Stratification and mapping of *Taxus baccata* L. bearing forests in Talle Valley using remote sensing and GIS

Mukunda Dev Behera*, Shalini Srivastava, S. P. S. Kushwaha and P. S. Roy

Forestry and Ecology Division, Indian Institute of Remote Sensing (NRSA), Dehra Dun 248 001, India

The yew plant (*Taxus baccata* L.) has acquired importance because it yields taxol, which is effective in the treatment of cancer the world over. There is great demand for *Taxus* from pharmaceutical companies and the species is being extracted heavily from its natural habitats throughout the world. This demand has necessitated the preparation of an inventory of *Taxus*-bearing forests for conservation and sustainable utilization. We have used remote sensing and Geographical Information System for identifying and mapping yew plants with reasonably good accuracy. IRS 1C LISS-III False Color Composite (FCC) data dated 2 January 1997 having 23.5 m ground resolution were applied for this purpose. These forests were visited on ground for a detailed vegetation analysis of the distribution of the yew plants. The raw data was corrected both radiometrically and geometrically and then enhanced using the standard image enhancement techniques such as linear contrast stretch. Various techniques of digital image classification such as hybrid clustering, masking and classification were tested to differentiate and delineate the yew-bearing forests in Talle Valley area falling in Lower Subansiri district of Arunachal Pradesh. Forests covered with various proportions of *Taxus* could be stratified and mapped with 85% accuracy. The preliminary results obtained in this study demonstrate that *Taxus*-bearing forests could be separated with *a priori* knowledge of vegetation types of the area.

TAXUS baccata L., a slow growing coniferous tree, has recently acquired much prominence because its leaves, bark and roots yield baccatin used for synthesis of taxol. It is used as a drug in the treatment of cancer of the ovary, testis, breast, lung and melanoma. Taxol interferes with the multiplication of cancer cells and slows down or stops the growth and development of cancer in the body. Like many other cancer drugs, taxol has serious side effects, including a decrease in white blood cells (which may cause susceptibility to infections), hair loss and numbness of fingers and toes. Ever since *Taxus brevifolia*, the Californian yew, was shown to contain taxol, other species of *Taxus* have been screened for this compound.

*For correspondence. (e-mail: mukundbehera@hotmail.com)

The genus *Taxus* is distributed in Europe, North and South America, Morocco, Philippines, Algeria and India. It occurs in temperate Europe up to 63°N and east to Estonia and white Russia and in western Asia and northern Africa[1]. The tree is distributed from Pakistan to south-west China including Nepal and Bhutan mainly along the Himalayas. In India, it occurs in Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Sikkim, West Bengal, Arunachal Pradesh, Meghalaya, Nagaland and Manipur in the shady and humid tracts above 1800 m^2. In Arunachal Pradesh, the tree is distributed in the districts Tawang, West Kameng, Lower Subansiri, Upper Siang, Dibang Valley, Lohit[2]. *Taxus* is represented by 10 species of which *baccata* is the most common. It is a dioecious gymnosperm ranging in size from an understorey shrub to a tree of height 32.5 m (refs 3 and 4). The stem is short, thick (7 m or more in girth)[2] and is covered by a reddish-brown bark that peels off easily. While yew is shade tolerant, it is much favoured by broken or thin canopy conditions, that have strong impact on its abundance and habitat preferences[5]. Yew is slow-growing and reaches maturity at *ca.* 70 years and lives up to >1000 years. It yields a strong decay-resistant wood. When not in fruiting condition, *Taxus* resembles the foliage of Fir (*Abies*) and Hemlock (*Tsuga*), but is at once distinguished by field characters of the latter two, such as tall and massive trunks (*Tsuga*) and a tall trunk (*Abies*). The underside of the leaves of *Taxus* is yellow-green without prominent stomatal lines which are seen in *Abies* and *Tsuga*[6].

