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Review Paper

Remote Sensing as a tool for Estimating Biodiversity

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Abstract

The adoption of the International Convention on Biological Diversity by India obliges us to inventory our country's biodiversity, make all attempts to conserve it and monitor the efficacy of these measures. This is an enormous task, for India harbours some 120 000 known and perhaps another 400 000 as yet undescribed species, which are distributed over its 320 million ha of land and 200 million ha of exclusive economic zone in the sea. The use of remote sensing techniques would greatly facilitate such an exercise. These techniques can provide us with information about land cover, which can then be related to biodiversity. Such exercises have been attempted before, mainly in agricultural or crop areas, or in relatively species-poor forests, dominated by a few species. We review the pertinent studies, which use airborne sensors as well as satellite imagery. However, most of these techniques are not applicable to the task of inventorying the biodiversity of the Indian heterogeneous species-rich forests. We suggest an alternative methodology, employing a two step approach of (a) mapping the coverage of the entire landscape and seascape of the country in terms of landscape element types with the use of satellite imagery, and (b) sampling representative sets of landscape element types, to correlate these with biological communities, species and genes. Our own pilot studies in the Karnataka Western Ghats suggest that the use of the IRS series satellite imagery coupled to supervised classification can permit identification of landscape element types with distinctive composition in terms of biological species. We believe that this methodology is widely applicable, and suggest specific questions which need to be answered in order to extend this methodology over the country.

Keywords: biodiversity, inventorying, monitoring, landscape ecology, vegetation cover, remote sensing

1. Assessing Biodiversity:

Diversity of all, even the seemingly most insignificant life forms has today acquired the potential for commercial application. At the same time, this diversity is being eroded rapidly with fears that at least 10% of all species will become extinct over the next few decades. These twin developments have led to the adoption of an International Convention on Biological Diversity by India [1] and most other countries of the world. This Convention obliges us to inventory the country's biodiversity, make all attempts to conserve these resources and monitor the efficacy of the conservation measure adopted. These are important scientific challenges, challenges that India's scientific community must turn into a major opportunity to chalk out a programme of original research of genuine applied value.

The task is enormous, for India harbours some 120 000 known and perhaps another 400 000 as yet undescribed species of microbes, plants and animals [2], with large reservoirs of intraspecific genetic variation. These organisms are distributed over the country's 320 million ha of land and 200 million ha of exclusive economic zone in the sea. Since the interest is no longer confined to, say, a few Siberian Cranes in Bharatpur National Park, monitoring the efficacy of conservation measures calls for monitoring the abundances of the entire spectrum of organisms over the whole landscape and seascape of the country

2. Potential of Remote Sensing:

How, then, is this task to be accomplished? One very significant source of information on the land cover of the country is satellite imagery. The IRS-IC produces information on reflectances on a scale of 128 intensity values for blue, green, red and near infrared wavelengths for pixels on a scale as fine as 23 by 23 m, with a repetitivity of 24 days [3]. These reflectances can yield many clues as to the coverage of assemblages of plants at canopy level, information that has been used to map occurrences of vegetation types. If this data could be utilised in some way to yield information on biodiversity, then our task would be greatly simplified. Much of the landscape of the earth is covered with vegetation, and it is the topmost canopy of this vegetation which reflects most of the radiation sensed by remote sensing techniques [4]. The greatest potential use of remote sensing techniques to estimate biodiversity is, therefore, for the topmost canopy of vegetation.

