Cloud Publications
International Journal of Advanced Earth Science and Engineering
2016, Volume 5, Issue 1, pp. 375-389, Article ID Sci-429
ISSN: 2320 – 3609

Short Communications | Open Access

Satellite Remote Sensing Technologies for Biodiversity Monitoring and Its Conservation

Khare S. and Ghosh S.K.

Geomatics Engineering Division, IIT Roorkee, Uttarakhand, India

Publication Date: 6 April 2016

Article Link: http://scientific.cloud-journals.com/index.php/IJAESE/article/view/Sci-429

Abstract Conservation of biodiversity is an essential issue due to increasing climate change and anthropological factors. Various rich biodiversity zones are greatly threatened and degrading with an alarming rate therefore it's required to safeguard these zones and their habitats at regional and local levels. In order to implement significant conservation schemes, exhaustive information on the distribution of species on a temporal basis are required. Recently, remote sensing and biodiversity communities have started coordinating their research ideas, problems and their solutions on a single platform. The likelihood of such type of co-operations has been significantly strengthened with the advancements in satellite remote sensing technology in last decade. Thus, this advancement has empowered the interdisciplinary research at regional and local scale with high temporal resolution to provide information about changes in species distribution, habitat degradation and fine-scale disturbances of forests. This paper presents the smart satellite remote sensing technologies, which can be very useful in retrieving relevant information about biodiversity present on earth surface. This paper emphasises on various advance remote sensing imageries and their utility in deriving relevant parameters and drivers required for biodiversity monitoring. This review paper incorporates the categorization of all important and advanced sensors with respect to the essential biodiversity variables required for its monitoring and conservation.
Keywords *Biodiversity; Satellite Remote Sensing; Conservation*

1. Introduction

In general, biological diversity, or in short, biodiversity has been defined by the leading Convention on Biological Diversity (CBD) 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". This includes diversity within species, between species and of ecosystems. Biodiversity may be divided into following components as shown in Figure 1.

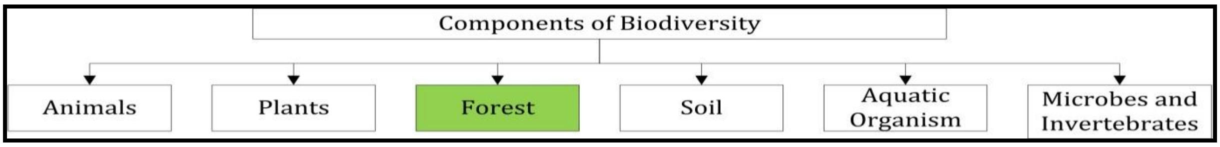

Figure 1: *Components of Biodiversity*

Conservation of biodiversity is proximately related to global environmental changes and globalisation issues, such as land use and land cover changes, climate change, and sustainable developments [45]. During the last century, human beings have caused changes to ecosystems more rapidly than in any comparable period in history due to rapid industrialization. As a result, biodiversity and their ecosystems are declining rapidly. This loss is further augmented by the lack of knowledge of biodiversity, especially amongst people with close relationship with the ecosystem. The global challenges relating to biodiversity include inventories to determine the magnitude and location of biodiversity existence and its change dynamics. At present, it is important to link biodiversity and human use of land in order to sustain biodiversity.

Remote sensing is a science of gathering information without coming in contact with earth [29], has wiped the fields of Ecology, Biodiversity and Conservation (EBC). Remote sensing has ability to provide consistent data of earth at various scales from global to local. In addition to this, remote sensing does not require labour and it also save time when compared to ground-based observations. The potential of synergies between remote sensing and biodiversity based research has been acknowledged by practitioners, researchers and data providers to better understand how remote sensing based studies can be utilised in bio diversity monitoring and its conservation [14, 20 & 34].

In this paper, smart technologies of satellite remote sensing have been highlighted. Satellite remote sensing incorporates three different prospects such as; satellite data, satellite data handling algorithms and software. In general satellite data can be obtained in the form of images, which includes low, medium and high resolution images. These satellite images contain variety of information of earth surface and level of details varies at different types of resolutions. To handle the complexity of information associated with these datasets various algorithms have been developed by researchers. These algorithms include statistical, probabilistic, artificial neural network and fuzzy based methods. Third prospect comprises of various types of commercial and open source softwares which take into consideration the algorithm and data handling. This paper presents the first prospect of satellite remote sensing i.e. different types of satellite remote sensing datasets and their utilities in biodiversity monitoring.

With this introduction, the aim is to highlight the importance of interdisciplinary perspective on satellite remote sensing and biodiversity monitoring and its conservation. This paper focuses on importance of space borne remote sensing in the field of biodiversity research from the angle of remote sensing specialists. It attempts to identify the specific remote sensing data set which may be applied to biodiversity monitoring.

2. Relevance of Remote Sensing Over Conventional Methods to Monitor Biodiversity

Biodiversity monitoring with traditional *in situ* methods normally requires as much effort as composing the initial inventory, as repeated measurements should be based on the same sampling methods and designs to explicitly detect changes. Some optimisation may be possible though using modeling and mathematical analysis [52]. Due to the inaccessibility of some habitats within a study region such as thick mangrove, steep slopes and practical considerations such as proximity to roads or observer populations may affect the inclusiveness of results obtained with traditional in situ methods.

Remote sensing cannot overcome traditional approaches for composing initial inventories of species, except in case of very large species identifiable on space-borne or airborne images. However, remote sensing is air replaceable large scale biodiversity monitoring tool at the level above species. If integrated with quality ground data and it can give more accurate results as compared to traditional methods. Remote sensing can be very advantageous for both planning surveys as well as monitoring biodiversity changes thereafter. To carry out repeated measurements under spatio-temporal conditions similar to the initial inventory, remote sensing is valuable tool in identifying when and where to monitor [7, 12, 31 & 49].

