



# Role of Geospatial Technology in Conservation, Monitoring and Management of Biological Diversity

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## Abstract

**Abstract:** Biological diversity is the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes. Assessment of the biodiversity becomes very difficult due to complexity in biodiversity nature. Recently, remote sensing (RS) and geographical information system (GIS) with biodiversity communities have shared their ideas, issues and possible way out to the problems of biodiversity assessment. For scientists, the assessment and prediction of responses of ecosystem to the climate change and subsequent threats and consequences has been a prime focus. The data related to distribution of species, their abundance, habitats and risks should be relevant and reliable for the proper management and conservation of biodiversity. The geospatial technology (RS and GIS) is an efficient and cost-effective means of data collection for conservation, management and planning of biodiversity and other resources. In order to observe fluctuations in biodiversity of freshwater, marine and terrestrial ecosystems, the technology plays an important character by providing images (satellite data) on regular basis. GIS accommodates a large variety of spatial and attribute data, used for target surveys and monitoring biodiversity. This paper reviews the need for biodiversity information and databases and applications of geospatial technology instruments (like high spatial resolution and hyperspectral data) and techniques [such as Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI)] in conservation, monitoring and management of biological diversity.

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## Introduction

Biodiversity, the term given by Walter G. Rosen in 1985, is defined as “the variability among living organisms from all sources including, *inter alia*, terrestrial,

marine and other aquatic ecosystems and the ecological complexes of which they are part". The biodiversity entails the sum total of complexities of all life forms, including different varieties of living organisms, their varying behavior and interactions. It is a multi-dimensional concept comprising biodiversity at genetic, species and ecosystem levels, with different compositional (e.g. population size), structural and functional attributes. As the world of living organisms is generally considered in terms of species, the number of species at a place (species richness) is usually taken as an indicator of biodiversity (Groombridge, 1992).

It becomes very hard to have biodiversity assessment due to its varied and complex nature. The biodiversity conservation has been turned out to be an important tool of interacting with the conversion and degradation of ecosystems, which are causing serious impacts on biodiversity. Due to continuous species loss and habitat destruction, the conservation of biodiversity has become very essential during recent times (Wilson, 1988; Kondratyev, 1998).

Bridgewater (1993) depicted two objectives for nature conservation that include sustaining the maximum biodiversity; and maintenance, development and management of ecological infrastructure through protected areas. Sufficient information related to distribution of species and changes in distribution with respect to time, is required to develop conservation strategies. It is very difficult to obtain such information merely on the basis of field assessment and monitoring (Heywood, 1995). A wide range of biodiversity zones are facing risk that lead to ecosystem degradation which in turn makes biodiversity conservation a core issue. Therefore, the preservation of these biodiversity rich zones and their habitats is very important at all levels i.e. local, regional and national levels. The conservation of these zones has become a top priority especially through Convention on Biological Diversity (CBD, 1992).

Directly or indirectly biodiversity has clearly a relationship with the changes that take place in the environment which include changes in land use land cover (LULC), climate and sustainable development (Nagendra *et al.*, 2010). Due to industrialization, urbanization and other anthropogenic activities, humans have caused severe damage to the surrounding ecosystem from the past few decades which in turn makes the survival of biodiversity difficult. Thus, it is indispensable to connect human activities with biodiversity to use resources for the sustenance and preservation of biodiversity.

It has been a revolutionary period from past few decades with respect to accessibility of information, development and application of tools for the information management (Harrison, 1995). For biodiversity assessment, the needs of information are many and different, and the state of knowledge is also insufficient for proper assessment to be made (Heywood, 1997). As a result, better assessment along with sufficient information can be very helpful in understanding the biological diversity and such assessment can also have serious impact for the development of indices and indicators,

which allows the monitoring of changes and trends over time. With the advent of modern technology comprising digital and electronic systems, it becomes very easy for the management of data related to the biodiversity. The data related to species, topography, environment, administrative and socio-economic parameters is available in almost all the formats such as tabular databases, text documents, spatial databases and satellite images. For better conservation of biodiversity, the strategy should incorporate the methods along with proper usage of existing information in a harmonizing manner. With the increasing demands for the assessment and monitoring regarding biological diversity and their status, there should be a diversity information system to utilize useful data expressing and evaluating the existing baseline conditions of environment, identifying the species and habitats at risk, direct land management decisions, and model the output of alternative conservation policies (Davis *et al.*, 1990).

