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Integration of GIS, Remote Sensing and Ecological Methods for Biodiversity Inventory and Assessment

Inventory and assessment of biodiversity have become essential for short-term management strategies as well as for developing and testing scientific hypotheses. Geographic Information Systems (GIS) and Remote Sensing (RS) both have special advantages in preparing inventories of species based on ecological parameters. Remote sensing can help procure valuable information on types of habitat, structures of vegetation, landscapes, and fragmentation, basically to assess the extent of diversity in biological species and make a record of the species extant. The significance of Geographic Informations Systems is in assessing the relative values; richness of species, dominance, fragmentation, porosity, and so on. Methods and parameters are described briefly with the use of tables to define some of the parameters. Useful reference material is given for those interested in pursuing this topic in depth.

Inventory of existing levels and spatial patterns of biodiversity are essential for short-term management strategies. They are also important for developing and testing scientific hypotheses and as baseline data in monitoring.

Remote Sensing can provide information on habitat types, vegetation structures, landscape geometry, and habitat fragmentation. It also provides the date to produce digital elevation models, net primary production rates, actual evaporation, amount of biomass, and leaf area indices. Percentages of vegetation cover for extensive grassland can be estimated using the Normalized Difference Vegetation Index (NDVI) and Transformed Soil Adjusted Vegetation Index (TSAVI) (Puredorj et al. 1998). These provide useful tools for monitoring livestock production, agriculture, and desertification of arid and semi-arid lands. Remote sensing technology procures information at regional and landscape levels.

Geographic Information Systems (GIS) can provide information on the relative richness, at the landscape level.

Geographic Information Systems (GIS) can provide information on the relative richness, dominance, fragmentation, porosity, patchiness, patch density, interspersion or CVC (Centre versus Neighbour), juxtaposition, and BCN (Binary Comparison Matrix) at the landscape level. Moreover, the spatial analyses and modelling capabilities of GIS render them useful in mapping and modelling habitats, analysing gaps in biodiversity, assessing degrees of biodiversity, conservation planning, and mapping of ecoregions at regional and landscape levels.

Stoms and Estes (1993) reviewed the work of Whittaker (1977) in which the scale continuum for species' richness was divided into seven ecological levels. Four levels represent inventory diversities and three levels represent differentiation diversities. They are briefly described below.

Assessment Scales for Species' Richness

Inventory Diversities

1. *Epsilon/Regional (the sampling unit is from 1 – 100 million hectares)*
   This scale covers the diversity of broad geographic areas incorporating more than one landscape. For example, the Hindu Kush-Himalayan Region.

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Within a community, individual plots will also contain different amounts of species due to micro-habitat differences and stochastic processes.

2. Gamma/Landscape (the sampling unit is from 1.0 – 1 million hectares)
This scale covers the number of species in a landscape containing more than one community type. The landscape can be comprised of a major or macro-watershed such as Shivarpuri watershed in Nepal.

3. Alpha/Within Community (the sampling unit is from 0.1 to 1.0 hectares)
This scale covers the richness within a single homogeneous community. It can be a sample plot in a particular forest or plant community.

4. Point/Micro-habitat (the sampling unit is from 0.01 to 0.1 hectares)
Within a community, individual plots will also contain different amounts of species due to micro-habitat differences and stochastic processes. This is referred to as point diversity. The point sample can be a particular grass community or range vegetation community.

Differentiation Diversities

5. Delta/Geographic Gradients
The sampling unit Alpha is used to show differences within the same community type. The domain varies from landscape to region.
It enables assessment of the differences in composition between similar communities within a landscape.

6. Beta/Environmental Gradients
The sampling unit is 'Alpha' in different communities. The domain is from community to landscape. It measures the differences in composition between various communities within a landscape.

7. Pattern/Micro-gradients
The sampling unit is a point in the same community. The domain is from point to community. It corresponds to the differences between points within a community.

To produce a rich inventory, maps of species' distribution at the gamma level should be prepared. Two basic methods can be used for this; either an overlay of individual range maps is made or species' distribution is modelled based on ecological niche. The spatial analyses and modelling capabilities of GIS can be used for ecological mapping at the gamma level.

At the point and alpha levels, ecological parameters or floristic representativeness are important parameters for establishing the uniqueness of an ecosystem. The ecological parameters (see Box 1), commonly derived for each plot, and the indices are useful for both point diversity and gamma level modelling of species' distribution. For example, the relative density of *Terminalia belerica Roxb* indicates a potential habitat for barking deer. Box 2 lists a biodiversity inventory and assessment based on commonly used richness, evenness, and diversity indices along with their relative performances and characteristics. These indices are illustrated comprehensively in Dombois and Ellenberg (1974); Turner (1989); Monmonier (1974); and Magurran (1988). Other comprehensive descriptions on quantitative methods can be found in Turner and Gardner (1994).