3. Remote Sensing Data Types and Their Applicability in Biodiversity

Remote sensing measures the electromagnetic waves reflected or emitted by distant objects present on Earth surface. Basically two types of sensors are attached with satellites: active or passive. The type of energy source required for both the sensors creates the basic difference between active sensors and passive sensors. Passive sensors, also known as optic sensors use Sun as an energy source and records reflected radiations of Sun from the Earth's surface. Multispectral scanners and Photographic cameras are passive sensors often used in satellite remote sensing Active sensors have their own energy source. They emit a signal that travels through the atmosphere, reflects on the Earth's surface and returns to the sensor, which measures the signal's travel time and strength. Synthetic Aperture Radar (SAR) is an example of an active sensor. Since it use signals with long-wavelength therefore, it can penetrate clouds or bad weather conditions [28].

3.1. Advanced Datasets in Remote Sensing of EBC

At present, remote sensing can provide data in different forms such as, hyperspectral, high spatial resolution, LIDAR and thermal infrared sensors. In order to avoid confusion between hyperspectral and high spatial resolution sensors, focus mainly given to medium spatial resolution hyperspectral sensors, such as Hyperion with 30m spatial resolution. Since radar sensors have their applications mostly in ice and snow, geology and agricultural domains therefore they have not selected in this discussion. Moreover, emphasis has been given to high spatial resolution sensors and their applications in biodiversity monitoring.

3.1.1. *High Spatial Resolution*

Normally in remote sensing high spatial resolution are also called as fine spatial resolution. The resolution is less than 10 m, and it ranges from 0.5 to 10 m in the commercial domain for environmental studies. Worldview-2 (WV-2), QuickBird, OrbView-3, IKONOS, and SPOT-5 (Satellite Pour l'Observation de la Terre-5) are the commonly used sensors. The advantage of high spatial resolution imagery is that it effectively increases the accuracy of characterization and identification of small objects at fine scales [20 & 59]. Gillespie et al. (2008) provided various examples for identification of plant species accurately based on the high spatial resolution imagery. Turner et al. (2003) revealed that it is viable and applicable to directly identify certain species and species assemblages at fine scale. In addition to this, fine scale imagery can be employed for the accuracy assessment of remote sensing derived from coarse or moderate spatial resolution imagery.

Wabnitz et al. (2008) has done the accuracy assessment for Landsat imagery of large-scale sea-grass mapping against patterns detectable with the help of fine resolution IKONOS images. In addition to this, security restrictions and data coverage is still a considerable constraint before easily acquiring fine resolution satellite data [46]. In addition to this, it is also observed out that fine spatial resolution imageries are still under-utilized and potential resources for biodiversity based research.

Harborne et al. (2008) highlighted intra-habitat variability in coral-reef fish by mapping heterogeneity among habitats. Fine resolution satellite data have opened the new gates for the development of species-level distribution maps along with structural information on canopy diameters, dominance, and distribution of age-class [54]. Moreover, some recent studies have revealed that the spectral bands of WV-2 ranging from 400 to 1040 nm are suitable for plant health analysis and it can also discriminate among various types of tree species [32 & 48]. Thus, WV-2 imagery may provide plenty of detailed information on a regular interval for various applications such as environmental, agricultural survey, ecological, geological, urban planning, and other areas.

Figure 2 is depicting the high spatial resolution satellite images of various sensors. Further, table 1 is showing the spatial and spectral information of various high spatial resolution sensors. The level of details present in the imageries and information associated with each object present on earth surface varies as the spatial resolution of sensors changes. Since these new generation sensors are playing a crucial role in biodiversity monitoring and its conservation by providing immense information of earth surface. Thus, these sensors are opening new dimensions in the field of biodiversity monitoring as discussed above.

Table 1: *Satellite Sensors with Spatial Resolution and Spectral Information* [66]

Sensor Name	Spatial Resolution		Spectral Bands		Area Coverage
	PAN	MS	PAN	MS	
Geoeye-1	0.46 m	1.84 m	1 band	4 bands	300 km ×50 km (per strip)
Rapideye	NA	5 m	NA	5 bands	77 km × 1,500 km (per strip)
IKONOS-2	0.82 m	3.2 m	1 band	4 bands	4700 km square (per strip)
Quickbird	0.65 m	2.62 m	1 band	4 bands	18 km × 360 km (per strip)
WorldView-2	0.46 m	1.84 m	1 band	8 bands	138 km × 112 km (per strip)
Landsat-8	15 m	30 m	1 band	10 bands	185 km× 180 km and can collect 500 scenes per day

PAN – Panchromatic, MS – Multispectral, NA – Not Applicable

Figure 2: *High Spatial Resolution Satellite Images* [66]

3.1.2. *Hyperspectral Data*

Hyperspectral data have the capability to collect plenty of spectral information across a continuous spectrum normally with 100 or more contiguous spectral bands. It is somewhat dissimilar from multispectral sensors which incorporate relatively few discrete bands [46]. Due to the availability of hundreds of spectral bands with narrower width such as 10-20 nm spectral bandwidths offer new aspects to detect fine differences between objects of interest (Figure 3). The best instance is to distinguish fine-scale; species-specific land covers such as soil type's or vegetation categories which make incredible contribution to the biodiversity based studies. In addition to this, it was also found out that hyperspectral data can also be successfully applied in recording information of important plant properties such as water content, leaf pigment and chemical composition. Thus, it is possible to discriminate tree species in landscapes, and accurately identification between different species [59]. Similar to the case with fines spatial resolution imagery, hyperspectral imagery is also under-utilized resource and due to its high cost problem, it is putting it out of research for ecologists predominantly those in developing countries who keenly required the data [20 & 59].

