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Source: Mountain Research and Development, 21(2) : 175-183

Published By: International Mountain Society

URL: https://doi.org/10.1659/0276-4741(2001)021[0175:LCCATA]2.0.CO;2

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Mountain Research and Development Vol 21 No 2 May 2001: 175–183

*Robert J. Zomer, Susan L. Ustin and Chris C. Carpenter*

# Land Cover Change Along Tropical and Subtropical Riparian Corridors Within the Makalu Barun National Park and Conservation Area, Nepal





*Low elevation riparian forests found within the Middle Hills of Nepal are both essential biological habitats and important resources for local subsistence farmers. Forming networks of habitat patches within the primarily agricultural matrix of the Middle Hills, these forests are repositories of a rich biological diversity. Dynamics of forest change along riparian corridors were investigated within the newly established Makalu Barun National Park and Conservation Area (MBCA) of eastern Nepal, based on a comparison of remote sensing data over a 20-year interval. Multispectral analysis and a supervised classification of Landsat TM (1992) and Landsat MSS (1972) data estimate approximately 7000 ha of low elevation riparian forests within the study area. Change detection analysis estimates based on the respective supervised classifications reveal little significant change in extent of the tropical and subtropical zone riparian forests. More impact was evident toward the upper elevational limits of the study area. A 4% (approximately 300 ha) loss of cover within areas previously designated as forest is estimated. For all areas in the study area, a net loss of forest of 11% is estimated. Land use is shown to be highly dynamic, with significant internal trading between land use classes. The important role of riparian corridors in biodiversity conservation within the Middle Hills of east Nepal is discussed. Further research on biodiversity within these patches and a specific recognition of the value of remnant riparian forests within the landscape and rural economy are required if conservation goals for the eastern Nepal Himalaya are to be met.*

***Keywords:*** *Land cover; forest vegetation; biodiversity; Makalu Barun National Park; Himalaya; Nepal.*

***Peer reviewed:*** *January 2000.* ***Accepted:*** *September 2000.*

## Introduction

Cut deep into the Middle Hills of eastern Nepal, a system of low-elevation riparian corridors extends tropical climatic conditions far into the high Himalaya. Remnant tropical and subtropical forest vegetation along these riparian corridors provides important biological habitat for numerous rare and endangered species (Cronin 1979; Shrestha 1989; Jackson et al 1990; Shrestha et al 1990) within an increasingly monotypic and cover-poor landscape. Remnant forest vegetation forms networks of habitat patches that are essential for numerous indigenous and migrating wildlife species. These forests contain a large number of rare and endangered plant species (Shrestha et al 1990). The occurrence of these forests provides essential habitat for a great variety of tropical birds and mammals, many of which are at considerable risk throughout the eastern Himalaya (Jackson et al 1990).

The vital role of forests within the mountain farming system and dependence on fertility transfer from forest to agricultural fields to maintain agricultural production are well described (Mahat 1987; Mahat et al 1987; Ives and Messerli 1989; Metz 1994, 1997). Within the agricultural zone of the Middle Hills, remnant patches of riparian vegetation constitute important resources for local subsistence agriculturalists, providing fodder, fuelwood, medicinal or other useful plant materials, and timber. Equally important to the mountain farming system, dense vegetation cover within the steep and highly erosive gullies and ravines provides important ecosystem and soil stabilizing functions (Young 1989). Local farmers generally recognize the important conservation value of protecting vulnerable riparian sites (Zomer and Menke 1992), although population growth, resource scarcity, and land tenure often put heavy demands on these marginal areas. Many of these sites are often highly utilized or, in some cases, semimanaged. Increased demands on these systems, with associated fragmentation and/or degradation of riparian forests, is facilitated through improved access, particularly in the case of extension of new roads along river corridors.

Tropical and subtropical monsoonal rain forests located along the upper reaches of the Arun River represent ecologically and economically important repositories of regionally endangered biological diversity (Cronin 1979; Shrestha 1989; Jackson et al 1990; Shrestha et al 1990). Approximately 7000 ha of these forest types occur within the boundaries of the Makalu Barun Conservation Area (MBCA) (LRMP 1986). The importance of riparian vegetation within the mountain landscape is generally recognized, particularly in relation to wildlife habitat, dispersal and migration (Harris 1984; Carlson et al 1991), refugia (Meave et al 1991; Dix et al 1997), and streamside management (Moyle et al 1996). However, relatively few hectares of these hill-variant tropical and subtropical forest types are found within protected areas of Nepal (Hunter and Yonzon 1993).

