Geoinformatics-based management of biodiversity from landscape to species scale – An Indian perspective

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Trans-scale information on biodiversity is fast becoming the critical for policy decision and action. Remote sensing systems addressing the structure and biophysical processes have the ability to achieve a seamless scalable information scheme. Necessity of down-scaling the coarse scale database to implementation scale is quite high under current circumstances, as practical schemes/ measures to reverse the erosion of biodiversity are needed. The nesting of information required should address the landscape heterogeneity and stakeholder conflicts arising out of socio-economic dimensions. Species level distributions can be predicted based on genetic algorithm-oriented fundamental niche mapping, enabling prioritization of areas for monitoring and conservation. Geoinformatics rendering of diversity on the principles of landscape ecology, integrated with spatialized anthropogenic demand patterns can be a potential interface to resolve conflicts in stake management.

Keywords: Conservation, ecosystem, geoinformatics, landscape, species.

ATTEMPT to derive biodiversity information from landscape to species level requires nesting of information prevalent across a hierarchical scheme[1]. But the need to evolve a comprehensive approach to handle the variability of diversity across scales is growing due to the range of hostile causes operating therewith[2–7]. Alteration of different units of natural resources in terms of their spatial and temporal contexts due to human-induced factors has been alarming and requires involved sustainable solutions to counter the undesired progressions[8]. The global scale impacts brought about by remote or local factors operating at large spatial extents, essentially demand synoptic observations. Detailed characterization of local scale structures and processes would have to be addressed using high resolution remote sensing capacity. Consequently, degradation stages, in hitherto healthy natural systems, need to be completely understood so as to set up a conservation plan and stem the disturbance.

Approach to generate information base regarding diversity in spatial sense, can be two pronged, either building it from the existing knowledge regime of local scales or use synoptic abilities to build database at regional scale and downscale it. Either case would involve efficient telescoping of the information so that processes are modelled in full perspective and representation of key structural components achieved. An attempt of such magnitude would require a collative and collaborative paradigm, to integrate details at finer scales using prevalent datasets and then to choose the optimal data layers for modelling coarse scale pattern.

The compilation addresses the wide ranging studies on the issue of biodiversity assessment and monitoring. Synthesis clearly shows initiation of regional level vegetation mapping over Indian peninsular region using satellite datasets with parallel permanent plot-based monitoring approaches. Studies have also brought out lists of valuable plant species and focused on potential of comprehensive utilitarian/conservation database. Recent application of emerging spatial techniques could also be noted in later studies which have addressed species, community, habitat landscape as well as issue of integration across scale (Table 1).

Advanced spatial tools for landscape level comprehension

Enhanced ability to map the earthbound land covers comprising multiresolution sensors has facilitated more detailed view in a panoramic perspective. Coarse scale remote sensing systems provide synoptic view of the natural vegetation, with real time monitoring abilities around the year. Innovative observations of the earth with remote

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Table 1. Assessments of biodiversity – View across scales

Core techniques	Scale	Theme addressed	Authors
Field phytosociology/inventory	Habitat/commmunity/species	Structure and floristics	Pascal and Pelissier[24]
		Monitoring using permanent plots	Sukumar *et al.*[25]
		Monitoring using permanent plots	Ayyappan and Parthasarathy[26]
		Dynamics of composition, abundance, stand structure	Parthasarathy[18,19]
		Tree diversity and endemism	Ganesh and Davidar[27]
		Species floristics	Chandrashekara and Ramakrishnan[28]
		Spatial patterns	Pelissier[29]; Pelissier and Goreaud[30]
		Pollination biology, species level	Devy and Davidar [31]
		Tree diversity and regeneration	Ganesh *et al.*[20]
		Wildlife habitat	Dutt[32]
		Wildlife habitat	Johnsingh[33]
		Forest fragmentation and density of large mammals	Krishnamurthy and Kiester[34]
		Effect of shape of patches on habitat	Prasad *et al.*[35]
	Regional	Endemics and RET species	Ahmedullah and Nayar[36]
		Endemics and RET species	Nayar[37]
		Endemism over region scale	Ramesh and Pascal[38]
		Inventory of endemism	Subbarayalu and Velmurugan[39]
		Species diversity across region	Harish and Utkarsh[40]
Geoinformatics	Regional/landscape	Gregarious species level mapping	Roy *et al.*[13]; Porwal *et al.*[14]
		Contours of species distribution pattern	Ganeshaiah and Uma Shaanker[41]
		Regional vegetation type map	Pascal[42–44]
		Regional vegetation type map	Ramesh *et al.*[45]
		Linking regional and landscape scales	Nagendra and Gadgil[9]
		Landscape types	Nagendra[46,47]
		Forest degradation at mesoscales	Lele *et al.*[48]
		Landscape complexity	Udayalakshmi *et al.*[10]
		Biodiversity characterisation	Dutt *et al.*[49]
		Patch traits and species diversity	Amarnath *et al.*[17]
		Biodiversity characterisation	IIRS[50]
		Deforestation at regional scale	Jha *et al.*[51]
		Forest type and growing stock	Dutt and Udayalakshmi[52]
Integration		Linking landscape to species scale	Giriraj[1]
		Biodiversity assessment across scales	Murthy *et al.*[53]