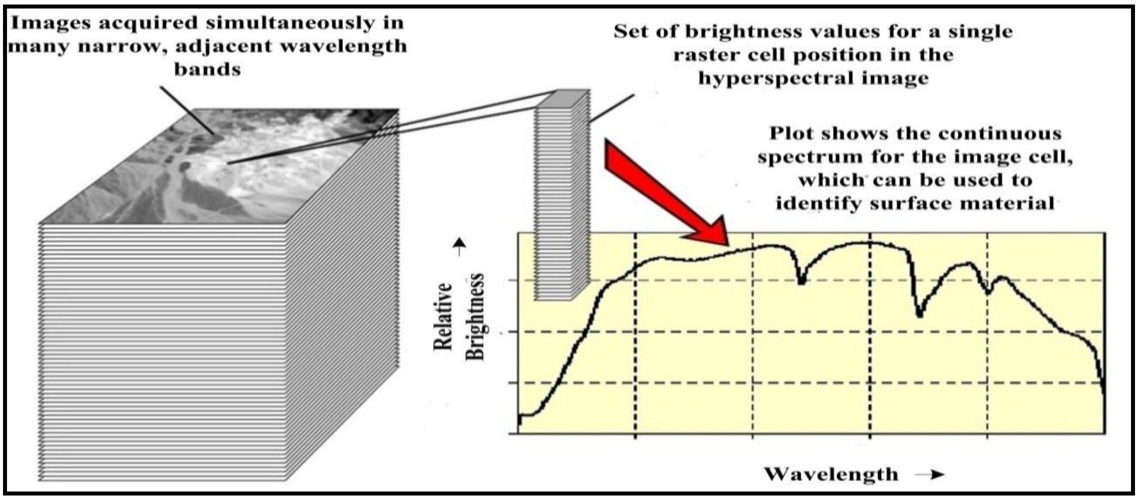

Figure 3: *Basic Concept of Hyperspectral Imaging* [46]

List of hyperspectral sensors is shown in Table 2:

Table 2: *List of Hyperspectral Sensors*

Sensor	Agency
Hyperion Sensor EO-1 (Earth Observing-1)	NASA (National Aeronautics and Space Administration)
CHRIS (Compact High Resolution Imaging Spectrometer)	European Space Agency
PROBA (Project for On-Board Autonomy)	US Air Force Research Lab
FTHSI (Fourier Transform Hyperspectral Imager)	US Air Force Research Lab

Among all these sensors, most commonly used and first civilian sensor is Hyperion, which is controlled by the EROS (Earth Resources Observation and Science) at a fairly low cost to the general public [53].

Hyperion hyperspectral imageries include applications in various fields such as forest biodiversity and ecology [21], vegetation, agriculture [3], fragmented ecosystem and coastal environment [37]. Recently in a Belgian heath land Natura 2000 landscape it was highlighted by the researchers that the potential and ability of airborne hyperspectral line-scanner radiometer (AHS-160) imagery was outstanding in mapping habitat extent and quality. Due to availability of 63 visual and near-infrared bands with a spatial resolution of 2.4 m, it became possible to map habitat extent, although the contrast was relatively low between heath land habitat types [22].

Hyperspectral imagery has numerous applications such as assessment of habitat degradation and stress [29]. Due to the availability of larger and narrower bands, it can also detect changes in structural and chemical traits. In addition to this, it can also detect changes in the level of nitrogen, phosphorus and other foliage compounds that could be linked with discrepancy in environmental factors such as quality of soil [58]. Further, comparison was also done between the field assessments and potential of airborne hyperspectral imagery to deliver information related to conservation status of two Natura 2000 heath land areas [56]. It was found that field based assessments estimated 43% of the variation in fine-scale indicators about habitat condition. While on the other side information obtained from remote sensing was less as compared to field based assessments and it was up to 39% only. In other studies such as assessment of invasive species, it was found that hyperspectral images are more useful for the mapping of individual species, whenever there is a low density scattered distribution of invader species [24].

3.1.3. *Active Remote Sensing Sensors*

Passive remote sensing data suffers cloud cover and haze related problems, however active remote sensing is not affected by atmospheric conditions. SAR is being used, with a number of new satellites such as, Terra SAR/Tandem-X. They are providing ample of opportunities for landscape monitoring at very high spatial resolution [20]. In particular, both SAR and LiDAR technologies have potential to gather information in different formats and it would be very useful for estimating above ground biomass and also the structure such as height and cover of woody vegetation. Further it can also be correlated to forest condition and biodiversity related issues. However, the usage of SAR and LIDAR data has been somewhat restricted in developing countries due to the technological and security challenges associated with them [5 & 26].

Active remote sensing data provides complementary information than passive sensors [57]. SAR data could be a best alternative to optical data for those areas which are more prone to cloud cover problems. The most important applications of Radar and also LiDAR is that it can provide three dimensional structure of any area which would be very useful in discrimination of different habitat types [35], which can be related to succession, age and species composition [9, 42 & 57]. RADARSAT-2 and ALOS PALSAR have shown immense potential for mapping wildlife habitat, especially when integrated with optical data through data fusion [64]. In brief, ALOS PALSAR L-band allows detection of non-forest and forest and retrieval of above ground biomass [50].

With its ability to penetrate below the top vegetation canopy, can be very useful for monitoring habitat degradation. An integration of SAR and Landsat data was used to differentiate among Amazonian forest patches during different stages of re-growth [37]. In a similar study, it was found that the Scots Pine and Norway spruce of Finland were classified to an accuracy of 83% and 90% respectively, on the other side birch trees were mixed with the other species [60].

3.1.4. *High Resolution Digital Elevation Model (DEM)*

Since forest biological parameters or attributes such as canopy density, tree height, canopy diameter and composition of species plays crucial role in biodiversity research. Thus, determination of these attributes is very important as they are required by forest planners, managers and policy makers for an estimation of forest conditions, volumes and biomass. At national and global levels, this information is required to estimate the existing carbon stock in the Earth's system, which would be very useful in deriving models for climate change studies, changes in biogeochemical cycling, and changes in wildlife habitats [18]. Traditionally in India we take field based survey of forest stock inventory which are tedious, costly, time-consuming and lack uniformity and accuracy [16 & 43].

