

ANTHROPOGENIC CHANGE IN THE LANDSCAPES OF HIGHLAND ECUADOR*

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ABSTRACT. The anthropogenic nature of Andean ecosystems is discussed in the framework of tree-line dynamics in selected sites in Ecuador. Indicators of human impact are evidence of the need for a scientific understanding of neotropical mountains that is better in tune with the special conditions of tropical Andean environments. Tropandean systems are neither tropical ecosystems nor midlatitude regions, and lessons from ecologically damaging activities in those ecosystems cannot be transferred readily to Tropandean systems. Better research from the ethnobiological and ecological fronts is needed if we are to comprehend the intricate functions of neotropical mountains, particularly the cloud-forest belt, which is regarded as the most threatened ecosystem when considering sustainability scenarios. *Keywords:* *Andes Mountains, Ecuador, geocology, páramos, tree-line change, tropical montane cloud forest.*

History—geological, archaeological, and agricultural—is a necessary main framework when delimiting the edge of the Tropandean ecoregion, or tropical montane cloud forest (TMCF). Landscape-level conservation planning must then acknowledge humans as the catalyst of landscape change. Today's TMCF landscape in fact reflects two tree lines: an upper one that correlates with the extension of grazing into the colder, higher reaches, which reduces the area of TMCFs from above; and a lower one that correlates with the ascending intensification of cropland agriculture and fuelwood consumption in the piedmont, foothills, and interior highland plateaus. This, in turn, diminishes the extent of TMCFs from below (Figure 1).

In this study I address six questions in order to explore cultural influences on Tropandean tree lines: How different is the *páramo* (grassland) tree line from the agricultural frontier? How distinct is the *páramo* tree line from the pasture frontier? How separate is the tree line from the fire line? Can prehistory tell us part of the story of tree lines? Does historical evidence account for forested highlands? And, Do place-names provide further evidence regarding tree-line environments? The methodology employed to answer these questions includes my field-research observations over many years and a critical review of the literature. These produce a different and more detailed understanding of Andean tree-line dynamics than does the more whimsical view that is currently in vogue.

Answers to the questions I have posed create a body of evidence, observed directly and indirectly, that supports belief in an intricate relationship between na-

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ture and culture that has created today's landscape mosaic (Gade 1999). The answers also speak to the value of ethnoecology as an essential contributor to the current discourse about conservation-with-development. It is both possible and desirable to apply sound environmental-design principles to support sustainable mountain societies amid human-driven change in the Tropandean ecoregion.

CONTEXT

Theory about mountain matters has been summarized in a state-of-the-knowledge compendium (Messerli and Ives 1997). Its final chapter addresses the need for a new science of mountain studies, dubbed with the neologism "montology," which some mountain geographers have echoed (Soffer 1982; Ives, Messerli, and Rhoades 1997; Smethurst 2000). Within this field of study, neotropical montology needs to be redefined in light of new paradigms for tropical mountains (Zimmerer 1999; Sarmiento 2000a, 2002). As one of the specifics, to paraphrase Narp Singh Jodha, deconstruction of the "tree-line theory" helps redefine the new narrative for neotropical montology (Jodha 1990; Zimmerer 2002).

Traditional mountain-ecology literature is based primarily on geocological characteristics that divide mountain systems into four altitudinally defined biogeographical provinces in the mountain biome or orobiome: "colline" areas of rolling hills in low-lying foothills that harbor tall, continuous forest cover; "montane" areas of gentle slopes and flanks of the cordilleras that are covered with stands of robust forest; "alpine" areas of highland plateaus and higher, steeper slopes with grassland vegetation; and "glacial" areas covered by snow or permanent ice and glaciers (Walter and Box 1976; Price 1981; Stadtmüller 1987; Gerrard 1990; Poore 1992; Mountain Agenda 1997). This traditional classification closely reflected the thermally driven approach that divided tropical mountains into hot, warm, cold, and gelid lands, a four-part hierarchy derived from 200-year-old Humboldtian science (Troll 1968).

In the spatial arrangement of the vertical model, scholars perceived the existence of invisible lines separating those layers or physical strata (Landolt 1983). Although the snow line can be readily separated as a boundary dividing the alpine and glacial provinces, lower boundaries are far less easily discerned. No set limit separates the colline portions of the foothills from the even lower flatlands of the piedmont, where tall trees emerge from the canopy of the lowland tropical rain forests and no slopes are steeper than 10 percent. The boundary between the montane and colline provinces is traditionally marked by shorter trees and an abrupt increase in slope, to between 20 and 40 percent (Meybeck, Green, and Vörösmarty 2001). In humid regions the most common boundary, the tree line, distinguishes forests (montane) from grasslands (alpine). Synonyms often equate grasslands with tundra, prairie, or meadow: The taxonomy is anything but precise. Alpine meadows are generically defined as areas that lack forest cover in the high environment. However, high mountains with tall forests, such as those in the Equatorial Andes, fail to fit this model. To clarify this biogeographical gap in neotropical montology, Misael Acosta-Solis called for replacement of "alpine" with "Andean," to indicate



FIG. 1—Sabanization of Andean forests is visible, as pasture replaces montane forest in the Playón de San Francisco, 3,200 meters above sea level, in Ecuador's Carchi Province. Note the fragmentation of forests in shreds instead of a checkerboard pattern along brooks and property boundaries. The same process in the higher reaches of the watershed is known as "paramization." (Photograph by the author, May 1991)

that this feature does not exist in the European Alps but does in the American Andes (1984). Michael Richter discusses the need to revise the terminology of altitudinal belts to include the special characteristics of neotropical mountains (Richter 2002).