This paper reports on a detailed landscape-level analysis of land use and cover change in relation to the status of tropical and subtropical riparian forests within the MBCA. A comparison of classified satellite remote sensing datasets is used to describe both spatial and temporal dynamics of forest change. A time interval of approximately 20 years, leading up to the establishment

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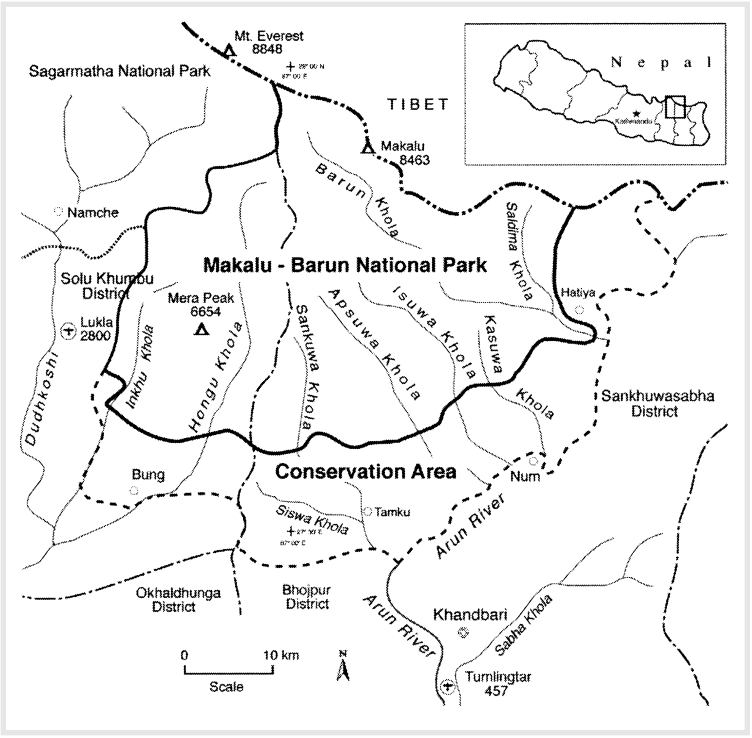



**FIGURE 1** Map of the Makalu Barun National Park and Conservation Area in eastern Nepal. The main study area lies within the Conservation Area, between the Siswa Khola (River) and the Kasuwa Khola (River).

of the MBCA in 1992, is evaluated for both impacts upon forests and changes in tree cover on agricultural lands. Areal extent, fragmentation, and recent historic changes in tropical riparian forest stands within the MBCA are discussed in the context of the dynamic nature of the mountain farming system.

## Study site

The study area lies along the upper reaches of the Arun River of the eastern Nepal Himalaya, within the area designated as the Makalu Barun Conservation Area (MBCA) (Figure 1). The MBCA (27°30′N, 87°10′E), established in 1992 by the Department of National Parks and Wildlife Conservation, H.M.G. Nepal, lies on the edge of the vast and relatively undisturbed Makalu Barun National Park (MBNP). Envisioned as a development-oriented buffer zone for the adjacent 1500 km$^2$ of uninhabited wilderness, the MBCA (700 km$^2$) supports nearly 40,000 subsistence agriculturalists. These farmers, with an average farm size of approximately 0.5 ha, depend heavily on local forest resources (Sherpa et al 1990; MBCP Task Force 1990).

Low-elevation riparian corridors within the eastern Himalaya are generally referred to as being within the tropical bioclimatic zone if below 1000 m (Shrestha 1989) or within the subtropical zone if below 2000 m. Although they are geographically outside of the tropics, the deeply cut river valleys are characterized by tropical climatic conditions due to orographic blocking of cold winter air from central Asia. This tropical/subtropical zone is frost free, with average monthly mean temperatures above 18°C throughout the year for elevations below 1000 m. Annual precipitation within this region of eastern Nepal is generally high (4000 mm), occurring mostly during the relatively long summer monsoon. Spatial distribution of precipitation is highly variable and strongly influenced by orographic effects associated with the complex mountainous terrain.

Within the MBCA, the main zone of cereal cultivation overlies the tropical and subtropical bioclimatic zones. Many of the native forests in these zones have been cleared for rice terraces and/or upland maize, particularly in the less rugged areas. Although the tropical zone is generally not as intensively cultivated as the subtropical zone, it is common for subtropical zone farmers to also have fields at lower elevations. The resulting vertical zonation associated with the agricultural calendar is partly due to a fragmentation of landholdings but is also regarded as an adaptation of the mountain agricultural system to climatic differentiation associated with the altitudinal gradient. Livestock are generally rotated to graze stubble on lower fields during the winter and are grazed in, or fed fodder from, nearby forest and riparian patches.

