Chapter Six

A Model of Anthropogenic Change in Mixed Broadleaved Forests of the Temperate Sikkim-East Nepal Himalaya

Abstract

I use data from human, plant, and animal communities at Chitre Village (pop. 50) to create a graphic model of anthropogenic environmental change in mixed broadleaved forests of the Temperate Sikkim-East Nepal Himalaya. The model's four sequential stages depict landscape-scale changes in vegetation and village development at a scale of ~18 km^2. Future conditions are based on satellite images of nearby Salleri Village (pop. 5368). Six additional figures depict associated patch-scale habitat conditions at a scale of ~40 ha. Corresponding changes in animal communities are presented in narrative, and referenced to supporting evidence in the preceding chapters.

In the transition from seasonal *khArka* (pasture) to commercial outpost, closed-canopy forest is largely replaced by cropland, pastures, and open-canopy secondary forest. In the early stages of development, most resident plant and animal species are associated with closed-canopy forest and natural canopy gaps. At intermediate stages, the proliferation of anthropogenic habitats results in peak habitat diversity and, consequently, peak animal species diversity, although woody plant diversity declines. Croplands and pastures become colonized by disturbance-tolerant species common in open habitats at lower elevations, and are particularly attractive to birds that nest in ground cavities or have herbivorous diets (Table 5.15). The proliferation of open secondary forest increases available habitat for bird guilds that nest or forage near the ground or in the mid-canopy, or forage facultatively on nectar, insects, or fruit (Table 5.15), and all small mammal dietary guilds except carnivores (Table 5.16). At the commercial outpost stage, open

anthropogenic habitats predominate and primary closed-canopy forest is reduced to small remnants. Animal species that utilize weedy thickets or ruderal patches, or are commensal with humans, become more common and diverse. Forest-interior species and endemic habitat-specialists become rare or absent, and available habitat declines for avian guilds that forage strictly on fruit or nectar, forage in the high canopy, or forage and nest strictly in the mid-canopy (Table 5.15).

Model predictions regarding future conditions should be field tested at villages of greater size. Coupled with careful negotiation, community education, and outside support, this model, and the supporting research, could be instrumental in curbing the degradation of biodiversity and high-value forest resources where forests are co-managed by local communities.

Introduction

Computer-based visualization is widely used in the natural sciences to help understand and communicate data, generate ideas, and gain insight into natural processes (O'Donoghue et al. 2010). Terrain visualization software allows users to represent 3-D terrains across a range of scales by draping images of vegetation (land cover) and other objects onto a high-resolution digital elevation model (DEM) of an area, producing artificial images of simulated 3-D environments that represent or depict real world landscapes (Ruzinoor et al. 2012). Terrain visualizations look more realistic than abstract two-dimensional maps and illustrations, so they are more easily understood (Patterson 2001). Terrains can also be modeled over time, either as a series of static scenes or as an animation, to provide insight or communicate knowledge about how the terrain has, or will, change over time.

Anthropogenic changes that have occurred in plant and animal communities at Chitre Village can serve to model and predict ecological changes elsewhere in the Temperate Sikkim-

East Nepal Himalaya (TSENH). The objective of this chapter is to present a generalized model of plant and animal communities at successive stages of rural development in the TSENH. The model predicts future conditions, and provides insight on past ecological conditions. Coupled with careful social analysis, community education, outside support, and the detailed analyses of preceding chapters, the model can be instrumental in curbing the degradation of biodiversity where forests are co-managed by local communities.

Methods

Study Area

Field data were collected at Chitre Village, Sankhuwasabha District, eastern Nepal (pop. 50, elev. 2350 m). The physical environment and cultural characteristics of Chitre Village are described in Chapter 1. Woody vegetation around the village is described in Chapter 3, and the birds, small mammals, and wildlife habitats are described in Chapter 4. In Chapter 5, I described how resource harvests affect the structure and composition of wildlife habitats and small animal communities. The broader area to which the results are extrapolated includes the entire TSENH, from central Nepal to eastern Bhutan (Figure 1.1).

Data Collection

Methods of data collection are described in Chapters 2 (forest use, village oral history), 3 (woody vegetation), and 4 (birds, small mammals, habitats). Here, I use recent Google Earth images of Chitre Village and Salleri Village (Solukhumbu District) to access the scale and geographic patterns of anthropogenic changes in vegetation and cultural features.

Data Analysis

In Chapter 3, I used ordination and correspondence analysis to characterize the associations of woody plant species near Chitre Village. In Chapter 4, I used correlation analysis and logistic regression to assess habitat associations of birds and small mammals in the area. And in Chapter 5, I used diversity analysis and chi-square tests to assess species diversity and turnover across progressively disturbed habitat zones around Chitre Village.

Here, I use photorealistic terrain visualization software (World Construction Studio, 3D Nature, Conifer, CO) to create a series of graphic depictions of how plant communities and animal habitats change as a remote pasture becomes transformed into a commercial outpost. Corresponding changes in animal communities are described narratively, based on my analysis of species turnovers at Chitre Village (Chapters 3-5).

The model depicts landscape-scale changes (~18 km^2) in vegetation and village development at four sequential stages: seasonal *khArka* (N. pasture), recent settlement, small village, and commercial outpost. I used a 10-m-resolution digital elevation model from the Sierra Nevada Mountains to render topography for the scene because a high-resolution digital elevation model was not available for the Chitre area. Associated patch-scale habitat conditions are depicted at a scale of ~40 ha.

Depictions of historic conditions are based on oral history of Chitre Village provided by local informants, and on my own observations and assessments of present day forest-interior *khArka*s near Chitre. Depictions of future conditions are based on 2014 Google Earth satellite images of Salleri (pop. 5368), a commercial outpost at the trailhead to Sagarmatha (Mount Everest) National Park, located 45 km west of Chitre at a similar elevation (2450 m, vs. 2350 m at Chitre).