The concepts dear to alpine tree-line studies belong to physical geography, meteorology, forestry, and ecology. They emphasize climatic and edaphic factors that influence forest growth, tacitly limiting forestry production in northern latitudes. Modern ecological literature often refers to the altitudinal forest border as the "tree line" and to the latitudinal ecotone as the "timberline" (Körner 1998). In the Tropics, harsh environmental conditions are viewed as the limiting factor for tree growth above a given altitude, mostly correlated with the threshold of the 10°C mean July isotherm, or the location of the frost line (Stadel 1992; Klötzli 1997; Körner 1999). This is analogous to tropical-to-polar plant distribution, a traditional argument (Troll 1973; Lauer 1981).

The tree line occurs at a lower altitude in northern latitudes and on north-facing slopes than in tropical mountains (Ives 1978). In addition, throughout the late Quaternary a variety of local factors, such as snowfall, wind velocity, soil conditions, aspect, exposure, and slope, affected tree-growth physiology and the altitude at which the alpine zone was encountered (Wright 1983). A subalpine transitional

of the verdant Cisandean domain, or the apparent irreversibility of the degraded Interandean domain, or the suggested restoration practices for returning healthy forested ecosystems to the Andes, the human imprint is barely seen as an important driver of the presence of forest and its limits (Sarmiento 1995a, 1998; Chepstow-Lusty and others 1998; Harden 1999). Moreover, the notion of a human-induced tree line is not prevalent in traditional bibliographical sources, making many scholars regard the high Andean páramos as still-natural primary ecosystems and perpetuating stereotypical opinions that some indigenous management techniques, such as fire, are detrimental to the so-called pristine páramo (Hofstede and others 1998; Wille and others 2002).

The vegetation of highland Ecuador, known as the Interandean domain of the Tropandean ecoregion (Figure 2), is so highly modified that a major geobotanical classification called it “anthropic” vegetation (Acosta-Solis 1984). People live—and have lived for millennia—in the high mountains of the Neotropics, whereas they do not live—and never have lived (with the exception of the Sami in Fennoscandia)—in high-latitude, northern mountain areas (Budowski 1968; Ellenberg 1979). These are manifestations of the responses of the long-standing human impact on tree borderlines in the history of the mountainous landscape of tropical America (Sarmiento and Frolich 2002).

Controversy over the origin of highland grasslands in forested mountains remains (Mark 1958; Luteyn 1999). The southern Appalachian Mountains in temperate North America harbor grassy areas locally known as “balds,” or openings in the otherwise continuous forest canopy. The history of balds can be traced to Pleistocene megafauna (Weigl and Knowles 1995). The action of humans, however, came to encroach on balds during the Holocene.

The long-term human presence in the mountainous Neotropics, especially Interandean Ecuador, may have created different determining factors for tropical tree-line dynamics (Stern 1983). Human-set fire, agricultural clearing, high-pasture grazing, and trade routes through the mountains may be far more important than climate or megafauna in establishing and maintaining tropical alpine zones, particularly grasslands (Ellenberg 1958). Tree-growth capacity based on the physiology of arboreal species in the TMCF is little known: The presence of tall guandera (*Clusia* spp.), colca (*Miconia* spp.), quishuar (*Buddleia* spp.), palma (*Ceroxylum* spp.), senecio (*Gynoxis* spp.), and yagual (*Polylepis* spp.) trees at high elevations in remote coves of isolated ranges in the Equatorial Andes may be evidence of a formerly robust climax forest formation rather than oddities of tropical Andean ecotones (Rundel, Smith, and Meinzer 1994). Conversely, the presence of *pajonales* (grass balds: *Calamagrostis* spp., *Festuca* spp., *Cortadeira* spp., *Stipa* spp.) and chaparral (heath balds: *Hypericum* spp., *Rubus* spp., *Bacharis* spp.) in the highland plateaus and areas formerly cultivated or grazed may indicate previous human impact.

The principle that temperate tree lines are based on altitude alone may have little or no validity in the Tropical Andes, where the presence of remnant patches of mature Andean forest above the páramo areas and the contemporary plantation

forestry of *Pinus radiata* and *Eucalyptus globulus* demonstrate the potential for viable tree growth in the highlands. Remnant fragments can be seen as shreds of the once-continuous matrix of Andean forests. In some Ecuadorian mountains a stunted, dwarfed subalpine zone is indeed encountered, such as on the summit of the Sumaco volcano; perhaps more common is an abrupt tree line characterized by full-grown, tall, primary forest bordering the treeless alpine grasslands with a straight-line division. In essence, the alpine tree line often differs little from forest borders with agricultural lands where recent clear-cutting is a known fact. According to Simon Laegaard, in northern Ecuador “the forest patches border directly on grass páramo vegetation and the forest line [that is, tree line] is nearly always sharply cut” (1992, 154). Moreover, no vernacular names for “páramo” or “elfin forest” exist in Ecuador.

