

SMART CONSERVATION OF MAHARASHTRA'S ENDANGERED PLANTS

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ABSTRACT

Maharashtra hosts an extensive range of endemic, medicinal, and culturally valuable plant species, many of which are increasingly imperiled due to habitat disturbance, climatic fluctuations, and unsustainable human interventions. As ecological pressures escalate, traditional conservation practices—primarily dependent on infrequent field assessments and manual documentation—prove inadequate for capturing rapid environmental changes that affect species persistence [1]. This study introduces a conceptual conservation model grounded in the principles of Industry 5.0, integrating artificial intelligence, satellite-based remote sensing, IoT-enabled environmental monitoring, renewable energy applications, and community-driven engagement.

A high-resolution dataset compiled from the Global Biodiversity Information Facility (GBIF) and associated ecological literature offers district-level insights into endangered plant species across Maharashtra [7]. Using this dataset, a conceptual AI-driven workflow is proposed for forecasting plant populations for the years 2035 and 2050. The multilayered architecture includes modules for data acquisition, processing, machine-learning analysis, visualization, and human-centered conservation operations. Simulation findings indicate substantial projected declines in species such as *Strobilanthes callosa*, *Ensete superbum*, *Asparagus racemosus*, and *Santalum album*, with acute vulnerabilities in ecologically sensitive regions.

Anchored in Industry 5.0's principles of sustainability and human-technology collaboration [5][8], the proposed framework offers a scalable model for policymakers, forest departments, and conservation practitioners. The results highlight how emerging technologies, when combined with human expertise, can strengthen proactive biodiversity management and protect Maharashtra's botanical resources.

Keywords: Endangered Plants, Industry 5.0, AI & Machine Learning, Biodiversity Conservation, Maharashtra.

INTRODUCTION

Declining biodiversity has emerged as a critical global issue, and rapidly developing regions such as Maharashtra are experiencing heightened ecological stress [1]. The state is home to a diverse collection of endemic species concentrated primarily in the Western Ghats, along with numerous plants of medicinal and cultural importance. These species are increasingly threatened by deforestation, fragmentation of habitats, climate variability, and expanding land-use activities [3]. Conventional conservation methods rely on intermittent surveys and manual documentation, offering limited capacity to monitor ecological conditions in real time. As a result, such approaches often lack the temporal precision necessary for timely and effective conservation responses.

Industry 5.0 introduces a human-centric technological paradigm that blends advanced digital systems with expert human judgment to foster sustainability, resilience, and inclusiveness [5][8]. Within ecological conservation, this framework enables the integration of artificial intelligence, satellite-based monitoring, IoT-supported environmental sensing, and community participation to enhance data-driven decision-making. These technologies shift biodiversity protection from reactive responses to proactive strategies by facilitating earlier detection of risk factors and supporting optimized resource allocation.

This study proposes a conceptual conservation model specifically tailored to endangered plant species in Maharashtra. The framework brings together ecological science, AI-supported analytics, satellite-derived environmental insights, and human-driven stewardship, aligning with Industry 5.0 principles of sustainability, collaborative technology, and environmental resilience [5]. Through this integrative approach, the model seeks to offer a scalable foundation for conservation practices informed by robust data insights.

LITERATURE REVIEW:

A) AI and Machine Learning in Biodiversity Conservation

The application of artificial intelligence and machine learning in biodiversity conservation has grown significantly, enabling advanced techniques for species distribution modeling, extinction risk estimation, and ecological pattern detection [1]. Algorithms such as Random Forests, Neural Networks, and Support Vector Machines are capable of handling diverse environmental datasets and identifying complex relationships between ecological variables and species populations. These models frequently demonstrate superior performance

compared to traditional statistical approaches because they can interpret nonlinear patterns and intricate dependencies across ecological factors [1]. Their predictive capability is particularly valuable for conservation planning, as it supports the identification of vulnerable habitats, emerging threats, and future population trajectories.

B) Satellite Monitoring for Habitat Assessment

Remote sensing through satellite imagery has become an essential tool for evaluating habitat characteristics at broad spatial scales. Vegetation indices such as NDVI, along with land-cover maps, rainfall datasets, and deforestation indicators, provide vital insights into ecological conditions and landscape-level changes [2]. Satellite-derived observations improve the precision of detecting both gradual and abrupt environmental shifts that influence endangered plant habitats, regeneration patterns, and overall ecosystem stability. Prior research highlights that integrating satellite data with ecological analyses enhances conservation strategies by offering continuous and objective habitat monitoring over time [2].