In extrapolating data from present-day Chitre to future developmental stages, I use proximity to the village as a proxy for time, because the effects of proximity and time (period of exploitation) are similar in many respects. Although my landscape- and patch-scale depictions are not statistical or quantitative *per se*, the densities, dimensions, and forms of plants and dwellings are based on measurements taken at Chitre Village and from Google Earth satellite images of both Chitre and Salleri.

Results

Seasonal khArka *stage*

Seasonal livestock grazing is usually the first human activity to have a lasting influence on the woody vegetation of pristine temperate Himalayan forests. Hunting, herb collection, or spiritual pilgrimages might precede herding but have little impact on woody vegetation. Livestock are typically managed according to the *goTh* system, whereby herds are kept at a series of remote herders' camps while crops are being sown in villages (Schroeder 1985, Chapter 1). As the herds are moved from one pasture to the next along well-established trails, they forage in the nearby forest. When the herd reaches a traditional *khArka* site, several tree saplings are cut to build or renovate a temporary shelter (N. *goTh*, Fig. 1.9). The herd will graze the surrounding area intensely for several days or weeks (Fig. 1.11), then move to the next *khArka*.

Generalized landscape-scale conditions resulting from seasonal *khArka* use are depicted in Figure 6.1. The landscape is largely covered with primary closed-canopy broadleaved forest. Along a well-worn footpath there is a narrow, highly disturbed, strip, just a few meters wide, consisting of low herbaceous vegetation and heavily-browsed shrubs. A *khArka* is essentially a pasture within a <1 ha forest clearing. The *goTh*, a temporary herder's shelter, is built from wooden stakes (N. *ghocha*) acquired nearby and woven bamboo panels, or *chitra* (Fig. 2.21), which are transported from *khArka* to *khArka*. Woody plants in the vicinity of trails and *khArka*s are disfigured from lopping and livestock browsing, and most are disturbance-tolerant pioneer species (Table 5.4).

Two patch-scale conditions are characteristic of the *khArka* stage landscape, primary forest and forest *khArka*s. Primary forest (Fig. 6.2) has a tall (>20 m), closed (>95% cover), multi-storied canopy, dominated by 10-20 characteristic climax species of the TSENH (Chapter 5). The diversity of woody plant species is at its maximum in primary forest (Table 5.6). The mid-canopy is relatively dense and consisting of young trees and a few pioneer species that occur naturally in primary forest canopies (Table 5.4). The understory is relatively dense and consists of young tress (including palatable and high-value species), shade-tolerant shrubby species, and bamboo (N. *bA~s, malingo*). The ground is covered with leaf litter, and logs and boulders are covered with moss. Where natural canopy gaps occur, mesic pioneer species flourish (Chapter 5).

Forest *khArka*s (Fig. 6.3) are small forest-interior pastures dominated by disturbance-tolerant herbaceous plants and weeds. There are usually no large trees near the center of the *khArka*, but there can be tall, heavily lopped, specimens of highly palatable species, which are regularly lopped to provide tree fodder for livestock (Chapter 2). At the forest-pasture edge, there is typically a "wall" of woody pioneer tree and shrub species, and sometimes a limited area of shrubby pasture. In the forest immediately adjacent to *khArka*s and major footpaths, the understory is open, except clumps of unpalatable or browse-tolerant shrubs. Palatable tree species and bamboo are rare or lacking in the understory. Beyond the daily ranging distance of livestock (~0.5 km), the forest approaches pristine conditions.

The dominant animal species of *khArka* stage landscapes are closely associated with closed-canopy broadleaved forest and forest-interior canopy gaps. The *khArka*s and trails comprise too little area to provide sufficient habitat for many open-habitat species. Well-represented ecological guilds in primary closed-canopy forest include birds that are strict frugivores or nectarivores and birds that forage in the high or mid-canopy, or nest in the mid-canopy or shrub canopy (Table 5.15). Species of several widespread animal genera are closely associated with primary temperate broadleaved forests of the TSENH, including *Arborophila*, *Brachypteryx, Ficedula, Muntiacus*, *Strix, Tarsinger*, *Tesia*, and *Tragopan*. A partial list of rare or threatened species associated with temperate broadleaved forests in northeastern Nepal is provided in Table 1.1.

Recent settlement stage

When an existing Himalayan village becomes overcrowded (e.g., through subdivision of limited arable land among male descendants), one or more families might elect to resettle, to an uninhabited site that will support the form of agropastoralism they customarily practice. Use of the new site must be negotiated with the community that holds customary use rights (for grazing, hunting, etc.; Chapter 1). Occasionally, recent settlements are abandoned because they prove to be unproductive or inhospitable. Modern settlements rely on agropastoral production (Chapter 1), a combination of fixed-field agriculture and livestock herding (historically, shifting slash-and-burn agriculture was widely practiced). The environment immediately around the village is profoundly influenced by crop production and livestock grazing. Village-based herds forage close to the village nearly every day, and itinerant *goTh*-based herds also graze nearby in winter (Chapter 1).

Figure 6.4 depicts generalized landscape-scale conditions of a recent settlement. Most of the landscape remains covered with primary broadleaved forest. *KhArka*s are also present, but at some distance from the village. Animal diversity increases at this stage due to increased heterogeneity of forest habitats and greater extent of open habitats (Chapter 5). Patch-scale elements that appear for the first time at this stage are fixed-field croplands, village pastures, and fuelwood felling areas.