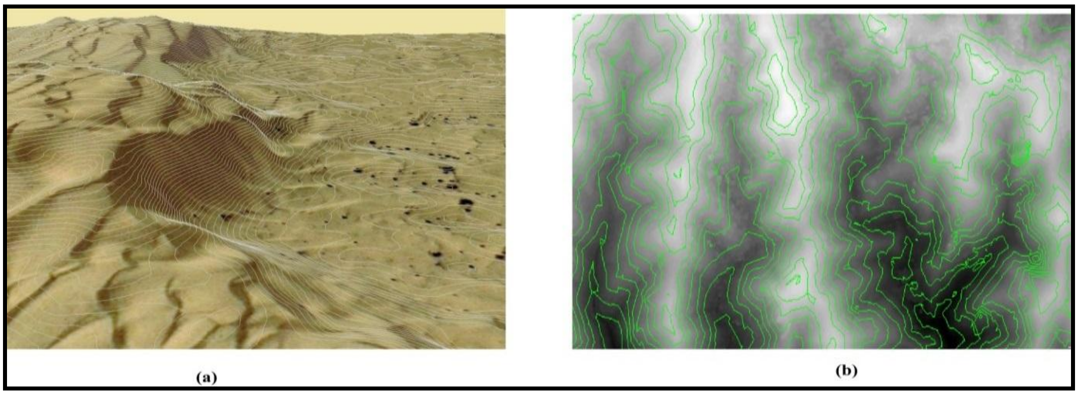

Figure 4: *Example Images of Extracted DEMs (a) 1 m DEM from stereo IKONOS Satellite Image Data (b) 10 m DEM Extracted from Stereo Cartosat-1 Satellite Image Data* [66]

Cartosat-1 with 2.5 m PAN stereo and Cartosat-2 with less than 1 m PAN stereo capability have opened up new gateways of applications in forest biodiversity studies. Due to the availability of fine resolution stereo data from satellites such as SPOT (Systeme Pour l' Observation de la Terre), IRS-1C/1D, IKONOS and Cartosat, it is becoming possible to create the fine quality DEMs. In addition to this, terrain variables required for many applications in natural resources management, including forest biodiversity studies [6 & 47]. Figure 4 depicts the extracted DEM from IKONOS and Cartosat satellite data. Various topographic variables such as height, slope, aspect and morphology can be derived from these DEMs, which would provide relevant information for biodiversity monitoring.

4. Monitoring Biodiversity Using Satellite Remote Sensing

Before proceeding to the various applications of satellite remote sensing in biodiversity research, it is essential to understand the possible approaches of remote sensing technologies to monitor biodiversity. Since, there are various components of biodiversity, thus remote sensing applications may vary as per the respective component. Suitability of approach depends upon the kind of environment in which biodiversity is to be monitored.

4.1. Advancement in Remote Sensing Methods for Biodiversity Monitoring

Recently, there is advancement in sensor technologies and digital image processing techniques, along with growing spatial detail. This led to challenge the remote sensing community to find out new methods of exploiting information present in these fine images more intelligently. Object Based Image Analysis (OBIA) is becoming a new paradigm in the field of remote sensing due to its ability to handle complex information associated with new generation satellite datasets mentioned above. This paper highlights the basic methodology of OBIA and its applicability in the field of biodiversity monitoring.

With the wide availability of fine resolution data, pixel-based classification algorithms seems to be not ideal to extract information desired from the data revealing high frequency components with high contrast and horizontal layover of objects [28]. Since, last several years, pixel based classification approaches are in vogue for classification of coarse and medium spatial resolution remote sensing data. However, the traditional pixel based classification approaches have limitations in incorporating the spectral, geometric, and contextual attributes such as shape, size, texture, shadow of land use features such as roads, buildings, trees etc., in the classification process [62]. Inclusion of these attributes may result in production of quality land use maps from high resolution data. This has given impetus to the development of OBIA recently.

OBIA is relatively a new concept applied for the extraction of meaningful objects of similar attributes from remote sensing images via a segmentation process. The classes involve a connection to nearby objects such as super and sub-objects in hierarchical order. Spatial relationship such as 'nearest neighbour' or statistical similarities can be applied on segmented image for assigning class. At its rudimentary level, OBIA involves image segmentation, attribute selection, classification and the ability to link individual objects in hierarchy. The basic flowchart is shown in figure 5. Basically, OBIA is based on the assumption that image objects provide a more appropriate scale to map environmental features and allows features with significant variations in their spectral reflectance signature to be mapped at specific scales [4].

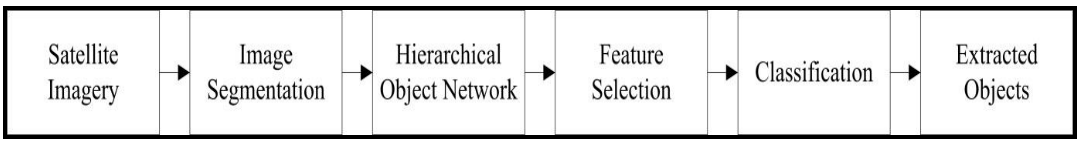

Figure 5: *Basic Flow Chart of OBIA Methodology*

A variety of studies have been carried using object based classification into the science of EBC. In a similar study it was proposed that object based classification may traverse the possible Landsat-gap on applications such as landscape pattern analysis or ecological models [64]. Moreover, biodiversity in an urban context in Bangalore was assessed and different challenges were found out in utilizing very high resolution GeoEye image for mapping of tree species and density estimation in human influenced urban areas. Here six different tree species were mapped using pixel-based and object based approaches and final comparison has been carried between the two approaches [1]. It is found that OBIA appears to have high potential over pixel-based approaches for monitoring changes in tree species distribution and tree felling in this highly data-poor, dynamic and fast developing city, which urgently requires better information on tree distribution for monitoring and management.