Lower slopes along the deeply cut rivers and streams tend to be steep and soils rocky due to active steam cutting processes and the unstable and erodable geologic substrate associated with the lower Middle Hills of the eastern Himalaya (Selby 1988). Geomorphologic processes are accentuated by sustained periods of intense precipitation, with frequent disturbance within riparian corridors due to seasonally swollen rivers and monsoonal downpours. River- and streamside zones are often left uncultivated with dense scrub and/or forest vegetation in a semiwild state. These patches of remnant forest provide access to fuelwood, fodder, and other valuable resources for local subsistence agriculturalists. Ives and Messerli (1989) outline the important interrelationship of agriculture and forests in the Nepal Himalaya. A transfer of fertility from forest to farm, primarily mediated by livestock and the collection of fodder, maintains on-farm agricultural productivity. Recently, farmers have responded to diminishing forests by planting more trees on their farms (Gilmore and Nurse 1991).

The forest vegetation of eastern Nepal is known for high levels of both species and community diversity (Hooker 1852; Singh and Singh 1987, Shrestha 1989). Low elevation riparian corridors within the MBCA are described as containing significant and important biodiversity and forest habitat (Jackson et al 1990; Shrestha 1989; Shrestha et al 1990). This point was highlighted at the time of establishment of the MBCA (MBCP Task Force 1990), as the study site lies adjacent to the proposed (but now dormant) Arun III Hydroelectric Project (Kattelmann 1990). Descriptions of forests of the Arun Basin include, among others, Hara (1966), Numata (1966), Stainton (1972), Dobremez (1976), Oshawa (1983), Numata (1983), and LRMP (1986). Lower ele-

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vational forests, specifically of the MBCA, have been described by Oshawa (1983), Shrestha (1989), Shrestha et al (1990), and Carpenter and Zomer (1996). Three major formations were identified within the study area (Zomer et al 2001a):

1. *Dipterocarpus* forest, dominated by *Shorea robusta* (*sal*), characterizes the tropical zone. It is found intermixed with palms, cycads, tree ferns, bananas, etc, below 800 m in the MBCA.
2. Low montane needle-leaf forest, dominated by *Pinus roxburghii* (*chir* pine), is relatively scarce in the Arun Basin (Shrestha 1989) and is mostly limited, within the MBCA, to a relatively xeric site above the confluence of the Sankuwa and Arun rivers.
3. Low montane evergreen broadleaf seasonal rainforest, generally indicated by the presence of *Schima wallichii*, prevalent throughout the Arun Basin and referred to as *Schima-Castanopsis* forest, is characteristic of the subtropical bioclimatic zone. Lower ecotonal variants of this formation are found within the MBCA to well below 600 m and form important components of the riparian vegetation of the tropical zone.

## Methods

### Field studies

Six field expeditions conducted between 1991 and 1994 surveyed forest vegetation within the greater MBNPCA and its environs (Carpenter and Zomer 1996). Site characteristics and vegetation data were sampled on 256 forest quadrats, of which 30 quadrats fall within the currently described forest types. Five community types within 3 forest formations were identified: *sal* forest, *chir* pine, and 3 subtropical evergreen broadleaf communities (including riparian subtypes). A detailed quantitative analysis of the structure and community ecology of these tropical zone riparian forest communities is presented in Zomer et al (2001a). Additionally, a set of georeferenced ground-control points (GCPs; $n = 33$) was selected within a stratified set of land use types. Land use and/or cover type within the immediate and general vicinity were qualitatively described. Site descriptions for both quadrats and GCPs included an estimation of use and impacts by grazing, woodcutting, and fodder collection. The nature and extent of these land use activities were categorized based on observation and (when possible) informal interviews. Nondifferentially corrected Global Positioning System (GPS) receivers were used to georeference all plots and GCPs. External antennas on 10-m collapsible fiberglass poles were used under closed canopy or among tall trees to improve satellite reception. GPS-derived elevation was compared with altimeter estimates, and a clinometer was used to sight slope angle and estimate canopy height.

### Image processing and remote sensing analysis

Two sets of satellite imagery, acquired approximately 20 years apart, were classified and compared to determine the extent, spatial distribution, and recent change in contemporary tropical and subtropical forests within the MBCA. The remote sensing-based datasets include (1) Landsat Thematic Mapper™ 7-band scene, acquired 22 September 1992 (level 1A data resampled to 25 × 25-m cell size) from the EOSAT Corp; (2) Landsat MSS 4-band scene, acquired 7 November 1972 (level 1A preprocessing, orbit-oriented, nearest neighbor resampled, 25 × 25-m cell size) from the Eros Data Center; (3) digital elevation model (DEM) of the study area, extracted from stereo SPOT imagery using a procedure described in Zomer et al (2001b).

All datasets were georeferenced to the Nepal GIS 1:250,000 database (ICIMOD 1996), that is, UTM, zone 45, Everest 1830 spheroid. Each satellite image was orthorectified to the extracted DEM (Zomer et al 2001b). Results were compared with the various datasets found within, or derived from, the Nepal GIS 1:250,000 database (ICIMOD 1996). Accuracy of georegistration was found to be significantly improved with orthorectification (Zomer et al 2001b).