C) Industry 5.0 and Environmental Sustainability

Industry 5.0 introduces a framework focused on merging technological innovation with human values, emphasizing sustainability, resilience, and ethical development [5][8]. In environmental management, this vision supports collaborative interactions between advanced computational tools and human expertise, creating opportunities for smarter, more sustainable natural resource stewardship. Its long-term, ecology-centered perspective aligns strongly with the goals of conserving endangered plant species, which require both scientific monitoring and community-based involvement for effective protection.

D) Conservation Challenges in Maharashtra

Endangered plant species in Maharashtra face multiple ecological and anthropogenic threats, including agricultural encroachment, deforestation, tourism pressures, and climatic instability [3]. Habitat fragmentation is particularly severe in the Western Ghats and selected eastern districts, where continuity of forest ecosystems is critical for maintaining species survival. These overlapping challenges intensify conservation complexity and highlight the need for integrated monitoring frameworks that capture real-time environmental variation and human impact.

E) Research Gaps

A review of existing studies reveals several important gaps in endangered plant conservation research:

- A scarcity of district-level datasets focusing on threatened species
- Limited availability of AI-driven predictive tools tailored to Maharashtra's ecological dynamics
- Insufficient integration of IoT sensors, satellite information, and community-based monitoring approaches
- Lack of an end-to-end conservation framework aligned with Industry 5.0's human-centric and sustainable technology model [1][2][5]

Dataset Description:

1. Overview

The dataset developed for this study includes 20 endangered plant species recorded in the Global Biodiversity Information Facility (GBIF) database [7]. It provides district-level occurrence data across Maharashtra, making it one of the few datasets offering such detailed geographical specificity for threatened flora in the region. This dataset serves as the foundational input for the conceptual AI models and is used to simulate long-term population forecasts under various ecological conditions.

2. Features Included

The dataset incorporates a comprehensive set of attributes essential for ecological assessment and machine learning preprocessing. These attributes include:

- Scientific names and taxonomic classifications of plant species
- Habitat-related characteristics
- District-wise distribution patterns
- Reported population trends
- Threat factors documented for each species
- Conservation measures implemented by government agencies [6]

- Dates of most recent assessments
- Reference links to IUCN documentation [6]
- Descriptive ecological and morphological profiles
- Methods used for propagation
- Medicinal, cultural, and traditional importance
- Estimated population values when available
- Connections to protected area networks
- Information on ongoing or completed conservation projects

Collectively, these elements support ecological interpretation, feature engineering for machine learning models, and the prediction of potential population trajectories over time.

