Meso-scale analysis of forest condition and its determinants: A case study from the Western Ghats region, India

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We present here preliminary results from a meso-scale analysis of forest condition in a region of the Western Ghats of India where the nature and extent of forest degradation and its causes have been intensely debated. We use 1 : 35,000 scale aerial photographs of 1973 to generate a detailed land-cover map, and overlay legal forest regime and village boundaries to associate forest condition with the rights regime and village-level socio-economic data. The differences between our land-cover map and an official forest cover map for that region are significant. Although denudation is expectedly higher in areas accessible to local communities than in state-controlled areas, both the absolute levels and the relative differences are much lower than indicated in the official map or earlier studies. Denudation in private access forests appears to be significantly influenced by the cropping patterns in the villages. We discuss the concerns in applying remote sensing and geographic information system techniques to densely populated and diversely utilized forests, highlighting the need for greater access to aerial photographs, the appropriate characterization of forest condition, and attention to slope information and positioning errors.

Development of sound forest conservation and management strategies requires an understanding of the spatio-temporal patterns in forest condition and of the biophysical and socioeconomic processes influencing these patterns. Generating such an understanding becomes simultaneously more pressing and difficult when centralized government agencies are not the only actors in the forest landscape, when the forest is a highly 'social' one[1], used and modified for a variety of purposes by a multitude of actors dispersed throughout the forested landscape.

Under these conditions, which prevail in India and much of south and southeast Asia, 'macro'-scale information on the extent of and trends in forest cover at the national, state or even district-level[2–4] does not suffice for policy formulation as it is too coarse. Attempts to correlate this information with country, state- or district-wise socioeconomic data have provided only broad indications[5,6]. 'Micro-scale' interdisciplinary field studies[7–9] are therefore essential for understanding the complex processes leading to the social use and misuse of forests. But such studies do suffer from limited generalizability as they are perforce conducted at the scale of a village or a few villages, and may miss larger-scale variations. There is thus a role for 'meso-scale' studies that can incorporate sufficient detail on local biophysical and socioeconomic conditions yet cover a large enough region so as to test and extend the micro-level insights and provide a basis for sound policy formulation.

The rapidly developing techniques of remote sensing (RS) and geographical information systems (GIS) can potentially play a significant role in such meso-scale analyses of forest condition and its determinants[10]. However, given that these techniques have initially been developed in North America and tested in regions such as the USA and the Amazon, their applicability in the Indian context needs to be carefully evaluated. We present here the preliminary results of a meso-scale study to estimate forest condition and understand some of its determinants in the Western Ghats region of peninsular India and also discuss the methodological insights gained through this effort.

Objectives of the study

The forests of the Western Ghats region of peninsular India have undergone significant transformations over the past century, and the nature, extent and causes of these transformations have been intensely debated[11–1]. We initiated a study to understand the condition of the forests and its relationship with forest rights regime and other village-level socioeconomic variables for part of Uttara Kannada district of Karnataka state, which is a heavily forested district straddling the Western Ghats. In this paper we present preliminary results from our attempts (i) to generate a land-cover map of the region for the year 1973 (a period prior to the initiation of large-scale afforestation activities in the region b

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the state forest department) and to compare it with existing benchmarks, (ii) to understand the influence of the distinct rights regimes governing forest use in the district on forest condition, and to explore the role of agricultural systems and population growth on forest condition within these regimes.

Study area and data

The study was conducted in Uttara Kannada district, which is covered by two sets of relatively high-resolution aerial photographs (1 : 35,000 and 1 : 25,000 scale b&w prints) taken at an interval of almost two decades (1973 and 1992 respectively). Its forests are governed by three distinct regimes of forest rights: Reserve Forests (RFs) that are largely state-controlled, Minor Forests (MFs) that are open-access, and *soppinabetta* lands that have privatized access. The entire uncultivated landscape is governed by one of these three regimes, and they have been in force for more than a hundred years. Uttara Kannada is also the only district in the state (and possibly in the entire Western Ghats region) where the boundaries of these legal forest regimes and cross-cutting village boundaries are indicated on theodolite survey maps (Bombay Forest Survey maps of 1897 at 4″ = 1 mile scale).