STUDY AREA AND METHODOLOGY

Ecuador, in northwestern South America, is often considered part of the ecologically based Northern Andes region; cultural geographers and landscape ecologists include it as part of the ethnobiologically based Central Andes region (Figure 2). Typically, seasonality of rainfall creates dramatic changes in water availability in the lower and middle mountains, but the higher mountains have a permanent high water table, saturated and waterlogged soils, and trees covered with mosses (“mossy forests”), where fog, fog drip, and clouds add significantly to the humidity of the Tropandean landscape. Because influences from trade winds can alter patterns of prevailing clouds and species presence and/or absence, I chose thirteen sites as case studies to test a new paradigm for Andean tree lines, “anthropogenic forcing.” The sites were: toward the Amazon Basin, in the Playón de San Francisco in Carchi Province, the Cumandá Ethnobotanical Reserve in Napo Province, and the San Francisco Field Research Station in southern Zamora Province; in the Interandean domain, in the Guandera Research Station in Carchi Province, the Guamani páramo in Antisana Reserve, the flats of Limpiopungu in Cotopaxi National Park, the brook of Sacha Wayku on Mount Cariwairazu, the Alao area in Sangay National Park in Chimburazu Province, and the Llaviucu area in Azuay Province; and on the western flank of the Andes, in the Maquipucuna Reserve in the Upper Guayllabamba River Basin, the flats of Chaupi on Mount Chimburazu, the páramos of Salinas in Bolívar Province, and the Paredones archaeological site in the Mullituru region of Azuay Province.

Data collected are my observations of contemporary land uses and vegetation type and cover, as well as historical and prehistoric land uses reported in the scientific literature. In most cases, the idea of prime pristine mountain environments has been utilized as a justification for conservation efforts; however, much closer analyses reflect an important underlying presence of “man-aged” systems.

HOW DIFFERENT IS THE PÁRAMO TREE LINE FROM THE AGRICULTURAL FRONTIER?

Subsistence crop production is common in highland Ecuador, as are heavily subsidized plantations of potato, wheat, barley, and corn. Long-enduring terracing, strip

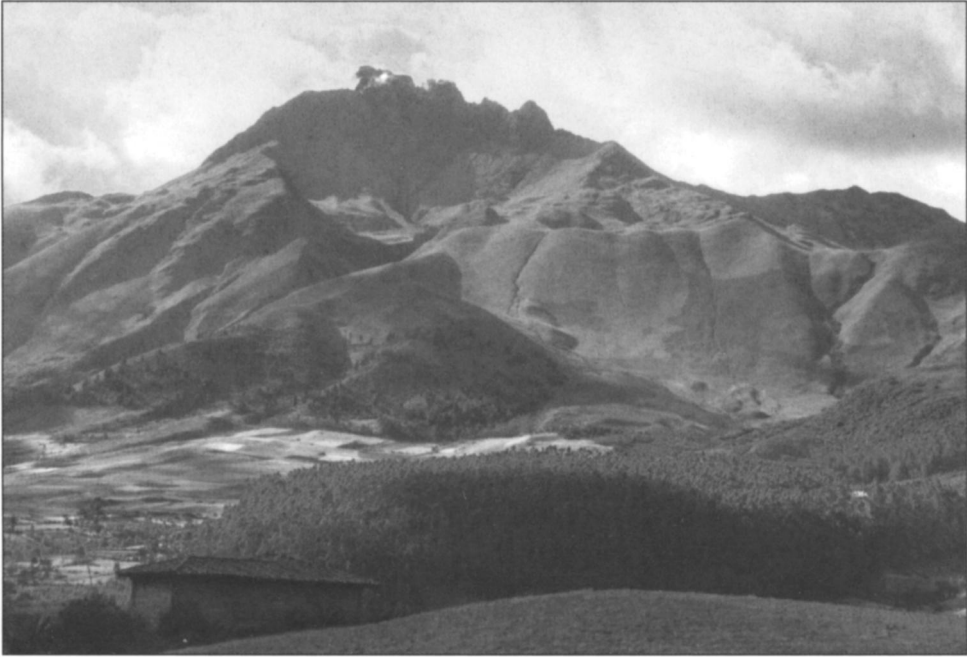


FIG. 3—Signs of landscape change in the Interandean forest of Imbabura Province, Ecuador. Note the tree lines, which isolate the cloud forest as a sandwiched belt between the grasslands from above (grass páramo) and from below (kikuyu grass), with eucalyptus plantations in the foreground. Also note the evidence of prior fires on the denuded slopes of Cotacachi volcano, 4,939 meters above sea level. (Photograph by César Cotacachi, June 2001)