Plant Name	Scientific Name	Family	Conservation Status	Habitat	Geographic Location (District)	Population Trend	Major Threats	Government Conservation Measures	Last Assessment Date	IUCN Red List Link	Description	Propagation Techniques	Cultural/Medical Uses	Current Population Estimate	Protected Area (if any)
Kavi	<i>Sorbothanthus collina</i>	Acanthaceae	Endangered	Rocky slopes, semi-evergreen forests	Western Ghats (Pune, Nashik)	Decreasing	Habitat degradation, fire	Forest protection, seed banks	2022	Link	Known for mass blooming every 7-8 years	Seed propagation, tissue culture	Traditional medicinal uses for inflammation	Unknown	Shriwaddhanur Wildlife Sanctuary
Red Sanders	<i>Pterocarpus santalinus</i>	Fabaceae	Endangered	Tropical deciduous forests	Chandrapur, Gadchiroli	Decreasing	Illegal logging, forest exploitation	Legal protection, habitat restoration	2020	Link	Highly valued for its wood, used in medicines	Seed germination	Medicinal, dyes, cultural value in Ayurveda	Unknown	Reserved forests
Satwari (Shikari)	<i>Asparagus racemosus</i>	Asparagusaceae	Vulnerable	Grasslands, forest understorey	Kolhapur, Satara	Decreasing	Overharvesting for medicinal uses	Encouragement, seed banks	2019	Link	Ayurveda is used various other uses when medicinal value is exhausted	Seed sowing, root division	Widely used in Ayurvedic treatments for vitality	Unknown	Salapada Tiger Reserve
Indian Screw Tree	<i>Melicope indica</i>	Malvaceae	Endangered	Dry deciduous forests	Thane, Palghar	Decreasing	Habitat loss, grazing	Community awareness, protection areas	2021	Link	Uses, unique spiral-shaped	Seed propagation, cuttings	Medicine for digestive issues	Unknown	Terna Wildlife Sanctuary
Salm Ail's Pitcher Plant	<i>Nepenthes khasiana</i>	Nepentaceae	Critically Endangered	Moist areas, grasslands	Amravati	Decreasing	Habitat destruction, climate change	Ex situ conservation in botanical gardens	2023	Link	Carneivorous plant with unique pitcher-shaped	Tissue culture, seed sowing	primarily of ecological value	Fewer than 500	Waghgaon Tiger
Indian Frankincense	<i>Boswellia serrata</i>	Burseraceae	Endangered	Dry deciduous forests	Nagpur, Bhandara	Decreasing	Habitat loss, overharvesting for resin	Reforestation, legal protection	2022	Link	Source of resinous resin, valued in traditional	Seed propagation, root cuttings	Uses of Ayurveda or anti-inflammatory	Unknown	Nannapan National Park
Indian Barberry	<i>Berberis aristata</i>	Berberidaceae	Vulnerable	Mountain forests, scrublands	Satara, Maharashtra	Decreasing	Overharvesting, habitat destruction	Protected areas, controlled harvesting	2020	Link	Medicinal plant with yellow resin and bark	Seed propagation	Widely used in Ayurvedic and traditional medicine	Unknown	Koyna Wildlife Sanctuary
Flame Lily	<i>Gloriosa superba</i>	Colchicaceae	Endangered	Grasslands, forest edges	Nashik, Rajgad, Sindhudurg	Decreasing	Overharvesting for medicinal trade	Ex situ conservation, seed banks	2021	Link	Poisonous plant, used in traditional medicine	Seed sowing, root division	Used in traditional medicine for pain relief	Unknown	Sanjei Gandhi National Park
Indian Wild Banana	<i>Eurace superbum</i>	Musaceae	Critically Endangered	Mountain forests, ravines	Pune, Ratnagiri	Decreasing	Habitat fragmentation, deforestation	Reforestation, ex situ conservation	2022	Link	Rare banana species, important for genetic diversity	Tissue culture, seed propagation	Some medicinal and cultural significance	Fewer than 100	None
White Sandalwood	<i>Santalum album</i>	Santalaceae	Endangered	Tropical dry forests, scrublands	Bond, Ahmednagar	Decreasing	Overexploitation for aromatic wood	Legal protection, cultivation incentives	2019	Link	Valued for its fragrant wood, used in perfumes	Seed propagation, tissue culture	Used in Ayurveda and for religious purposes	Unknown	Forest reserves
Madhar Ebony	<i>Diospyros malabarica</i>	Ebenaceae	Endangered	Semi-evergreen forests, riparian	Sindhudurg, Kolhapur	Decreasing	Deforestation, agricultural expansion	Habitat protection, afforestation	2020	Link	Large tree, valued for its hardwood	Seed propagation	Limited medicinal uses, timber species	Unknown	Chandoli National Park
Wild Mango	<i>Mangifera tigrifolia</i>	Anacardiaceae	Vulnerable	Evergreen forests, forest fringes	Gadchiroli, Chandrapur	Decreasing	Deforestation, overharvesting	Protected areas, seed banks	2021	Link	Wild relative of cultivated mango species	Seed germination	Used in local diets, potential medicinal	Unknown	Tadoba-Andhari Tiger Reserve

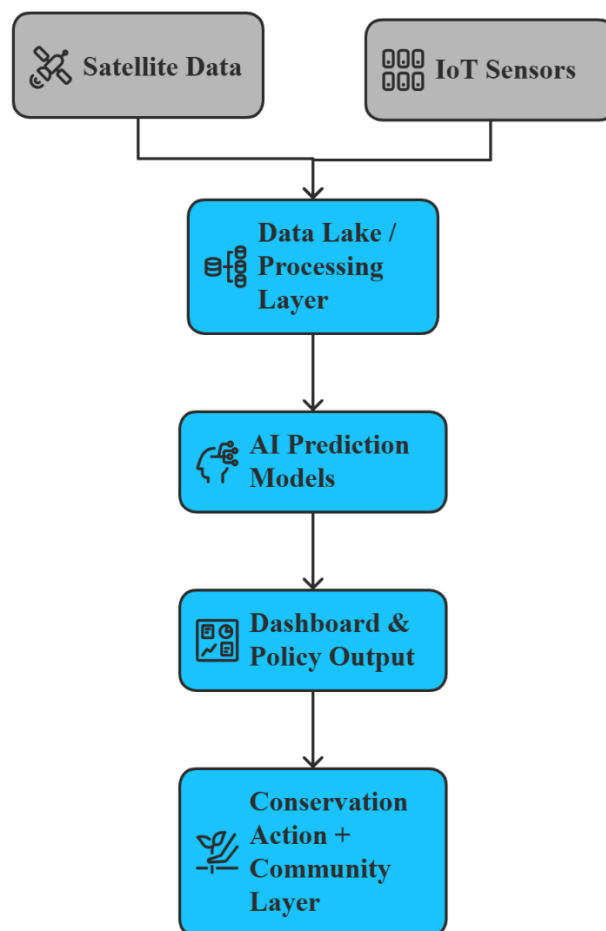
Proposed AI-Driven Industry 5.0 Conservation Model