The sample region chosen for this study is the area around Sirsi town (14°37′N lat./74°50′E long.) coinciding with the boundaries of one 1 : 50,000 scale toposheet published by the Survey of India (reference number 48J/14). The terrain is a rolling one, with the valleys given over to agriculture, primarily arecanut orchards and paddy fields, and the hills covered with forests. Local communities extract large quantities of leaf manure and mulch, fuelwood, fodder and small timber from the forests, especially from the *soppinabetta* and MF lands to a lesser extent from state-controlled and RFs. Consequently, the forest landscape is a mosaic of different vegetation morphologies, including dense groves, tree savannas, pure grassy patches, and degraded scrub. Of particular importance is the formation of 'telephone-pole' tree morphology in the *soppinabetta* lands due to heavy pruning or lopping for leaf manure/mulch, similar to that observed in lopped oak forests in the Western Himalaya[15]. Thus, the relationship between tree canopy cover and tree density or standing biomass is quite different for these patches than it is in unlopped forests. Similarly, highly productive grasslands actively managed by livestock owners[16] can, in dry season imagery, be easily confused with degraded scrub or barren land on the one hand, or with harvested paddy land on the other.

Land cover classification and interpretation

At the outset, those areas clearly managed by the forest department, viz. forest plantations and clearfelled land, were distinguished from 'natural' forest. Then, keeping in mind the vegetation morphologies described above, the natural forest was categorized on the basis of tree densities and other vegetation into the following classes: (i) high-density forest (> 400 trees/ha), (ii) medium density forest (250–400 trees/ha), (iii) low density forest (100–250 trees/ha), (iv) tree savannas (25–100 trees/ha, usually with grass in the understorey), (v) degraded scrub or barren land, and (vi) pure grasslands. (For the purpose of calculating tree densities, trees were defined as single-stemmed plants with girth at breast height greater than 10 cm.) Other land-cover classes identified annual cropland, arecanut orchards, other orchards (coconut/cashew), settlements, water bodies and roads. The interpretation key for these land cover classes is given in Table 1.

Ground data were collected through a number of visits to the field. Qualitative information was gathered at over a 100 points, and tree densities were estimated using 30 strip transects. Efforts were made to (i) take samples in locations that appeared unchanged from 1973 (by comparing with 1992 photographs) and (ii) to ask local villagers of the condition of the particular patch 20 years ago. The photographs were interpreted using mirror stereoscopes, with each run traced on one sheet and the sheets mosaiced after digitization. Although the unavailability of actual ground data for 1973 prevents a full-fledged assessment, the interpretation accuracy is estimated to be more than 90% for most land cover classes, except in distinguishing between degraded scrub and grassland and between low-density forest and tree savannas, where it is estimated to be about 80%.

Overlays

Eight Bombay Forest Survey maps (reference nos.280/NE1-4 & 280/SE-14) were obtained and the legal (RF/MF/*soppinabetta*/revenue) and the administrative (village) boundaries were digitized as separate layers. The digitized results were checked by comparing the village-wise areas with official figures provided by the Forest Department, and errors corrected to the extent possible using individual village cadastral maps. The number of villages with an acceptable error in each forest regime boundary ($\leq 15\%$ or ≤ 10 ha error in area) came to 66 out of a total of 151 complete villages in the sample region. The interpreted land cover layer and the village and forest regime layers were brought to a common projection and overlaid. Root-mean-squared (RMS) error of ~ 50 m was observed when attempting to overlay the land cover layer onto the administrative boundary layer. Hence a buffer of 100 m (2*RMS) was used (i.e. points within 100 m of the boundary of any administrative/legal boundary were not considered) when calculating the percentage of different land cover types in each village or legal forest category.