4.2. Application of Satellite Remote Sensing in the Field of Biodiversity Monitoring

Degradation and loss of habitat along with invasion of alien species are among the potential threats to biodiversity. Landsat imagery was mostly used to detect and map anthropogenic disturbances in desert environments and focus was also given to oil exploration in the Sahara in one of the case study [13]. In a similar study it was examined that the projected and current regional distributions of an invasive species in the United States, Ailanthus altissima, integrating ground-based measurements from the United States Forest Service's Forest Inventory and Analysis program with new data products from NASA's Terrestrial Observation and Prediction System [8]. Essential biodiversity variables (EBV) help in prioritizing by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, complementary to one another and to other environmental change observation initiatives. Table 3 illustrates the relationship of EBVs with satellite images. Table 4 highlights the important research work carried out by remote sensing analysts in the field of biodiversity monitoring.

Table 3: *Relationship among Essential Bio-Diversity Variables & Remote Sensing Measurement Scales* [27& 63]

EBV (Ecosystem Structure)	Spatial Resolution satellite imagery with type of measurement scales (including available remote sensing sensors)	Relevance and related information for biodiversity
Temporal phenology metrics	Low/coarser spatial resolution (Global Scale) (MODIS, AVHRR etc.)	Phenology types, Forest / Non Forest, Deforestation and Biomass burning.
Habitat Structure, Ecosystem extent and fragmentation	Medium spatial resolution (Regional Scale) (Landsat, IRS, SPOT etc.)	Forest type distribution and agricultural expansion.
Habitat types and structures, and Ecosystem composition by functional type	High spatial resolution (Local scale) (IKONOS, QuickBird, Rapid Eye historic GeoEye, WorldView-2 etc.)	Species-level distribution, canopy diameters, stand-level analysis, individual tree detection, to differentiate species at a finer scale.
Habitat types and structures	Active remote sensing data	Habitat degradation monitoring by generation of 3D structures.

Table 4: *Applications of Remote Sensing in Biodiversity Monitoring*

Issues addressed	Data used	Focusing Area
1) Land-use and land-cover mapping and monitoring	IRS and Landsat	1) Landscape and regional dynamics of canopy damage in Eastern Amazon forest [2] 2) LULC identification in Nubra Valley [30] 3) Estimated the extent of forest habitat and loss over the last 20 years within and surrounding 198 of the most highly protected areas [10] 4) Bio-resource conservation study in Western Himalayas [36]
2) Biodiversity characterization and assessment	IRS, IKONOS and Landsat	1) Measured the structure and composition of tropical dry forests [15] 2) Predicted woody-plant species richness in tropical dry forests of South Florida, USA [19] 3) Mapped the species richness and composition of tropical forests [17] 4) Investigation of tree diversity mapping in the Hyrcanian forests of Iran [44] 5) Assessed the plant diversity in a dry tropical forest of central India [25]
3) Forest degradation and Species invasion	IRS, Landsat, QuickBird, IKONOS, Worldview-II	1) Forest management and land use/cover changes in the mid elevation zone of Central Himalaya, India [39] 2) QuickBird high resolution (2.8 m) satellite imagery was used to distinguish giant reed invasion along Rio Grande in southwest Texas [40] 3) Quickbird Satellite to estimate the flowering population of *Tabebuia guayacan* trees at Barro Colorado Island (BCI), in Panama [51] 4) Impact of anthropogenic pressure on forest cover has been analysed using satellite data and field observations [55]

5. Summary and Conclusion

Based on the above studies, it is now possible to use smart technologies such as satellite data, computing algorithms and techniques to analyse complex and difficult phenomenon such as biodiversity monitoring. Table 5 gives a summary of the different types of remote sensing data that is useful in biodiversity monitoring. Based on the type of application, it is possible to now select the appropriate satellite dataset in order to reach to possible monitoring scenarios.

On the basis of above discussions following conclusion can be drawn.

i) Satellite remote sensing offers smart solutions for biodiversity monitoring and to prepare conservation strategies with less effort.
ii) Due to the availability of multi-date, multi-resolution, multi-sensor datasets, it has become possible to acquire huge details of earth surface without making tedious field visit.
iii) Since high spatial resolution datasets can acquire very fine details over small areas at a regular interval of time. Thus, this information will provide basis for regional scale monitoring of biodiversity.
iv) This review primarily highlights the role that remote sensing can play in assisting environmentalists to characterize and map biologically rich zones, generating information on changes in biodiversity, alteration and distribution in species diversity.

Table 5: *Summary of Active and Passive Remote Sensing Data Useful for Biodiversity Monitoring*

Sensor	Biodiversity Monitoring
Coarse Spatial Resolution (MODIS, AVHRR)	Forest / Non Forest, Biomass burning studies at global scale.
Medium spatial resolution (Landsat, IRS, SPOT)	Indicators of overall species richness and diversity at regional scales, forest type distribution and agricultural expansion.
High temporal resolution data (Multi season data or images corresponding to specific seasons)	Information on invasion species and other species of interest (e.g. using images acquired corresponding to critical phonological stages of flowering or leaf senescence.

Very high spatial resolution (IKONOS, QuickBird, Geoeye, WorldVeiw-2)	Indicators of overall species richness and diversity, identification of fine scale degradation in forests, fine scale monitoring of urban sprawl, Species-level distribution, canopy diameters, stand-level analysis, individual tree detection.
Hyperspectral (ASTER, HyMap, AVIS-2, AHS-160)	Differentiation of plant communities that are spectrally similar, mapping top canopy tree species or genus level and identification of invasive species, relating heterogeneities to species richness and diversity.
Active Remote sensing Data (SAR, LIDAR)	Floral and Faunal diversity in habitats (e.g. forests) with complex three dimensional structures.