The multispectral analysis included calculation of the normalized difference vegetation index (NDVI) for each image. A visually enhanced RGB composite image was produced for each of the datasets. The supervised classification of the imagery relied on a set of preselected image classes identified within the enhanced RGB composite image. Training sites were selected based on the field survey and the georeferenced field data. In order to compensate for the pronounced effects of topography within the Middle Hills of Nepal (Millette et al 1995), image classes and their respective training sites were chosen separately on sunny and shaded slopes. A Bayesian maximum likelihood supervised classification (confidence interval 95%) was performed on all spectral bands plus the NDVI to obtain the best results for each image class. Sunny and shaded slope variants of each image class were combined afterward to represent the aggregated class. Results are given in hectares and relative to the percent of the elevational zone (% zone), the percent of the total study area (% total area), the percent of all area classified as forest in 1972 (% MSS forest), and the percent of all area classified as forest in 1992 (% TM forest) (see Tables 1–3).

### Land use and land cover change

The change detection analysis compared contemporary tree cover, as estimated by the classified Landsat TM (1992) data, to historical tree cover, as estimated by the Landsat MSS (1972) classified image. The 2 classified images were compared to iterate all combinations of change between the 2 dates. Two classes of change are

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| Forest type | Zone (m) | Area (ha) | % Zone | % Total study area | % Total forest area in 1972 | % Total forest area in 1992 |
|---|---|---|---|---|---|---|
| Tropical monsoonal | 0–500 | 40 | 44.44 | 0.15 | 0.52 | 0.56 |
| | 500–1000 | 1178 | 32.62 | 4.31 | 15.43 | 16.52 |
| | 1000–1500 | 862 | 8.63 | 3.15 | 11.28 | 12.08 |
| | 1500–2000 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| Subtotal | | 2080 | | 7.61 | 27.24 | 29.16 |
| Subtropical evergreen | 0–500 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 500–1000 | 575 | 15.92 | 2.10 | 7.53 | 8.06 |
| | 1000–1500 | 2394 | 23.97 | 8.76 | 31.35 | 33.57 |
| | 1500–2000 | 2083 | 15.28 | 7.62 | 27.28 | 29.21 |
| Subtotal | | 5052 | | 18.49 | 66.15 | 70.83 |
| Total | | 7132 | | 26.1 | 93.39 | 100.00 |

**TABLE 1** Areal extent of contemporary forest found below 2000 m within the Makalu Barun Conservation Area, based on a supervised classification of Landsat TM (1992) data.

| Land use change | Zone (m) | Area (ha) | % Zone | % Total study area | % Total forest area in 1972 | % Total forest area in 1992 |
|---|---|---|---|---|---|---|
| Forest to agricultural | 0–500 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 500–1000 | 56 | 1.54 | 0.18 | 0.73 | 0.78 |
| | 1000–1500 | 312 | 3.12 | 1.01 | 4.08 | 4.37 |
| | 1500–2000 | 260 | 1.91 | 0.85 | 3.41 | 3.65 |
| Subtotal | | 628 | | 2.04 | 8.22 | 8.81 |
| Agricultural to forest | 0–500 | 1 | 0.63 | 0.00 | 0.01 | 0.01 |
| | 500–1000 | 115 | 3.17 | 0.37 | 1.50 | 1.61 |
| | 1000–1500 | 152 | 1.52 | 0.49 | 1.98 | 2.13 |
| | 1500–2000 | 32 | 0.24 | 0.10 | 0.42 | 0.45 |
| Subtotal | | 299 | | 0.97 | 3.91 | 4.19 |
| Net loss | | 329 | | 1.07 | 4.31 | 4.62 |

**TABLE 2** Change in tree cover within forested areas. Change detection analysis based on comparison of a supervised classification of Landsat TM (1992) and Landsat MSS (1972) data. Only change within areas designated as a forest type on the LRMP Land Use Map (1986) is included.

| Land use change | Zone (m) | Area changed (ha) | % Zone | % Total study area | % Total forest area in 1972 | % Total forest area in 1992 |
|---|---|---|---|---|---|---|
| Forest to agricultural | 0–500 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 500–1000 | 38 | 1.04 | 0.12 | 0.49 | 0.53 |
| | 1000–1500 | 496 | 4.96 | 1.61 | 6.49 | 6.95 |
| | 1500–2000 | 749 | 5.49 | 2.43 | 9.80 | 10.50 |
| Subtotal | | 1282 | | 4.16 | 16.79 | 17.98 |
| Agricultural to forest | 0–500 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 500–1000 | 123 | 3.40 | 0.40 | 1.61 | 1.72 |
| | 1000–1500 | 350 | 3.51 | 1.14 | 4.59 | 4.91 |
| | 1500–2000 | 208 | 1.52 | 0.67 | 2.72 | 2.91 |
| Subtotal | | 681 | | 2.21 | 9.55 | 8.92 |
| Net loss | | 601 | | 1.95 | 7.24 | 9.06 |

**TABLE 3** Change in tree cover within agricultural areas. Change detection analysis based on comparison of a supervised classification of Landsat TM (1992) and Landsat MSS (1972) data. Only change within areas designated as an agricultural type on the LRMP Land Use Map (1986) is included.

