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Assessment of large-scale deforestation in Sonitpur district of Assam

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The study highlights the deforestation and encroachment in the moist deciduous and other forest areas in Sonitpur District of Assam. The time series analysis of satellite imagery was carried out. Satellite images of 1994, 1999 and 2001 and intensive ground truthing were used for forest type mapping and change detection. Alarming rate of conversion of well-stocked forests into cultivable land was noticed. The spatial distribution of forests showed progressive decline from 1994 to 2001 through 1999. The loss of forest cover was more pronounced between 1999 and 2001 than between 1994 and 1999. This coincides with increased levels of insurgency in lower Assam. An overall loss of 232.19 km^2 of forests was noticed in the Sonitpur District between 1994 and 2001. The study demonstrates unique potential of remote sensing and geographical information system for forest cover assessment and monitoring.

TROPICAL regions around the world are currently experiencing rapid, wide ranging changes in the land cover. The changes in the land cover, in particular the tropical deforestation, have attracted worldwide attention because of their potential effects on soil erosion, run-off and carbon dioxide level[1]. Large-scale deforestation has been reported in India in the past[2]. Forest cover in India has more or less stabilized after 1980 due to ban on clear felling. However, forest degradation and small-scale deforestation still continue. The loss of forest cover in India for the period between 1990 and 2000 is 380.89 km^2, annually as reported by FAO[3] and 1889 km^2 between 1991 and 1999 as reported by Forest Survey of India[4].

The state of Assam falls in the tropical climate belt in the northeastern region of India. The state is well known for its rich flora and fauna. Out of 15,000 flowering plants reported from India, 5000 grow in this region. The forest areas form a network of habitat patches in the primarily agricultural landscape of Assam. These forests fall in one of the two mega biodiversity hot spots identified in India, viz. the Western Ghats and the Eastern Himalayas. Recorded forest area is 3.07 million ha, which constitutes 39.15% of the geographical area of the state. According to the legal classification, reserved forests constitute 59%, protected forests 13% and unclassed forests 28% (ref. 4). Agriculture occupies a significant place in the economy of the state and forms the major occupation of the people. The average density of population per

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km^2 in Assam (286/km^2) is slightly higher than that of the whole country (273/km^2)[5]. The state of Assam is facing insurgency for quite sometime. Taking advantage of the disturbance, local people have clear-felled large areas of forests in lower Assam.

Monitoring of deforestation in the state using ground-based methods has become a difficult proposition due to insurgency. Satellite remote sensing is a better option under such situations. Temporal images allow detection of land cover changes over a period of time. Beginning in 1972, when the first Earth Resource Technology Satellite (ERTS) was launched by USA, satellite remote sensing has established its use in assessment and monitoring of the forest resources[6]. Its capability to provide real-time data with synoptic and repetitive coverage gives significant advantages over traditional methods. Remote sensing has played an important role in generation of valuable information on the forest cover, vegetation type and land use changes[7–11]. Remote sensing data coupled with geographical information system (GIS), offer good opportunities to monitor regional ecosystem processes in tropical environments that are undergoing rapid change[12]. A large number of studies have been carried out using visual interpretation techniques. Howarth and Wickware[13] have discussed the procedures for environmental change detection. Nelson and Holben[14] delineated the extent of deforestation in Rondonia, Brazil from MSS, LAC, GAC and GOES in order to identify appropriate satellite data for monitoring deforestation on continental scale. Temporal Landsat MSS data have been used to detect changes in forest cover due to shifting cultivation by Miller *et al.*[15] and Eden[16]. Singh[17,18] has evaluated automated methods for forest change detection. Leucas *et al.*[19] suggested a post-classification change detection technique based on time series analysis of Landsat data. Forest to agriculture conversion and extent of shifting cultivation were investigated earlier[20–22]. These studies relied on visual interpretation technique. In general, visual interpretation technique has been more successful than digital techniques in mapping tropical vegetation[12]. Sader *et al.*[23] have concluded that vegetation diversity and interspersion of land cover are high in humid tropics and spectral reflectance characteristics of mixed vegetation are often not distinct, causing problems in digital classification. The present study was undertaken mainly to highlight the ongoing large-scale deforestation in Sonitpur District of Assam in north-eastern India.