Land cover in Sirsi region in 1973

Our land-cover map (Figure 1) differs significantly from a forest cover map prepared by the Forest Survey of India (FSI; Figure 2). The FSI map shows more area under forest plantation and agriculture and much less under high density forest (Table 2). Such difference between two maps based on photographs taken only 6 years apart is surprising. The difference in resolution of the two source photographs does not explain these differences in the results. With higher resolution, one would expect more accurate depiction of boundaries and systematic area increases only in the case of features that are typically thin/small. This description applies only to agricultural lands, but in fact the area under agriculture is lower in the map prepared with higher resolution photographs. A closer examination reveals the following.

a) The FSI map indicates an area of more than 8000 ha under forest plantations, whereas our estimate is ~ 1300 ha. It is likely that all the area seen as clearfelled in 1973 was replanted and hence classified as plantations in 1979; but this would account for at most 1600 ha of the difference. Large areas in the southwest quadrant are depicted as forest plantations in the FSI map, but most of them appear as medium or low density lopped forest or savanna with lopped trees in our interpretation. Extensive traverses through the region and examination of forest department records indicate a complete absence of forest plantations in the southwest quadrant in the 1970s. It seems therefore that the FSI has misinterpreted the lopped morphology and relatively even spacing of trees in *soppinabetta* lands as plantations. This becomes clearer from Figure 3, which presents closeups of the two maps for a cluster of villages that we had studied in detail earlier in collaboration with the Centre for Ecological Sciences[9]. The closeups also indicate some misclassification of arecanut orchards as high density forest in the FSI map. Both misclassifications are an

Table 1. Interpretation key for black and white aerial photographs (1 : 35,000 scale)

Landcover class	Characteristics in aerial photographs: Tone	Texture	Shape	Size	Association	Slope
Cropland	Med. grey to white	Smooth	Long, irregular	~ 1–100 ha	Invalleys	Nil/gentle
Arecanut	Dark grey/black	Smooth	Regular: thin and long	~ 1–10 ha	In narrow valleys	Nil/gentle
Grassland	Light grey/white	Smooth	Irregular	~ 1–10 ha	Cultivation edge, fenced	Gentle/ moderate
Degraded scrub/ barren	Light grey/white/ spotted	Mottled, rough	Irregular	~ 1–100 ha	Often around roads, hilltops	Mixed
Tree savanna	Light-medium grey	Dotted trees, smooth understorey	Irregular	~ 1–100 ha	Often fenced	Mixed
Low-density forest	Medium-dark grey/ black	Dotted trees/ clumps	Irregular	~ 1–100 ha	100–250 trees/ha	Mixed
Medium-density forest	Dark grey/black	Rough, canopy has many gaps	Irregular	~ 1–100 ha	250–400 trees/ha	Mixed
High-density forest	Dark grey/black	Rough, closed canopy/very dense dots	Irregular	~ 1–100 ha	> 400 trees/ha	Mixed
Clearfelled	Light grey/white/ spotted	Mottled, rough	Regular: straight edges, often rectangular	Large: ~ 20–100 ha	Distinct height change at edges	Mixed
Forest plantation	Dark grey/black	Smooth	Regular: straight edges, often rectangular	Large: ~ 20–100 ha	Little height variation in trees	Mixed
Settlement	White and black/ grey	Rough	Regular	Small (~ 1 ha) except in towns	Usually trees on edges	Flat
Water bodies	Grey/black	Smooth	Snaky (river) or semi-cicular (tanks)	Variable	Tanks at upstream end of cultivation	Flat
Other orchards	Grey	Dotted (individual trees visible)	Regular	Small (~ 1–10 ha)	Next to cropland	Gentle
Roads	White/light grey	Smooth	Thin, snaky	Very narrow	Trees along edge	Mixed

indication of unfamiliarity of the interpreters with the specifics of the region being interpreted (see association, shape and size clues in the interpretation key in Table 1).