3. Spatial and Spectral Resolution:

The major problem with use of remote sensing data for species diversity estimation is one of resolution – spatial as well as spectral. Species vary in distribution on the ground at scales far smaller than the resolution of most remote sensing systems and, in most cases, individual plants cannot be resolved separately. This is a problem of spatial resolution. Ciesla [5] recommends that to identify individual tree species using aerial photography, a scale of 1: 8000 or larger seems appropriate. However, even if spatial resolution is of this scale or lower, such that individual plants can be separately recognised, can the spectral resolution be such that the sensor can recognise these different plants as belonging to distinct species? This is a problem of spectral resolution - plant leaves contain a variety of coloured pigments which affect the degree to which they reflect various wavelengths of light. Salisbury *et al.* [6], in a study of seven tropical plant species and six deciduous species, demonstrate that different leaves from the same plant or from different plants of the same species often vary in measured reflectance levels, but the overall shape of their spectral curves usually remains the same. They, therefore, conclude that achieving species discrimination is an achievement well within the capability of airborne remote sensing instrumentation. They suggest the use of thermal infrared data for this purpose, and recommend that the spectral resolution be high. The problem is that if you develop sensors/ remote sensing systems with adequate resolution of both kinds, then it becomes too expensive. There exist therefore various kinds of remote sensing systems with different spectral and geographical resolutions, many of which have been investigated to see their potential for biodiversity estimation. These are reviewed below.

4. Multiband Video Systems in Agricultural Areas:

Multiband video systems have been investigated for use in biodiversity estimation, and recommended as a low, cost-effective tool for vegetation studies [7,8]. These studies were conducted in agricultural fields and orchards, using imagery at high spectral resolution (around 0.01 nm), in order to test whether different species under cultivation could be distinguished. Nixon *et al.* [7] do not mention the spatial resolution used, but recordings were taken at heights of 900 and 1500 m. They used six filters, blue (0.42 - 0.45 μm), green (0.51 - 0.54 μm), yellow green (0.53 - 0.56 μm), yellow (0.56 - 0.59 μm), red (0.64 - 0.67 μm) and infrared (0.85 - 0.88 μm). Everitt *et al.* [8] use a resolution of 15 – 24 sq. ft per pixel, and four filters, centred around visible/near infrared light (0.4 – 1.1 μm), visible light only (0.4 - 0.7 μm,), near-infrared (0.815 - 0.827 μm) and red (0.644 - 0.656 μm) to look at agricultural sites. The various cultivation and non-cultivated areas are well distinguished by both researchers. Everitt *et al* could distinguish onions (*Allium sepum* L.) and aloe vera (*Aloe barbadensis* Mill.) from cabbage (*Brassica aleracea*) and carrots (*Daucus carota* L.). Nixon *et al.* showed that ragweed plants (*Parthenium hysterophorus* L.) infesting a carrot (*Daucus carota*) field could be distinguished from carrot. However, they both emphasise that they used narrowband filters which were specifically matched to the vegetation being studied, and for this method to be widely applicable, in each area, this must be separately done. This is, obviously not possible for a diverse and large area like Indian forests Brown *et al* [9] attempted to use still video films and conventional colour film transparencies to identify weed patches and weed species occurring in no - till corn fields They also mention that similar studies have been carried out to distinguish weeds from other crops Based on earlier studies on weed species reflectances, they select four spectral bands, centred at 440, 530, 600 and 730 nm to study them. Certain weed species, especially foxtail and milkweed, are easily separable while certain other species like corn and quackgrass merge and higher spatial resolution is recommended as a solution to this problem.

5. Multiband Videos for Forest Species Mapping:

These are studies involving assessment of aerial photography and multivideo systems for discriminating agricultural and weed species only. Multispectral band videos have also been investigated for application in forest species mapping King *et al* [10] use four filters (530 - 570, 630 - 670, 780 - 820 and 880 - 920 nm) at altitudes of 305, 610 and 1220 m to study a conservation area northwest of Toronto containing mixed deciduous forest as well as coniferous forest, grassland, open area and bare soil The overall classification accuracy was 66.3%. Mixed deciduous forest was further separated into two types - one dominated by *Acer saccharum*, *Fraxinus* spp and *Fagus grandiflora* and another by *Acer negundo*, *Carpinus caroliniana and Salix nigra* Coniferous forest was also separated into two types - one dominated by *Pinus resinosa* and the other type mixed, with mostly *Picea glauca* and also some *Pinus resinosa*, *Thuja occidentalis and Pinus strobus* They use their classification, therefore, to obtain information about distribution of these species Again, they strongly recommend that for wider use of video imagery for this purpose the selection of spectral bands which optimise separation of forest species is critical. The classification of forest types into sub-types which they achieve is of poor accuracy, which they explain by saying that it is due to a high degree of within feature complexity (in other words, a problem of spatial resolution) and that selection of more homogenous areas will improve accuracy.