The entire district of Sonitpur, Assam (Figure 1), which falls in 9A and 9B biogeographic zones, i.e. northeast Brahmaputra valley and northeast-northeast hills[24] was covered in this study. The geographical area of Sonitpur is 5103 km^2. It is located on the right bank of river Brahmaputra within 26°24′ and 26°59′N latitude and 92°18′ and 93°48′E longitude. Land use in the district is divided primarily among tropical semi-evergreen, moist deciduous, riverain forest, grassland, agricultural land and tea garden. According to Champion and Seth[25], Sonitpur has east Himalayan moist deciduous forest (I/3/3c/3cb), Assam valley semi-evergreen forest (I/2/2B/C1), eastern alluvial semi-evergreen forest (I/2/2B/2S2) and riverain forest. Moist deciduous forests dominate the forest cover in the district. The temperature ranges from 7°C in January to as high as 38°C in May. The annual rainfall in the district is 2393 mm (ref. 26). Both south-

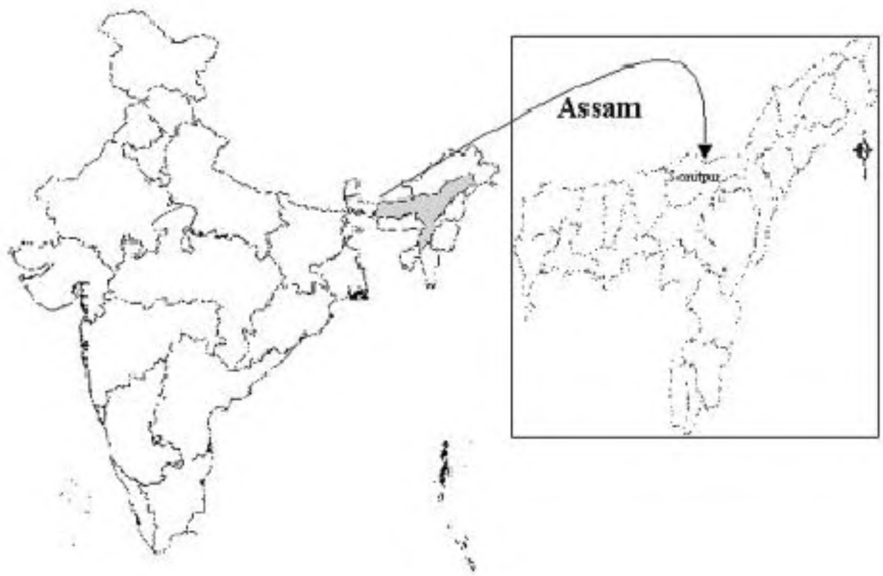

Figure 1. Location of the study area.

Table 1. Satellite data used for the study

Data type	Path/row	Date of acquisition
Landsat-TM	136–41,42	25 January 1994
Landsat-TM	136–41	27 January 1999
IRS-1C LISS-III	111–52	4 March 2001