sensing technology and realization of global scale anthropogenic impacts, clarified landscape view of the natural systems and have made us realize the immediacy of the conservation priorities. Conceiving vegetation and allied components of land-bound systems as landscapes, in tune with principles of landscape ecology was strengthened due to remote sensing, consequently enabling quantitative approaches for holistic management.

Coarse spatial resolution (~ 1000 m) imaging systems compiled for entire globe over a period of annual and decadal period revealed the status of the vegetation vis-à-vis biophysical juxtaposing having the anthropogenic dimension as the key agent. Moderate resolution sensors operating at around 30–60 m pixel size enable delineation of vegetation types (using dominant vegetation reflectance), fragmentation and association with observable anthropogenic structures[9–10] which can be used for coupling with medium to coarse resolution physiographic/terrain information. Information content at further level can be derived from very high spatial resolution remote sensing images acquired from platforms set at low earth to polar orbits. The imaging provides near-meter to sub-meter detail, which would be rather the sole information available at such a modest cost compared to aerial imaging. Structural details of the forest canopy regimes experiencing various degrees of disturbance and recovery can be conveniently demarcated for inclusion into further modelling efforts.

Deducing species level diversity

Coarse resolution imaging with its high multitemporal frequency provides functional characterization of landscapes and helps to develop regional understanding of processes essential for maintaining and sustenance of a variety of life forms. Incorporation of process understanding like annual net photosynthesis, primary productivity, phenological trends towards developing framework of biodiversity conservation can be critically important. Gradients of vulnerable portions of landscapes can be delineated using multicriteria approach involving such parameters, enabling focus of action at relevant biogeographic contexts. Global scale landscape parameters can be derived from coarse resolution sensors operating from kilometer to 250 m pixel level. Data from Advanced Very High Resolution Radiometer (AVHRR) sensors has been employed for understanding forest fragmentation at global scale[11] which provides regional prioritization of global level focus of action. Moderate Resolution Imaging Spectroradiometer (MODIS) data stream can also facilitate land cover assessment as well as land cover change understanding which act as key input for modelling the disturbance regimes. On the other hand its suite of biophysical parameters has ability for improved eco-physiological valuation of landscapes in spatially explicit manner.

Necessity of down-scaling the coarse scale database to implementation scale is quite high under current circumstances, as practical schemes/measures to reverse the erosion of biodiversity are needed urgently[12]. The sense of urgency is due to the fact that economies at either end of resource availability, strain natural resource in complex and unsustainable ways, coupled with the looming danger of ubiquitous global warming. Delineation and analysis of species-specific habitats vis-à-vis the biophysical variables assumes considerable significance as the activity at scale immediate to landscape, since their wellbeing ensures the holistic survival of the components of biodiversity. Multispectral satellite datasets like IRS Linear Imaging Self Scanner (LISS) III have been used effectively in mapping colonies dominated mostly by *Hippophae rhamnoides* in the Spiti region and *Ephedra gerardiana* in complex terrain conditions of Lahul and Spiti district with prior knowledge of their occurrence and vegetation types of the area using remote sensing technique[13,14]. Lahul and Spiti fall in the cold desert region in Himachal Pradesh known for its alpine vegetation composition.