contour cultivation, alley cropping, and other techniques are also employed in the Interandean region. As Larry Frolich and Esmeralda Guevara point out, the agricultural frontier in the northern province of Carchi is always pushing the lower limits of the tree line upward because of the need for fresh, fertile volcanic soils for improved potato yields in an ever-hungry external market (1999). A similar process is described in the páramos of Cotopaxi, which have been transformed into *Pinus* plantations and other highland cropping (Sarmiento 1988). It is not uncommon in Carchi to find a great diversity of crops, including cultivation of heirloom potatoes on steep slopes. Worldwide, recent technoagricultural practices may have affected cloud forest–tree-line dynamics more than any other single factor. Although potato monoculture is the cash crop that fuels the economy of the study areas, the high price of fertilizers prevents campesinos from continually using their patches of land and makes it less expensive for them to go farther upslope or farther into the headwaters in search of profitable yields (Figure 3). As higher and steeper hillsides are cleared, erosion can become severe, the water table drops, and degradation of the watershed becomes unavoidable, setting up an unsustainable cycle of farmers clearing new land rather than tending depleted acreage and forcing the agricultural frontier to ever-higher reaches.



FIG. 4—Pasture grazed by cattle in the Sacha Wayku forests, 4,500 meters above sea level near Mount Cariwairazu, in central Ecuador. Note the definite boundary between the *Polylepis* stand and the grasses, both above and below the incline. (Photograph by Jennifer Osha, June 2000)

In time, soil nutrients on farm sites become exhausted, and potatoes develop nematode infestations and other pests that push farmers to increase their use of pesticides, herbicides, artificial fertilizers, and manure. Uncertainty of land tenure and unclear colonization rules in the study areas make intensification of agricultural production the driving force to claim new lands from the forests (Frolich and others 1999). Little of the production is subsistence oriented; the bulk of the harvest is transported and sold in the cities of Tulcán, Ibarra, Quito, Riobamba, and Cuenca. Over the last forty years, smallholder potato production based on monocropping and chemical-intensive technologies, mechanized tillage, synthetic fertilizers, and pesticides quickly supplanted traditional farming throughout the Ecuadorian Andes. As a result, areas under traditional cultivation and labor-intensive production have grown dramatically. Osvaldo Barsky showed that, between 1954 and 1974, potato production in Ecuador increased by 40 percent and worker productivity by 33 percent (1984). Charles Crissman and others argue that this trend has continued in Carchi Province, where yields rose from about 0.5 tons per hectare in 1974 to about 21 tons per hectare in 1997—three times the national average (1998). As a result, the value of Carchi farmland has skyrocketed. Crissman and others also note that the

increased potato production in Carchi has had severe collateral environmental and social consequences (1998).

With an expanding population, production pressures have driven a rapid expansion of agricultural land into forested areas. Only seventy years ago, large proportions of the Interandean valley floor below 3,000 meters were forested; today, the agriculture–forest frontier lies higher up on the valley slopes, between 3,200 and 3,400 meters. This border is an abrupt transition, punctuated by clearings where forest patches have recently been cut, and it strongly resembles the páramo frontier in the upper tree line. When clearings are not maintained in potato cultivation and go unburned, they return to a succession of land covers, starting with grasses and leading to a fern–ericacea scrub (bald) that resembles what is seen at higher elevations at the older forest–páramo frontier. However, because fallow areas are routinely grazed by cattle, fire management becomes a favored tool for maintaining pasturelands in grass, not shrubs.

Hence the agricultural frontier boundary is strikingly similar to the páramo tree line, with intensification from the lower tree line due to crop expansion and with extension from the upper tree line due to ephemeral grazing.

HOW DIFFERENT IS THE PÁRAMO TREE LINE FROM THE PASTURE FRONTIER?

In the Equatorial Andes the presence of megaherbivore fossils, including mastodons (*Mastodon cuvierii*, *M. carchensis*), giant sloths (*Oreomyodon orcesi*), Andean horses (*Equus andium*), and the precursors of modern llamas (*Paleolama* spp.) suggests a Pleistocene origin for clearings that were opened for forage in mountain forests and provides a reasonable explanation for the appearance of grass balds in today's Andean forests (Owen-Smith 1987; Weigl and Knowles 1995).

Evidence of early animal husbandry in the Equatorial Andes is supported by pottery of ancient origin that depicts ungulates. Items that are now museum artifacts were clearly employed in animal herding. In the south, the Paredones site was built by expansionist rulers on an important trade route to the coast from the main Inca settlement of Tomebamba. However, Carchi was never subjected to Inca rule, and only dubious evidence of camelidae husbandry is found that far north. After the Spanish conquest, vast areas of the high-mountain forests were cleared to introduce livestock, mainly sheep and cattle (Figure 4). Later the ubiquitous goat farming arrived in the drier Chota floodplain and slowly advanced upward, toward the hills and middle basin. In Carchi, Pichincha, Chimburazu, Bolívar, and Azuay Provinces, today's household herds include cows, pigs, sheep, donkeys, and goats. Another important source of grazing pressure is horses, both domesticated and feral, which roam the highlands of the Cotopaxi and Antisana volcanoes, Cariwairazu brooks, and Alao and Mullituru grasslands.