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reported—forest to agriculture and agriculture to forest. The forest class was defined to include all significant tree cover, as detected within the respective datasets. Since most land in the study area that is not directly farmed is most likely grazed, the agricultural class was defined to include all other image classes except bare rock and river, for example, grazing land and agricultural scrub. Results of the change detection analysis were compared with the LRMP Land Use Map (1986), as digitized within the Nepal GIS 1/250 database (ICIMOD 1996), in order to evaluate the results within the framework of existing land use assessments, that is, those maps that are currently the basis for policymaking. Two main categories of change are investigated based on 2 aggregated LRMP land use designations: (1) change in tree cover within forested areas and (2) change in tree cover within agricultural areas. Forest and agriculture classes are aggregated for the LRMP as described above.

## Results

Visual analysis of the Landsat TM scene from 1992, based on an overlay of the forest classes on the enhanced false color imagery (Figure 2), reveals a landscape pattern typical of the relatively heavily populated Middle Hills of the eastern Himalaya. Forest fragments are clustered along the steep riparian corridors of tributaries and along the banks of the Arun, interspersed by agricultural land uses, including terraced and nonterraced cropping areas, grazing land, and agricultural scrub. Tree cover appears relatively contiguous along the major tributaries and forms a patchy corridor finely articulated along the riparian network. Several conspicuous breaks in cover (ie, agricultural zones) are evident on the less steep slopes along the west side of the Arun corridor. Two main lower elevation forest formation types were distinguished: tropical semideciduous monsoonal forest (defined to include *chir* pine and *sal* community types) and subtropical evergreen hill forest. Forest represents approximately 26% of all area below 2000 m, with agriculture making up 32%. Forest is estimated to occur on approximately 7132 ha classified into 2 broad forest classes (Table 1). Tropical forest comprised 29% of the total areas classified as forest within the TM scene (% TM forest), with the subtropical forest class comprising 71%. Tropical forest (2080 ha) occupied more than 40% of all area below 500 m, with the majority (1178 ha) found between 500 and 1000 m. The tropical forest formation showed a distinct northern latitudinal limit at approximately 27°34′, consistent with reports by Shrestha et al (1990). Subtropical evergreen forest (5052 ha) was found primarily above 1000 m, with a substantial presence in the upper tropical zone between 500 and 1000 m (575 ha; 16% of zone). There is very little agricultural land use in the lower tropical zone, extending from 345 to 500 m (3 ha, 3% of zone), with more than 90% of the total study area classified as agricultural (8656 ha) occurring above 1000 m. Agriculture occupied more than 40% of the lower subtropical zone (1000–1500 m) and almost 30% of the upper subtropical zone (1500–2000 m). Less than 600 ha of agricultural land use types occurred below 1000 m.

The supervised classification of the 1972 Landsat MSS data was not able to distinguish between the tropical and subtropical forest classes, and consequently all forest (ie, tree cover or high biomass) classes were aggregated into 1 forest class. The MSS data had significantly more unclassified area. Forest classes represent approximately 26% of all area below 2000 m, with agriculture occupying approximately 20%. Total forest cover in the classified 1992 data was approximately 12% less than in the classified 1972 data. Change detection analysis of forest cover (Figure 3) reveals substantial forest loss at higher elevations and the upper margins of the study area, while gains in tree cover appear at relatively lower elevations. Within areas designated as forest types in the LRMP Land Use Map (Figure 4), 628 ha of forest have been converted to agriculture, comprising more than 8% of existing forest in 1972 (Table 2). Within this same area, almost 300 ha are shown as having gained substantial tree cover, representing an increase of slightly less than 4%. The resulting net loss of forest within the LRMP-designated forest zone was 4%. Within areas designated as agricultural in the LRMP Land Use Map, 1282 ha have lost high biomass cover in agricultural areas of almost 17% of all forest in 1972 (Table 3). Within this same area, 680 ha are shown as having gained tree cover, representing an increase of more than 9%. The resulting net loss of forest within the LRMP-designated agricultural areas was more than 7%. Net loss of low-elevation forest for the study area was 11%.

## Discussion

Extent and spatial distribution of current forest cover below 2000 m in the MBCA indicates that closed canopy tree cover is now mostly restricted to riparian corridors and the slopes of associated gullies and ravines. However, within the highly articulated and complex topography of the study area, this network of remnant patches continues to represent an essentially contiguous corridor. Upland subtropical evergreen (nonriparian) forest community types appear to have been the most impacted by recent conversion to intensive agricultural uses. Although intensity of cultivation within the MBCA has increased, most riparian zones along the tributaries of the Arun still remain heavily vegetated.