Fixed-field croplands (Fig. 6.5) are positioned on relatively gentle slopes with southern exposure. Irrigation is generally not employed. The principle subsistence crops in the TSENH are potato (*Solanum tuberosum*), maize (*Zea mays*), and wheat (*Triticum vulgare*) (Chapter 1). Over the past decade, cash crops have expanded rapidly, especially the medicinal herb chirata (*Swertia chirayita*). Rock retaining walls are sometimes present to stabilize terraced fields. They are sometimes planted sparsely with browse-tolerant woody plants to create living fences (Chapters 3 and 5). Wild woody plants are generally excluded from croplands, except where they serve as living fences or are semi-cultivated for tree fodder (Chapter 5). The best fields are fertilized and cropped every year, whereas auxiliary fields are often managed as short-rotation (3-7 yr) shrubland swiddens (Chapter 1). Dwellings are usually simple huts made of rough-hewn poles, woven bamboo panels, and wooden or shale roof shakes (At Chitre, bamboo huts are traditionally roofed with multiple layers of woven *chitra*).

Village pastures (Fig. 6.6) are located just beyond the cultivated fields. They are grazed year-round by cattle (*Bos taurus*), and seasonally by sheep (*Ovis* sp.), goats (*Capra* sp.), yak (*Bos grunniens*), or cattle-yak hybrids (Chapter 1, water buffalo *Bubalo bubalis* at Chitre are somewhat unique for temperate elevations). The high canopy is nearly absent (Chapter 5), although a few large trees might be retained for tree fodder. Small, low-stature, patches of secondary canopy are comprised primarily of low-value, disturbance-tolerant, pioneers, including species of *Eurya*, *Lyonia*, *Symplocos*, and *Viburnum* (Chapter 3). Most plants are multi-stemmed and disfigured as a result of repeated lopping for stakes (N. *ghocha*). Most woody plants around pastures are shrubby xeric-site pioneers that tolerate direct sunlight, browsing, and lopping. Some bear thorns (e.g., *Berberis* spp.). Pastures are also the primary source of dry branches for kindling cooking hearths (Chapter 2, Fig. 2.7).

Fuelwood felling areas (Fig. 6.7) occur in a zone of patchy, secondary forest just beyond village pastures and shrubland fallows. The different techniques used to harvest fuelwood impact forest habitats somewhat differently (Chapter 5). Gathering of dead wood from the forest floor has little or no direct or immediate impact on the composition or structure of vegetation, although habitats of ground-dwelling organisms are diminished, and over time forest soils become deprived of nutrients. Smaller households are more inclined to gather dead fuelwood, because they lack sufficient labor resources to fall and process large trees. Wealthier households often do have the resources to fall large trees of the preferred species (Chapter 2).

In closed-canopy forest, felling of large, choice, trees for fuelwood creates small gaps in the forest canopy, to which canopy-gap-adapted mesic-edge pioneer species respond positively (e.g., avian frugivores, lianas, *Hydrangea* spp.). In heavily harvested secondary forest, the canopy is more open, with maximum vertical and horizontal heterogeneity (Fig. 6.7). Sometimes entire swaths of small-stature fuelwood species are harvested by households with high fuelwood demands, creating forest clearings 0.1 ha or larger within secondary forest.

Although the diversity of woody plants is diminished relative to primary forest (Table 5.6), woody pioneer species (Table 5.4) flourish in secondary forest openings, particularly in the shrub and mid-canopy vegetation layers (Fig. 5.4). Patch-scale small animal diversity peaks in the heterogeneous habitats of fuelwood felling areas, in accordance with the intermediate disturbance hypothesis (Chapter 5, Tables 5.11 and 5.12).

The characteristic animal species and guilds of closed-canopy forest remain well represented at the recent settlement stage. Fuelwood harvest areas increase habitat area for species and guilds associated with open secondary forest, particularly bird guilds that nest or forage near the ground or in the mid-canopy, or forage facultatively on nectar, insects, or fruit

(Table 5.15), and all small mammal dietary guilds except carnivores (Table 5.16). Shrubby pastures and croplands increase habitat area for widespread generalist species associated with very open habitats and human dwellings, as well as avian herbivores. A greater number and diversity of passage migrants now forage on grains available in croplands and pastures (including crops), and on berries available in secondary forest and shrubby pastures (e.g., fruits of *Berberis* and *Cotoneaster* spp.).

Small village stage

Where recent settlements succeed, the number of households grows and individual household prosperity increases. As the area of land under agricultural production increases, the area of forest resource extraction expands. As household prosperity increases, larger herds of more valuable breeds are acquired, more cropland gets fertilized, and larger and more durable homes are built. Agricultural production sometimes exceeds subsistence needs, and is used as barter for goods or services. Some households begin growing cash crops. Fuelwood and timber harvest increase the extent and structural complexity of secondary forest. Declining supplies of high-value forest resources lead to community-enforced harvest restrictions on certain species (e.g., bamboo and medicinal herbs).

Figure 6.8 is a generalized landscape-scale depiction of a small village, based loosely on Chitre Village in the mid-1990s. At the center are cultivated fields and dwellings. Wealthier households build houses (N. *GhAr*) from timber and stone rather than poles and woven bamboo, and they invest in more terracing and retaining walls. Substantial areas of auxiliary cropland are maintained as shrubland swiddens.

A zone of shrubby pastures lies just beyond the croplands, and further out, a zone of secondary forest. Beyond ~1 km, the forest is still essentially primary forest. *KhArka*s still occur along major trails through secondary and closed-canopy forest. At the small village stage, timber and stone construction requires felling of large trees, so timber harvest areas (Fig. 6.9) are evident just beyond fuelwood felling areas, at the leading edge of secondary forest expansion. Closer to the village, the supply of large timber trees has been exhausted (Chapter 5). Patch-scale effects of timber harvest are similar to those of fuelwood felling, except fewer trees are harvested at a given site and harvest sites are more dispersed (Chapter 5). Mesic pioneer species flourish in canopy gaps created by timber felling.