References

[1] Agarwal, S., Vailshery, L.S., Jaganmohan, M., and Nagendra, H. *Mapping Urban Tree Species Using Very High Resolution Satellite Imagery: Comparing Pixel-Based and Object-Based Approaches.* ISPRS International Journal of Geo-Information. 2013. 2 (1) 220-236.

[2] Asner, G.P., Keller, M., Pereira, Jr, R., Zweede, J.C., and Silva, J.N. *Canopy Damage and Recovery after Selective Logging in Amazonia: Field and Satellite Studies.* Ecological Applications. 2004. 14 (sp4) 280-298.

[3] Bannari, A., Khurshid, K.S., Staenz, K., and Schwarz J. *Potential of Hyperion EO-1 Hyperspectral Data for Wheat Crop Chlorophyll Content Estimation.* Canadian Journal of Remote Sensing. 2008. 34 (sup1) S139-S157.

[4] Blaschke, T. *Object Based Image Analysis for Remote Sensing.* ISPRS Journal of Photogrammetry and Remote Sensing. 2010. 65 (1) 2-16.

[5] Boyd, D.S., Phipps, P.C., Foody, G.M., and Walsh, R.P.D. *Exploring the Utility of NOAA AVHRR Middle Infrared Reflectance to Monitor the Impacts of ENSO-Induced Drought Stress on Sabah Rainforests.* International Journal of Remote Sensing. 2002. 23 (23) 5141-5147.

[6] Carleer, A., and Wolff, E. *Exploitation of Very High Resolution Satellite Data for Tree Species Identification.* Photogrammetric Engineering & Remote Sensing. 2004. 70 (1) 135-140.

[7] Chawla, A., Yadav, P.K., Uniyal, S.K., Kumar, A., Vats, S.K., Kumar, S., and Ahuja, P.S. *Long-Term Ecological and Biodiversity Monitoring in the Western Himalaya Using Satellite Remote Sensing.* Current Science (Bangalore). 2012. 102 (8) 1143-1156.

[8] Clark, J., Wang, Y., and August, P.V. *Assessing Current and Projected Suitable Habitats for Tree-of-Heaven Along the Appalachian Trail.* Philosophical Transactions of the Royal Society B: Biological Sciences. 2014. 369 (1643) 20130192.

[9] Costa, B.M., Battista, T.A. and Pittman, S.J. *Comparative Evaluation of Airborne Lidar and Ship-Based Multi-Beam Sonar Bathymetry and Intensity for Mapping Coral Reef Ecosystems.* Remote Sensing of Environment. 2009. 113 (5) 1082-1100.

[10] DeFries, R., Hansen, A., Newton, A.C., and Hansen, M.C. *Increasing Isolation of Protected Areas in Tropical Forests over the Past Twenty Years.* Ecological Applications. 2005. 15 (1) 19-26.

[11] Dodge, S., Bohrer, G., Bildstein, K., Davidson, S.C., Weinzierl, R., Bechard, M.J., and Wikelski, M. *Environmental Drivers of Variability in the Movement Ecology of Turkey Vultures (Cathartes Aura) in North and South America.* Philosophical Transactions of the Royal Society B: Biological Sciences. 2014. 369 (1643) 20130195.

[12] Dubois, G., Clerici, M., Peedell, S., Mayaux, P., Grégoire, J.M., and Bartholomé, E. *A Digital Observatory for Protected Areas-DOPA, A GEO-BON Contribution to the Monitoring of African Biodiversity.* Proceedings of Map Africa. 2010. 23-25.

[13] Duncan, C., Kretz, D., Wegmann, M., Rabeil, T., and Pettorelli, N. *Oil in the Sahara: Mapping Anthropogenic Threats to Saharan Biodiversity from Space.* Philosophical Transactions of the Royal Society B: Biological Sciences. 2014. 369 (1643) 20130191.

[14] Duro, D.C., Coops, N.C., Wulder, M.A., and Han, T. *Development of a Large Area Biodiversity Monitoring System Driven by Remote Sensing.* Progress in Physical Geography. 2007. 31 (3) 235-260.

[15] Feeley, K.J., Gillespie, T.W., and Terborgh, J.W. *The Utility of Spectral Indices from Landsat ETM+ for Measuring the Structure and Composition of Tropical Dry Forests1.* Biotropica. 2005. 37 (4) 508-519.

[16] Forest Survey of India, 1996: *Volume Equations for Forests of India, Nepal and Bhutan.* Dehradun, India: Forest Survey of India, Ministry of Environment and Forests, Government of India.

[17] Foody, G.M., and Cutler, M.E. *Mapping the Species Richness and Composition of Tropical Forests from Remotely Sensed Data With Neural Networks.* Ecological Modeling. 2006. 195 (1) 37-42.

[18] Franklin, S.E., Wulder, M.A., and Gerylo, G.R. *Texture Analysis of IKONOS Panchromatic Data for Douglas-Fir Forest Age Class Separability in British Columbia.* International Journal of Remote Sensing. 2001. 22 (13) 2627-2632.

[19] Gillespie, T.W. *Predicting Woody-Plant Species Richness in Tropical Dry Forests: A Case Study from South Florida, USA.* Ecological Applications. 2005. 15 (1) 27-37.

[20] Gillespie, T.W., Foody, G.M., Rocchini, D., Giorgi, A.P., and Saatchi, S. *Measuring and Modelling Biodiversity from Space.* Progress in Physical Geography. 2008. 32 (2) 203-221.

[21] Guerschman, J.P., Hill, M.J., Renzullo, L.J., Barrett, D.J., Marks, A.S., and Botha, E.J. *Estimating Fractional Cover of Photosynthetic Vegetation, Non-Photosynthetic Vegetation and Bare Soil in the Australian Tropical Savanna Region Upscaling the EO-1 Hyperion and MODIS Sensors.* Remote Sensing of Environment. 2009. 113 (5) 928-945.