The highly articulated landscape and dissection of the narrow riparian corridors by their streams are major factors influencing the evaluation of forest and

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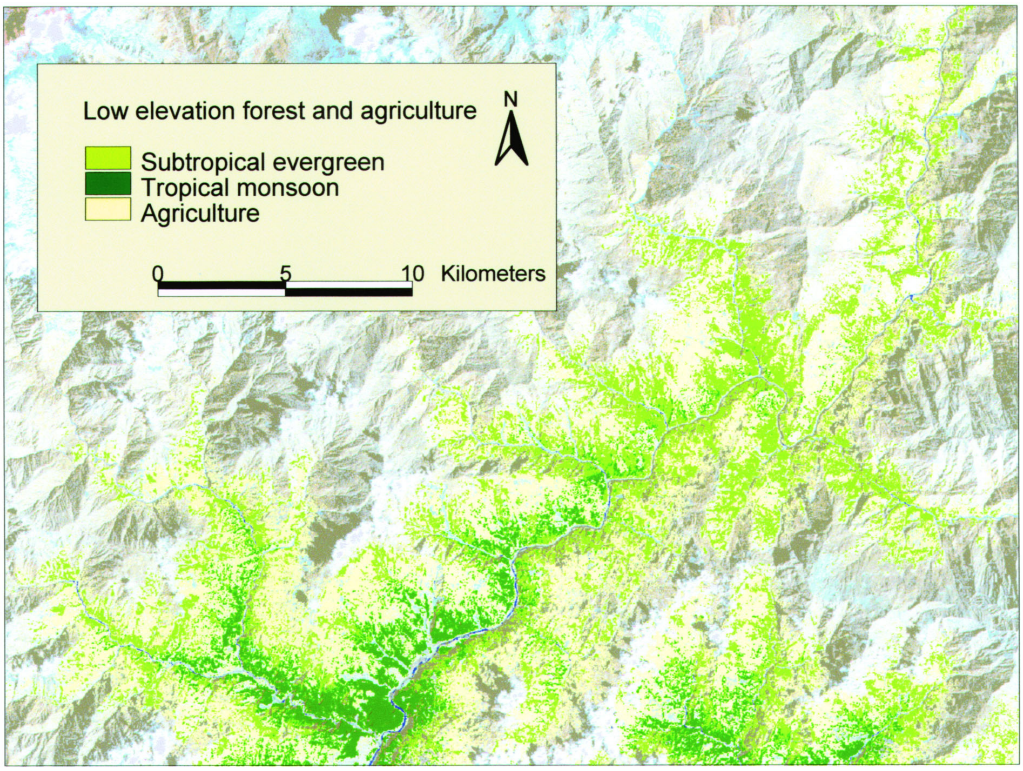



**FIGURE 2** Distribution of 2 low-elevation forest types within the upper Arun River Valley of eastern Nepal. An overlay of the forest classes on the enhanced false color Landsat TM (1992) imagery reveals a landscape pattern typical of the relatively heavily populated Middle Hills of the eastern Himalaya. Forest fragments are clustered along the steep riparian corridors of tributaries and along the banks of the Arun River, interspersed by agricultural land uses, including terraced and nonterraced cropping areas, grazing land, and agricultural scrub. Tree cover forms a patchy corridor of habitat, finely articulated along the riparian network. Several conspicuous breaks in cover (ie, agricultural zones) are evident on the less steep slopes along the west side of the Arun corridor.