Landscape-scale animal diversity peaks at the small village stage, due to the juxtaposition of closed-canopy primary forest, open-canopy secondary forest, and very open village environments. Croplands, shrublands, swiddens, and pastures cover sufficient area to support small populations of widespread disturbance-tolerant generalists (Chapter 5). Ecological guilds that benefit from expansion of these non-forest habitats include birds that nest in ground cavities or have herbivorous diets (Table 5.15), and pass-through migrants (Appendix 1.3). Some regionally widespread genera with species that breed in open habitats include *Cettia*, *Dicaeum, Dicrurus*, *Garrulax, Lanius*, *Luscinia*, *Motacilla*, *Mus*, *Prinia*, *Pycnonotus, Rattus*, *Saxicola, Soriculus*, and *Suncus*.

The extensive area of secondary forest greatly increases habitat area for animal species associated with forest edges. Tree felling for timber and fuelwood creates high vertical and horizontal heterogeneity and, correspondingly, peak patch-scale diversity of animal species and guilds that nest or forage in the shrub layer or forage on insects or nectar (Table 5.15). Regionally widespread genera with species that breed in patchy secondary forest include *Aethopyga*, *Alcippe*, *Brachypteryx*, *Cuculus*, *Ficedula*, *Heterophasis, Lophura, Martes*, *Megalaima*, *Minla*, *Niltava*, *Niviventer, Parus*, *Phylloscopus, Pnoepyga*, *Pomatorhinus,* *Pteruthius*, *Seicercus*, *Soriculus*, *Stachyris*, *Tesia*, *Turdus,* and *Yuhina*.

The apparent attractiveness of disturbed secondary habitats could hypothetically lure some species into an ecological trap, where survival and reproductive success are diminished due to elevated competition and predation, but this question requires further study (Chapter 5).

Commercial outpost stage

Figure 6.10 is a landscape-scale depiction of a generalized commercial outpost, loosely based on Salleri Village. At this stage, a motorable road has reached the village. The road has brought growth, commercial activity, wealth, more diverse livelihoods, additional ethnicities, primary education, rudimentary health services, and a decline in *goTh* agropastoralism. Craft specialists place additional demands on local forest resources, including production of charcoal. The area under cultivation is greatly expanded to meet local food demands, as well as for regional export. The variety of crops has increased to meet the demands of diverse ethnic groups and commercial restaurants. Crop fertilization with locally available biomass and dung (N. *mal*, Chapter 1) is difficult to practice because deforestation has greatly reduced the supply of leaf litter close to the village. Wealthier farmers purchase commercial fertilizer. Village-based livestock graze on small parcels of ruderal (weedy) vegetation scattered throughout cropland and dwelling areas where the terrain is too steep or eroded for construction or cultivation. The roofs of commercial buildings and wealthier homes are made from brightly colored steel sheets.

Nearly all forest cover within 1-2 km of the village consists of moderately- to highly-disturbed secondary growth, where the understory is open and dominated by disturbance-tolerant species due to persistent grazing and lopping. Easily over-harvested species are rare or absent. More than an hour’s walk might be required to harvest preferred fuelwood species. Large timbers are not available nearby, so most are trucked in from elsewhere. Gullies and streams are deeply eroded due to the loss of forest cover and soil disturbance by livestock. Primary closed-canopy forest occurs only in remote patches, at sites that are inaccessible due to dangerously steep terrain.

The animal community is dominated by species and ecological guilds associated with open secondary forest and croplands (see small village stage above and Appendices 1.3 and 1.4). Species richness and diversity remain high (Tables 5.11 and 5.12), but uncommon specialists associated with closed-canopy forest are replaced by widespread generalists of open habitats (McKinney and Lockwood 1999, Tabarelli et al. 2012).

Secondary forest continues to harbor relatively high diversity of animal species (see Small village stage above and Tables 5.11 and 5.12), but where human and livestock's activity is high, species that forage or nests near the ground are diminished.

In village environments, expansion of shrubland has increased the diversity and abundance of shrub-associated animal species, especially widespread generalists. Species associated with ruderal patches and weedy thickets (e.g., babblers) are more common and diverse, as are species commensal with humans (e.g., *Mus musculus*). Illegal hunting and use of chemical pesticides and herbicides could keep populations of some cropland-associated species below carrying capacity of the habitat.

Animal taxa associated with primary forest (see seasonal *khArka* stage above) are greatly diminished, as are bird guilds that nest or forage near the ground or in the mid-canopy, or forage facultatively on nectar, insects, or fruit (Table 5.15), and all small mammal dietary guilds except carnivores (Table 5.16). Species that require large blocks of a contiguous forest canopy (forest-interior species) are rare or lacking. Endemic habitat-specialists are rare or absent because characteristic habitat features of primary forest understory - bamboo, ferns, moss-covered logs -

are rare or absent. Large species are rare or absent due to habitat fragmentation and over-hunting (e.g., barking deer *Muntiacus muntjak*, serow *Capricornis sumatraensis*, *Tragopan* and *Lophura* pheasants).

Discussion

The Chitre data, and any inferences I draw from them, become less applicable with increasing distance from the village. A few circumstances at Chitre might have been truly unique, such as water buffalo husbandry at 2350 m elevation. The plant and animal data reflect Chitre's topographic, meteorological, phytogeographic, and cultural (ethnic) makeup, as well as its settlement history and agropastoral practices, but these circumstances are not unique, *per se*. They likely vary within the range found among other villages in the TSENH. When applying the model, it will be necessary to substitute ecologically or taxonomically similar species indigenous to the area. This is the strength and appeal of guild-level community analysis. Where long-rotation swidden, goats, or sheep, are more important components of agropastoral production (or cha˜ri less important), different impacts on the structure and composition of vegetation must be considered.