In modern times governmental subsidies offered to the dairy industry have prompted the replacement of forest with pasture (Stadel 1986). Milk, cheese, and other dairy products are more profitable than crops; in many places good agricul-

tural soils have been converted to pasture using introduced African kikuyu grass (*Panicetum clandestinum*). Other “improved” species are also planted for grazing purposes. In the Maquipucuna Reserve the aggressive *pasto miel* grass (*Setaria sphacelata*) has taken hold of deforested slopes in the montane landscape (Sarmiento 1997b). Beef-cattle grazing is now the main activity for large landholders on the Interandean valley floor. Most farming families in this area are involved in cattle ranching, either for subsistence milk intake or as a source of revenue to invest in sugarcane production. On many occasions during the dry season, large cattle herds are left to graze on the *monte* (secondary growth) in cloud-forest patches. Even within the boundaries of national parks (Cotopaxi, Antisana, Las Cajas, Sangay), however, most grazing takes place in the pastures of the higher reaches. Grazing lands may be burned at any time of the year, but set fires are especially common in the dry season. Elsewhere in highland Ecuador, smoke and fire regimes have prompted a species composition favoring ground bromeliads, grasses, and many serotonous plants that resemble the pyrophytic species composition of the páramo. Large herds of cattle were common before the 1960s in the páramos of Yuracruz and Mariano Acosta and in Buenos Aires in the north. Some of these cattle escaped and became feral. Feral bulls from the páramos of Mount Cayambe, for instance, were utilized for bullfighting in nearby towns for Andean festivals. In Carchi Province, highland cattle ranching was prominent along the mountain passes wherever a dirt road facilitated transportation of dairy products to markets.

The pasture frontier is an effective line separating grassland from forest; it is equivalent to the páramo tree line. Planted kikuyu grass identifies the lower tree-line boundary, and natural tussock grasses identify the higher tree-line boundary.

HOW DIFFERENT IS THE TREE LINE FROM THE FIRE LINE?

The colonial practice of burning forest margins for charcoal making is still in use by *carboneros*, who sell their loads to mountain households and also peddle their wares in the markets of nearby towns and cities. On-site production of charcoal in kilns has left a permanent record in the structure and chemical composition of the soil, preventing recolonization of the cleared, usually round, kiln site by forest species. I argue that burning intensively in order to produce charcoal kills all of the mycorrhizal components of the soil that are needed to jump start succession, creating a crust of burned soil that is unsuitable for the establishment of seeds from forest species. In fact, most tropical seeds are recalcitrant and will not survive for long in this inhospitable environment, remaining viable for only a few days.

It has been argued that ecological succession has not operated at kiln sites and in most of the Interandean domain because of an arrested phase due to the continuing burning regime favoring graminoids and serotonic shrubs (Grubb 1970; Sarmiento 1997a). Burning the grasses promotes an invigorated growth of tussocks, which makes the root mats stronger (Hofstede 2001). This supports the notion among campesinos that “after burning, a better pastureland will soon be available for the herds.” In their view, burning is the simplest method of pruning and mowing.



FIG. 5—A helicopter carrying supplies lands near the campground in the Cayambe-Coca Ecological Reserve, Carchi Province, northern Ecuador. Fire has formed a distinct forest edge on the shore of Puruhanta Lake, 3,700 meters above sea level. No fire other than this one, set some time ago by anglers and poachers who were clearing an area for the camp, has been documented in the region. (Photograph by the author, May 1988)

Fire scars and charcoal deposits are interspersed along the tree line, or border, as unequivocal evidence of human-induced creation of the line that separates forest from alpine grassland, for no natural fires have been documented in TMCFS (Laegaard 1992). Also, the presence of the round balds with páramo vegetation in the TMCF border zone is a clear indicator of the use of the accessible borders as sources of “exportable” charcoal.

But firewood gathering by Andean peasants is not a strong enough factor to account for the more common practice of burning for either pasture management or charcoal production, the two economic activities that benefit landowners of large or intermediate-sized properties. Subsistence fuelwood production by the peasants meets the needs of families in the forest boundary, although longer trips for wood gathering are sometimes necessary in Carchi and Azuay Provinces. A fast way for campesinos to generate cash, however, is to produce and sell sacks of charcoal, which are often seen being hauled down to the towns and cities in the valley below. Carboneros, most of whom are men, exert a definite tension in the dynamics of the tree line, as opposed to the fuelwood gatherers, most of whom are women. Fire is an effective tool, one generally used with deliberation (Figure 5).

In older grazing frontiers the straight-line boundary left from previous—and in most cases, repeated—burning is a clear, artificially leveled fire line that abruptly

separates forest and pasture. Karsten Wesche, Georg Miehe, and Meinhard Kaeppeli describe similar scenarios for Afro-alpine vegetation (2000). Laegaard also points out direct evidence of burning—fire scars, burned tissue, charcoal residue, defoliation by burning, removal of dry matter from poles and stems of páramo shrubs and trees—that can easily be recognized along the rectilinear border (1992).