Multispectral remote sensing at fine resolution scale enabled by IRS P6 RESOURCESAT and precursors with LISS III sensor onboard offers potential to understand ecosystem-wise community delineations. Datasets obtained over specific seasons can be used to understand dominant vegetation responses coupled with sound field protocol so that overall sub-ecosystem variability is delineated. As the sensor offers sensing in SWIR region sensitive to canopy moisture and crown cover, scope, for instance, can be harnessed of mesic canopy patches as key habitat. For instance, riverine patches in dry deciduous systems can potentially provide supportive niches during dry months by virtue of water regimes. SWIR region (1.55–1.77 μm) has special sensibility to differentiate canopy moisture levels in the land surface and can help to discern the same. Such a value can be significant in tropical seasonal forest tracts, especially in view of the global warming pushing habitability to extremes.

Spatial datasets for conservation zoning

Study of forest landscapes in terms of patch composition and configuration can generate important information[15,16] for conservation and ecorestoration purpose. Large-scale gradients in landscape heterogeneity can be related to broad-scale patterns in the environment. Due to sustained pressure, small fragmented forest patches experience lesser density of population and increase in the risk of extinction[4]. A study was conducted for spatial characterization of evergreen forests, Western Ghats of Tamil Nadu using remote sensing and GIS-based analysis in conjunction with phytosociological data and landscape metrics (Figure 1). Evergreen forests in this part of Western Ghats are distributed in four distinct hill ranges namely Nilgiri, Anamalai, Palni and Tirunelveli having different topographic, bioclimatic, disturbance levels and are characterized for their uniqueness in terms of floristics[17]. Vegetation type map was prepared using IRS LISS III satellite data and used to study the patch characters in terms of patch size, number, shape, porosity and land cover diversity. The phytosociological characters namely species richness, diversity, similarity and community assemblages were studied using ground data collected from 95 sample points of 0.1 ha size. Patch size and number revealed distinct intactness and disturbance levels in these four hill ranges.

Evergreen forests in Tirunelveli hills (216.09 sq. km area) are distributed in 306 patches and in Palni hills (285 sq. km area) are distributed in 1029 patches indicating large level of fragmentation. Land cover diversity indicating the spatial heterogeneity (as indicated by Shannon–Weiner index (H′)) of the land cover was high in Nilgiri hills (2.75 H′) and low in Tirunelveli hills (2.02 H′). The spatial analysis helped to delineate homogenous large patches of evergreen forest, which can be adopted for appropriate conservation strategies. Only 15–28% similarity in terms of species distribution was found across the hill ranges[17]. Conjunctive analysis of patch characteristics and species distribution showed high species richness in less fragmented evergreen forests and vice versa. The study identified the areas of prioritization of Palni and Nilgiri hills in terms of eco-restoration and Anamalai and Tirunelveli hills for conservation based on patch and phytosociological characteristics.

Floristic characterization and species habitat relations

While medium resolution satellite datasets, in tandem with ancillary spatial and non-spatial data, can build information framework for local scale priority setting, very high resolution datasets capable of high temporal flexibility and across track pointing would provide images hitherto with limited and convoluted access. These images can be collected at modest prices compared to aerial imaging