The initial stages of the model - transitions from pristine forest to seasonal *khArka* to recent settlement - might only be of academic interest. Nearly all remaining primary broadleaved forest in physical settings that would support permanent settlement in the TSENH have been, or soon will be, incorporated into National Parks, or otherwise protected from future settlement. Predictions and postulations of the later stages - the transition from recent village to small village to commercial outpost - can, and should be, tested in the field and refined. Salleri Village, 45 km west of Chitre Village, would be an excellent site to test predictions about changes in the transition from small village (i.e., Chitre) to commercial outpost.

For science-based conservation programs to succeed, and forestall some of the ecological changes my model predicts, they must be understood and desired by local people. Local communities should be provided the knowledge and tools necessary to execute on-the-ground aspects of a conservation program, within scientific guidelines established and monitored by the responsible government agency. Outside advocates must understand and appreciate the cultural connections local people have to a forest, and use these as starting points to craft locally meaningful, scientifically credible, conservation programs.

All major cultural groups in the TSENH recognize some kind of sacred, inviolate, forest, which is usually associated with a holy site or temple (Pei 1991, Ramakrishnan 1998). Many communities also have a history of negotiating and enforcing community control over scarce, high-value, forest resources (Gilmour 1990, Gilmour and Fisher 1991). The ecological knowledge reflected in this model and its supporting research should be explained to local communities in a manner that builds upon their current understanding of forest ecology. In particularly, they should understand: 1) population age structure of trees and other high-value resources, 2) sustainable harvest rates, 3) ecological niches, niche-gestalts, and habitat associations, and 4) the ecological and economic benefits of biodiversity and rare species. Many individuals will recognize these concepts from practical experience, but their indigenous knowledge will need to be squared with current scientific understanding of forest ecology (Shrestha et al. 2010). Provided with this knowledge, and with culturally-sensitive guidance and encouragement, communities might be inclined to expand the boundaries of existing sacred forests, or create new community-managed forest reserves based on a new ecological ethos.

Circumstances at Chitre itself bode well for implementation of conservation programs. The recent construction of Phinchho Norling *Gomba* (S. temple) and “bazaar” facilities at Kali

Khola *Mandir* (N. temple) have increased local awareness of, and commitment to, the cultural value of these sites, and engendered some trust in the Makalu-Barun Project, which supported the construction, despite widespread and long-standing mistrust of government at all levels (Regmi 1978). Because the cultural significance of these sites is based partly on cultural connections to nature, it might be feasible to expand their purpose (and area) to include biodiversity conservation.

There will also be cultural obstacles to overcome. Most local people have limited formal education, so learning the factual and interconnected ideas of forest ecology will be challenging. Also, the new *gomba* and *mandir* are revered and tended by people of different ethnic communities, so negotiations over expanded roles of these sites will differ, and potentially create social friction between communities if not conducted properly.

Conclusions

The model I have developed provides insight into past and future ecological change in mixed broadleaved forests of the Temperate Sikkim-East Nepal Himalaya. It is intended to stimulate additional research and to help responsible agencies institute forest co-management programs that will optimize biodiversity conservation, and will be particularly useful where villages are at the small village stage of development. At that stage, local biodiversity is at a peak, yet rare or sensitive species could be on the brink of extirpation. If appropriate conservation measures are introduced at the small village stage, the loss of biodiversity can be minimized, and sustainable supplies of high-value forest resources are more likely.