[22] Haest, B., Thoonen, G., VandenBorre, J., Spanhove, T., Delalieux, S., Bertels, L., and Scheunders, P., 2010: *An Object-Based Approach to Quantity and Quality Assessment of Heathland Habitats in the Framework of NATURA 2000 Using Hyperspectral Airborne AHS Images.* GEOBIA 2010-Geographic Object-Based Image Analysis.

[23] Harborne, A.R., Mumby, P.J., Kappel, C.V., Dahlgren, C.P., Micheli, F., Holmes, K.E., & Brumbaugh, D.R. *Tropical Coastal Habitats as Surrogates of Fish Community Structure, Grazing, and Fisheries Value.* Ecological Applications. 2008. 18 (7) 1689-1701.

[24] He, K.S., Rocchini, D., Neteler, M., and Nagendra, H. *Benefits of Hyperspectral Remote Sensing for Tracking Plant Invasions.* Diversity and Distributions. 2011. 17 (3) 381-392.

[25] Hernández-Stefanoni, J.L., Alberto Gallardo-Cruz, J., Meave, J.A., and Dupuy, J.M. *Combining Geostatistical Models and Remotely Sensed Data to Improve Tropical Tree Richness Mapping.* Ecological Indicators. 2011. 11 (5) 1046-1056.

[26] Hyyppä, J., Hyyppä, H., Inkinen, M., Engdahl, M., Linko, S., and Zhu, Y.H. *Accuracy Comparison of Various Remote Sensing Data Sources in the Retrieval of Forest Stand Attributes.* Forest Ecology and Management. 2000. 128 (1) 109-120.

[27] Innes, J.L., and Koch, B. *Forest Biodiversity and Its Assessment by Remote Sensing.* Global Ecology & Biogeography Letters. 1998. 7 (6) 397-419.

[28] Jensen John, R., 2009: *Remote Sensing of the Environment: An Earth Resource Perspective 2/e.* Pearson Education India.

[29] Joseph, S., Murthy, M.S.R., and Thomas, A.P. *The Progress on Remote Sensing Technology in Identifying Tropical Forest Degradation: A Synthesis of the Present Knowledge and Future Perspectives.* Environmental Earth Sciences. 2011. 64 (3) 731-741.

[30] Joshi, P.K., Rawat, G.S., Padaliya, H., and Roy, P.S. *Land Use/Land Cover Identification in an Alpine and Arid Region (Nubra Valley, Ladakh) Using Satellite Remote Sensing.* Journal of the Indian Society of Remote Sensing. 2005. 33 (3) 371-380.

[31] Jürgens, N., Schmiedel, U., Haarmeyer, D.H., Dengler, J., Finckh, M., Goetze, D., and Zizka, G. *The BIOTA Biodiversity Observatories in Africa—A Standardized Framework for Large-Scale Environmental Monitoring.* Environmental Monitoring and Assessment. 2012. 184 (2) 655-678.

[32] Kanniah, K.D., 2011: Worldview-2 Remote Sensing Data for Tropical Mangrove Species Classification. Research Report submitted to DigitalGlobe Incorporated, USA for the Worldview-2, 8-Bands Research Challenge. Longmont, CO: DigitalGlobe.

[33] Ke, Y., Quackenbush, L.J., and Im, J. *Synergistic Use of Quickbird Multispectral Imagery and LIDAR Data for Object-Based Forest Species Classification.* Remote Sensing of Environment. 2010. 114 (6) 1141-1154.

[34] Kerr, J.T., and Ostrovsky, M. *From Space to Species: Ecological Applications for Remote Sensing.* Trends in Ecology & Evolution. 2003. 18 (6) 299-305.

[35] Koch, B. *Status and Future of Laser Scanning, Synthetic Aperture Radar and Hyperspectral Remote Sensing Data for Forest Biomass Assessment*. ISPRS Journal of Photogrammetry and Remote Sensing. 2010. 65 (6) 581-90.

[36] Kumar, Amit, Chawla, Amit, and Rajkumar, S. *Characterization of Solang Valley Watershed in Western Himalaya for Bio-Resource Conservation Using Remote Sensing Techniques.* Environmental Monitoring and Assessment. 2011. 179 (1-4) 469-478.

[37] Kuplich, T.M. *Classifying Regenerating Forest Stages in Amazonia Using Remotely Sensed Images and a Neural Network.* Forest Ecology and Management. 2006. 234 (1) 1-9.

[38] Lee, Z., Casey, B., Arnone, R., Parsons, R., Montes, M.J., Davis, C., and Goode, W. *Water and Bottom Properties of a Coastal Environment Derived from Hyperion Data Measured from the EO-1 Spacecraft Platform.* Journal of Applied Remote Sensing. 2007. 1 (1) 011502.

[39] Lele, N., and Joshi, P.K. *Analyzing Deforestation Rates, Spatial Forest Cover Changes and Identifying Critical Areas of Forest Cover Changes in North-East India during 1972–1999.* Environmental Monitoring and Assessment. 2009. 156 (1-4) 159-170.

[40] Lucas, R., Bunting, P., Paterson, M., and Chisholm, L. *Classification of Australian Forest Communities Using Aerial Photography, CASI and HyMap data.* Remote Sensing of Environment. 2008. 112 (5) 2088-2103.

[41] Mahtab, A., and Narender, B. *Satellite Derived Digital Elevation Model and Terrain Parameters-Generation, Accuracy Assessment and Validation.* Journal of the Indian Society of Remote Sensing. 2003. 31 (1) 19-24.

[42] Mallet, C., and Bretar, F. *Full-Waveform Topographic Lidar: State-of-the-art.* ISPRS Journal of Photogrammetry and Remote Sensing. 2009. 64 (1) 1-16.

[43] Maslekar, A.R. *Remote Sensing and Its Scope in Indian Forestry.* Indian Forester. 1974. 100 (3) 192-201.