Recently the traders of *Taxus* have shifted their operations to the eastern Himalayas[2]. In April 1993, the government of Arunachal Pradesh issued permits for harvest and export of more than 5000 metric tons of leaves[7]. The ideal altitudinal zone where the tree occurs is between 2000 and 2500 m throughout the state in the temperate forests[2]. Talle Valley satisfies this criterion very well. The tree is seen associated with broad-leafed species such as *Quercus lamellosa* Smith, *Quercus elegans* Bl., *Rhododendron arboreum* Sm., *Rhododendron grande* Wight, *Ilex griffithii* Hk.f., *Betula alnoides* Buch-Ham., *Acer* spp., *Sorbus* spp. and conifers like *Abies densa* Griffith ex R. Parker., *Tsuga dumosa* (D. Don) E., *Larix* sp., *Cupressus* sp. etc. The associations vary from place to place.

Research in the remote sensing and Geographical Information System (GIS) programme ranges from completely theoretical to applied; from pure remote sensing, GIS and Global Positioning System (GPS) to various combinations of all three; and from highly general studies of larger areas to more detailed studies of smaller areas. Remote sensing coupled with GIS and GPS techniques are useful in locating different types of bioresources, to identify appropriate corridors surrounding

natural habitats and protect them from human intervention and other harmful influences which endanger the existence of these habitats[8].

The forest stands vary considerably in terms of species, structure, understorey vegetation and background reflectance[9]. Undergrowth vegetation and/or background consisting of swamp soil, scrub and forest litter have a significant effect on the spectral reflectance of a forest stand. The climatic gradient caused by elevation controls the species composition of the forest stands[10]. Franklin[11] found that the dominant feature affecting spectral reflectance was canopy closure or the amount of bright background covered by overstorey within a pixel. Coniferous forest internal shadows appear in darker red than a broad-leafed forest canopy. Red and near-infra red radiance was strongly and negatively correlated with a range of structural properties and with the age of the stands but weakly correlated with canopy cover[12]. Since mountain ranges are rarely continous[13], it results in isolation as per topographic difference of communities. It is here that remote sensing technology can be utilized to identify broad communities having similar functional and structural properties. For detailed mapping, computer-aided techniques have been suggested[14,15].

Eastern Himalaya is recognized as one of the major biogeographic zones of India[16]. Arunachal Pradesh covers a large part of the eastern Himalaya. It is a state rich in bio-diversity[17,18]. The state owes this floral and faunal diversity to its strategic location at the junction of three biogeographic realms[19], viz. the Palaeoarctic, the Indo-Malayan and the Indo-Chinese realms. The altitude ranges from 50 m in the plains to 7000 m, which results in the high diversity of the forests – tropical, subtropical, temperate and alpine. Due to difficult terrain and lack of proper communication, many of the pockets in the state still remain undisturbed. The economic potential of the entire forest wealth has not been assessed. Perhaps this is the only state in India which has the maximum number of living collection of gymnosperms[20].

Talle Valley is located about 30 km away from Ziro, the headquarters of Lower Subansiri district. Three rivers, namely the Subansiri, Sapu and Pange roughly surround the area. The valley is surrounded by gentle sloping hills with thick vegetation. The altitude ranges from 1500 to 2825 m. Precipitation and air temperature vary considerably along this elevational gradient. During winter the minimum temperature goes below freezing point and maximum temperature during summer reaches 38°C. Many small rivers flow through the valley forming deep gorges and rapid falls. The hills as expected run in a roughly east–west direction. The geological formation includes pre-Cambrian to Upper Pleistocene sequences[21]. The thin peat beds of the Pleistocene age are the characteristics of the main valley. The soil-shaded area is clay loam and is comparatively humus-rich with a blackish colour. Soil and the stream water are acidic in nature and pH was observed to be 4.09 and 4.78, respectively.

According to Champion and Seth[22], the following forest types occur in the study area: East Himalayan subtropical forest (8B/C1); East Himalayan wet temperate forest (11B/C1); Lauraceae forest (11B/C1a); Buk oak forest (11B/C1b); High level oak forest (11B/C1c); East Himalayan mixed coniferous forest (12/C3a).