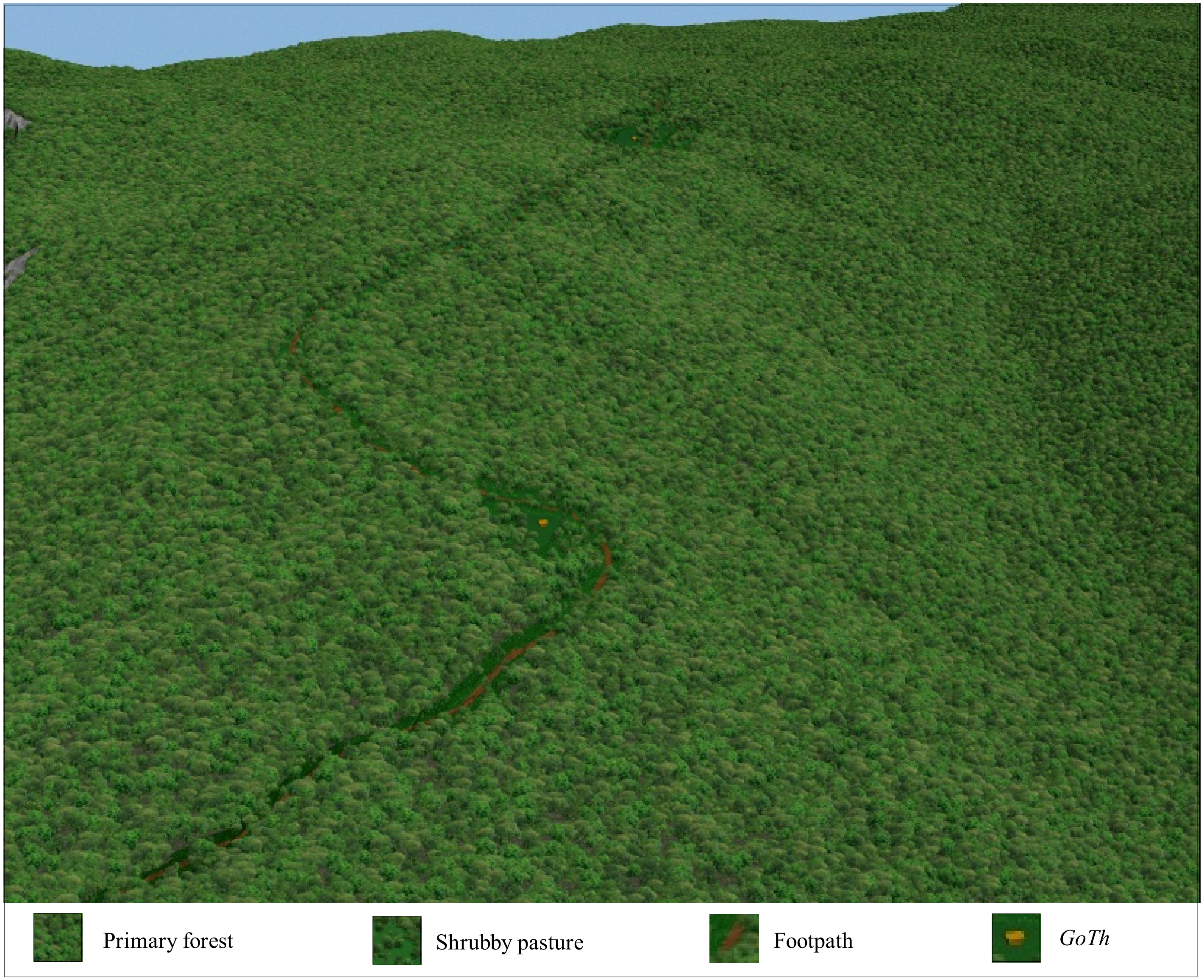

FIGURE 6.1. Seasonal *khArka* landscape.

FIGURE 6.2. Primary forest patch.

FIGURE 6.3. *KhArka* patch.

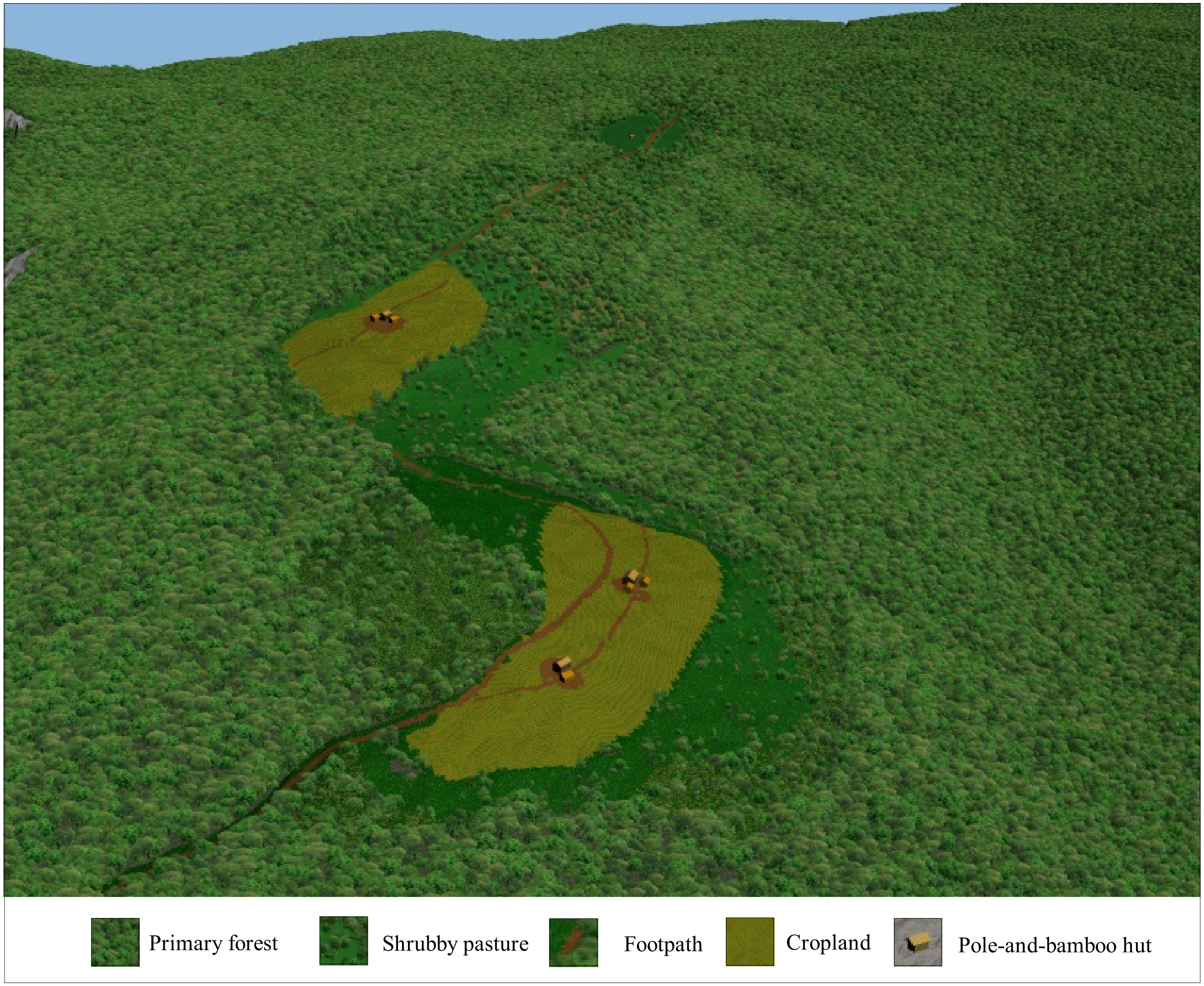

FIGURE 6.4. Recent settlement landscape.