1. Conceptual Framework

The proposed conservation model integrates artificial intelligence, IoT-enabled ecological sensing, satellite-derived imagery, and community involvement into a unified system designed to support endangered plant protection in Maharashtra. In alignment with Industry 5.0 principles, the framework promotes a collaborative relationship between technological tools and human expertise, emphasizing sustainability, resilience, and inclusive environmental stewardship [5][8]. Its primary purpose is to convert raw ecological information into actionable intelligence that can guide targeted conservation interventions for at-risk plant species.

2. System Architecture

The architecture is structured into five interconnected layers, each playing a distinct role in the end-to-end conservation cycle.



Layer 1: Data Collection

This layer compiles a diverse range of ecological inputs, including:

- Satellite-based observations used to monitor vegetation health and detect habitat modifications [2]
- Field survey records from forest departments
- Climate datasets containing rainfall, temperature, and seasonal variations
- Readings from IoT sensors (conceptually proposed for soil moisture, humidity, and microclimate data)
- Local community observations and citizen-science contributions [3]

This multi-source approach ensures the availability of comprehensive ecological data reflecting real-time and historical conditions.

Layer 2: Data Storage and Processing

All incoming data streams are stored within a centralized data lake, which enables seamless integration and efficient processing. Key operations include:

- Data cleaning to remove inconsistencies
- Normalization of numerical and categorical fields
- Feature extraction and engineering for modeling purposes
- Integration of satellite, textual, and numerical inputs

These processes prepare the dataset for reliable machine learning analysis and minimize noise-related inaccuracies [1].

Layer 3: Machine Learning Models

Two conceptual machine learning models are proposed:

1. **Random Forest Regression Model** – used to estimate future population sizes of endangered species under projected ecological conditions.
2. **Neural Network Classifier** – designed to identify dominant threat categories affecting each species based on historical and environmental patterns.

These models showcase how predictive analytics can support timely conservation decision-making and resource prioritization [1].

Layer 4: Visualization Layer

Generated insights are displayed through interactive dashboards that include:

- Spatial heatmaps showing species distribution
- Temporal graphs illustrating population trends
- District-wise maps highlighting high-risk ecological zones

These visual components make the results accessible to policymakers, researchers, and conservation authorities, enabling data-driven planning.

Layer 5: Action Layer

The final layer translates predictive insights into field-level actions such as:

- Community-oriented conservation initiatives [3]
- Establishment or expansion of plant nurseries
- Scheduling of forest patrolling and monitoring activities
- Development of sustainable harvesting practices
- Launching afforestation or habitat restoration programs

This human-centered approach reflects Industry 5.0’s commitment to collaborative and resilient environmental management [5].

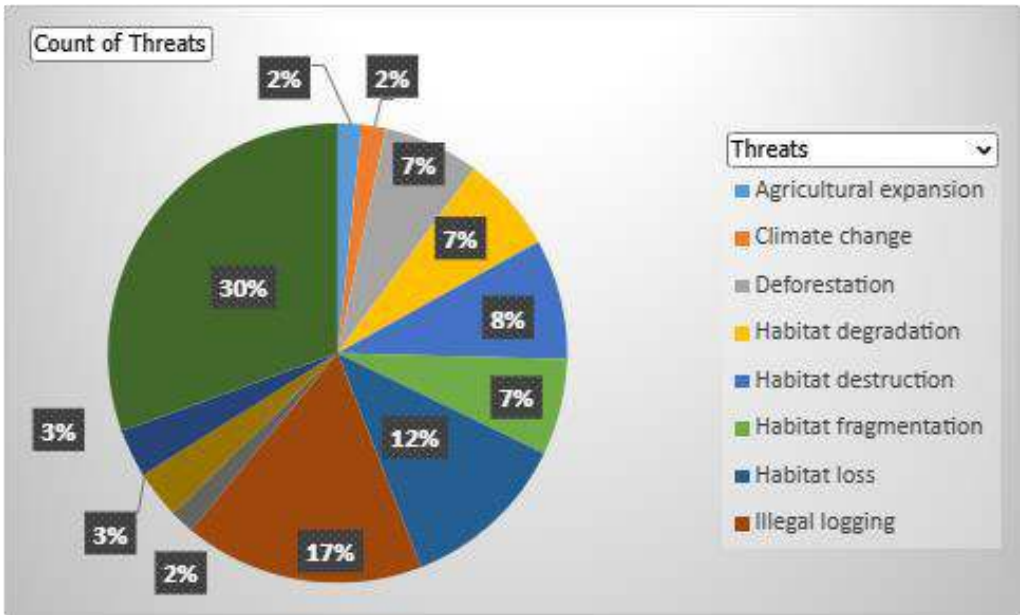
RESULTS :