b) The extent of agriculture (including settlements) in the FSI map is about three times the area of cropland plus arecanut orchards and settlements estimated in our study. This might suggest a dramatic expansion in cultivated area in the 6 years between 1973 and 1979. But an examination of 1992 photographs or a visit to the field indicates otherwise. The closeups in Figure 3 show that degraded scrub and grassland are misclassified as cultivated land in the FSI map. As the interpretation key in Table 1 indicates, there is often little difference in the tone and texture of these land-cover types. But we found it possible and essential to use slope information (derived stereoscopically from the photographs) to demarcate the edge of croplands.

c) Our map indicates a much larger area under high-density forest than estimated by FSI. Part of this difference is explained by the different definitions: in *soppinabettas*, it is possible to find patches with density more than 400 trees/ha but having lopped morphology that results in crown cover of less than 60%. This appears to be the case in the western edge of the mapped region. On the eastern side, the difference appears to have been introduced due to crude cartographic generalizations of the cultivation boundaries in the FSI map.

Variation in forest condition across forest rights regimes

The variation in forest condition across forest rights regimes was estimated in terms of the percentage of each land cover type in the total area in each regime. For the sample region as a whole the distribution of

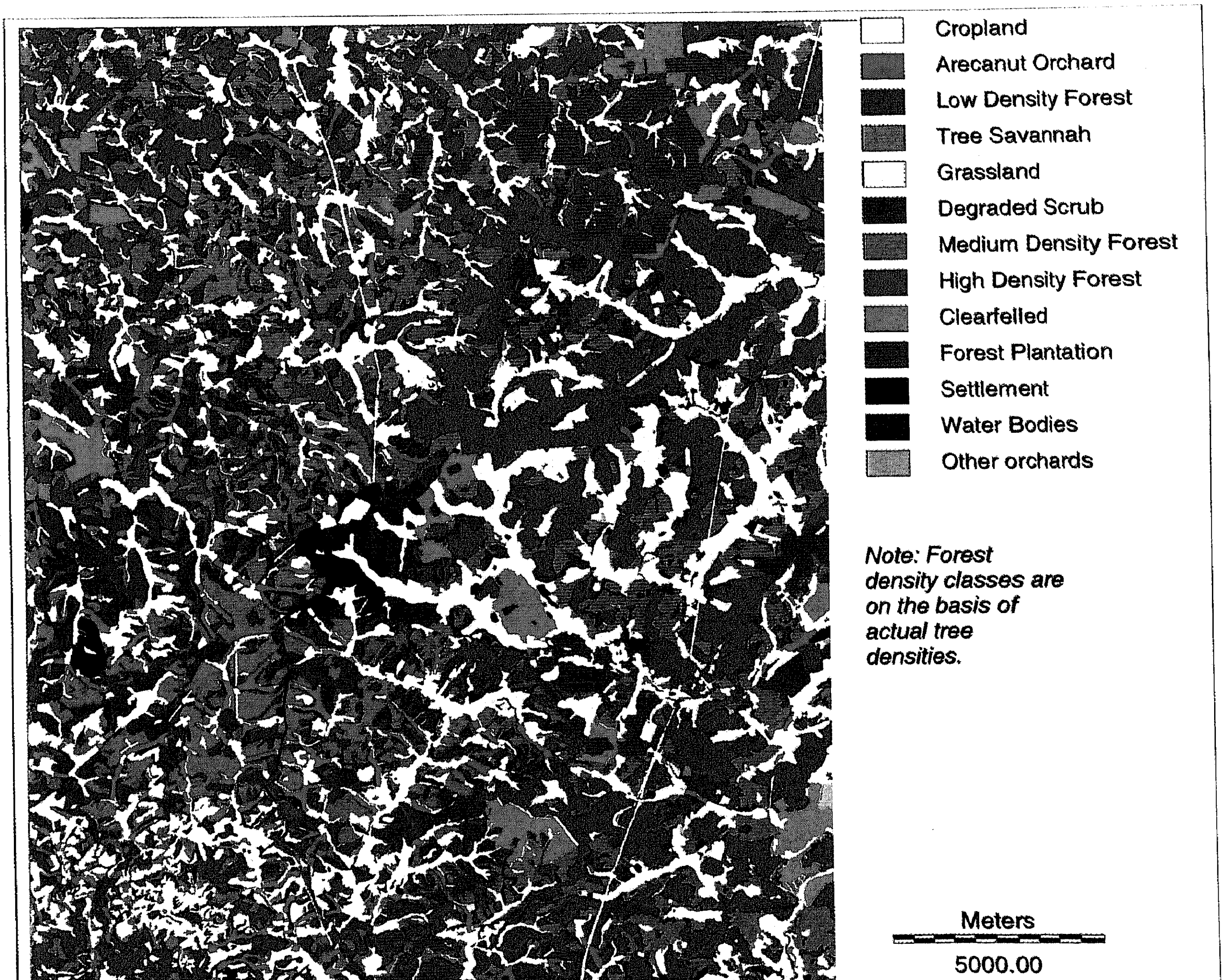

Figure 1. Land cover in Sirsi region of the Western Ghats in 1973 as per present study.