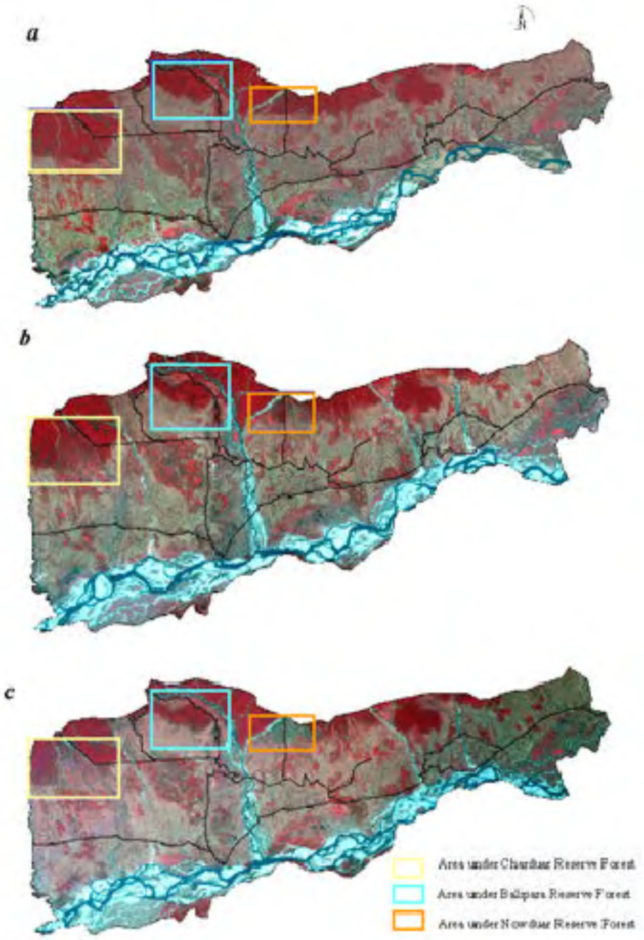

Figure 2. False colour images of Sonitpur pertaining to periods ***a***, Landsat-TM (136-41/42), 25 January 1994; ***b***, Landsat-TM (136-41) 27 January 1999; ***c***, IRS-1C LISS-III (111-52) 4 March 2001.

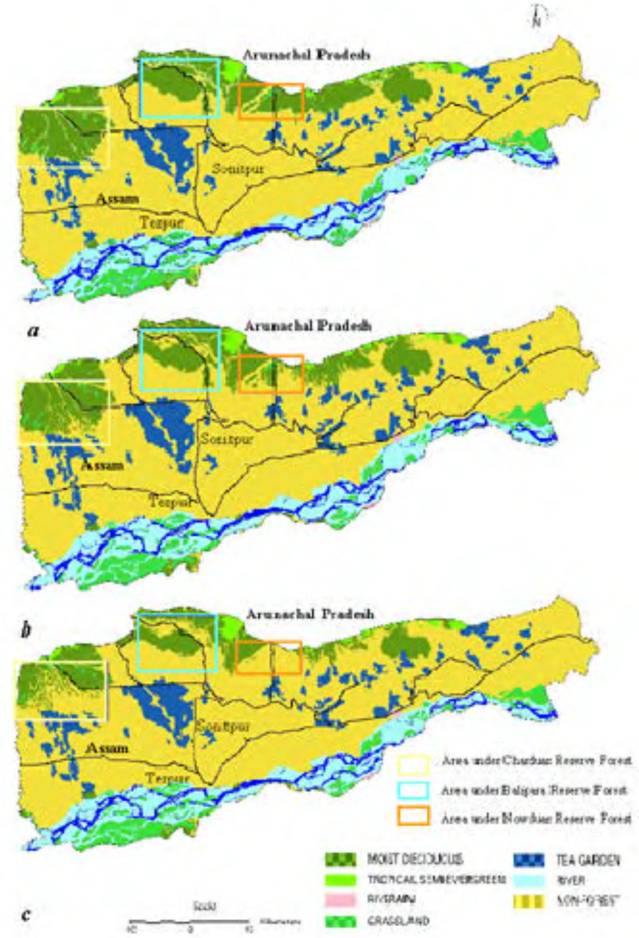

Figure 3. Forest and other land cover categories in Sonitpur.