Vegetation of Talle Valley is described as a pristine climax type. It includes many rare and endangered plants, maintaining its uniqueness. Broadly the study area includes temperate broad-leafed and temperate coniferous forests which were discernible by satellite data. In the temperate broad-leaved forests, the dominant associations are of *Quercus-Exbucklandia-Schima, Magnolia-Rhododendron-Quercus, Acer-Betula-Rhododendron, Quercus-Acer-Magnolia, Magnolia-Rhododendron-Betula*, etc. The top canopy trees are *Quercus lamellosa* Smith., *Quercus fenestrata* Wall., *Quercus oxyodon* Miq., *Exbucklandia populnea* R. W. Br., *Schema khasiana* Dyer., *Betula alnoides* Buch-Ham ex D. Don., *Acer pictum* Auct. Non Thumb., *Magnolia campbelli* Hk.f. etc. The middle storey consists of *Illicium griffithii* Hk.f., *Eurya acuminata* DC., *Achronychia* spp. etc. The shrub layer consists of *Lindera* spp., *Rubus* spp., *Berberis* spp., *Vaccinum* spp., *Gaultheria* spp., *Daphne* spp., etc. The herbaceous layer comprises *Polygonum* spp., *Rosa* spp., *Begonia* spp., *Senecio* spp., etc. Epiphytes are mainly orchids and ferns. Climbers like *Vitis* spp. and *Emblica* sp. are found occasionally. *Taxus* is found scattered in temperate coniferous forest and the adjacent broad-leafed forests of the valley.

The valley is a very unique ecosystem. Usually in an altitudinal variation of forest types, the coniferous types appear above the broad-leafed type. But here the sequence is reversed and the conifers appear in the valley surrounded by broad-leafed forest on the hill tops. It looks as if the hill tops are sunken with the vegetation. The forests here are of temperate conifer type dominated by *Tsuga dumosa* (D. Don.), *Abies densa* Griffith Ex Parker. and *Cephalotaxus* sp. *Taxus baccata* L. was found occurring towards the hill slopes among the conifers and broad-leafed species. However, these conifers do not form a close canopy and are found scattered.

Ground truth is essential in any remote sensing study. It is the collection of ground information for its correlation with signature resulting in calibration of the thematic units. As the desired level of detail sought from remotely sensed data is increased, so must the amount and quality of the ground truth be increased. Prudent preparation of ground truth activities and the accurate measurement and/or observation of sampling parameters are the underpinning of the quality of the results. During field visits (Phase I, during the second week of March and the first week of April 1999 and Phase II, during the

IRS-1C LISS -III, 112/52 (NIR:R:G)

Figure 1. False colour composite image of Talle Valley.