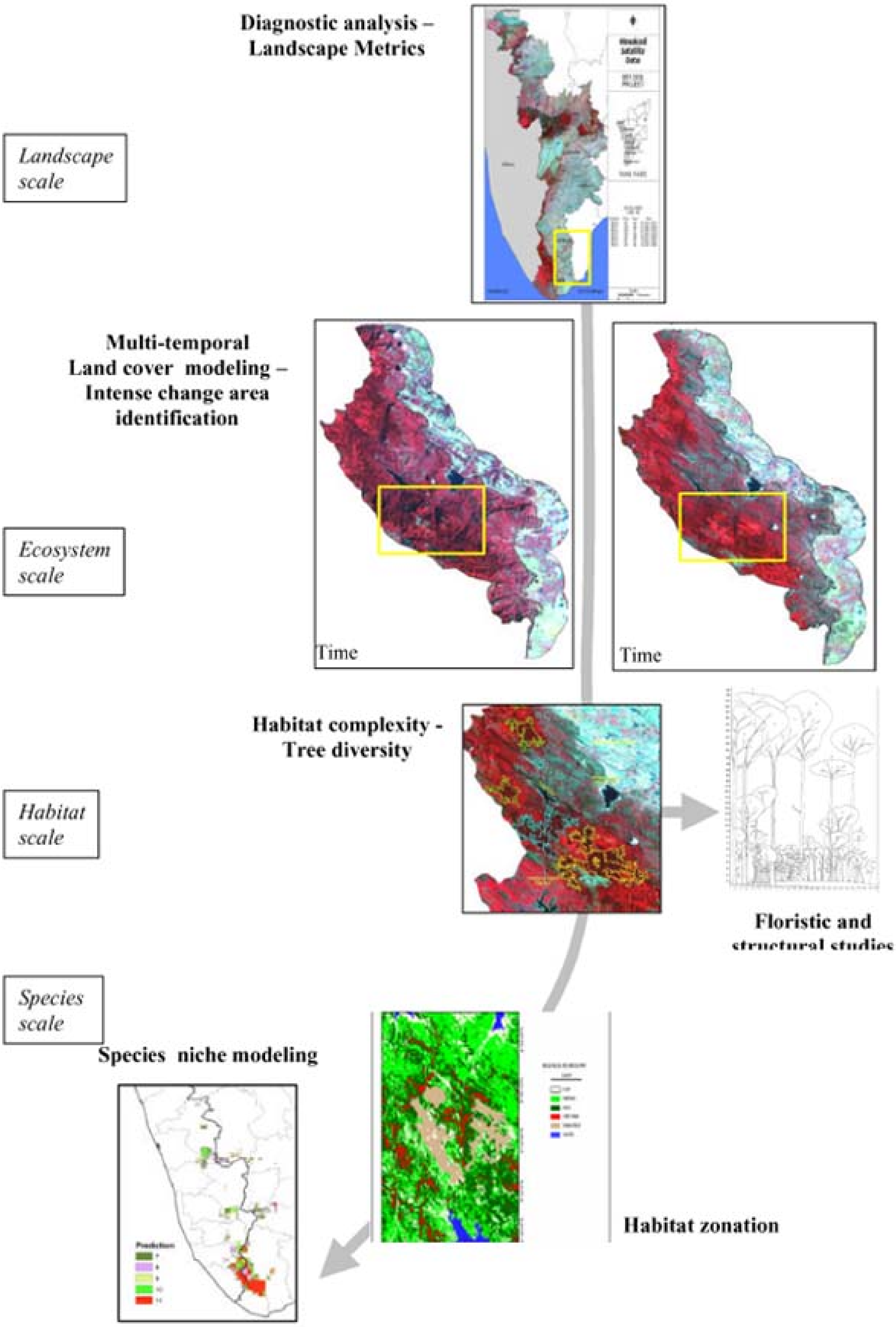

Figure 1. Geoinformatics in biological diversity – landscape to species approach.

campaign, without being perturbed by very high degree security clearance protocols as well as in multispectral mode compatible to medium resolution pixels. This enables synthesis of multiscale database in time and cost efficient fashion, in turn helping a desired framework for data plugging from varied research/operational domains. Such a high degree of details available with their regional and global scale spatial alignment stacked in the information system can be an ideal test bed to integrate local scale observations, manipulations, perceptions and aspirations into it. Developing scenarios of utilization, exploration and conservation of resources can be accomplished by virtue of image-based spatial modelling using GIS capabilities.

Floristic understanding of the regimes of diversity (Figure 2) is important, as far as the validity of the spatial information generated is concerned. End use of this information, especially to characterize the life form patterns and related resource allocation trends also add to the significance. Ability of this data to indicate several other bio-edaphic relations makes it unique as a signature of ecosystem health. Current phytogeographic problems such as invasive species, climate change linked species vulnerability and range of similar situations do rely on precise definition of baseline vegetation composition, which in turn relies on floristic data. Potential inherent in the remote sensing approach, to define vegetation patches better in terms of spatial contours, has strengthened the way sampling schemes are decided to understand the land cover health and changes. The significance lies in avoiding errors in field sampling, possibly arising due to non-understanding of vegetation and its biophysical set up in a continuum.