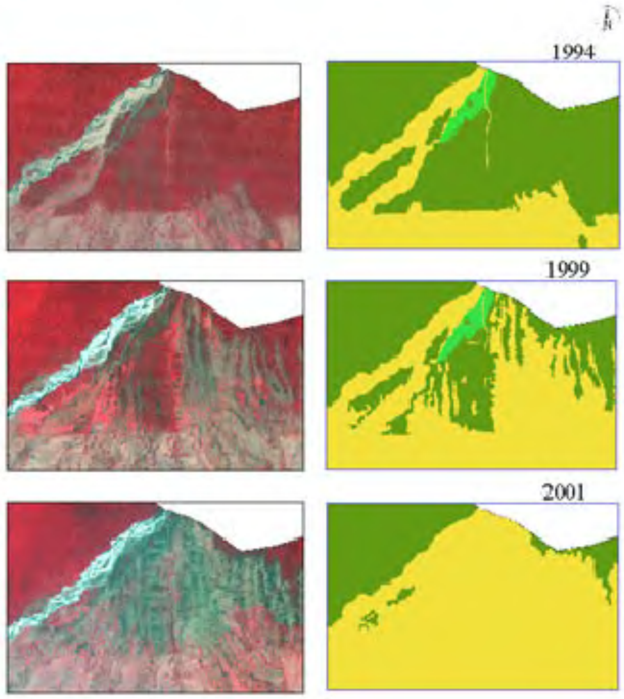

Figure 4. Subset of area around Nowduar Reserve Forest showing deforestation.

west and northeast monsoons bring rain to this region. Relative humidity ranges from 67% (in March) to 87% (in July)[27].

Landsat Thematic Mapper and IRS 1C LISS-III digital data pertaining to 1994, 1999 and 2001 were used to monitor the forest cover changes. Details of the data are given in Table 1. Survey of India (SOI) toposheets and Forest Survey of India (FSI) report for Assam were also consulted and used as collateral data.

Ground truthing was done in December 1999 and May 2001. Landsat-TM scene and IRS LISS-III were radiometrically corrected using dark pixel subtraction techni-

Table 2. Area (km^2) and species composition under different forest and non-forest categories in Sonitpur

Category	1994	1999	2001	Net change	Species composition
Moist deciduous	743	656.76	513.36	(–) 64	*Terminalia myriocarpa*, *Duabanga grandiflora*, *Pterospermum acerifolium*, *Ailanthus grandis*, *Bombax ceiba*, etc.
Tropical semi-evergreen	59.70	59.19	57.15	(–) 2.55	*Artocarpus chaplasha*, *Dipterocarpus turbinatus*, *Tetrameles nudiflora*, *Castanopsis hystrix*, *Vatica lancaefolia*, *Terminalia bellerica*, etc.
Riverain	7.65	7.65	7.65	Nil	*Bombax ceiba*, *Terminalia arjuna*, *Albizia lebbeck*, *Dalbergia sissoo*, *Lagerstroemia speciosa*, etc.
Grassland	249.03	251.07	250.56	(+) 1.53	*Saccharum* sp., *Arundinaria* sp., *Erianthus* sp., *Phragmites* sp., etc.
Tea garden	383.24	385.28	384.77	(+) 1.53	–
River	658.80	658.80	658.80	Nil	–
Non-forest	3001.58	3084.25	3230.71	(+) 229.13	–
Total	5103	5103	5103	–	–

Figure 5. Forested land converted to agriculture in Nowduar Reserve Forest.

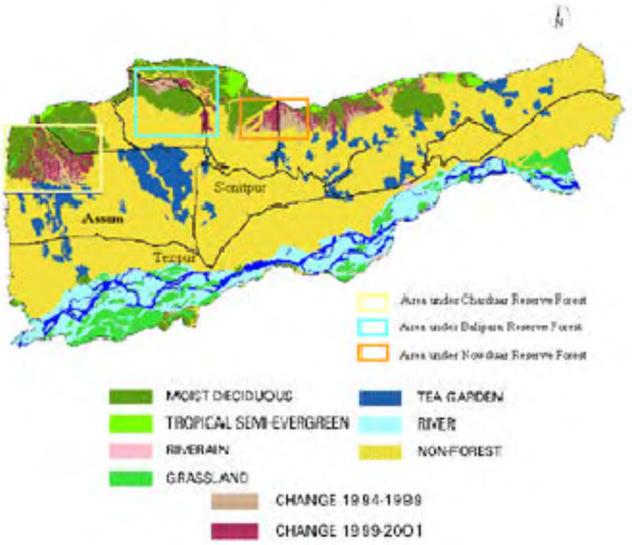

Figure 6. Map showing deforestation in Sonitpur District from 1994 to 2001 through 1999.