land cover in each regime, estimated using the 100 m buffer on the legal boundaries, is given in Table 3. For select villages for which a much better fit of the vegetation map was obtained (RMS error ~ 30 m), the unbuffered results are presented in Table 4. For comparison, we present in Table 5 estimates given by Shyam Sunder and Reddy[11].

Our results indicate the following:

a) The fraction of degraded scrub plus grassland – which can legitimately be called 'denuded' land[17] – comes to 20%, 18% and 5% of the *soppinabetta*, MF and RF areas respectively in the buffered sample. The results do not change significantly in the unbuffered case: denuded fraction increasing somewhat for the RF, indicating the 'nibble' effect on its periphery. In all cases, the percentage of denudation is significantly lower than the estimates given by Shyam Sunder and Reddy. Even the inclusion of tree savanna areas into the 'denuded' category does not substantialy alter this finding.

b) That RFs are most densely forested is not surprising as they are both under state control and also demarcated in relatively sparsely populated area. More interestingly, the fraction of *soppinabettas* and MFs with significant tree cover (low, medium or high density forest) is also very substantial, being 48% and 59% respectively (unbuffered results). Note that our definition of low-density itself corresponds to 100–250 trees per hectare. This suggests that local communities do not continuously 'degrade' forests: they prefer to maintain a land cover in a form that is most suitable to them, viz. heavily pruned trees that produce leafy biomass for mulch and