The Ecuadorian study areas offer clear indications that the tree line is a fire line. When fires encroach on the edge from the lower tree line, there is always a risk associated with wind that could cause crown fires; fires that encroach from the upper tree line are most often surface burning connected with dry tussocks.

PALEOECOLOGICAL DATA AND BIOGEOGRAPHICAL EVIDENCE FOR TREE-LINE CHANGE

Paleobiogeography in the Tropics is understudied relative to northern countries, primarily due to scarce resources and the lack of strong scientific and governmental infrastructure for pursuing such studies. Detailed geological maps, based on detailed pollen and soil analyses of the kind frequently available in the United States, are unavailable for most of the Tropics, particularly in the mountains. Limited data are thus interpreted on the basis of corollaries with temperate-climate studies. The prevalent view of montane–alpine tree-line dynamics is that, along with glacial recession, the tree line is progressively advancing to higher altitudes (Van der Hammen and others 1981). However, the detailed tropical analyses that do exist—for example, for El Junco in the Galápagos Islands (Colinvaux 1972), the Sabana de Bogotá (Van der Hammen and others 1981), the lakes of Cajas in Ecuador (Colinvaux and others 1997), a crater floor in Panama (Bush and others 1992), a small lake in Costa Rica (Clement and Horn 2001), and a bog near Cuzco in Peru (Chepstow-Lusty and others 1998)—reveal a complex situation, thus implicitly arguing that both methodologies and paradigms merit revisiting in the light of new narratives.

Although paleoecological studies have not been undertaken in my study areas, locations in Imbabura and Azuay Provinces—Yaguarkucha Lake (Colinvaux and others 1988) and Llaviucu Lake (Colinvaux and others 1997)—have been analyzed. These show a rearrangement of the cold-tolerant species, instead of a vertical shifting of the tree line with glacial cooling. Furthermore, in comparable neotropical mountains there is evidence that introduced multiuse trees accompanied human population forays into high altitudes. Examples of this are oak (*Quercus* spp.) in Costa Rica and alder (*Alnus acuminata*) in Peru and Mesoamerica (Chepstow-Lusty and others 1996; Kappelle 1996). The paleoecology of the now seemingly pristine forests of the Charral Mountains in southern Costa Rica reflects agricultural uses that ceased after the 1500s but began again in the 1950s (Clement and Horn 2001). The same seems to be true for the mountainous area of the Mixteca Alta in southern Mexico and throughout Belize (Spores 1969; Campbell 2002). On both sides of the Andean cordillera, findings of abundant pottery pieces and other archaeological artifacts in what seems to be pristine montane forest support the intriguing notion of a prior, heavily human-driven Tropandean landscape in Ecuador. New geographical inquiries in the agricultural

landscapes of the Andes are helping to reaffirm the framework for the anthropogenic nature of the Andean tree line (Denevan 2001).

Overall, palynology is constrained by the difficulty of finding species-specific pollen markers for some families that may have both shrubs and tree forms. The presence of alder trees (*Alnus* spp.) is a clear discriminator, but other trees (Melastomataceae, Rubiaceae, Asteraceae) are identifiable only at the family level, which could include both tree and shrub forms, such as the prominent colca tree and the cafetillos shrubs, both of which are melastomes. This makes it difficult to be specific about tree-line dynamics and forces palynologists to generalize comparisons at the gross level of “forest” versus “prairie.” Based on cores from the Andes and the Amazon, Paul Colinvaux and others concluded that “Andean vegetation did not respond to glacial cooling or Holocene warming by movement in belts” (1997, 77). By refuting the postulated steepening of temperature gradients in glacial times driven by high dry-air lapse rates in the Tropics and the postulated compression of Andean vegetation zones in a shifting tree line (Van der Hammen and others 1981; Haffer 1990), Colinvaux’s team proposed a new interpretation: “Vegetation did not move up and down slope as belts. Rather, plant associations were reformed as temperature-sensitive species found different centers of distribution with changing temperature” (Colinvaux and others 1997, 69).

The presence of páramo endemics such as *Espeletia pycnophylla* is still enigmatic, implying that vicariance plays an important role. The use of the caulirosula life-form as indicative of high páramo is particularly relevant for the Northern Andes of Colombia and Venezuela, where several species of *Espeletia* exist (Hedberg and Hedberg 1979). However, in the Equatorial Andes the presence of only one species in two distinct ranges—El Angel in the north and Llanganatis in central Ecuador—invites further explanation.

PRECOLONIAL HUMAN ACTIVITY IN THE HIGH MOUNTAINS

When the Spaniards came to the region they discovered a place already degraded and deforested by extensive agriculture (Denevan 1992; Mann 2002). Vestiges of previous human intervention in the landscape discovered by the Europeans included abandoned *cangahua* (a hard tuffa, or paleosol) pyramids, terraces, and irrigation channels. The area around Pimampiro, for instance, had been established as an important commercial center for the exchange of goods from the coastal plain (such as *Spondilus* conchs) and from the Amazon region (tropical feathers). Evidence of human presence was also found around Cotopaxi, Sangay, and Chimburazu, particularly in areas associated with mountain passes, such as the Quijos River Valley in Napo Province, or Mullituru and Paredones in Azuay Province. The montane belt was an active and populated area, with known human settlements in cloud forests that today seem pristine, and pre-Colombian influence had already changed the original forested landscape (Molestina 1985).