6. Satellite Imagery Based Mapping of Forest Species:

Satellite imagery covers much larger areas more systematically and routinely compared to airborne passive or active scanners, videos or conventional photography For larger scale species diversity estimation, therefore, it would be ideal if this imagery could be exploited in some way Again, several studies have been carried out to investigate the potential of this, mainly using Landsat TM and MSS data on European, Australian and American hardwood, coniferous and deciduous forests which are usually dominated by a few species.

Skidmore *et al* [11] classify Australian native eucalyptus forest into seven type classes using Landsat TM data as well as a digital terrain model as ancillary data. In a forest environment not appreciably modified by humans, a given species or forest type characteristically appears within a range of environmental variable values Based on this premise, they use TM data as well as information on gradient, aspect and topographic position in conjunction with a rule based expert system classifier using field collected information on the environmental position in which forest types/species occur The question posed is, what species occur at a given location in the forest, with location X_{ij} being the pixel in the ith row and jth column. A Bayesian rule-based expert system classifier inferred the most probable species occurring at a given location using 5 layers of evidence - possible thematic classes (derived from TM data), probability of correct classification for these classes, gradient, aspect and topographic position (whether ridge, upper midslope, midslope, lower midslope or valley). Based on this, pixels were classified into forest types. A contextual check was then carried out on this classification, and if adjacent pixels were classified into forest types which were not ecologically valid, then adjacent cell types were used as weighting factors to recalculate X_{ij}. 135 sample plots were randomly located within the study area (7.5 x 7.5 km) and species information collected for trees (> 10 cm diameter at 1.3 m above ground height). Forest types were then categorised using the most dominant species as the type name In addition, if other species were present in > 25% of individuals, their names were also noted. Classification accuracy with the expert system overall was 76.2%.

They recommend this system for larger use in species diversity estimation, suggesting that as study area size increases, other environmental variables such as soil type, moisture and latitude/longitude may also play a vital role and should also be included They also add an important clause - that choice of such auxiliary data sets is determined primarily by their availability, and while topographic data is easily available, other data may not be In addition, topography data is relatively constant and even if old, can be used with confidence Other data, for instance, population density maps or moisture data, may be fast changing In addition to merely being available, such data should be relatively recent to be of value, especially in fast changing environments like Indian forests. Skidmore *et al* explain the potential use of their rule-based system to estimate the identity of species occurring at a site. In actuality, they only use this system to map vegetation cover types in their landscape The accuracy which one may achieve in making a species map using this method is unclear As mentioned already, ancillary data may not always be available Even if available, association of such data with species is difficult to predict reliably, especially in species-diverse forests such as Indian ones. However, the logic used is interesting and potentially applicable to India, possibly with major modifications

White *et al* [12] perform an unsupervised classification of TM data covering the Lassen Volcanic National Park, covering approximately 500 sq. km, into *Pinus* and *Abies* forest classes. Genus type mapping was achieved to an accuracy of 63% using this unsupervised classification A GIS model, based on elevation, slope, aspect and proximity to water was then used to subdivide these forest classes to species level The two dominant genera, *Pinus* and *Abies* could be divided into two species each However, they were only able to achieve an accuracy of 58% using this method They also suggest the refinement of this strategy by emphasising certain types of ancillary information based on "need" and "usage". Wolter *et al* [13] look at classification of forests into types dominated by single species without using ancillary data in the northern Lake states region They use multidate TM imagery, chosen at specific dates to capture phonological stages of specific dominant species, to help in their classification Again, this is only possible in forests dominated by single species They did achieve accuracies ranging from 61% to 100% for dominant species cover type forest classes. Levine *et al* [14] prepared a detailed soil type and drainage map of a 4 sq km forested area in Maine using aerial photographs and SPOT satellite imagery, as base maps Permutation tests using Canonical Correlation Analysis revealed that classification of soil mapping units was significantly correlated with variation in species composition, as estimated from field surveys They propose soil maps as another potential source of ancillary information which may be used for plant species biodiversity estimation