Very high resolution image-based information can act as the key link in upscaling phytosociological understanding. Currently the medium resolution dataset permits coarse level spatialization of this and limits a sound site scale appreciation at times. The upscaling can be spectrally and spatially explicit to yield a hierarchically robust teleology in managing diversity patterns.

Quantitative floristic inventories based on one-hectare plots have been used in recent years to characterize forest vegetation throughout the tropics[18,19]. Quantitative floristic inventory conducted using three-hectare plots showed high species richness, diversity and endemism. Species packing can be more reliably understood for fine scale understanding using plots of higher spatial coverage. Based on the species dominance, the Kakachi evergreen forests of Tamil Nadu can be designated as *Cullinea exarillata–Palaquium ellipticum–Aglaia bourdillonii* series[1,20]. Analysis of the floristic data in Kakachi reserve allowed the detection of five main mesoscale floristic units[1].

With the present conservative practices and increasing resident population due to tea, coffee and cardamom plantations activities in the core areas of Kalakad–Mundanthurai Tiger Reserve, the forest types can be expected to be disturbed evergreen system or fragmentation of climax forest or undergo change in type and kind of species in the near decade. The tribal/local people also exploit the natural resources for their regular need. Thus, management of medium elevated evergreen forests must necessarily depend on knowledge of recognizable community types and their environmental variables. These methods of data collection and analysis offer the environmental managers to

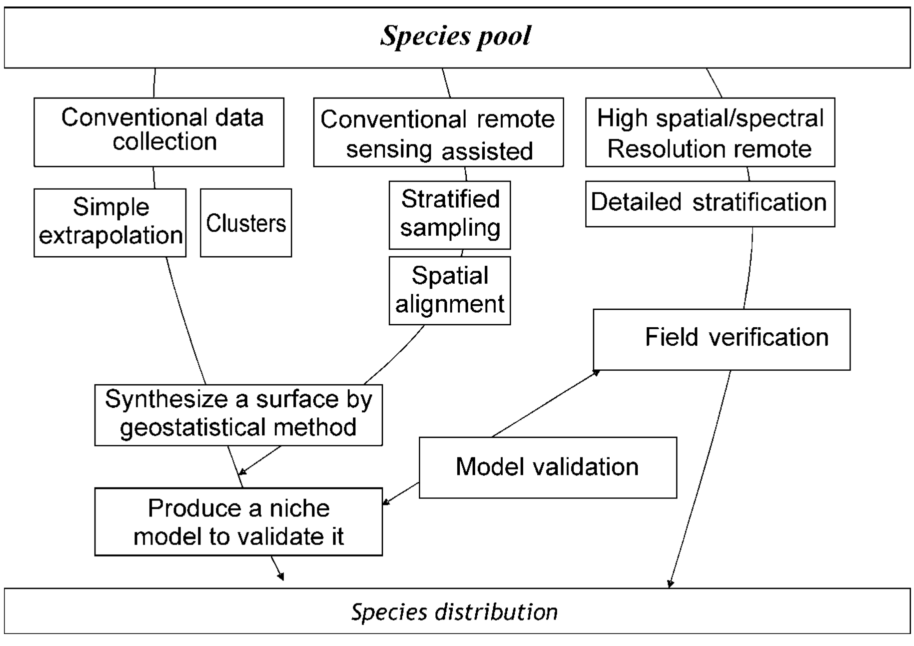

Figure 2. Understanding species presence – spatial and point-based approaches.

sustain and preserve such communities. This approach comprising of intrinsic data associated with landscape characteristics can be utilized by the ecologists to predict endemic habitat zonation.

