustainable conservation of Odisha flora requires a multidisciplinary and landscape-level approach integrating biodiversity assessment, habitat restoration, geospatial monitoring, climate-resilient conservation planning, and community participation.

Understanding these ecological interactions and vegetation dynamics is essential for developing scientifically informed conservation strategies and sustainable ecosystem management approaches within the Eastern Ghats biodiversity corridor. The integrated conceptual perspective further highlights the ecological significance of Odisha as an important center of floristic diversity, phytogeographical transition, and biodiversity conservation in eastern India.

CONCLUSION

Odisha represents one of the ecologically significant floristic regions of eastern India due to its remarkable vegetation heterogeneity, phytogeographical complexity, and diverse vascular plant resources distributed across the Eastern Ghats landscape. The coexistence of coastal ecosystems, riverine habitats, tropical deciduous forests, semi-evergreen hill vegetation, plateau ecosystems, and ecologically sensitive forest landscapes contributes substantially to regional biodiversity richness and ecological stability. Variations in climatic conditions, topography, soil characteristics, and habitat connectivity further regulate floristic composition, species distribution patterns, and vegetation dynamics throughout the state.

The present review highlights that Odisha functions as an important phytogeographical transition zone supporting floristic elements derived from peninsular India, Indo-Malayan regions, and coastal ecosystems. Ecological heterogeneity across the state has facilitated species diversification, habitat specialization, and localized endemism, particularly within the Eastern Ghats hill systems. Forest ecosystems of Odisha additionally provide critical ecological services, including carbon sequestration, hydrological regulation, soil conservation, climate moderation, and maintenance of ecosystem resilience. The floristic wealth of the region also possesses considerable ethnobotanical, medicinal, socio-economic, and cultural significance for indigenous and forest-dependent communities.

Despite the substantial ecological importance of Odisha flora, increasing anthropogenic disturbances, including deforestation, mining activities, habitat fragmentation, overexploitation of forest resources, invasive species expansion, land-use transformation, and climate variability, continue to threaten vegetation integrity and long-term biodiversity conservation across several ecological regions. Many floristically important habitats remain insufficiently explored and inadequately protected, thereby increasing the vulnerability of endemic and ecologically sensitive plant taxa within the Eastern Ghats biodiversity corridor (Dash *et al*., 2022; Behera *et al*., 2021).

The review further identifies several important research gaps related to floristic inventories, molecular taxonomy, geospatial biodiversity assessment, ecological monitoring, climate change biology, and conservation prioritization. Future interdisciplinary research integrating vegetation ecology, geospatial technologies, molecular systematics, ecological modeling, and participatory conservation approaches will therefore be essential for improving scientific understanding and sustainable management of Odisha flora.

Effective long-term conservation of floristic diversity in Odisha will require integrated and landscape-level strategies combining habitat protection, ecological restoration, climate-resilient conservation planning, community participation, sustainable utilization of plant resources, and strengthening of biodiversity documentation programs. Conservation prioritization should particularly focus on endemic-rich landscapes, ecologically fragile hill ecosystems, underexplored forest regions, and habitats experiencing intense anthropogenic pressure.

Overall, the floristic diversity and ecological heterogeneity of Odisha highlight the importance of the Eastern Ghats region as a major center of tropical biodiversity and ecosystem sustainability in India. Strengthening scientific research, conservation awareness, interdisciplinary collaboration, and

evidence-based environmental management will be critical for safeguarding the ecological integrity and floristic wealth of Odisha for future generations. The present review provides an integrated ecological synthesis of Odisha flora and may serve as a scientific baseline for future floristic exploration, biodiversity conservation planning, and sustainable ecosystem management within the Eastern Ghats region.

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