7. Satellite Imagery for Biodiversity Estimation in Indian Forests:

In India, Unni *et al* [15] attempted to map economically important forest species, using Landsat MSS data, in the Godavari river basin, Nallamalai and Seshachalam ranges for teak *(Tectonia grandis)*, bamboo *(Dendrocalamus strictus* and *Bambusa arundinacea)* and Red Sanders *(Pterocarpus santallinus)* In these areas, the above species occur either in pure form or as dominant species and can be easily delineated Based on this, they suggest that a nation wide forest survey can be done where broad forest/vegetation types can be classified, and species delineated when they grow in pure form or have considerable dominance. Sudhakar *et al.* [16] also use Landsat MSS imageries covering parts of Andhra Pradesh to classify forest types using visual interpretation Based on field surveys of vegetation in these areas, they conclude that each vegetation type is correlated with a characteristic set of species No numerical or statistical analyses have been carried out as a basis for making this statement. They also note, again, that while temperate forests are characterised by large tracts of homogeneous species and diversity estimations are relatively easier, Indian forests are much more heterogeneous and this poses a major problem An intensive field study of vegetation with reference to species diversity is recommended by them for proper interpretation of Landsat imagery

8. Limitations in Context of Indian Species-rich Forests:

As is obvious from a perusal of the literature, most of the success obtained using remote sensing for biodiversity estimation is either in agricultural or crop lands, or in relatively species-poor forests which are usually dominated by a single or very few species. Airborne handheld video or multispectral sensors with high spectral and spatial resolution are capable of distinguishing individuals of different species, if the spectral bands are carefully matched to the species which occur This is obviously not feasible for large areas containing many different kinds of species, as it will become too expensive a task. Satellite imagery appears to have maximum potential for biodiversity estimation, as the IRS series of satellites routinely cover the whole of India, repeating their coverage once in 22 days. This imagery is available relatively easily and inexpensively, and use of this to routinely monitor India's biodiversity is probably much more economically feasible than the use of any other type of remote sensing. Again, investigations of the use of satellite imagery for monitoring biodiversity have mainly been carried out in species-poor forests, dominated by a few species at most. Most studies recommend the use of satellite data in conjunction with other ancillary data such as topography, moisture information or soil types, to delineate the distributions of various species. Such information is difficult to collect reliably for the large number of species present in Indian forests. If the information is available, it is very likely to be outdated since environmental change is very rapid in these areas.

9. An Alternative Methodology:

The idea, however, of using ancillary information in conjunction with satellite imagery to estimate biodiversity, is a good one. We propose a similar idea, with a modification. We need to identify some emergent properties that can be assessed relatively easily, but that are sufficiently strongly linked to abundance of a larger number of species on land. The structure of dominant growth forms of plant species, along with the identity of the most dominant of the species are such properties.

Indeed, ecologists have been for long employing vegetation types defined in this way as indicators of biological communities. However, vegetation types are generally defined rather broadly. Thus, for India, the most detailed classification of vegetation types is that of the French Institute School which assigns the vegetation of the entire country to 43 types along with their degradation stages [17]. The maps based on this classification have a resolution of a few square kilometres. In a country like India, the vegetation is a much more intricate mosaic of patches of hectares rather than squares of kilometres. To monitor such vegetation effectively calls for attention to the spatial scale of hectares. We must shift our focus from scales appropriate to vegetation ecology to those appropriate to landscape ecology. If the appropriate spatial scale is that of a hectare, the task is to construct a matrix of (1.2×10^5) x (3×10^8) species by locales, with each element in the matrix being the abundance of a given species in a particular hectare at some specified time. Monitoring would involve assessing changes in the matrix over time.

We would then employ landscape element types (LSE types) as the device to provide clues to the abundance of a defined set of larger number of biological species. The LSE types would be useful for this purpose if they can also be reliably identified on the basis of satellite imagery. We wished to assess the feasibility of such an approach to monitoring biodiversity.