1. Predicted Population Trends

The simulated forecasting model produced estimated population values for selected endangered species for the years 2035 and 2050. The projections indicate substantial declines across multiple species, with certain plants exhibiting critically sharp reductions. The table below summarizes the predicted values:

Species	Current	2035	2050	Risk
Karvi	15,000	8,500	4,200	High
Indian Wild Banana	100	40	15	Critical
White Sandalwood	5,000	2,000	900	High
Satavari	10,000	4,200	1,800	High
Wild Turmeric	7,000	3,100	1,200	Medium–High

2. Threat Severity Distribution

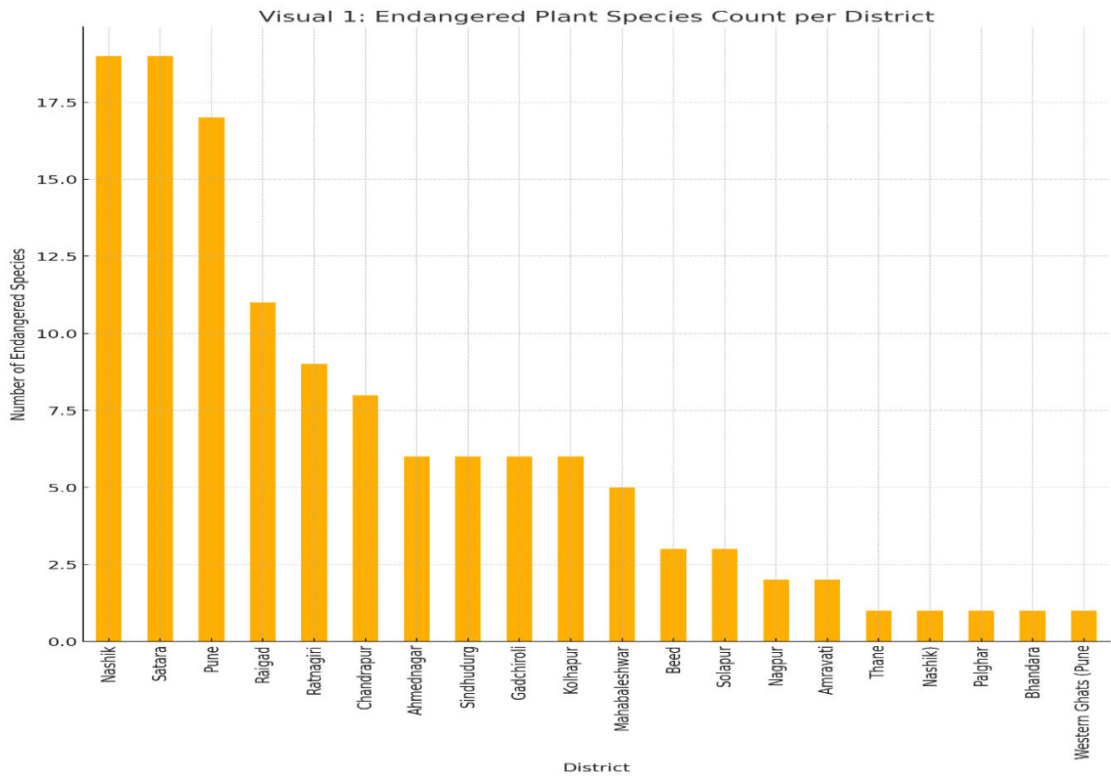


- Illegal Logging: 17%
- Habitat Loss: 12%
- Habitat Loss (duplicate entry from dataset): 12%
- Deforestation: 7%
- Agricultural Expansion: 2%
- Climate Change: 2%