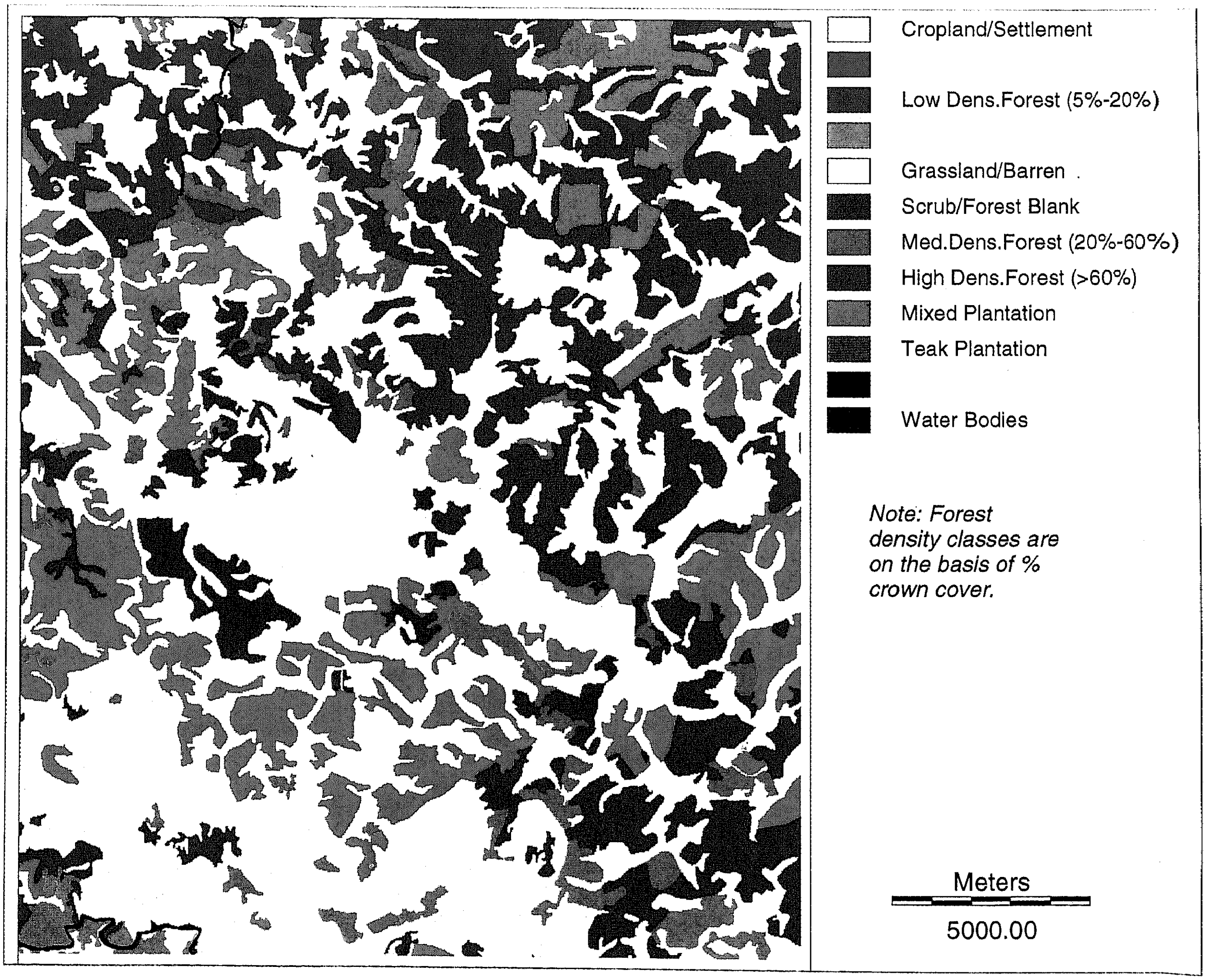

Figure 2. Land cover in Sirsi region of the Western Ghats in 1979 as per Forest Survey of India.

manure and permit the growth of fodder grasses in the understorey.

c) It is also worth noting that 21% of the RF area (estimated from the buffered sample, which has a wider coverage) has been converted into plantations or has been clear-felled. In absolute terms, this is more than the combined total area of degraded scrub, grassland and tree savanna in *soppinabetta* and MFs. This indicates that the state forest department is also responsible for very substantial modifications of the forest landscape.

Effects of other socioeconomic factors

A regression analysis of denuded fraction in each of the three regimes against four independent variables, viz. population, livestock, area under arecanut and area of cropland was carried out. In the case of *soppinabettas*, arecanut area turns out to be the only significant independent variable ($p < 0.05$, $r^2 = 0.3$), whereas in the case of MFs and RFs, no significant correlates were observed. Though the analysis is preliminary, the result suggests that degradation of *soppinabetta* is primarily due to increased demand for mulch and manure for expanding arecanut cultivation.

Discussion and concluding remarks

We have shown that the extent of forests – not tree canopy cover but the presence of natural trees as such – in the hilly agricultural region of Uttara Kannada district in 1973 was higher than estimated by either the accounts of state foresters or the forest map prepared by the Forest Survey of India. We have also shown that the extent of unequivocal degradation in areas legally accessible to local communities was much lower than official estimates, and that much of the transformation is from closed canopy forests to open canopy tree-grass combinations: a transformation that may increase the production of socially useful biomass. The absence of difference in the level of denudation in private access and open-access regimes runs counter to that expected from the theory of natural resource economics[18] and needs further analysis. While state-controlled forests show lesser area under degraded scrub, they have witnessed very substantial clearfelling or conversion to plantations by the state forestry agency.