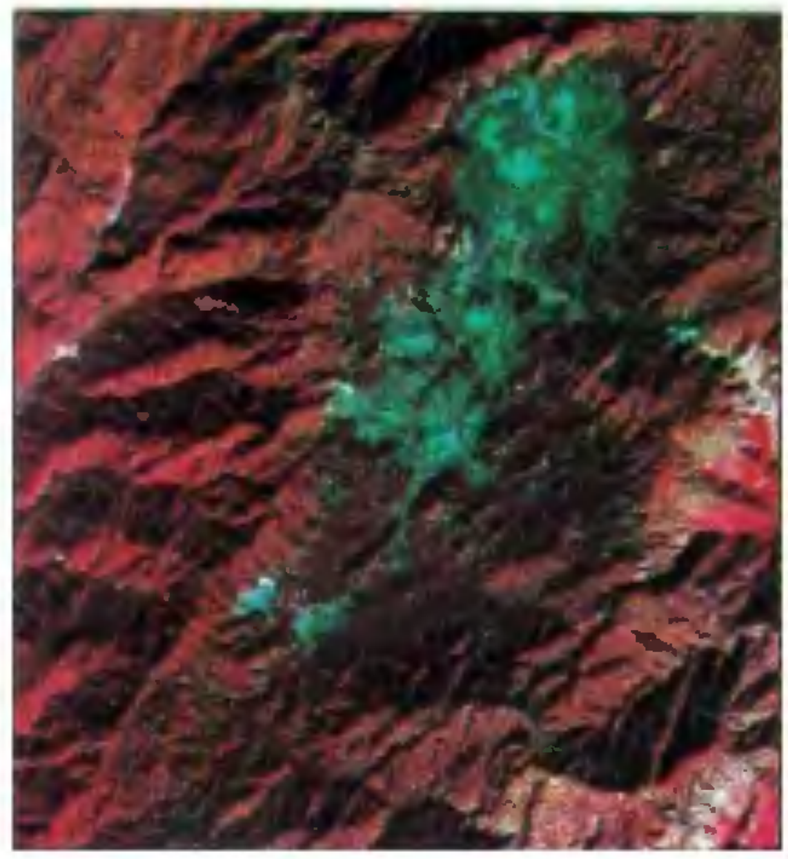

Figure 2. Linear stretched FCC image of Talle Valley.