Species niche modelling

Population spread of the species can be modelled on the basis of spatial logic using field samples collected using random or systematic scheme. Field data configured for spatial 2D alignment can be subjected to spatial autocorrelation tools of geostatistics to provide possible contours of spread of the species *per se* or its habitat. The method might rely on more assumptions, since predicted contours may mostly obey linear directive due to mathematical rigidity. The predictions in practice may be refined for nonlinearities, prevalent due to nature of biological compulsions, once the validation is effected. To overcome the problems inherent in such an approach, methods taking care of spatially corresponding parameters are devised, which would act according to a spatial model, which takes care of nonlinearity inherent in biological systems. In general, geographic information systems can be resorted to generate such a spatially explicit spread of the species by hierarchical rule sets. However, handling a large number of empirical as well as quantitative data, genetic algorithm-based tree classifiers has shown considerable promise. The ability to create possible set of rules by writing off the totally irrelevant ones, using chromosome formation logic, has opened immense possibilities to predict species niches across range of scales. Genetic algorithms operate on the same principle of retention of good, performing combination of genes.

Genetic Algorithm for Rules set Prediction (GARP) can be used to identify regional limits and managed habitat associations incorporating the fine-grained land use/land cover map and other bioclimatic variables. The environment uses genetic algorithm to arrive at different set of rules as alternatives with spatial inputs, for modelling the fundamental niche of a given species[21]. Whereas field observations are obviously from a realized niche, the model points to the habitability (theoretically possible fundamental niche) of the individual, which should in turn be validated[1,22,23]. GARP models of species' distributions visualized in geographic space are expected to provide a guide for future sampling. Modelling RET (rare, endangered and threatened) species using GARP can identify the probable areas of their occurrence for conservation purpose. Currently GARP is applied for modelling an endemic and threatened plant species *Aglaia bourdillonii* (Meliaceae) in Western Ghats to identify extent of ecological niche in geographical space[1]. The distribution of *Aglaia bourdillonii* is restricted mainly by terrain and topography. In fact, in conservation of *Aglaia bourdillonii* it is essential that the association of *Aglaia bourdillonii*, *Cullenia exarillata* and *Palaquium ellipticum* is conserved. This fact points to the potential of achieving conservation of multiple species by that of one specialist species.

Biodiversity in land resource management

Majority of the demographic situations capable of bringing about land use changes especially in biodiversity hotspots need to be handled for a win–win situation with greater reliance on participatory management. Prerequisite for a successful, strong sustainable solution would be a more non-language/non-text-oriented depiction of solution, rather than verbal or textual communication. Geoinformatic rendering of diversity-related data as well as scenarios can be a potential opportunity to associate various stakeholders with respective scales of operation. Multiresolution database comprising of information from landscape diversity to species level diversity should be part of such a plan, so that threats and opportunities with regard to local and regional diversity should be properly addressed.

Coarse resolution datasets along with regional modelling of anthropogenic demands in space and time can reveal the scope of staggered handling of biodiversity erosion. Diagnosis of pressures of commerce vis-à-vis diversity using geographic analysis especially in terms of proximities, market linkages, harvest channels, terrain amenability for access, sustenance demands, etc. would demarcate zones of immediate concerns. Based on such a scheme, participations may be initiated to induce required changes in land management. Objectives of dialogue can address: Significance of landscape level quality to the land manager; impact of networked action of natural resource managers/entrepreneurs on the upkeep of landscape health; adding global value to the resource by achieving conservation of individual species especially endemics and RET; Highlight the incentives accruing from the conservation for base level land managers.

Significance of regional level information network

Magnitude of land cover changes bringing in depletion of forested landscapes is varied across global contexts. Variability of degraded fragments in forest landscapes mainly in terms of permanence, patch size and shape, demands characterization across scales. Relevance of solutions to stabilize and manage, achieved at local scales of land use, can be valid elsewhere or at different scale. A strong network built around tools capable of demonstrating the approach spatially, can render immense support to the issue. Coarse resolution global scale databases attempting to characterize biodiversity would help to set a global context. Fine scale resolution-based information collected *in situ* (GPS survey) or interpreted (high resolution data) can be dovetailed into this, so that a spatial registry of such

