



ADVANCEMENTS IN BIODIVERSITY ASSESSMENT THROUGH COMPUTATIONAL TOOLS

DR. DANDE SWAPNA SREE¹ AND SREE ASHRIT DANDE

¹Lecturer in Botany, Silver Jubilee Government College, Cluster University, Kurnool, Andhra Pradesh, India.

Abstract:

Application of Computational tools in Biodiversity Assessment is a multidisciplinary research approach that integrates biodiversity data with information technology and computational tools through remote sensing, satellite imaging, sensor systems, signal processing, data modelling, and statistical analysis. Technological applications enable large-scale monitoring of ecosystems, climate variables, and species distribution. The application of computational tools lies in advancements in sensor technology, enhanced AI algorithms, improved scalability and network connectivity. The utilization of big data and cloud computing will further help in revolutionizing the assessment of various levels of biodiversity (Species, Genetic and Ecosystem). This research article explores the advancements in computational tools applicable in assessment of biodiversity highlighting the data acquisition systems, imaging techniques, and computational modelling. The study emphasizes principles involved in various computational tools that support accurate biodiversity assessment and contribute to sustainable environmental management.

Key Words: Biodiversity Assessment, Computational tools, Remote Sensing, Data Modelling, eDNA tools.

Introduction:

Biodiversity conservation has become a global scientific priority due to rapid environmental degradation and climate change. Traditional biological surveys alone are insufficient to handle large-scale ecological data. Biodiversity integration with information technology emerged as a solution by combining biology with computational sciences. Physics contributes significantly through measurement techniques, sensor development, satellite-based observation, and quantitative modelling. These approaches allow precise monitoring of environmental parameters influencing biodiversity. Computational tools used for biodiversity assessment encompasses a wide array of software, algorithms, and platforms designed to measure, monitor, and analyse the diversity of life ranging from species, genetic to ecosystem levels. GBIF (Global Biodiversity Information Facility) is a network and database for accessing species occurrence data worldwide. These tools are crucial for transforming large, heterogeneous datasets used in satellite imagery, acoustic recorders, and environmental DNA (eDNA) into actionable insights for conservation and management of biodiversity. Several works concerning ecological networks have been published (Bascompte and Jordan, 2007) but too few of them are mechanistic and predictive, despite the plea by Ings *et al.*, 2009. On the other hand, online dataset collections and international research interest is rapidly growing, especially for soil organisms (Van den Hoogen *et al.*, 2020; Philips *et al.*, 2021). The future of more effective biodiversity assessment lies in development of AI and IoT tools which also help in promoting sustainable resource management. Technological tools developed using physics principles support applied biodiversity conservation. Automated species identification systems use optics and image processing. Drones based on aerodynamics and control systems survey inaccessible regions. Climate models based on thermodynamics predict ecosystem responses. These applications transform biodiversity informatics research into practical solutions.

Remote Sensing and Image Analysis:

Remote sensing is one of the most significant tools in biodiversity assessment. Satellites operate using electromagnetic wave theory and optical principles. They provide large-scale data on vegetation cover, land-use changes, and climate patterns. Multispectral and hyperspectral imaging help identify plant species and ecosystem health. Physics-based image processing techniques improve data interpretation. Remote sensing enables non-invasive, continuous monitoring of biodiversity over vast regions (Liu, J.G. and Mason, P.J., 2016). These tools use data from satellites, drones (UAVs), and camera traps to map habitats and monitor species (Table 1)

Table 1: Remote Sensing and Image Analysis Tools

GEE (Google Earth Engine)	Acts as a cloud platform for planetary- scale data analysis related to environmental parameters.
YOLO (You Look Only Once)	Provides deep learning models for identification of animals in camera trap images
LIDAR (Light Detection and Ranging)	Supports in creating 3D maps of vegetation structure
Random Forests	Used to classify land cover and map habitats based on remote sensing data with Machine Learning Algorithm.
Global Forest Watch	To identify land use changes like deforestation by using high resolution satellite images.