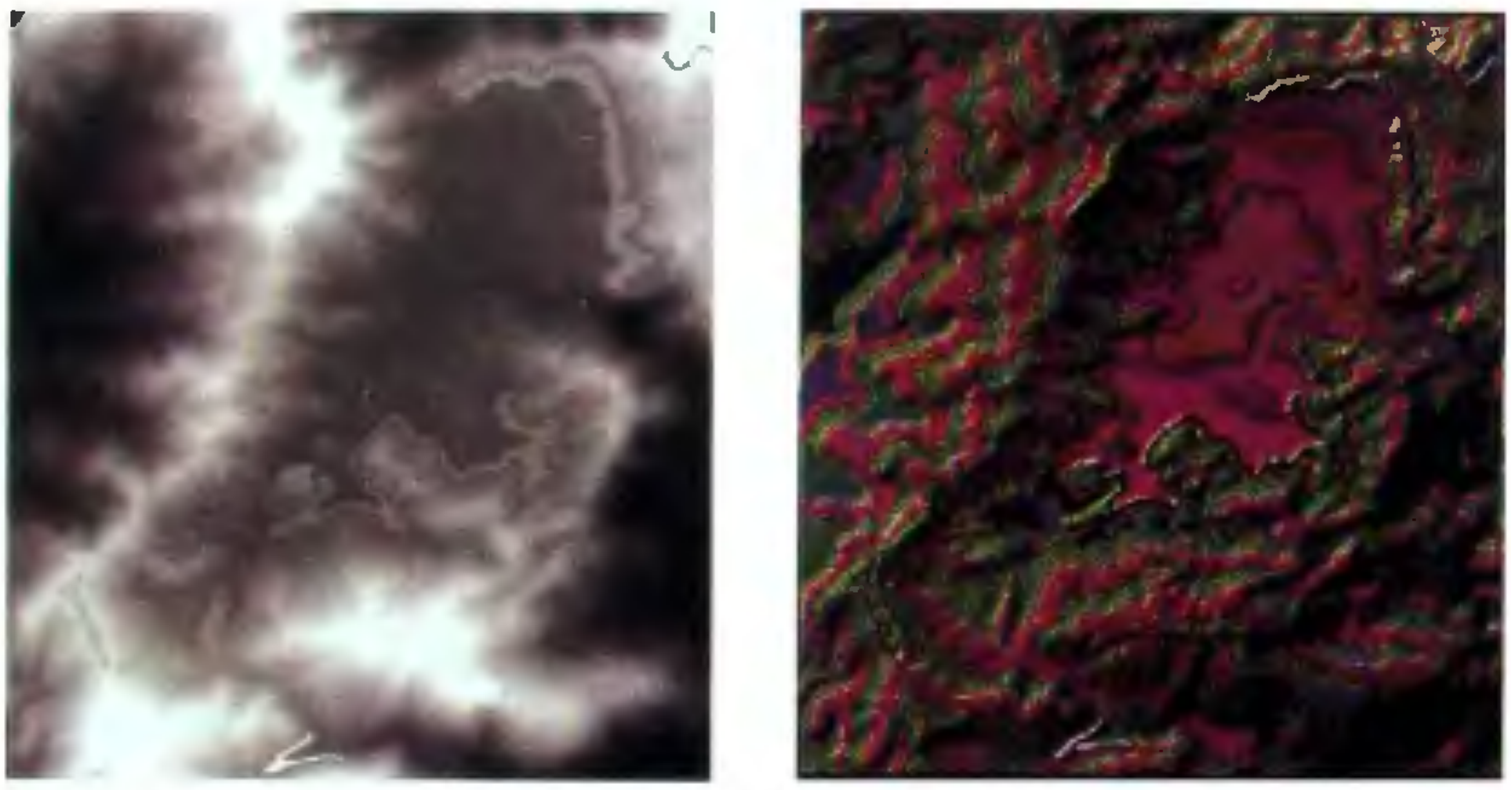

Figure 3. Digital elevation model of Talle Valley, *a*, coloured; *b* gray scale.