### **Role of geospatial technology in conservation, monitoring and mapping of biodiversity**

The conservation has become an essential approach of dealing with increasing rate of degradation and conversion of different ecosystems, which have led to serious consequences on biodiversity. The geospatial techniques such as remote sensing (RS), the science of procuring information without any physical contact with the target object (Jensen, 2007), has been very useful and cost-effective in the field of ecology, biodiversity and conservation. RS offers a systematic; synoptic view of earth cover at regular time periods; and has been proven to be valuable for this task (Soule and Kohm, 1989, Lubchenco *et al.*, 1991, Roughgarden *et al.*, 1991, Stoms and Estes, 1993, Debinski and Humphrey, 1997, Innes and Koch, 1998). Two groups of RS approaches have been revealed, viz. direct and indirect (Rapport *et al.*, 1998). The former involves observation of individual organisms, species or communities directly, with the help of satellite sensors, such as hyper-spectral and high spatial resolution data (Chambers *et al.*, 2009). The second one is based on parameters such as habitat parameters (composition of species, land cover) using RS data as an alternative for the estimation of species richness, their pattern and ranges (Gibbons *et al.*, 2008). Coupled with GIS, RS can provide information related to landscape history, topography, soil, rainfall, temperature and other climatic conditions, as well as about present day habitat and soil coverage- factors on which the distribution of species depend (Noss, 1996). The RS technique generates extracted information from remotely sensed data at scales ranging from local to global; whereas, GIS is used to store, analyze and visualize spatial data (Foody, 2008). For the proper management and analysis, the data related to environment and ecological systems is collected and stored with the help of GIS (Aspinall, 1995). Relationships between species distribution patterns and geospatial technology can be used to estimate the distribution of species or group of species over larger extent (Debinski and Humphrey, 1997). The GIS plays a crucial role in analyzing, measuring, locating and planning for assessment and monitoring of biodiversity; and is useful in target surveys and monitoring schemes (Marqules and Austin, 1991). Davis *et al.* (1990) reported about comprehensive

national diversity information system, to organize existing data and improve the spatial aspects of the assessment in GIS environment.

For the conservation of biodiversity, geographical information system (GIS) contributes effectively by providing integration of information (i.e. maps and images) in spatial overlays for analysis and interpretation, and viewing. So far as conservation is concerned, the analysis, evaluation and planning linked to biodiversity must be taken into consideration in the context of GIS (Aspinall, 1995). Gillespie *et al.* (2008) reported the development of modeling and measuring biodiversity from space with a prime focus on modeling biodiversity, species and land-cover classifications and conservation planning. Kerr and Ostrovsky (2003) described ecological remote sensing in three main areas- land cover classification, integrated ecosystem measurements and change detection studies. The land cover classification can be used to identify particular habitats and predict the species assemblage and distribution at a large spatial extent (Imam *et al.*, 2009). The integrated ecosystem measurements are very useful in derivation of functions such as leaf area index (LAI) and net primary productivity (NPP) mostly based on the normalized difference *vegetation index* (NDVI) at different spatial scales (Tagesson *et al.*, 2009). The change detection offers near-continuous, long-term assessment of vital ecological parameters for spatio-temporal ecosystem monitoring, such as climate change and habitat loss (Pellikka *et al.*, 2009). Aplin (2005) also reported the significance of applications of remote sensing in ecology, and in terrestrial and marine ecosystem. There are various instruments and techniques based on remote sensing technology which provide valuable information essential for biodiversity conservation.

GIS is considered as an effective tool for mapping the pattern of environmental variations and modeling distributions of a range of species using maps of vegetation types and observations on species distribution (Salem, 2003). Mapping species richness and distribution is a significant feature of land use planning and conservation (Spellerberg, 1991; Miller and Allen, 1994). The mapping of species biodiversity can be very helpful in identifying areas where resource conservation is of prime importance. These areas comprise regions significant for species assemblages and 'hot spots' of high species richness (Cardillo *et al.*, 1999). Biologists emphasize on identifying habitats important to the preservation of species diversity as the present extinction rate of species extinction causes growing concern (Wilson, 1988; Debinski *et al.*, 1999). RS technology can offer information related to many variables useful for inventorying, modeling and monitoring species richness (Stoms and Estes, 1993) in order to identify and conserve regions with high biological importance.