GIS and SDM:

GIS integrates spatial data obtained from satellites and field measurements. Physical Principles of coordinate systems and mathematical transformations are used in spatial mapping. It involves Species Distribution Modelling (SDM) and Spatial Analysis. GIS supports modelling of species distribution and habitat fragmentation. Spatial statistics and modelling tools help to identify biodiversity hotspots. GIS thus acts as a bridge between physical Principles involved in biological approach for ecological interpretation (Catalano *et al.*, 2023). These tools help in predicting and plotting the potential distribution of species and analyse habitat suitability.

The below data lists the important GIS tools and their applications in biodiversity assessment.

1. Linkage Mapper: It is a GIS tool used to map habitat connectivity
2. Circuitscape: It is a GIS tool used to model habitat connectivity and fragmentation using Circuit theory.
3. SDM Tool box: It is a python-based GIS tool kit used in analysis of landscape, biogeography and species distribution models.
4. BIOMOD2 (R Package): It provides a framework for ensemble the forecasting of species distribution.
5. MaxEnt (Maximum Entropy): A GIS tool to predict species distributions.

Of the above tools MaxEnt is a widely used modelling method in predicting the species level biodiversity.

AI and IoT:

The development of Artificial Intelligence (AI) and Internet of Things (IoT) led to the transformative advancement in assessment of biodiversity like species identification, habitat mapping and health assessment of a particular ecosystem. The integration of IoT and AI technologies not only enhances ability to conduct biodiversity surveys to monitor ecological changes but also help in developing adaptive management strategies to mitigate biodiversity loss to promote conservation. eDNA sampling and analysis helps to detect species involved in soil, water and air (Rathoure and Rathaur, 2024).

IoT devices like GPS collars and radio tags also help in tracking individual animals, collecting movement data used to study behaviour, migration patterns, and habitat use. Machine learning algorithms also help in analysing the movement patterns and habitat preferences derived from IoT collected data thus providing insights into species ecology and need of biodiversity conservation.

Sensor networks designed using electronics and solid-state physics play a vital role in biodiversity monitoring. IoT-based systems continuously record environmental variables such as temperature, sound, and light. Acoustic sensors help in monitoring bird and insect populations using signal analysis. Low-power electronics and energy optimization are physics driven innovations. These technologies support real-time biodiversity data collection. Sensor networks enhance research accuracy and temporal resolution.

Biodiversity Indices and Software tools:

These tools are used to measure species richness, evenness, and composition, often analysing datasets to calculate alpha and beta diversity (Victor *et al.*, 2018). The other software tools used to study biodiversity indices are listed in Table 2.

Table 2: Software tools used for analysis of biodiversity indices

BAT (Biodiversity Assessment Tools — R package)	This software tool is used for measuring and estimating alpha and beta diversity at taxon, phylogenetic, and functional levels.
PAST (PAleontological STatistics)	It is a user-friendly software for scientific data analysis, including biodiversity indices.
PRIMER (Plymouth Routines In Multivariate Ecological Research)	This tool is used for multivariate analysis of community data.
VBioindex	It is a JAVA based program used for calculating Shannon-Wiener index, species richness, evenness, and relative dominance.
Vegan (R package)	It is a popular open-source R package for community ecology.
EstimateS	It provides a Software for estimating species richness and evenness

BEFANA is also a free, open- source software tool which can be implemented in Python for analysis and visualization of ecological network in a particular ecosystem. This tool aims to achieve simplicity, interactivity and extensibility by providing methods and implementations for data loading, Pre-processing, network analysis and interactive visualisation, modelling with experiential data and predictive modelling with machine learning (Marzidovsek *et al.*, 2022).

Ecoacoustics and Bioacoustics:

These tools process audio data to monitor species presence and ecosystem health.

1. Kaleidoscope Pro: Software for detecting and identifying species in acoustic recordings.
2. Arbimon: A cloud-based platform for ecoacoustic analysis
3. Soundscape Analysis (e.g., in R): Calculating acoustic indices to assess biodiversity, such as Spectral Entropy or Bioacoustic Index.