Methodologically, this study highlights the potential of, and pitfalls in, the use of remote sensing and GIS for the meso-scale analysis of forest degradation in the context of densely populated and diversely utilized forest regions in the tropics.

Firstly, high-resolution imagery and small minimum mappable units are an absolute must for such analyses. Aerial photographs are available for periods earlier to IRS 1C data at a much better resolution: 1 : 25,000 scale prints can, under magnification, effectively resolve trees ~ 5 m apart. But they are not generally available to the scientific community owing to outdated national security concerns, at least in India. It is imperative that these valuable sources of land-cover information be made easily available to the scientific and general community.

Table 2. Comparison of land cover estimates from Forest Survey of India map and land cover map from present study

Source	FSI	This study
Year of photos	1979	1973
Scale of source photos	1 : 50,000	1 : 35,000
Land cover category	Area (ha)	Area (ha)
Agriculture	21,015	5,438
Areca plantation	–*	2,048
Grassland	3,024**	4,320
Scrub	1,392	7,564***
Low-density forest	2,939	7,821
Medium-density forest	3,105	6,710
High-density forest	9,615	10,968
Clearfelled	–	1,661
Forest plantation	8,037	1,339
Settlements	–*	763
Other (Other orchards, water bodies, roads, uninterpreted)	122	619
Total	49,249	49,251

*Included in agriculture
**Includes barren/waste/forest blank
***Includes tree savanna.

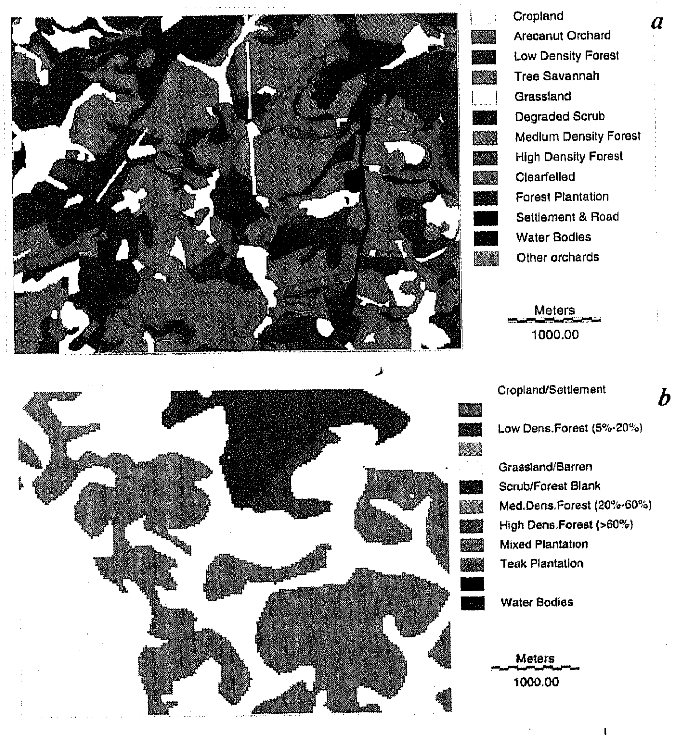

Figure 3. Closeup of portion from southwest quadrants of mapped region: (*a*) present study, (*b*) FSI map.