The Mira watershed in Carchi Province was heavily populated in the Formative period and also in the Late Formative period by cultures such as the Capuli, Pastos,

and Quillasingas. Their artifacts are now the only tools that relate to the ancient human occupation of the Mira-Chota watershed (Knapp 1991). Archaeological findings along the Upper Guayllabamba River, in the Quijos River Basin, and in Cotopaxi, Sangay, and Las Cajas National Parks confirm the notion of ancient human imprint.

Some highland areas are crisscrossed by ancient terracing systems and channels built on sloped terrain, bringing water toward the Interandean plateau. The scale of effort indicated by the archaeology of the Pimampiro Basin suggests that several tens of thousands of people probably lived in the area (Mothes 1987). Physical evidence of the mountain road network survives in the Maquipucuna site and in Sacha Wayku. More sophisticated construction of mountain roads can be found in Sangay, Cotopaxi, and Llaviucu. The more refined design of the Inca imperial road network can be found in the ruins of Paredones, in Azuay Province.

The strong effects of the commercial center in Pimampiro and its concomitant connecting networks with trade routes to the south and north, as well as to the lower tropical plains of the Amazon (via Puruhanta lake) and to the coast (via Mira Canyon), made the Mira-Chota Basin an important cultural center in pre-Colombian times. The same situation may be inferred for Mullituru, which connected the western sites of the Huancavilca culture and the eastern sites of the Shwar culture with the Cañari indigenous territory in the Interandean valley. The Quijos settlement in Cotundo and Baeza is estimated to have had at least 20,000 inhabitants. Satellite imagery has singled out the strategic locations of forts at several key points in the Interandean valley; however, further studies are needed before we can determine the antiquity of other linear features (possible ditches with extra stonework) or raised fields and terraces in some parts of the watershed. Similar archaeological evidence has been found in highland sites of Peru and Bolivia. Gregory Knapp described fossil ridges and ditches in northern Ecuador but did not consider the impact of such structures on some sites, now under grass cover as páramo, in areas of the towns of Yuracruz, Sigsipamba, and Nueva América, or on those of the pristine-looking watershed of Puruhanta Lake, now covered by forests (1991).

The concept of megafauna as a driver for tree-line change has its best example in Ecuador, where a mastodon skull with an encrusted obsidian arrowhead was discovered in Los Chillos Valley. Here, estimates for human intervention go back to 14,000 B.P. (Bonifaz 1972). So, precolonial human activity has definitely played an important role in setting the boundaries of the forest.

CHANGES IN HIGH-ALTITUDE FORESTS IN COLONIAL TIMES

There is evidence of the extent of TMCFS within the Interandean basin during the colonial era. The construction of large colonial houses and churches in the cities of Ibarra, Tulcán, El Ángel, Latacunga, Riobamba, Azogues, and Cuenca was accomplished with the use of local old-growth timber. The colonizers of the kingdom of Quito and its chiefdoms to the north (including those of the Mira-Chota watershed) reportedly contained vast expanses of forest (Salomon 1986). Records kept at

the bishopric in Ibarra, for instance, attest to the wealth of forest products, including caoba (*Platymiscium pinnatum*), canelo (*Nectandra reticulata*), nogal (*Juglans neotropica*), cedro (*Cedrela montana*), and aliso (*Alnus acuminata*), being exported from the Chota Valley and its surrounding hills (Vázquez-Fuller 1988). Today the Chota Valley lacks significant forest cover, and the surrounding hills are denuded.

In some locales, planted tree species survive because of care by the township or the owners of old haciendas. In Machachi, for instance, the Central Plaza offers a good example of mature, tall native trees, including *Podocarpus oleifolia*. In several convents and haciendas the customary ramos palm (*Ceroxylum andicola*) can still be found, protected within their lands. Furthermore, as evidence of the Inca presence, on the private property tall palm trees (*Parajubea cocoides*), with no known wild relatives in Ecuadorian montane forests, survive well. In my own lifetime, the history of forest clearing in the Guamani Pass on Mount Antisana reflects the process of creating and maintaining the highland grasslands, in what I have called “paramization” by an aggressive and effective cutting and burning of the yaguales (*Polylepis* spp.) on flatter terrain. Sacha Wayku and Las Cajas contain good examples of mature Andean forests of yagual (*Polylepis sericea*, *P. incana*), which can serve as a proxy for altitudinal distribution of what was once a continual forest cover. The presence of these trees at record altitudes can be generalized over broader areas to suggest where trees would have been in areas that are now devoid of forest cover.