[44] Mohammadi, J., and Shataee, S. *Possibility Investigation of Tree Diversity Mapping Using Landsat ETM+ Data in the Hyrcanian Forests of Iran.* Remote Sensing of Environment. 2010. 114 (7) 1504-1512.

[45] Nagendra, H., Rocchini, D., Ghate, R., Sharma, B., and Pareeth, S. *Assessing Plant Diversity in a Dry Tropical Forest: Comparing the Utility of Landsat and IKONOS Satellite Images.* Remote Sensing. 2010. 2 (2) 478-496.

[46] Nagendra, H., and Rocchini, D. *High Resolution Satellite Imagery for Tropical Biodiversity Studies: The Devil is in the Detail.* Biodiversity and Conservation. 2008. 17 (14) 3431-3442.

[47] Navalgund, R.R. *CARTOSAT-1: The Latest from the Indian Remote Sensing Satellite Series.* ISPRS. 2005. 10 (3) 30-31.

[48] Omar, H., 2010: *Commercial Timber Tree Species Identification Using Multispectral Worldview-2 Data.* Research Report submitted to DigitalGlobe Incorporated, USA for the WorldView-2, 8-Bands Research Challenge. Longmont, CO: *DigitalGlobe*.

[49] Raes, N., Roos, M.C., Slik, J.W., Van Loon, E.E., and Steege, H.T. *Botanical Richness and Endemicity Patterns of Borneo Derived from Species Distribution Models.* Ecography. 2009. 32 (1) 180-192.

[50] Rahman, M.M., and Sumantyo, J.T.S. *Mapping Tropical Forest Cover and Deforestation Using Synthetic Aperture Radar (SAR) Images.* Applied Geomatics. 2010. 2 (3) 113-121.

[51] Sánchez-Azofeifa, A., Rivard, B., Wright, J., Feng, J.L., Li, P., Chong, M.M., and Bohlman, S.A. *Estimation of the Distribution of Tabebuiaguayacan (Bignoniaceae) Using High-Resolution Remote Sensing Imagery.* Sensors. 2011. 11 (4) 3831-3851.

[52] Sewell, D., Guillera-Arroita, G., Griffiths, R.A., and Beebee, T.J. *When is a Species Declining? Optimizing Survey Effort to Detect Population Changes in Reptiles.* PloS ONE. 2012. 7 (8) e43387.

[53] Shippert, P. *Why Use Hyperspectral imagery?* Photogrammetric Engineering and Remote Sensing. 2004. 70 (4) 377-396.

[54] Singh, J.S., Roy, P.S., Murthy, M.S.R., and Jha, C.S. *Application of Landscape Ecology and Remote Sensing for Assessment, Monitoring and Conservation of Biodiversity.* Journal of the Indian Society of Remote Sensing. 2010. 38 (3) 365-385.

[55] Somodi, I., Čarni, A., Ribeiro, D., and Podobnikar, T. *Recognition of the Invasive Species Robinia pseudacacia from Combined Remote Sensing and GIS Sources.* Biological Conservation. 2012. 150 (1) 59-67.

[56] Spanhove, T., VandenBorre, J., Delalieux, S., Haest, B., and Paelinckx, D. *Can Remote Sensing Estimate Fine-Scale Quality Indicators of Natural Habitats?* Ecological Indicators. 2012. 18; 403-412.

[57] Strittholt, J., Steininger, M., Loucks, C., White, B., Wilkie, M.L., and Guariguata, M. *Trends in Selected Biomes, Habitats, and Ecosystems: Forests.* In Sourcebook on Remote Sensing and Biodiversity Indicators. Secretariat of the Convention on Biological Diversity, Montreal Technical Series. 2007. (32) 35-63.

[58] Townsend, A.R., Asner, G.P., and Cleveland, C.C. *The Bio-Geochemical Heterogeneity of Tropical Forests.* Trends in Ecology & Evolution. 2008. 23 (8) 424-431.

[59] Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., and Steininger, M. *Remote Sensing for Biodiversity Science and Conservation.* Trends in Ecology & Evolution. 2003. 18 (6) 306-314.

[60] Vauhkonen, J., Korpela, I., Maltamo, M., and Tokola, T. *Imputation of Single-Tree Attributes Using Airborne Laser Scanning-Based Height, Intensity, and Alpha Shape Metrics.* Remote Sensing of Environment. 2010. 114 (6) 1263-1276.

[61] Wabnitz, C.C., Andréfouët, S., Torres-Pulliza, D., Müller-Karger, F.E., and Kramer, P.A. *Regional-Scale Seagrass Habitat Mapping in the Wider Caribbean Region Using Landsat Sensors: Applications to Conservation and Ecology.* Remote Sensing of Environment. 2008. 112 (8) 3455-3467.

[62] Walker, J.S., and Blaschke, T. *Object-Based Land-Cover Classification for the Phoenix Metropolitan Area: Optimization vs. Transportability.* International Journal of Remote Sensing. 2008. 29 (7) 2021-2040.

[63] Walters, M., Pereira, H.M., Ferrier, S., Geller, G.N., Jongman, R., Scholes, R.J., and Reyers, B. *Essential Biodiversity Variables*. Science. 2013. 339 (6117) 277-8.

[64] Wang, K., Franklin, S.E., Guo, X., He, Y., and McDermid, G.J. *Problems in Remote Sensing of Landscapes and Habitats.* Progress in Physical Geography. 2009. 33 (6) 747-68.

[65] Wegmann, M., Santini, L., Leutner, B., Safi, K., Rocchini, D., Bevanda, M., and Rondinini, C. *Role of African Protected Areas in Maintaining Connectivity for Large Mammals.* Philosophical Transactions of the Royal Society B: Biological Sciences. 2014. 369 (1643) 20130193.

[66] DigitalGlobe. *Satellite Imaging Corporation*. www.digitalglobe.com. 2001-2014.