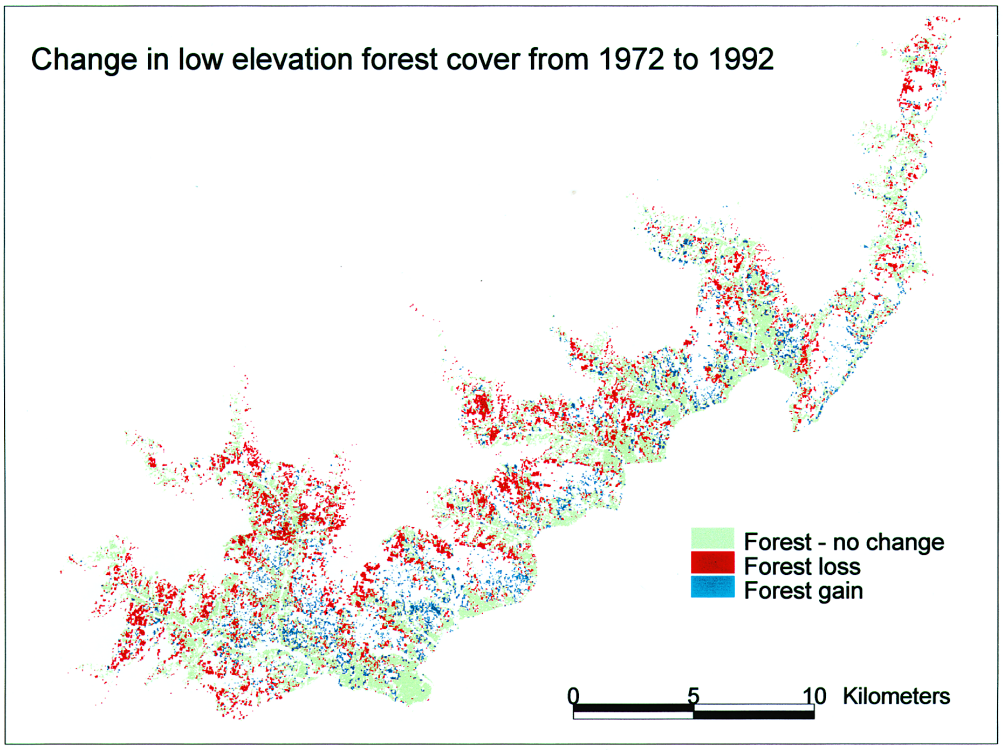



**FIGURE 3** Change detection analysis of low elevation forests within the Makalu Barun Conservation Area over a 20-year interval. Results are based on a direct comparison of the classified Landsat MSS (1972) and Landsat TM (1992) datasets.

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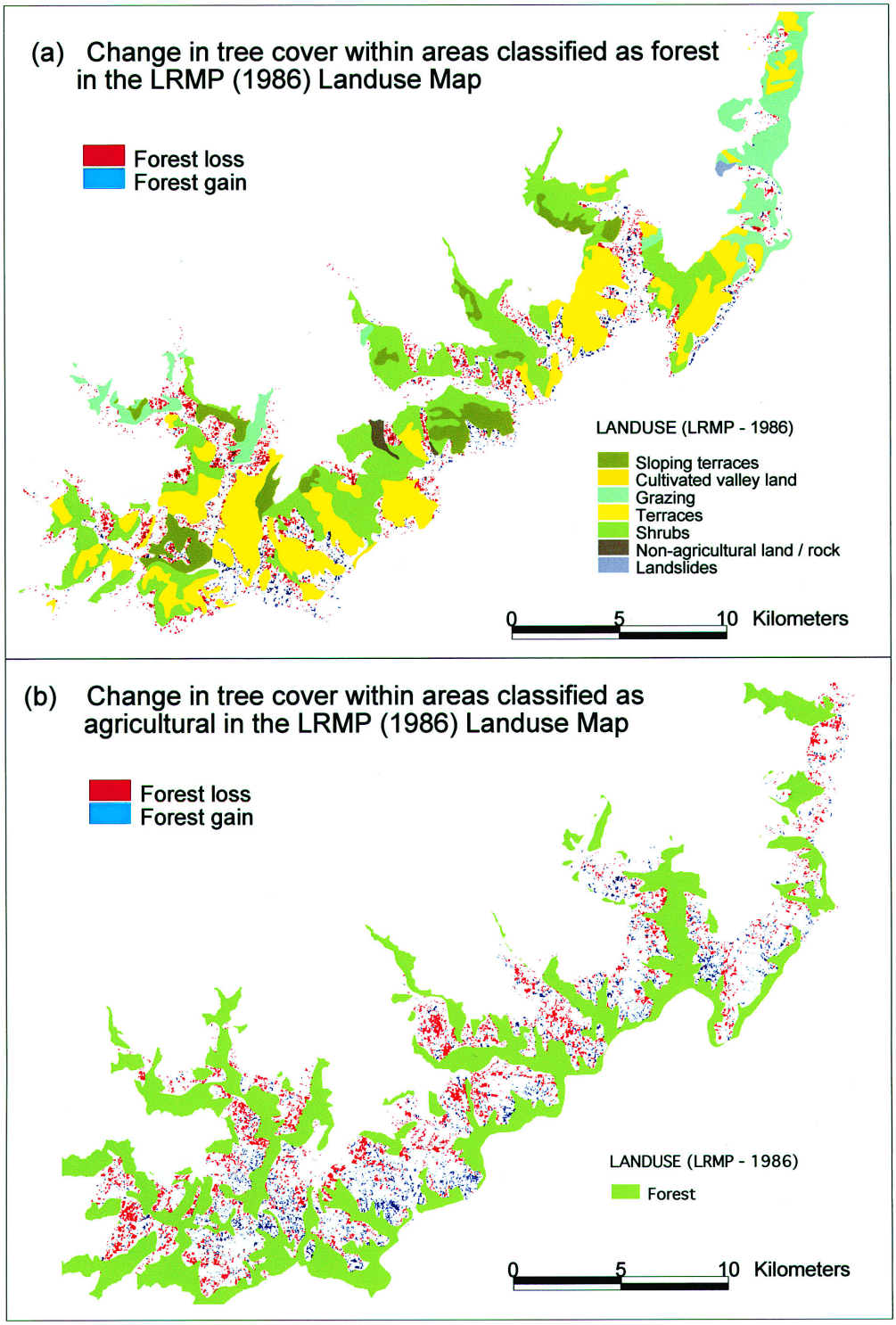



**FIGURE 4** Change detection analysis of low elevation forests within the Makalu Barun Conservation Area over a 20-year interval. Results are based on a direct comparison of the classified Landsat MSS (1972) and Landsat TM (1992) datasets and are shown in relation to the Land Resources Mapping Project (LRMP 1986) Land Use Map.