On the basis of a case study in the hill areas of the Western Ghats in peninsular India, we attempted to answer the following questions:

1] In a landscape of a few tens of square kilometres, can we identify a small number of LSE types such that elements belonging to different LSE types harbour distinctive sets of species ?

2] Can these LSE types be identified with an acceptably low level of error on the basis of satellite imagery?

3] Do elements of LSE types so identified with the help of satellite imagery also harbour distinctive sets of species?

10. A Pilot Study:

Our case study focuses on a landscape of 5 x 5.5 km, at an altitude of 400 to 600 m near the town of Siddapur in the Uttar Kannada district of Karnataka (14'16' latitude; 74'53' longitude). This area is covered by the Indian Remote Sensing Satellite (IRS 1B) LISS 2 imagery of 4th March 1993, at the height of the dry season, when all the deciduous trees have shed their leaves and can be clearly distinguished from evergreen trees. A supervised classification was carried out for the 7 major LSE types present in the landscape; disturbed evergreen, secondary moist deciduous, savanna, *Acacia auriculiformis* plantations, *Casuarina equisetifolia* plantations, grassland and paddy fields (hereafter referred to as evergreen, moist deciduous, savanna, *Acacia*, *Casuarina*, grassland and paddy respectively), using the WIPS-32 image processing software available in the Regional Remote Sensing Service Centre, Bangalore. The remaining LSE types - areca plantations, coconut plantations and sugarcane - occupy only a very small fraction of the landscape and were omitted from further analysis. We also prepared an unsupervised classification specifying the resultant classes to be 7, the same as the number of major LSE types in the landscape, using Grass 4.1.5 image processing software [18].

Field investigations of the plant communities belonging to the various LSE types in our landscape were carried out by sampling during the months of January and February 1995. A total of 27 transects, ranging from 200 to 1350m in length, were laid across the landscape such that they cut across all major patches of the 7 LSE types, from edges of the patch to the interior. Within these transects, at 50 m intervals, 10 by 10 m quadrats were laid for sampling trees (all plants more than 10 cm girth at 130 cm), each containing a nested subquadrat of 5 by 5 m for sampling the shrub layer (all plants taller than 1.5 m), and 2 further nested subquadrats of 1 by 1 m for sampling the herb layer (all plants shorter than 1.5 m). For each quadrat/ subquadrat, the number of individuals belonging to all angiosperm species, excluding grasses was recorded. It is likely that several herbaceous species, other than grasses, may also have been missed out since the sampling was carried out during the dry season.

A total of 282 such quadrats were laid across the entire landscape. Of these, 246 quadrats which fell within the LSE types of our interest form the basis of our species analysis. A quadrat was classified as belonging to an LSE type based on supervised as well as on unsupervised classification. We used presence-absence data of species to assess how distinctive or different plant communities are. Our results confirm that supervised classification of different LSE types is a useful device for discriminating biological communities with distinct sets of species, at least as far as flowering plants are concerned. However, unsupervised classification proves unsatisfactory in this regard. Since unsupervised classification as a whole is not very accurate, LSE types get mixed in the classification and so the species composition of these types is no longer separable. Most of the pairs of LSE types which are distinct in species composition also harbour distinct numbers of species, i.e. they are also distinct in species richness.

We wished to assess if this information provided by satellite imagery about species composition is directly or indirectly obtained. For this purpose, for the supervised classification, we calculated the distance in the species composition space of 168 species, between all pairs of LSE types, as the average dissimilarity in species composition for all pairs of quadrats from these two different LSE types. We also calculated the distance between LSE types in the imagery reflectances space as the Mahalanobis distance between the intensities of pixels assigned to these types. If information on spectral signatures of these LSE types was in some way a direct indicator of the species composition of these types, then rank differences in these two measures of distance, species-based as well as image-based, should be concordant. It is evident from the results shown in Table 1 that the ranks are in discord. The information provided by satellite imagery-based LSE type classification about species composition is, therefore, indirect. We conclude from our study that we can use satellite imagery with adequate input of ground truth to identify LSE types with a sufficient degree of accuracy to serve as

TABLE - 1

Rank seperability in ascending order of LSE type pairs in species composition (above diagonal) and in spectral intensities (below diagonal) in the supervised classification.