Box 1: Ecological Parameters

Density	:	Number of individuals
Frequency	:	The number of times a species is recorded in a given number of small quadrants or a given number of sample points
Dominance	:	Either of crown and shoot area or basal area
Relative Density	:	{Number of individual species / total number of individuals} * 100
Relative Frequency	:	{Frequency of a species / sum of frequency of all species} * 100
Relative Dominance	:	{Dominance of species / sum of dominance of all species} * 100
Important value	:	Relative density + relative frequency + relative dominance

Source: Dombois and Ellenberg 1974

Box 2: Performance and Characteristics of Indices

Indices	Discriminant Ability	Sensitivity to Sample Size	Richness or Evenness Dominance	Calculation	Widely Used?
Log Series	Good	Low	Richness	Simple	Yes
Log Normal	Good	Moderate	Richness	Complex	No
Q Statistics	Good	Low	Richness	Complex	No
S (Species' Richness)	Good	High	Richness	Simple	Yes
Margalef Index	Good	High	Richness	Simple	No
Shannon Index	Moderate	Moderate	Richness	Intermediate	Yes
Brillouin Index	Moderate	Moderate	Richness	Complex	No
McIntosh U Index	Good	Moderate	Richness	Intermediate	Yes
Simpson Index	Moderate	Low	Dominance	Intermediate	Yes
Berger-Parker Index	Poor	Low	Dominance	Simple	No
Shannon Evenness	Poor	Moderate	Evenness	Simple	No
Brillouin Evenness	Poor	Moderate	Evenness	Complex	No
*McIntosh Index	Poor	Moderate	Dominance	Simple	No

The indices in this table provide various means of assessing richness of cover in terms of density and variety.
For details see Magurran 1988.

Suitable sites for plots representing different communities for the purpose of ecological quantification can found by using image segmentation techniques in remote sensing. Image segmentation or partitioning enables spatial domain analysis. Segments or regions are created in an image based on spectral and/or spatial homogeneity. The two basic methods of image segmentation are region growing and edge detection. In region growing, edges are defined as the boundaries between regions. In edge detection, the regions are defined as the areas surrounded by edges (American Society of Remote Sensing 1983). An alternative approach, developed by the author, uses spatially-defined and spectrally-homogeneous field samples (SSS) that can detect the image segments of both region growing and edge detection methods. The SSS have been successfully tested at Alaungdaw Kathapa National Park in Myanmar (Myint 1996). The ecological parameters, richness, evenness, and diversity indices for each spatial segment SSS can be calculated at the point and alpha levels using field data. These spatial segments and SSS can be used as training samples for image classification.

At the landscape level, GIS can play a vital role in calculating the fragmentation, patchiness, porosity, patch density, interspersion and juxtaposition, relative richness, diversity, and dominance in order to characterise landscape properties in terms of structure, function, and change. These are the several different landscape level measures that have been implemented in GIS. The characteristics are illustrated in Box 3.

Biotic and abiotic data (see Box 4) are also important for biodiversity inventory and assessment. They are used by integrating Remote Sensing, GIS, and ecological methods. Moreover, existing vegetation, land use, land cover, forest types, and large expanses of intact habitats and biota extant are also essential biotic data for biodiversity inventory and assessment.

Any spatial unit, such as a forest patch or grassland or a sample plot, will have spatial, physical, social, and biological attributes. In the context of the Hindu Kush-Himalayan region, these attributes (see Box 5) are quite diversified and should be collected for field sample plots. When attached to the spatial unit or the sample plot in a Geographic Information System, the results can have an important influence on planners and decision-makers.

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Conclusions

- Remote sensing technology can be used for spatial segmentation, classification of forest types, land use, land cover, and estimation of habitat and vegetation cover percentages at the gamma and epsilon levels.
- Geographic Information Systems can be used for spatial database development, landscape patterns, habitat assessment, and gap analyses based on ecological niche of different species, biodiversity assessment, conservation planning, and ecoregional mapping.
- Attributes of overall biodiversity characteristics at the alpha and point levels can be derived using ecological methods. This is a promising approach not only for assessing biodiversity, making inventories, and monitoring at the alpha level, but also for mapping the extent and quality of range and forest resources in the Hindu-

Box 3: Important Indication for Landscape Analysis

Fragmentation can be calculated using an n*n window convoluted with the spatial data layer with the criterion of deriving the number of patches (for example: forest) within the n*n window. A higher value indicates more fragmentation (Monmonier 1974).