Molecular eDNA tools:

These tools analyse genetic material from environmental samples (soil, water, air) to detect species without direct observation.

- Bioinformatics Pipelines (e.g., QIIME, Mothur): These tools are used for processing and interpreting metabarcoding data.
- BOLD (Barcode of Life Data Systems): It is a global repository for DNA-based biodiversity data.
- SeqAPASS (Sequence Alignment to Predict Across Species Susceptibility): A tool for cross-species extrapolation to predict chemical impacts.

Conclusions:

Environmental management, conservation science, and ecological research could all benefit greatly from the use of computational tools in biodiversity assessment in the future. These methodologies aid in demonstrating the diverse applications of computational tools in biodiversity assessment, emphasizing their potential to improve ecological knowledge by providing information on conservation tactics and to lessen the effects of human activity on biodiversity worldwide. In order to improve accessibility and collaborative research, future work will focus on developing sophisticated, cloud-based data management platforms to store, manage, and analyse massive amounts of biodiversity data. These systems will automate data quality control and enable advanced predictive modelling by utilizing AI-driven analytics and visualization tools to offer deeper insights into ecological patterns and trends.

References:

1. J. Bascompte, P. Jordano. Plant-animal mutualistic networks: the architecture of biodiversity. *Annu. Rev. Ecol. Evol. Syst.*, 38 (1) (2007), pp. 567-593.
2. Ings, T.C., Montoya, J.M., Bascompte, J., Blüthgen, N., Brown, L., Dormann, C.F., Edwards, F., Figueroa, D., Jacob, U., Jones, J.I., Lauridsen, R.B., Ledger, M.E., Lewis, H.M., Olesen, J.M., Van Veen, F.J.F., Warren, P.H. and Woodward, G. (2009), Review: Ecological networks – beyond food webs. *Journal of Animal Ecology*, 78: 253-269. <https://doi.org/10.1111/j.1365-2656.2008.01460.x>
3. Van den Hoogen, J., Geisen, S., Wall, D.H., Wardle, D.A., Trautspurger, W., de Goede, R.G., Adams, B.J., Ahmad, W., Ferris, H., Bardgett, R.D. and Bonkowski, M., 2020. A global database of soil nematode abundance and functional group composition. *Scientific data*, 7(1), p.103.
4. Phillips HR, Bach EM, Bartz ML, Bennett JM, Beugnon R, Briones MJ, Brown GG, Ferlian O, Gongalsky KB, Guerra CA, König-Ries B. Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. *Scientific data*. 2021 May 21;8(1):136.
5. Liu, J.G. and Mason, P.J. (2016). References. In *Image Processing and GIS for Remote Sensing* (eds J.G. Liu and P.J. Mason). <https://doi.org/10.1002/9781118724194.refs>
6. Catalano, Giuseppe Antonio, Federico Maci, Provvidenza Rita D'Urso, and Claudia Arcidiacono. 2023. "GIS and SDM-Based Methodology for Resource Optimisation: Feasibility Study for Citrus in Mediterranean Area" *Agronomy* 13, no. 2: 549. <https://doi.org/10.3390/agronomy13020549>.
7. Rathoure AK, Rathaur AK. 2024. AI and IoT in biodiversity assessment. *J Aquac Mar Biol*. 2024;13(3):108–115. DOI: 10.15406/jamb.2024.13.00404.
8. Victor N. Mose, David Western, Peter Tyrrell, 2018. Application of open source tools for biodiversity conservation and natural resource management in East Africa, *Ecological Informatics*, Volume 47, Pages 35-44, ISSN 1574-9541, <https://doi.org/10.1016/j.ecoinf.2017.09.006>.
9. Marzidovšek, Martin & Podpečan, Vid & Conti, Erminia & Debeljak, Marko & Mulder, Christian. (2022). BEFANA: A tool for biodiversity-ecosystem functioning assessment by network analysis. *Ecological Modelling*. 471. 110065. 10.1016/j.ecolmodel.2022.110065.