### **Role of RS and GIS in Wildlife Management**

In wildlife management practices, the distribution and protection of wild species of both plants and animals are key factors and for that purpose RS and GIS techniques are very useful especially for analysis, visualization and management of the data. With the

help of GIS technique, it becomes very easy to analyze and map the distribution and movement of wildlife; and their habitat pattern, which in turn avails important information related to management strategies of wildlife (Gibson *et al.*, 2004). As a result of improvements in RS and GIS techniques in past few decades, an increasing trend is being observed so far as the accessibility and efficacy of the techniques in research and management of ecosystem are concerned (Guisan and Zimmermann, 2000).

### **Role of RS and GIS in Agricultural biodiversity**

The term 'Agricultural biodiversity' in a broad range includes all biodiversity components related to food and agriculture, structure and processes of agricultural ecosystems. Agro-bioinformatics is an electronic documentation of different aspects (biographical, ecological and taxonomical) of agricultural and other related issues for the purpose of analysis, exploration and management of agricultural related problems with the help of informatics. It is a multi-dimensional database system where the information related to agriculture is stored in digital form, using geospatial technology. In addition, spatial analysis is also very helpful in knowing the constraints in agriculture biodiversity. The application of multi-spectral and multi-temporal data sets, besides local knowledge and simulation models have been recognized as effective method for identification and monitoring of broad range characteristics of agriculture (Oliver *et al.*, 2010). For the precision of agriculture, the spatial variability in crops is done by identification of variability in crops yield using RS data and GIS approach models (Taylor *et al.*, 1997). For the purpose of crop yield prediction before harvesting, aerial images have been widely used (Senay *et al.*, 1998). For the proper management and monitoring of resources, it has been observed that analysis of vegetation (such as crop vigor analysis) and change detection in its pattern are very important (Thiam and Eastman 1999). For the effective monitoring of crop cover, yield, health, moisture content of soil, nitrogen stress; the bands of visible (red, green, blue) and near-infrared (NIR) regions of the spectrum have been widely used (Magri *et al.*, 2005). A number of spectral indices have been effectively applicable in estimation of crop cover, distribution, yield, etc. Such indices include: (a) soil adjusted *vegetation index* (SAVI), based on red and NIR based on red and near-infrared (NIR) spectral bands (b) perpendicular *vegetation index* (PVI), based on red and NIR spectral bands (c) normalized difference *vegetation index* (NDVI), (d) green *vegetation index* (GVI), based on green and NIR.

### **Satellite data for biodiversity conservation**

**High spatial** resolution is generally less than 10m and ranges from 0.5-10m in the commercial field for environmental research purposes. QuickBird, IKONOS, OrbView-3 and SPOT-5 are some examples of normally used high spatial resolution data (Toutin, 2009). The high spatial resolution image significantly increases the accuracy of identification and characterization of small objects at spatial scales (Gillespie *et al.*, 2008), previously available only from airborne platforms (Turner, 2003). The high spatial

resolution has also been found to be feasible and applicable in direct identification of certain species and their assemblages (Turner, 2003). The image can also be used to assess the accuracy of RS precuts obtained from moderate or coarse spatial resolution images. For example, Wabnitz *et al.* (2008) reported such assessment of Landsat-based large-scale sea grass mapping against patterns detectable with IKONOS images. Additionally, for the quantification and evaluation of spatial structure of critical habitats and its influence on endemic species, IKONOS images play an important role (Perotto-Baldivieso *et al.*, 2009).