que. They were then co-registered with SOI toposheets using Lambert Conformal Conical projection. Well-identified ground control points (GCP) were taken to rectify the satellite images. Sub-pixel image to map registration accuracy was achieved through repeated attempts. Histogram matching was done to correct the radiometric difference prevailing in the mosaic of the year 2001. The district image was extracted by superimposing the Sonitpur District boundary (Figure 2). The three period images were then visually interpreted on-screen. A classification scheme was developed and the overall number of classes in each case was kept constant. The visually interpreted images were superimposed to detect changes from one period to the other. All operations were carried out using ERDAS IMAGINE software. Phytosociological analysis and Shannon–Weiner index of plant diversity were calculated in the respective forest types to assess the loss of phytodiversity due to deforestation.

Figure 2 shows the loss of forest cover with the passage of time. As evident from Figure 3, three types of forest, viz. tropical moist deciduous, tropical semi-evergreen and riverain forest could be identified and mapped from three data sets of different time periods. Three most affected reserve forests in the district are Charduar Reserve Forest, Balipara Reserve Forest and Nowduar Reserve Forest. Figure 4 shows deforestation in Nowduar Reserve Forest. Figure 5 shows a view of actual

Table 3. Biodiversity status in different forest/vegetation types of Assam

Forest/vegetation type	No of samples (N)	Species diversity (H)	Total species	Economically important species	Medicinally important species	Endemic species
Semi-evergreen	25	5.45	250	105	62	21
Moist deciduous	127	6.49	640	257	179	37
Grassland	16	2.00	90	24	25	01

deforestation on ground in Nowduar Reserve Forest. Figure 6 shows change in the reserve forests from 1994 to 2001 through 1999. The results indicate that moist deciduous forests occupy the maximum area in Sonitpur followed by tropical semi-evergreen and riverain forests (Table 2).

The following species composition was noted in different forests:

Tropical moist deciduous forest: These forests were found along Arunachal Pradesh border. This type corresponds to east Himalayan moist deciduous forest (I/3/3c/3cb) type of Champion and Seth[25]. The important species in these forests are *Terminalia myriocarpa*, *Duabanga grandiflora*, *Pterospermum acerifolium*, *Ailanthus grandis*, *Bombax ceiba*, *Chukrasia tabularis*, *Albizia odoratissima*, etc.

Tropical semi-evergreen forests: These forests were found in the hilly areas of the district towards the north. This type corresponds to Assam valley semi-evergreen forest (I/2/2B/C1) and eastern alluvial semi-evergreen forest (I/2/2B/2S2) of Champion and Seth[25]. The forests are of mixed type, with deciduous upper canopy trees. The major tree species are *Artocarpus chaplasha*, *Dipterocarpus turbinatus*, *Tetrameles nudiflora*, *Terminalia myriocarpa*, *Castanopsis hystrix*, *Vatica lancaefolia*, *Albizia lucida*, *Terminalia belerica*, etc.

Riverain forest: This type of forest is confined along the banks of large rivers. The species composition of this forest is *Bombax ceiba*, *Terminalia belerica*, *Albizia lebbeck*, *Dalbergia sissoo*, *Terminalia arjuna*, *Lagerstroemia speciosa*, *Zizyphus* sp. etc.

Maximum loss (229.64 km^2) was noticed in the case of moist deciduous forests and the decline was more pronounced between 1999 and 2001 (143.40 km^2) than between 1994 and 1999 (86.24 km^2). An area of 2.55 km^2 under semi-evergreen forest was lost, while riverain forests did not suffer any loss. Nearly all the deforested area (232.19 km^2) has been converted to cultivable land. The rate of deforestation in the district worked out to be 10.7% from 1994 to 1999 and 20.1% from 1999 to 2001. The overall rate of the forest decline was estimated to be 28.65% between 1994 and 2001, which may be the highest rate of deforestation anywhere in the country. Table 3 indicates these forests are storehouses of rich biodiversity with high Shannon–Weiner index value, and large number of species of medicinal (27.14%) and economic importance (39.39%). Many of them are also endemic (6.0%). Moist deciduous forest was found to possess highest biodiversity, with a high Shannon–Weiner index (6.49) as well as the maximum number of species (640).