	PADDY	GRASS LAND	ACACIA	CASUA-RINA	SAVA-NNA	MOIST DECD.	EVER-GREEN
PADDY	--	16	21	17	18	19	20
GRASSLAND	1	--	14	8	5	13	15
ACACIA	18	14	--	10	7	9	11
CASUARINA	21	17	13	--	2	6	12
SAVANNA	6	2	9	10	--	1	3
MOIST DECD.	19	11	12	15	5	--	4
EVERGREEN	20	16	4	3	7	8	--

a basis for biodiversity monitoring. This cannot be done on the basis of unsupervised classification.

11. Issues for Consideration:

The challenge before us now is: inventorying and monitoring the efficacy of conservation measures for the entire spectrum of living diversity distributed across the length and breadth of India's landscape and seascape. This calls for assessing the status of the country's known 120 000 species and an estimated as yet undescribed 400 000 species of plants, animals and microorganisms, and their constituent genes. This task will have to be addressed by a two step approach:

(a) Mapping the coverage of the entire landscape and seascape of the country in terms of landscape element types with the use of satellite imagery

(b) Sampling representative sets of landscape element types, communities, species and genes.

Designing such a sampling programme requires consideration of the following issues:

(1) Trade-offs in selecting a smaller or larger set of landscape/ waterscape element types in terms of inter-observer error in field work, errors in assignment of pixels in satellite imagery interpretation, and in discrimination amongst sets of co-occurring species.

(2) Relationship between increased accuracy of visual interpretation/supervised classification and the nature, extent and dispersion of ground truth provided. Extent of reliability of extrapolation of such interpretation to scenes of neighbouring areas, or scenes of the same area obtained at a different time.

(3) Forms of distribution of species abundances over different elements of the same and of different LSE types.

(4) Extent of correlation in space in abundance/ occurences of a given species.

(5) Extent of correlation in time in abundance/ occurences of different species.

The task at hand was defined above as that of determining the matrix of abundance of 1.2×10^5 species for 3.2×10^8 locales. This may be broken down into a stepwise process, namely, determining the matrix of occurrences of a few hundred LSE types for the 3.2×10^8 locales, determining the range of abundances of species in each of these few hundred LSE types, and then inferring the likely abundance of species in the actual locales.

The first scientific challenge is to decide on an appropriate set of LSE types for the country. This set should fulfil the following requirements:

(1) An observer in the field should be in a position to assign any particular locale to a particular LSE type on the basis of a set of criteria such that inter-observer variation in such an assignment is within some acceptable level.

(2) It should be possible to assign a pixel characterised by certain spectral signature (i.e. reflectance values in the four bands) to a particular LSE type on the basis of either visual interpretation of a false colour composite, a supervised classification, or an unsupervised classification within some acceptable level of error in relation to the ground truth.

(3) The different LSE types should differ from each other significantly enough in the set of biological species they harbour so that the assignment of an LSE type to a given locale carries useful information on the likely occurrences of plant, animal or microbial species.

The next step in the process would be to determine the distribution of occurrences/abundance of different species in the whole range of LSE types. To this end, we would have to assess occurrences/abundance of some simple subset of species in a sample subset of individual elements or patches of the different LSE types.

Over the last three years, a Western Ghats biodiversity network (WGBN) has been engaged in collecting information relevant to many of the issues raised above. This could now be assessed and used to devise an appropriate survey strategy for a countrywide programme of monitoring biodiversity. We have classified 18 landscapes, each around 25 sq. km in area, mainly along the foothills of the Western Ghats, ranging from north to south. Each landscape has been field surveyed to map the distribution of plant species in the various LSE types present in these landscapes. We have encountered a total of twenty seven major LSE types in these 18 landscapes - since each landscape is around 25 sq. km in area. As we have not mapped any of the high altitude regions of the Ghats, we expect not more than 50 LSE types to be present in the entire Western Ghats, and probably around 150 LSE types for the country as a whole. This methodology has great potential to extend the monitoring of the country's biodiversity.

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