**Hyperspectral** data is capable of collecting spectral information across a continuous spectrum usually with 100 or more contiguous spectral bands. In order to collect the information regarding critical plant properties such as water content, leaf pigment and chemical composition; differentiation and accurate identification among tree species, the hyperspectral data has been found to be very effective and applicable (Nagendra and Rocchini, 2008). The Hyperion hyper-spectral imagery is very effective for information related to ecology and biodiversity in forest, agriculture (Bannari *et al.*, 2008), grassland (Guerschman *et al.*, 2009) and vegetation (Walsh *et al.*, 2008), coastal environment, fragmented ecosystem and ecosystem succession (Lee *et al.*, 2007), *etc.* For example, classification of vegetation types and densities in support of the wildfire management, i. e., fire propagation simulation models and fire risk assessment are based on a Hyperion classification map with 93% accuracy (Keramitsoglou *et al.*, 2008). Using hyperspectral imagery from EO-1 Hyperion, Foster *et al.* (2008) reported the mapping of low-lying woody lianas critical for tropical forest dynamics due to their strong influence on biodiversity, regeneration of forest and disturbance ecology.

**Thermal Infra-red (TIR)** satellite data detects the energy emitted from the surface of earth in the thermal infrared (TIR, 3 to 15 $\mu$ m) band of the spectrum, which can be radiated by all ground features above absolute zero. Theoretically, the TIR sensor measures the surface temperature and thermal properties of target features on the ground surface (CSRS, 2007), which are indispensable for developing better models and appreciable understanding of land-surface energy balance interactions (Quattrochi and Luvall, 2009). TIR remote sensing is very important for observing earth surface characteristics, and also very significant in research related to analysis of biophysical earth processes such as measurement of land surface processes and landscape characterization (Quattrochi and Luvall, 2009). TIR remote sensing is significantly capable of exploring the principles of ecological patterns of structure and function due to the improvement of ecological thermodynamics (Quattrochi and Luvall, 2009). A disturbance detection index using Moderate Resolution Imaging Spectro-radiometer (MODIS) 16-day Enhanced *Vegetation Index* (EVI) and 8-day Land Surface Temperature (LST) have been effectively applied to detect events such as irrigated vegetation, wildfire, precipitation variability, and the progressive revival of disturbed landscapes (Mildrexler *et al.*, 2007). Some other considerable applicability of TIR satellite data is to evaluate soil moisture, evaporation and evapo-transpiration. The well-known recognized

sensors with TIR bands include the Enhanced Thematic Mapper Plus(ETM+) and Landsat Thematic Mapper (TM); and Advanced Very High Resolution Radiometer (AVHRR) onboard the Polar Orbiting Environmental Satellites (POES), Reflection Radiometer (ASTER) on the Terra Earth observing satellite platform and the Advanced Spaceborne Thermal Emission (Quattrochi and Luvall, 2009).

**Light Detection and Ranging (LIDAR)** comprising non-scanning and scanning systems, is based on the fact that a laser is used to illuminate a target object and a photodiode for receiving the backscatter radiation (Lim *et al.*, 2003; Stehman and Foody, 2009). Turner *et al.* (2003) reported about the airborne LIDAR remote sensing technique for the study of biodiversity and its conservation. Lim *et al.* (2003) revealed the significance and applicability of LIDAR within forest ecosystem and its structure (vertical information), e.g., tree height and canopy, biomass, and volume. It has also been found that species distribution models used to quantify vegetation structure have been improved through LIDAR remote sensing (Goetz *et al.*, 2007).