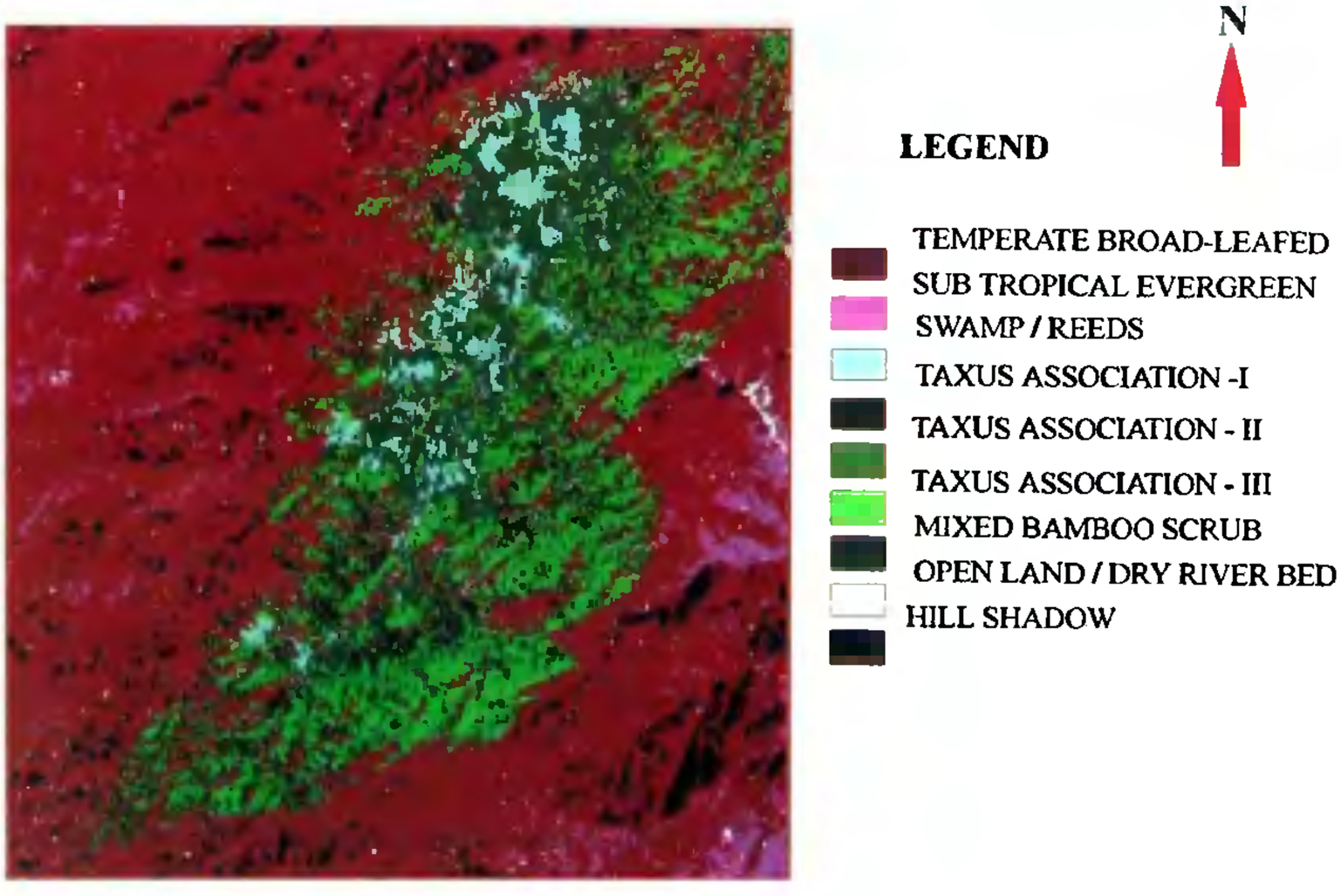

Figure 4. Classified image of Talle Valley showing different vegetation associations.

third week of May 1999), detailed ground truthing and sampling was done. This led to stratification of the various *Taxus*-bearing forests.

IRS 1C LISS-III digital data was used for the study. After suitable radiometric and geometric corrections, an area of 418 × 379 pixels was selected for investigation. Intergraph Corporation's MGE software was used for DIP and GIS work. SOI topomaps no. 83 E/14 and 83 I/2 were used for geometric registration and DEM generation.

Three training set selection techniques that could be employed were the supervised clustering technique, the unsupervised clustering technique and the controlled clustering technique. The last technique is a combination of the unsupervised and supervised techniques and was the approach utilized for training set selection. Extensive ground check and sampling were done throughout the valley to tap as much spectral variation of surface cover as possible. Their location was achieved through GPS. The spectral variation was caused by the different vegetation communities present as well as the presence of environmental parameters such as moisture content, soil characteristics, crown size and crown density. The surface cover types whose spectral reflectance may be altered due to environmental parameters have been mentioned earlier. The detailed procedure followed for data extraction is described in Table 1.

In open swamp/reeds, sunlight could reach the ground directly. The Peuda and Talle rivers flow in the valley in a winding, snaky-like manner. Such areas are found to occur mostly along the curves of the streams which impart a cyan to light green tone on the false colour composite (FCC) image. Along the banks and open places there is lush growth of herbs such as *Forestia hookerii* Has., *Piper thomsonii* (D. Don.) Hk.f,, *Piper peepuloides* Roxb., *Galinsoga parviflora* Cav., *Anaphalis contorta* Hk.f., *Velariana glandulifera* Wall. Ex DC., *Eurya japonica* Thunb., *Polygonum alata* Linn., *Erigeron macronata* L., *Potentilla khleniana* Wight & Arn., *Anemone rivularis* Ham., *Viburnum foetidium* Wall., *Epilobium* spp., *Pontilla* spp., *Fragaria* spp., *Alocaria* spp., *Marsine* spp., *Gentiana* spp., *Oenothera* sp., *Sonerilla* sp., *Ranunculus* sp., *Anaphalis* sp., *Phragmites* spp., *Drynaria* sp., *Plantago* sp., *Cypsela* sp., etc.

The gregarious bamboos on the valley form a unique community and are spectrally differentiated to separate classes. Bamboo species found are *Arundinaria* spp. and *Pleioblastus simonii* often reaches a height up to 10–15 m forming impenetrable thickets. *Pleioblastus simonii* is found in India only in this place. Trees like *Litsea leata* B. Hk. f., *Abies densa* Griffith ex R. Parker., *Tsuga dumosa* (D. Don.), *Betula alnoides* Buch-Ham ex D. Don. etc. are found in a scattered manner among the bamboo scrub. *Betula alnoides* Buch-Ham D. Don., *Cephalotaxus* spp. are often found clumped together in some places. Shrubs like *Dioscorea tebricuga* Buch-Ham ex D. Don., *Ilex khasiana* Wall ex D. Don., *Strobilanthus* spp. and herbs like *Piper peepuloides* Roxb., *Solanum nigrum* L., *Vibrunum foetidium* Wall., *Galinsuga parviflora* Cav., *Vitis* spp., *Taecealabis* sp., *Disporus* sp. etc. were observed. This imparts a dark to bluish-green tone on the FCC. Soil was swampy, covered with various peats and non-vascular cryptograms. The bamboo scrub retain a great amount of moisture.