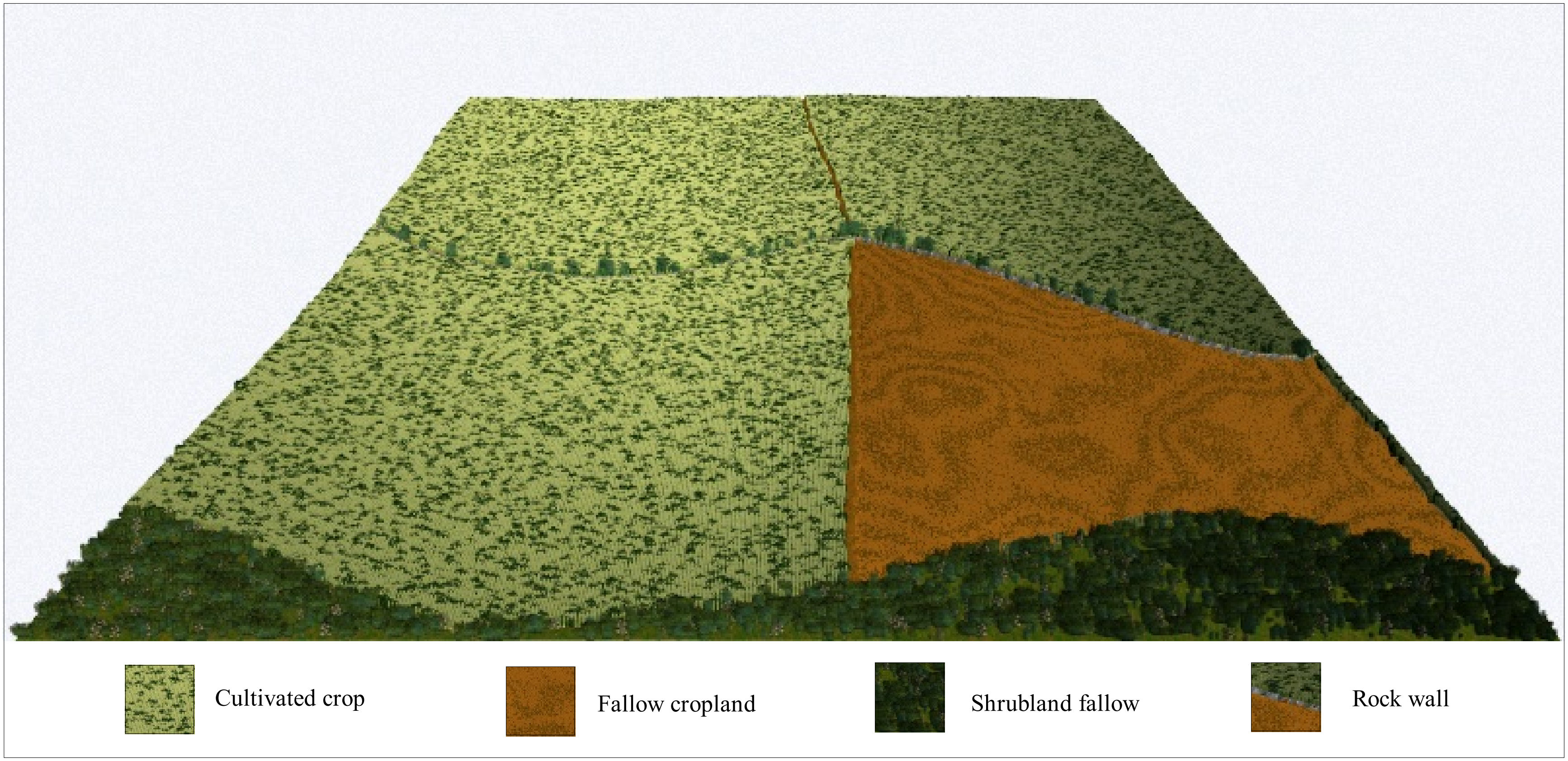

FIGURE 6.5. Cropland patch.

FIGURE 6.6. Pasture patch.

FIGURE 6.7. Fuelwood felling patch. Conditions after most recent harvest are at lower right; less recent, at lower left; oldest (secondary forest), at rear.