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landscape. Because the linear nature of the deeply cut corridors limits dispersion and migration of both plant and animal species, even relatively limited fragmentation within corridors can be significant, although impact is species specific. Within the study area, low elevation riparian forests form a fairly contiguous network and intermingle at their upper margins with the densely covered and extensive areas of oak, hemlock, and fir forests of the upland National Park area. This spatial continuity enhances both their value to seasonally migrating species and their resilience to periodic disturbance.

### Change detection analysis

Comparison of the 1992 Landsat TM supervised classification with the classification derived from the 1972 Landsat MSS data shows that forests have been significantly impacted by conversion to agriculture during the period leading up to the establishment of the MBCA in 1992 (Table 2). Comparative analysis, however, is confounded by the coarser spatial resolution of the Landsat MSS data and its more limited spectral bandwidth. The complexity of the farming landscape, a highly differentiated cropping calendar, and small farm and field size further confound classification of land use and cover within the Middle Hills (Millette et al 1995). The Landsat MSS classification was not able to achieve a fine discrimination of forest cover type classes, that is, compared with the TM imagery. To accommodate this incongruity and to facilitate the comparative analysis, all forest classes in the MSS classification were aggregated into a single inclusive forest class.

Relatively little change in the overall extent or the pattern of spatial distribution for LRMP-designated forested areas is evident. The tropical zone exhibited a slight net increase of forest cover (approximately 3%), attributed to abandonment of marginal low-elevation terraces. The majority of forest loss appears at the upper margin of the subtropical zone, indicating a movement further up onto more marginal upland slopes. A high degree of both temporal and spatial heterogeneity of land use and vegetation dynamics is revealed in both the quantitative and spatial analysis. Results differ somewhat compared with earlier studies of land use change in the lower Arun (Virgo and Subba 1994) and in the hills of the western and central regions of Nepal (Gilmore and Nurse 1991; Fox 1993). These studies detected no statistically significant changes (over a similar time interval), but considerable internal trading between land use categories was evident. Schreier et al (1994) reported results similar to these earlier studies, however, also detecting significant internal trading of land use categories.

## Conclusions

Analyses of land use and cover change processes within the MBCA suggest that remaining riparian stands are under pressure and are subject to disturbance and degradation. Evidence that overall extent of low elevation forests within the MBCA has decreased in the period from 1972 to 1992 indicates substantial conversion to agricultural land uses. Complete loss of forest stands occurred primarily within the subtropical nonriparian forests of the MBCA. Loss of spatially limited but ecologically significant remnant stands within the monotypic agricultural landscape further increases the significance of remaining riparian zones.

The ecological and economic significance of remnant riparian forest within the landscape and the mountain farming system create a unique conservation challenge for managers, policymakers, and researchers interested in regional or landscape-level approaches to biodiversity management. Increasing population and livestock numbers threaten riparian forest with degradation and local extinction throughout the Middle Hills of east Nepal. On this regional level, conservation and biodiversity management are faced with several challenges. Spatially discrete patches within roughly contiguous corridors, interspersed within a primarily agricultural landscape, do not easily lend themselves to protection within the national park or protected area conservation model. Community forestry (Gilmore and Fisher 1991) on a local level has proven an effective model for other similarly restricted forests in the Middle Hills but has not specifically addressed the role of biodiversity conservation or wildlife habitat. Further research on biodiversity and wildlife habitat relationships within these patches and a specific recognition of the value of remnant riparian forests within the landscape and rural economy are required if conservation goals for the eastern Nepal Himalaya are to be met.

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**ACKNOWLEDGMENTS**

This study was conducted at the Center for Spatial Technologies and Remote Sensing (CSTARS) at the University of California Davis and was supported by grants from EOSAT Corp and The Mountain Institute. The authors are grateful for reviews, assistance, and/or other help from Prof Jack Ives, Dr John Menke, Dr Gabriel Campbell, Dr Alton Byers, Dr T.B. Shrestha, and many others. We wish to extend thanks to the people who assisted with our fieldwork, especially scientists and staff affiliated with the Makalu-Barun Conservation Project, The Mountain Institute, San Francisco State University's Wildlands Studies Program—Nepal, and especially Laxmi Dewan and the staff of Nilgiri Treks.

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