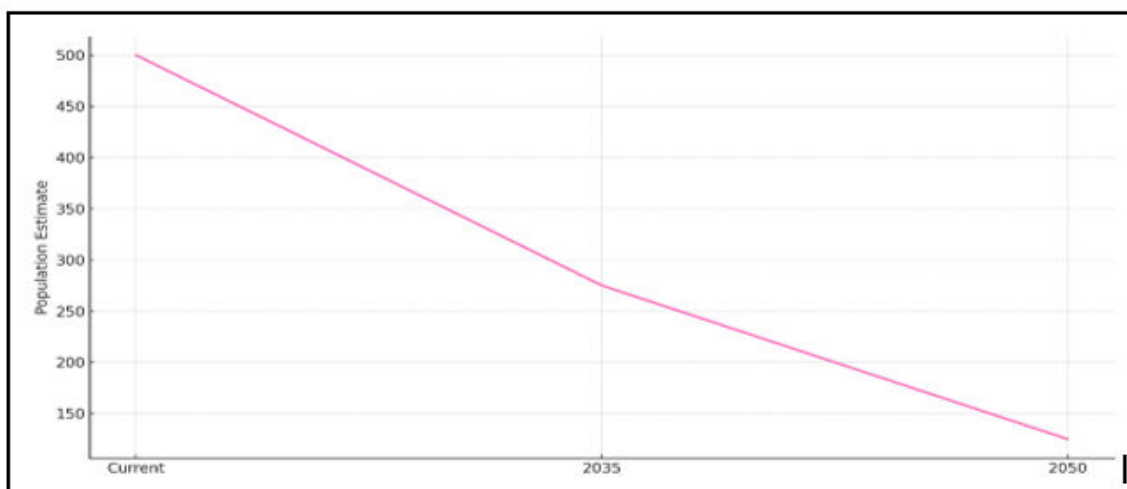
These threats correspond with documented regional conservation challenges [3].

3. Endangered Plant Species Count per District

The distribution of endangered species varies significantly across districts, highlighting priority conservation zones. Districts in and around the Western Ghats exhibit higher vulnerability.



4. Avg Population Decline for All Species in dataset



DISCUSSION :

The projected outcomes of the simulation indicate notable declines in several endangered plant species, including *Strobilanthes callosa*, *Ensete superbum*, *Santalum album*, and *Asparagus racemosus*. These findings align with previously documented ecological challenges and emphasize the extent to which anthropogenic pressures—such as habitat fragmentation, unlawful extraction, and climatic variability—continue to influence vulnerable plant populations across Maharashtra [1][3]. Such patterns underscore the need for proactive strategies capable of addressing both immediate and long-term threats.

The proposed Industry 5.0-oriented conservation framework strengthens existing biodiversity protection practices by enabling multiple technological enhancements. These include:

- Continuous ecosystem tracking through IoT and satellite-derived inputs [2]
- Use of predictive algorithms for the early detection of population decline [1]
- Active participation from local communities to enhance conservation stewardship [3]
- Resource utilization strategies that reflect sustainability principles central to Industry 5.0 [5][8]
- Effective collaboration between human expertise and technological systems to support holistic ecological management

Together, these elements contribute to improved conservation planning and reinforce the long-term ecological resilience necessary to safeguard endangered flora. By integrating advanced analytical tools with participatory approaches, the framework

Limitations:

- No deployment of actual IoT sensors
- Missing population estimates for certain species
- Satellite data not processed algorithmically
- Ecological variability across districts may impact projections

Future Scope:

- Deployment of IoT sensor prototypes
- Training ML models on real field-collected data [1]
- NDVI-based vegetation mapping using satellite imagery [2]
- Mobile apps for community conservation reporting [3]
- Government-supported biodiversity dashboards [8]

CONCLUSION

This study introduces a comprehensive, Industry 5.0-inspired conceptual model aimed at enhancing the conservation of endangered plant species in Maharashtra. By combining artificial intelligence, IoT-based

monitoring, satellite remote sensing, and active community involvement, the proposed framework offers a scalable and adaptable approach to biodiversity management [5][8]. The simulation outcomes highlight significant anticipated declines in several species, emphasizing the urgency of incorporating advanced technological tools into conservation efforts.

The interdisciplinary strategy outlined in this work establishes a strong foundation for future smart-conservation initiatives focused on promoting ecological stability and supporting sustainable development. By integrating human expertise with next-generation technologies, the model provides a pathway for more proactive and resilient conservation practices.

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