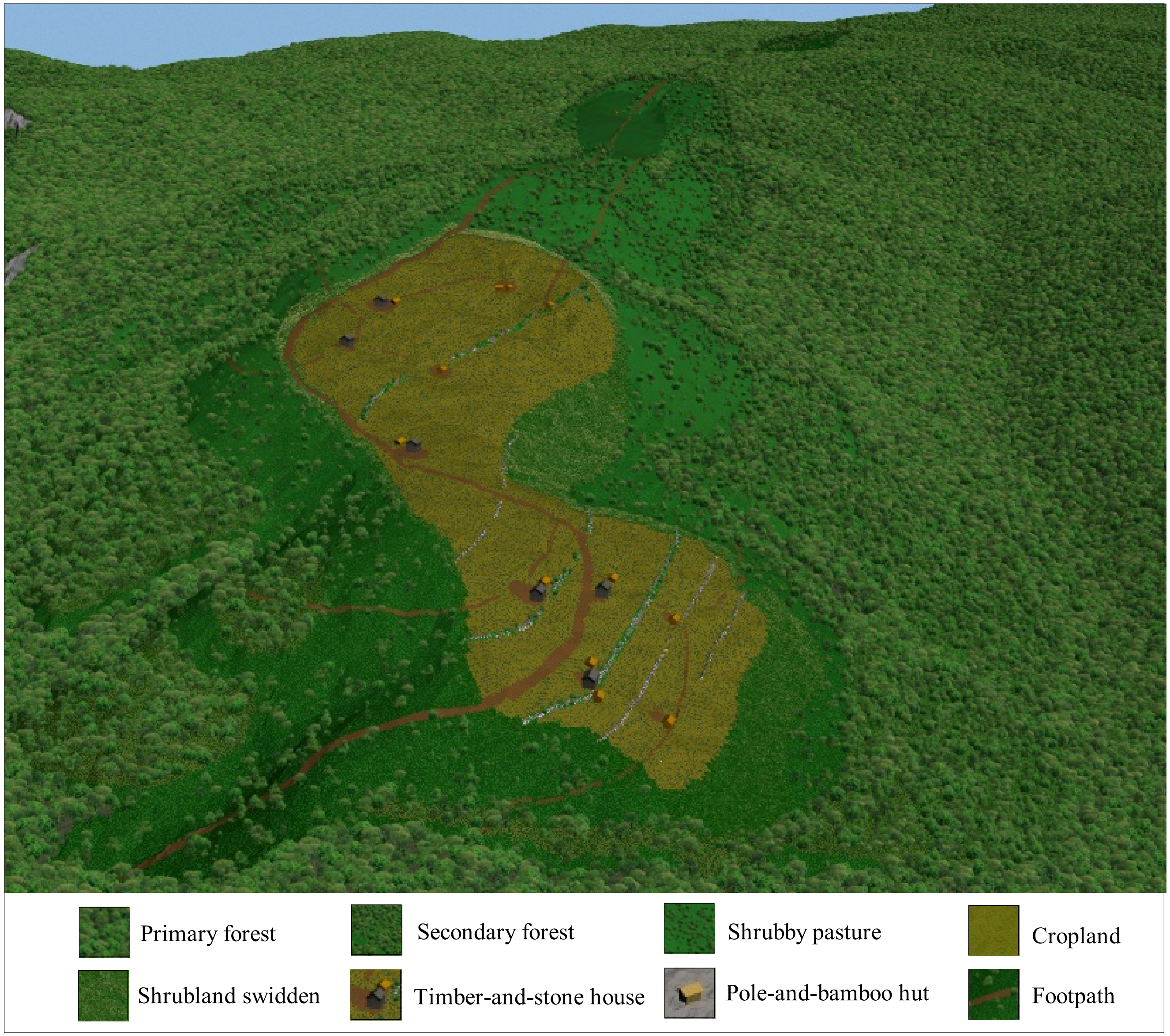

FIGURE 6.8. Small village landscape.

FIGURE 6.9. Timber felling patch. Conditions after most recent harvest are in foreground; older harvest at rear.

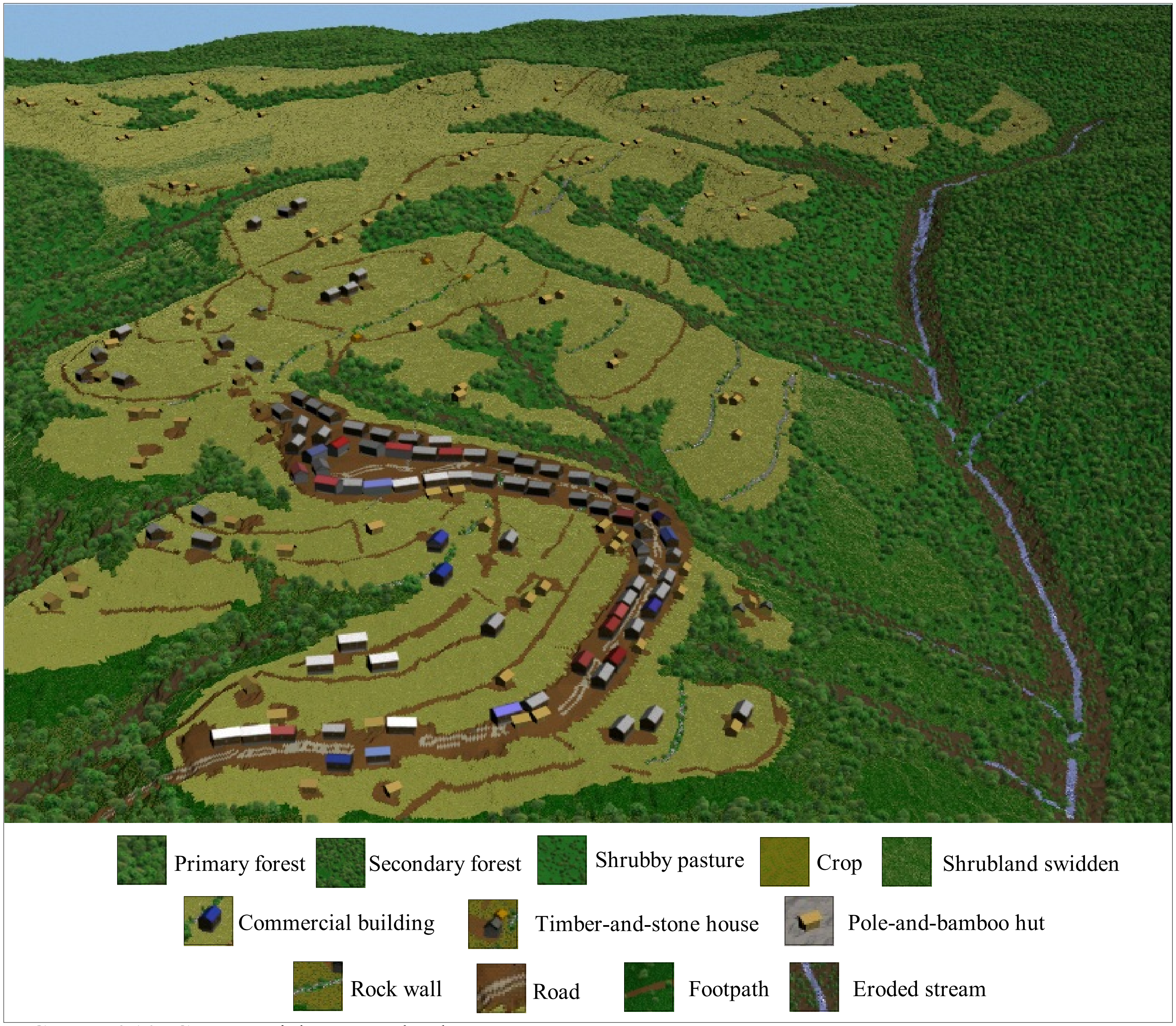

FIGURE 6.10. Commercial outpost landscape.