Table 3. Land cover in different legal regimes estimated using 100 m buffer on legal boundary

Land cover	Fully private (revenue) land (%)	Private access forest (Soppinabetta) (%)	Open access forest (MF) (%)	State controlled forest (RF) (%)
Cropland	36	3	3	4
Arecanut orchard	3	4	1	1
Degraded scrub	17	14	16	2
Grassland	15	6	2	3
Tree savanna	3	23	7	2
Low-density forest	5	24	19	8
Medium density forest	3	15	19	13
High density forest	6	9	24	47
Clearfelled	2	1	6	8
Forest plantation	0	0	1	13
Other	10	2	2	0
Total	100	100	100	100
Sampled area (ha)	2012	2962	3213	8667

Table 4. Land cover in select villages estimated without buffering

Land cover	Fully private (revenue) land (%)	Private access forest (Soppinabetta) (%)	Open access forest (MF) (%)	State controlled forest (RF) (%)
Cropland	33	3	6	7
Arecanut orchard	13	4	1	1
Degraded scrub	8	12	14	5
Grassland	13	6	4	5
Tree savanna	4	25	11	2
Low-density forest	11	26	21	8
Medium-density forest	7	17	16	12
High-density forest	7	5	22	45
Clearfelled	1	0	3	7
Forest plantation	1	0	1	8
Other	2	2	1	0
Total	100	100	100	100
Sampled area (ha)	1944	2208	1962	2789

Table 5. Estimated denudation in different forest regimes in Uttara Kannada district (Shyam Sunder and Reddy)[11]

	Denudation (%)	
Regime	1960	1980
Soppinabettas	51	82
Minor Forests	46	95
Reserve Forests	3	22

Secondly, the conventional categorization of forest condition in terms of tree crown cover may be particularly inappropriate for characterizing forest condition when crown cover is likely to be poorly correlated with the ultimate parameters of concern such as the production of useful biomass. Alternative categories and interpretation techniques will have to be evolved.

Thirdly, accurate interpretation requires that interpreters be thoroughly familiar with the landscape and the agro-silvicultural practices of the region being interpreted, demanding more effort in ground truthing. The role of RS as an authentic means of monitoring ground conditions should not be compromised[19]. Fourthly, slope information is an extremely important clue to image interpretation in the context of land-cover mapping[20].

Finally, the application of RS and GIS to assessing the variation in land-cover across legally distinct parcels of land is seriously constrained by the problem of positioning errors, a problem that is distinct from that of spatial resolution. Positioning errors of 100 m may be irrelevant when generating a forest cover map for a 700 km^2 region, but are often critical in regions of intense landuse where holding sizes are of a few hectares. Positioning errors accumulate from several sources: imagery, interpretation, cartography, and the base maps. The scarcity of good quality geo-referenced maps showing legal and administrative such boundaries is a particularly serious constraint: the maps we had were a century old, and had undergone serious distortion, and for most other areas un-referenced and un-mosaiced cadastral maps are the only current source of such boundary information. Overcoming such constraints will be the challenge of meso-scale RS–GIS work in the future.

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MEETINGS/SYMPOSIA/SEMINARS

IBRO Seminar on Neuroscience

Date: 6–13 December 1998
Place: Mahabaleshwar

The 1998 Mahabaleshwar Seminar series will be an intensive course of lectures and discussions The areas expected to be covered include properties of cells in the nervous system, communication between excitable cells, sensory systems, signal processing, neural development and systems neuroscience.

Participation is particularly sought from Ph D students and post-doctoral fellows interested in pursuing a career in Neuroscience research and young investigators likely to initiate research programmes in the area. Application on plain paper should include a brief statement of purpose, curriculum vitae and sealed letters of recommendation. Local hospitality will be provided to all selected candidates. Limited number of travel grants are available for deserving applicants. Applications should reach the address below, by 15 September 1998. Selected candidates will be informed by 15 October 1998.

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VII International Symposium on Avian Endocrinology

Date: 28 January to 2 February 2000
Place: Varanasi

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Diamond Jubilee Celebrations and 39th Annual Conference of 'Association of Microbiologists of India'

Date: 5–6 December 1998
Place: Mangalore

There will be symposia on the following topics: Agricultural microbiology; Microbial biodiversity and biotechnology; Aquatic and environmental microbiology; Medical and veterinary microbiology; Food and dairy micro-biology; Industrial microbiology and biotechnology.

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