In *Taxus* association I forest cover type, *Taxus baccata* L. trees were found distributed in a scattered manner along with other conifers like *Abeis densa* Griffith ex R. Parker., *Tsuga dumosa* (D. Don.), *Cephalotaxus* spp. etc. They were intermingled with *Betula alnoides* Buch-Ham (D. Don.), which was noticed to be leafless (senescence). Thus, this group of association was spectrally differentiated and could be mapped into a separate class. Soil was marshy, but with less moisture as the elevation was increased. Here comparatively more light penetrates. Some of the shrubs noted are *Ilex khasiana* Purk., *Ligustrum rubostum* Bedd., *Abies spectabilis* (D. Don.) Mirb., *Ardisia nerifolia* Wall., *Strobilanthus* sp. etc. It reflectes a darkish-red to greenish-redtone on FCC.

In *Taxus* association II forest cover type, the conifers are dominantly distributed in the eastern and southern side of the valley and the surrounding areas. *Taxus baccata* L. was found often forming second storey, but its signature could not be differentiated separately. Thus it was included in a separate class having similar composition. Here the other conifers occur dominantly along with other broad-leaved like *Jatropha gossypifolia* Linn., *Phyllanthus* spp., *Macrotanax denticulata* Miq., *Illicium griffithii* Hk.f., *Ilex khasiana* Purk., shrubs like *Legastem robustum* (Roxb.) Bl., *Ardicia nerifolia* DC., etc. Soil is comparatively less marshy and covered with bamboo bushes.

In *Taxus* association III forest cover type, in the surrounding high-elevated forest in the eastern side of the valley, broad-leafed trees were found mixed with conifers containing *Taxus baccata* L. Species such as *Crylopsis himalayensis* Griff., *Michelia punduana* Hk.f., *Litsea leata* B.Hk.f., *Rhododendron wallichii* Hk.f., *Litsea selicifolia* Hk.f., *Illicium griffithii* Hk.f., DC., *Rhodendron maddeni* Hk.f. and shrubs like Dioscorea *tebricuga*, *Strobilanthus brunonianus* Nees., *Legastem robustum* (Roxb.) Bl., *Ardisia nerifolia* DC., *Glautheria pyrisobalifolia* Hk.f., *Strobilanthus* sp. were noticed. These patches reflect a dull reddish-green colour on the FCC.

This study is part of a large project on biodiversity characterization at landscape level using remote sensing and GIS in Arunachal Pradesh sponsored by Department of Space and Department of Biotechnology, Government of India. After the first field visit to Talle Valley, it was felt