### **Remote Sensing Techniques**

**Vegetation Indices (VIs)** comprising biophysical indices and biochemical indices (He *et al.*, 2006), are dimensionless, indicating radiometric relative abundance and activity of green vegetation, including chlorophyll content, percentage green cover, leaf area index (LAI), absorbed photo-synthetically active radiation (APAR) and green biomass (Jensen, 2007). VIs may change considerably with vegetation density (Ji and Peters, 2007). Hence, a statistical sensitivity function was developed and put forward to assess the overall relationship between VIs and biophysical parameters (Ji and Peters, 2007). The applications of VI such as *Normalized Difference Vegetation Index (NDVI)* have been reported in many studies related to conservation of ecology and biodiversity (Kerr and Ostrovsky, 2003; Duro *et al.*, 2007; Gillespie *et al.*, 2008). Such VIs are very simple to understand and execute, valuable to track temporal characteristics and easy to calculate. Jensen (2007) reported the advantage of using VI in normalizing or modeling external effects, enhancing sensitivity to biophysical parameters, normalizing internal effects, and assisting validation effort and quality control. Biophysical indices include those that are used to relate with bio-physical characteristics of vegetation such as structure and condition, can be grouped into soil line-related indices (e.g., *Soil Adjusted Vegetation Index (SAVI)* [Huete and Liu, 1994]), simple ratio-based indices (e.g., *Simple Ratio* [Schlerf *et al.*, 2005]) and chlorophyll-corrected indices [*Transformed Absorption in Reflectance Index/Optimized Soil Adjusted Vegetation Index- TCARI/OSAVI*] (Haboudane *et al.*, 2004). The Biochemical indices are generally used to estimate biochemical properties of vegetation such as *Cellulose Absorption Index (CAI)* and *Lignin-Cellulose Absorption Index (LCAI)* (Serbin *et al.*, 2009). The application of modified soil adjusted *vegetation index (MSAVI)* has been studied in tropical forests in the Amazonian state of MatoGrosso (Brazil) for mapping canopy fractional cover using linear mixture model (Wang *et al.*, 2005). Haboudane *et al.* (2004) revealed that VIs such

as NDVI, SAVI, Triangular *Vegetation Index* (TVI) and Modified Chlorophyll Absorption Ratio Index (MCARI) were either responsive to chlorophyll concentration changes or at high LAI levels affected by saturation, whereas modified chlorophyll absorption ratio index (MCARI2) and modified triangular *vegetation index* (MTVI2) are confirmed to be the best predictors of green LAI. In addition, some other suitable VIs includes Litter-corrected Adjusted Transformed Soil Adjusted *Vegetation Index* (L-ATSAVI) (He *et al.*, 2006), Wide Dynamic Range Vegetation Index (WDRVI) (Gitelson, 2004) and *Vegetation Index* based on a Universal Pattern Decomposition (VIUPD) (Zhang *et al.*, 2007).

## Conclusion

The present study revealed the significance, applications and capabilities of different satellite data such as high spatial resolution and hyper-spectral data; and the techniques of geospatial technology for the conservation, monitoring and mapping of biodiversity. Biodiversity is the natural variability within and among living organisms and the ecological systems in which they occur, in addition to the different interactions between organisms with the physical environment. With the increasing rate of degradation and conversion of various ecosystems which lead to serious impacts on biodiversity, it becomes very important to have a reliable information system and tools for the conservation and management of biodiversity and other natural resources. Due to the large scale industrialization, urbanization and other activities; the survival of different species in their natural habitat is becoming very difficult. With the advent of modern technology it becomes very easy for the management of data related to biodiversity with the help of digital and electronic technology. The data is available in almost all formats in the form of tabular databases, text documents, spatial databases, and satellite imagery; related to species, topography, environmental, administrative and socio-economic parameters. For better conservation of biodiversity, the strategy should incorporate the methods along with proper usage of existing information in harmonizing manner. The geospatial technology (RS and GIS) can provide information about landscape history, topography, soil, rainfall, temperature and other climatic conditions, as well as about present day habitat and soil coverage- factors on which the distribution of species depend (Noss, 1996). Remote sensing plays an increasing role in Ecology, Biology and Conservation research, especially regarding large spatial and/or long-term temporal scales. Remote sensing and GIS are being used more widely in governance and planning at national, regional and local scale. Remote sensing is indispensable for ecological and conservation biological applications and plays a key role in characterizing and mapping habitats within and surrounding protected areas and ultimately assisting their management. RS provides the means of measuring the characteristics of habitats across broad areas and detecting environmental changes that occur as a result of human or natural processes. The RS systems provide opportunities to develop and apply new measurements of ecosystem function across landscapes, regions and continents. The GIS plays a crucial role in analyzing, measuring, locating and planning for assessment and



monitoring of biodiversity. Further, the spatial analysis and modeling capabilities of GIS render them useful in mapping and modeling habitats, assessing degree of biodiversity and conservation, planning and mapping of various eco-regions. The dynamic nature of natural ecosystems requires the widespread and consistent use of satellite based remote sensors and GIS tools for effective management and monitoring.

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