



Integrating GIS and Remote Sensing for Plant Conservation

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INTRODUCTION

The global flora—comprising some 390 000 known vascular plant species—faces unprecedented threats: an estimated 15 000 species are now classified as under threat of extinction. Traditional conservation approaches (e.g., field surveys and manual plot monitoring) struggle to adequately document and respond to pressures that operate across vast spatial and temporal scales. In response, conservation biology has increasingly turned to the synergistic application of GIS and remote sensing. These technologies provide an integrated framework for gathering, analysing, and visualizing spatial data, from local quadrats to continental extents. Over the past three decades, improvements in satellite sensors, airborne platforms, and analytical algorithms have transformed basic land-cover classification into sophisticated, real-time monitoring and predictive modelling systems. This review details the conceptual foundations of GIS and remote sensing in plant conservation, outlines key methodological approaches, showcases representative case studies, and examines emerging innovations and challenges.

Theoretical Foundations:

1. GIS Principles

GIS represents a paradigm shift in ecology, predicated on three interrelated concepts:

- **Spatial Autocorrelation:** Nearby locations tend to exhibit more similar environmental and biological characteristics than distant ones. Quantifying these relationships helps identify habitat clusters, fragmentation patterns, and the environmental drivers of species distributions.
- **Scale Dependency:** Ecological processes unfold across multiple spatial and temporal scales—from square-meter plots to entire biomes. Effective conservation planning requires GIS tools capable of multi-scale analyses, allowing managers to align interventions with the appropriate ecological context.

- **Ecological Connectivity:** Maintaining gene flow and ecosystem resilience depends on linking suitable habitats. GIS facilitates the identification and prioritization of corridors and stepping-stone patches essential for species movement and long-term viability.

2. Remote Sensing Principles

Remote sensing leverages the unique ways in which vegetation and other materials interact with electromagnetic radiation:

- **Spectral Signatures:** Healthy vegetation absorbs visible red wavelengths and strongly reflects near-infrared light. Metrics such as the Normalized Difference Vegetation Index (NDVI) exploit this contrast to map vegetation Vigor, detect stress, and monitor phenology over vast areas.
- **Hyperspectral Imaging:** By capturing hundreds of narrow, contiguous spectral bands, hyperspectral sensors enable species-level discrimination and detailed physiological assessments. Coupled with machine learning classifiers, this approach supports automated species identification and early stress detection.

3. Methodological Approaches

Species Distribution Modelling

Species distribution models (SDMs) predict where a species is likely to occur based on environmental correlates and known occurrence records. The Maximum Entropy (Max Ent) algorithm is widely employed for presence-only data, estimating habitat suitability by maximizing predictive entropy subject to observational constraints. Recent enhancements integrate high-resolution remote sensing variables and ensemble machine learning techniques, improving prediction accuracy and extending applications to climate change impact assessments.

Habitat Mapping and Classification

Automated classification of satellite or aerial imagery underpins rapid habitat mapping:

- **Object-Based Image Analysis (OBIA):** Segments imagery into meaningful objects before classification, yielding higher accuracy in heterogeneous landscapes than pixel-based methods.
- **Machine Learning Classifiers:** Algorithms such as Random Forests, Support Vector Machines, and Neural Networks can

differentiate complex vegetation types by learning non-linear relationships between spectral, structural, and textural features.

Vegetation Health Monitoring

Beyond NDVI, indices like the Enhanced Vegetation Index (EVI) and Normalized Difference Water Index (NDWI) offer improved sensitivity to biomass and water stress, respectively. Time-series analyses of these indices reveal phenological shifts, enabling detection of drought effects, disease outbreaks, or restoration progress.

Invasive Species Detection

Early detection of invasive plants is critical. Hyperspectral and multispectral data can expose unique spectral or structural signatures of invaders. Deep learning models, particularly convolutional neural networks, have shown promise in identifying nascent invasions at high spatial resolution.