F = (n-1)/(c-1)
n = number of different classes present in the n*n window
c = number of cells considered (9 if a 3*3 window was used)

Patchiness or NDC (Number of Different Classes) is the measurement of the density of patches of all types or number of clusters within the n*n window. In other words, it is a measurement of the number of polygons over a particular area. The greater the patchiness, the more heterogeneous the landscape (Murphy 1985).

Porosity is the measurement of the number of patches or density of patches within a particular type, regardless of patch size. The lower the porosity value indicates the lower the interaction among landscape elements: it indicates homogeneous and habitats with a low degree of fragmentation.The higher the porosity value the higher the interaction among landscape elements: it indicates heterogeneous habitats with a high degree of fragmentation.

Patch Density is a measurement of the density of a particular type in a unit space. It is inversely proportional to the porosity of the patch.

Interspersion or CVN (Centre Versus Neighbor) is a measurement of the number of different classes or types within a 3*3 window with respect to the central pixel or class. Should the interspersion value of the central pixel or class be high,it indicates that the dispersal ability of the central class will be low or less than it ought to be and may lead to fragility (Murphy 1985).

Juxtaposition is a measurement of the proximity of the vegetation . It measures the relative weight assigned to the importance of the adjacency of two cover types for the species in question. A 3*3 cell window is convoluted with the derived layer in an iterative manner by assigning a higher weight to natural vegetation and a lower weight to unnatural vegetation.

BCN (Binary Comparison Matrix) is a number of different pairs in each 3*3 cell neighborhood. (Murphy 1985).

Relative Richness is a measurement of the number of classes present within an n*n or 3*3 window with respect to the total number of classes in the landscape.

R = (n/nmax) * 100

where,
n = the number of different classes present within an n*n window, and
n max = total the number of classes in the landscape.
(Turner 1989)

Diversity, especially the Shannon diversity index (H), can be implemented using the 3*3 or n*n window. The characteristics and performance of different diversity indices are given in Box-2.

H=-SUM (p*ln (p))

where,
p = proportion of the landscape in each class (Turner 1985).

Dominance can be implemented using the 3*3 or n*n window using the following formula

D = (Hmax – H),

Where,
H = Diversity,
Hmax = Maximum diversity = ln (n),
n = number of different classes present in the n*n window.
(Turner 1985)

Box 4: Biotic and Abiotic

Abiotic Themes : Elevation, rainfall, temperature, soil, geology, rivers, drainage, watersheds, population density, roads, railroads, settlements, towns, cities and protected areas

Biotic Data : Distinct community, keystone ecosystems, habitat and species' distribution of vascular plants, birds, mammals, reptiles, amphibians, invertebrates, and fish

Box 5: Important Spatial, Physical, Social and Biological Attributes for the Hindu Kush-Himalayan Region

Physical - Elevation range, temperature, rainfall, soil type or soil physical status, landslide, weathering and erosion, geology (lithology, structures such as faults, thrusts, folds, and other linear features), neotectonic activities, moisture regimes, seismic zones, location of major earthquakes (magnitude), major drainage systems (main rivers)
Spatial - Location, country, height of snow line (ELA: Equilibrium Line Altitude), distance from the snow line, timber line height (TLA: Timberline Altitude), distance from the timber line
Social - People (cultural, tribe, socioeconomic), anthropogenic disturbance activities, legal status (government, private, public), past use history (last 50 years)
Biological - Definition of land cover by parent country, iso-potential ecological zones, species' association, dominance species, potential biomass, plant's potential growing period

Kush-Himalayan region. Such analyses should be complemented by collecting field data and by ground truthing at alpha and point levels.

- Complementary application of RS and GIS and ecological methods is a promising approach for biodiversity inventory and assessment in the Hindu Kush-Himalayan region.

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Moe Myint
GIS Specialist
&
Pramod Pradhan
Division Head
Mountain Environment and Natural Resources' Information Systems, ICIMOD
e-mail: moe@icimod.org.np
e-mail: pramod@icimod.org.np

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Editors: **Shahid Akhtar/Archana S. Karki**
ICIMOD, P. O. Box: 3226, Kathmandu, Nepal
Tel. (977 1) 525313 or Fax (977 1) 524509, e-mail: distri@icimod.org.np