The spatial distribution of different forest types from 1994 to 2001 shows that forest cover in Sonitpur is undergoing massive reduction with time. The district may be devoid of its forest cover in another 10 to 15 years if such a high rate of deforestation goes unchecked. This will of course lead to immense biodiversity loss. The increasing insurgency problem and constant increase in human and cattle population are to be blamed for this. Incidently, the Supreme Court of India has banned all kinds of clear-felling in the northeastern region from 1996 onwards, with a view to protect the remnant forests. Unfortunately, illegal felling like the one in Sonitpur, still continues. The study shows high reliability and excellent potential of remotely sensed data for mapping and change detection, especially in problematic areas. This correlates well with earlier works on change detection.

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Pattern of yolk internalization by hatchlings is related to breeding timing in the garden lizard, *Calotes versicolor*

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Pattern of yolk internalization by hatchlings born in early (May–June), mid (July–August) and late (September–October) breeding season in relation to maternal, egg and hatchling sizes was studied in *Calotes versicolor*. The maternal snout-vent length (SVL), body mass, clutch size, clutch mass and egg mass were recorded. Eggs from five clutches each, from early, mid and late breeding periods were incubated at ambient room temperature until hatching. At hatching, SVL and body mass of the hatchlings, and amount of yolk internalized by hatchlings were recorded. The internalized yolk mass of hatchlings was not related to maternal SVL, body mass, clutch mass and hatchling SVL. Internalized yolk mass was positively correlated with egg mass and hatchling body mass. Significantly greater amount of yolk was internalized by hatchlings born in the later part of the breeding season. Production of heavier hatchlings with greater amount of internalized yolk appears to be an important strategy to enhance the fitness of hatchlings of later clutches that have to compete for food with conspecific hatchlings of earlier clutches.

HIGHER vertebrates expedite the growth of their offspring by providing post-natal parental care, especially by feeding the young. Parental care is uncommon among reptiles[1]. However, reptiles aid their offspring's post-natal nutritional state by deposition of extra yolk than actually required by the developing embryos. The portion of yolk that remains unutilized at the time of hatching (often referred to as 'residual yolk') is drawn into the body of the hatchling before it emerges from the egg[2,3]. The residual yolk represents reserve energy to offspring during their early post-hatching activities[2,4–6]. In turtles, residual yolk serves as reserve energy during their dispersal from nest to water[2,6].

Inter-clutch variation in the amount of residual yolk is reported in a single species of lizard, *Iguana iguana*[5]. In this lizard, the inter-clutch variation in the internalized yolk is attributed to the difference in the availability of nutrients to the mother. All the previous studies on reptiles concerned with yolk internalization are on species that lay eggs in a single clutch or those have not been examined for the influence of maternal body size, clutch size and mass, and egg size, if any, on the pattern of yolk internalization between clutches oviposited at different times of the breeding season. Hence, the actual consequences of breeding time on yolk internalization are poorly understood in reptiles.

Calotes versicolor is a multiclutched lizard and has an extended breeding season (May–October)[7,8]. Therefore, it serves as a good model to study the pattern of yolk internalization by hatchlings from eggs laid at different times of the breeding season. The present study was undertaken to know whether maternal size, clutch and egg size, and breeding timing have any influence on residual yolk mass of hatchlings in *C. versicolor*.

The eggs from gravid *C. versicolor* were obtained during the breeding period (May–October 1999) from surrounding areas of Dharwad city (15°17′N and 75°3′E). The maternal snout-vent length (SVL; cm) and mass of body (g), clutch (g) and eggs (mg), and total number of eggs (clutch size) were recorded for these lizards. The clutches were categorized as early (May–June), mid (July–August) and late (September–October) depending upon the capture of gravid lizards following the procedure described previously by Shanbhag *et al.*[8]. For each

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