Table 1. Summary of data extraction techniques

Technique	Function	Output product
Geometric correction of digital data (IRS 1C LISS-III)	Registered and geo-referenced to Survey of India (SOI) topomaps.	Geo-referenced image was obtained.
Extraction of the area of interest	Study area (418 × 379 pixels) was extracted (Figure 1)	For further analysis
Image enhancement	Linear stretching was done to obtain better contrast (Figure 2)	Enhanced image with better contrast was obtained.
Unsupervised classification	Maximum likelihood classifier was used with 20 clusters. Seven clusters were merged to two classes (shadow and sub-tropical evergreen forest).	Subtracted image of two classes was obtained.
Mask generation	DEM was generated with contour interval of 20 m (Figures 3 *a* and *b*). Contour value of 2480 m was adjudged for masking of the valley in N–W direction. Zeroing of the masked-out area was done from the scene.	Image pertaining to the valley proper was masked-in. Subjected to further supervised classification and analysis.
Supervised classification	Training sets were assigned based on ground check, sampling and GPS readings. Maximum likelihood classifier was used. Generated 11 classes were merged to 9 classes for the masked-in area.	Classified map with 85% overall accuracy was obtained.
Combining of the masked-in and masked-out areas	Masked-in and masked-out areas were added. Subtracted two clusters were added. Similar classes of masked-in and masked-out areas were assigned the same values. Remaining 13 clusters of masked-out areas were clubbed to a single class of temperate broad-leafed forest. Area statistics were calculated (Table 2)	Classified output for the total study area was obtained. Output of nine different classes were obtained.
Passing through low pass filter (LPF)	LPF of 3 × 3 was passed through the classified image to remove noise.	Smoothed image was obtained.
Suitable colour assignment	Colour was assigned	Suitable colour-coded map was obtained.
Legend preparation	Proper legending was done	Final classified image was prepared (Figure 4).

Table 2. Area estimates of different land cover types

Class	Area (sq km)
Temperate broad-leafed forest	53.82
Sub-tropical evergreen forest	2.33
Swamp/reeds	2.12
Taxus association I	4.54
Taxus association II	10.41
Taxus association III	2.18
Mixed bamboo	8.24
Open/barren land	0.31
Shadow	3.53
Total	87.48

that *Taxus*-bearing forests could be delineated and mapped. An attempt, therefore, was made to correlate the image tone and texture of different forest stands bearing this species in various proportions. As mentioned earlier, many image enhancement techniques were tested to improve the overall image contrast especially the contrast between *Taxus*-bearing forests and other forest classes and the results have been encouraging. As a result, three types of miscellaneous *Taxus*-containing forests (Figure 4, Table 2) shown as *Taxus* association I, II and III could be finally discriminated and mapped using digital classification techniques.

This study was driven by observations on *Taxus* made during a regular field visit to one of the otherwise biodiversity-rich areas. The *Taxus*-containing forests were located first on ground and then efforts made to classify and map them. This work is field-driven to a large extent. However, it should be feasible to map similar areas elsewhere using remote sensing and GIS. The use of GIS in this case was limited to geometric correction of the

image with respect to SOI topomaps, contour digitization and DEM generation to obtain the contour value for mask generation. GPS was successfully used to obtain training sets.

The advantages of such a study on inventory of *Taxus* forests could be many. First, the forest departments will be able to identify and map the forests bearing such economically-important species for any conservation/utilization planning. The search of *Taxus* for any research and development activities in turn can be narrowed down.

This study makes it possible to differentiate and map *Taxus baccata* L. in a temperate forest zone of Arunachal Pradesh in north-eastern India. The methods involve a good amount of satellite data processing for image enhancement and classification. The average contrast of *Taxus*-containing forests on IRS-1C/1D LISS-III imagery was satisfactory. Classification itself involved many steps right from unsupervised clustering to supervised classification and a combination of best of both – a hybrid approach. Such an approach has been found to be effective in hilly and mountainous areas with multiple problems like haze, hill shadows, etc[23]. It is expected that this study will open new frontiers towards identification of plant species or species associations using remote sensing techniques.

Obtaining species level information is still a distant dream with satellite data owing to its coarse spatial resolution. Our method of estimating the presence and distribution of *Texus baccata* L. by examining variations in properties of landscape forms and composition of species association based on GPS and GIS databases offers an alternative to the conventional method of orchestrating field studies to prepare species check lists for multiple landscape parcels. The presence or absence of specific species cannot be definitely ascertained with our protocol, yet it should be possible to use the technique to identify probable locations of such species once their composition, community characteristics and habitat requirements are known in detail.

Additional research should be conducted to confirm the spectral/successional stage relationships found here. This work could include research using linear mixing models to develop a better understanding of how the proportion of successional stages and forest cover determine the spectral responses in large pixels. It appears that satellite data have a potential for stratifying natural forests and mapping community classes in reference to a specific species with substantial ground truthing.

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