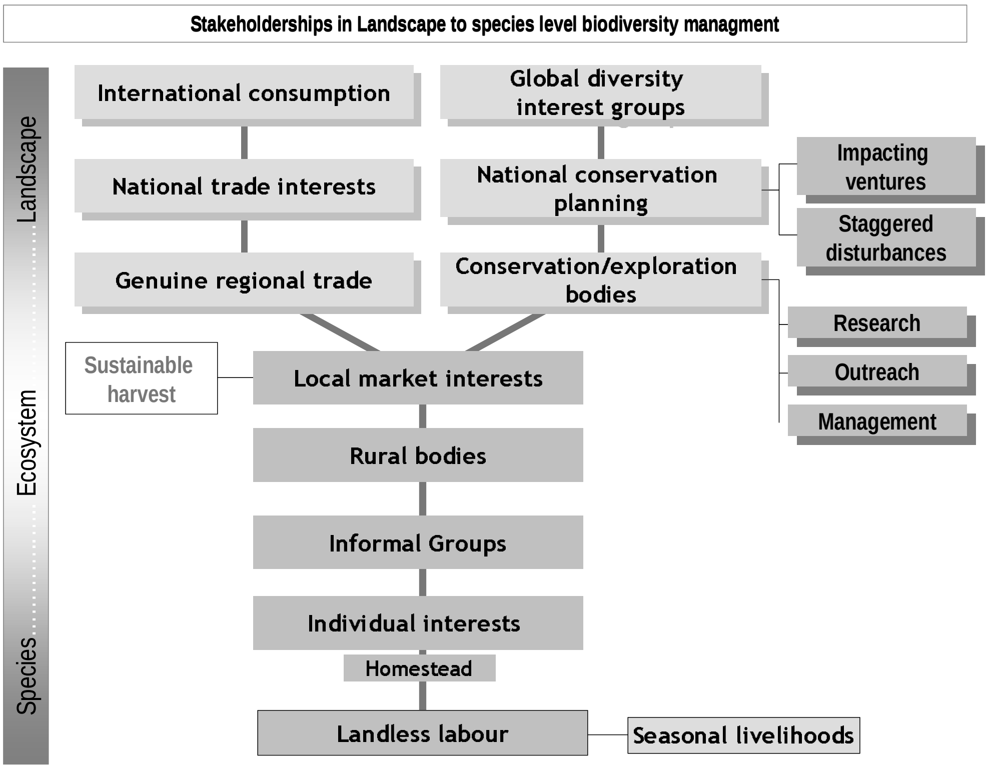

Figure 3. Stakeholdership in landscape to species level biodiversity management.

efforts is available on line. This can facilitate review and monitoring by a wide range of stakeholders (Figure 3).

Networking would help in bringing out the spatial and temporal magnitude of the precipitous situations. Many of the flagship species fall prey to illegal trade endangering sustainability of the complete trophic systems. Land use changes keep on inducing a low key, but high level erosion of the flora and fauna. Feedbacks by concerned groups on such instances and influence on policy through networks can help to stem the damage. On the other hand, genuine requirement of products and services based on diversity, often not considered bonafide, can be addressed by exploring newer productive contexts as well as alternate resources.

Diverse stakes ranging from sustenance to corporate interests can be moderated over a formalized network. Degree of tangibility of the species utility varies across hierarchy of scale. While most of ecosystem values of diversity are generally realized, for instance, just as value of a molecule or an infestation menace, their impact on the economy, health and other social systems is increasingly acknowledged. Intangible values like microclimate moderation, wilderness value, recreation, conservation of flagship species need to be internalized in the valuation system. Both values can be better realized based on feedback regarding impact on livelihoods of individuals, interest groups and regional economies available across the network.

Conclusion

Given the significance of the variability of the life and its variety, conservation paradigm should consider a seamlessly integrating information base for holistic action. Absence of such database can hamper the conservation efforts to be taken in a hierarchical fashion, hence may restrict action to conventional approach of attempting to revert to pristine systems. Deriving such a base can be a paramount prerogative of spatial information domain, wherein synergy of a suite of multispectral and multiresolution sensors on board satellite and aerial platforms is available. Enriching the information using the ground-based data to validate as well as to integrate with the satellite-derived datasets, on the lines of studies conducted using principles of landscape ecology, can facilitate a comprehensive approach in this regard. Database can be further put to advanced niche modelling to derive species distribution and potential habitats as defined by its biophysical parameterization. Derived spatial distribution suitably integrated with coarser scale information of spatial and non-spatial nature, can be used for resolving the stakeholder interests to achieve conservation and sustainability, by geospatial query, visualization and analysis.

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