4. Applications and Case Studies

a. Endangered Species in Morocco

In the High Atlas Mountains, GIS and remote sensing guided the conservation of *Salvia taraxacifolia*. GPS-grounded occurrence data coupled with environmental layers produced habitat suitability maps that informed both in situ and ex situ strategies, identifying optimal sites for population reinforcement.

b. Forest Fragmentation in Romania

By comparing 1970s Corona satellite imagery with present-day Sentinel-2 data, researchers quantified decades-long fragmentation trends in the Bucegi Mountains. GIS analyses of patch size, edge density, and connectivity illuminated conservation hotspots and guided corridor restoration.

c. Habitat Suitability in Egypt

Distribution models for two endangered Egyptian species—*Periploca angustifolia* and *Ebenus armitagei*—integrated climate, soil, and topography layers to pinpoint current and future refugia. These spatial forecasts prioritized field surveys and habitat protection measures.

d. Bryophyte Conservation in Portugal

At the Lisbon University Botanical Garden, GIS underpinned the conservation planning of endangered bryophytes (*Bruchia vogesiaca*), informing reserve design and evaluating impacts of the invasive *Carpobrotus edulis* on native cryptogams. Ecogeographical GIS surveys optimized seed-collection site selection for ex situ banking.

e. Global Conservation Prioritization

A random-forest machine learning analysis of over 150 000 species combined geographic, climatic, and trait data to assess extinction risk at unprecedented scale. The resulting maps guided international funding allocations and red-list assessments.

5. Advanced Technologies

a. Hyperspectral Imaging

Miniaturized drone-mounted hyperspectral sensors now offer sub-meter resolution species mapping and health assessment. Their integration with AI classifiers enables rapid, non-invasive monitoring of rare or commercially threatened taxa (e.g., *Dalbergia* spp.).

b. LiDAR for Structural Analysis

Airborne and terrestrial LiDAR provide three-dimensional vegetation structure metrics—canopy height, density, and layering—that correlate with biodiversity and habitat complexity. Combined hyperspectral–LiDAR workflows yield comprehensive ecological insights.

c. Unmanned Aerial Vehicles

UAVs equipped with multispectral, thermal, and LiDAR payloads facilitate fine-scale surveys of sensitive or inaccessible populations. Pilot studies demonstrate UAV efficacy in monitoring threatened herbs (e.g., *Phacelia submutica*) without disturbing fragile habitats.

d. Machine Learning and AI

Deep learning systems (e.g., convolutional neural networks) have revolutionized pattern recognition in large remote-sensing datasets—automating vegetation classification, detecting disease outbreaks, and generating early-warning alerts from continuous data streams.

6. Challenges and Limitations

- **Data Quality & Validation:** Atmospheric interference, cloud cover, and sensor noise necessitate rigorous preprocessing. Ground-truthing remains costly and may lag behind satellite acquisition.
- **Technical Barriers:** High costs of high-resolution imagery, specialized software, and hardware can limit adoption—particularly in resource-constrained regions.
- **Data Integration & Scale Mismatches:** Merging heterogeneous datasets (e.g., coarse climate layers with fine-scale

occurrence records) demands careful treatment of projection, resolution, and uncertainty.

- **Ecological Complexity:** Remote sensing may not capture all biotic interactions or demographic processes critical for population viability analyses. Phenological variability and cryptic species further complicate mapping efforts.

7. Strategic Pathways and Key Recommendations

a. Multi-Source Data Fusion

Develop robust algorithms to integrate satellite, airborne, ground-based, and citizen-science data, leveraging the strengths of each platform to create holistic ecological models.

b. Real-Time Monitoring & Early Warning

Deploy IoT sensor networks alongside near-real-time remote sensing to detect and respond to emerging threats (e.g., pest outbreaks, habitat degradation) before they escalate.

c. Climate-Adaptation Modelling

Combine species distribution models with demographic projections under climate scenarios to identify refugia, inform assisted migration, and design climate-smart protected areas.

d. Capacity Building & Open Science

Promote open-access tools, cloud-based platforms, and standardized protocols. Invest in training programs and foster international collaborations to democratize geospatial conservation methods.

CONCLUSION

GIS and remote sensing have fundamentally reshaped plant conservation, offering scalable, data-driven approaches to tackle biodiversity loss. From fine-scale habitat assessments to global risk analyses, these tools enable evidence-based decision-making at speeds and scales previously unattainable. Continued innovation in hyperspectral imaging, LiDAR, UAVs, and AI—paired with strategic investments in data integration, capacity building, and policy support—will be essential to harness the full potential of geospatial technologies. As conservation challenges intensify under climate change and human pressures, GIS and remote sensing stand as indispensable allies in the quest to safeguard the planet's botanical heritage.