More recent human impacts can also be traced indirectly in lakes (Puruhanta, Llaviucu) that are surrounded by so-called pristine TMCFS. Over sixty years the fish fauna in these otherwise unspoiled lakes have been modified by attempts to develop rainbow-trout fisheries in highland Ecuador, especially in Imbabura and Azuay Provinces, the country’s lake districts. Despite the false pristine surroundings, the area of Puruhanta (or Chique) was indeed altered during the 1950s, when the introduction of exotic fishes (*Onorhynchus mykiss*, *Salmo gairdnerii*) into the lake resulted in the extinction of local native fauna of preñadillas (*Astroblepus* spp.) and bagrecitos (*Rhamdia* spp.). Páramo tussock grasses appeared in ensuing decades where a campground for fishermen was built and where the forest was cut and burned along the lakeshore (Figure 5). This patch is so localized that it is a clear manifestation of the human impact on a previously forested flat. Around Llaviucu Lake, despite the deceptive primitivism of the surrounding landscape, evidence of fire regime, grazing, and deforestation abounds at both the higher and the lower tree lines. Even though the area is considered part of the old National Recreational Area of Las Cajas, now redefined as Las Cajas National Park, the effect of human presence on the lacustrine environment cannot be denied.

A BIRD SPECIES HINTS OF CULTURE

Field research on the ethology of the Andean lapwing (Charadriidae: *Vanelus resplendens* Tschudi 1840) led me to believe that biological processes in tropical moun-

zone characterized by increasingly stunted and dwarfed trees is the norm in circumpolar and northern Temperate Zone mountains (Halloy 1989; Kullman 1998). Vertical zonation is depicted when altitudinal belts are mentioned as specific com-

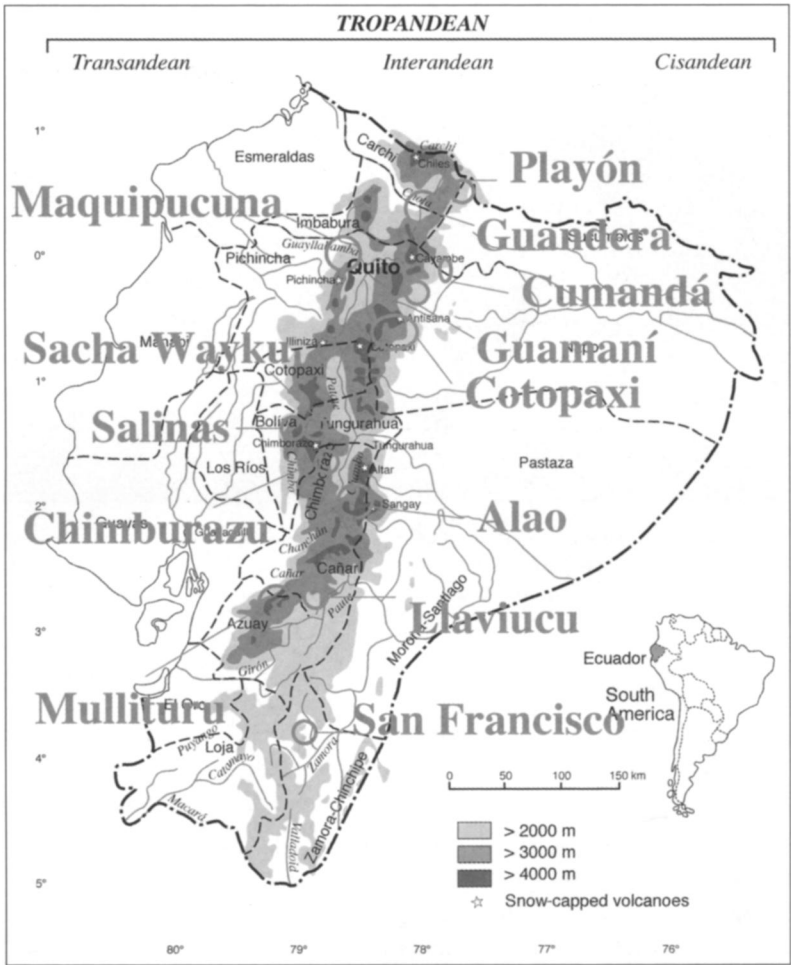


FIG. 2.—The Equatorial Andes, showing the Tropandean ecoregion with the different domains and the study sites in continental Ecuador. *Source:* Modified from Jørgensen and Ulloa 1994.

ponents of temperate mountains (Whittaker 1952). Therefore, in extratropical mountains a combination of elevation, latitude, and local climate defines where the forest–alpine border occurs.

In the Tropical Andes evidence for human imprint on control over the altitudinal tree line is substantial. Despite the false notion of the “unspoiled” state of montane forests in the Transandean domain, or the seemingly prevalent “naturalness”



FIG. 6—Deep, black volcanic soils provide fertile ground for potatoes around the Guandera Reserve, 3,500 meters above sea level, in Ecuador's Carchi Province. The agricultural frontier is keeping the tree line sharply cut from below. Note that few stumps are left in the clearing and that no terracing is practiced for cultivation, as indicative of ephemeral economic-ecological transactions with the land. (Photograph by Larry Frolich, June 2001)

tains, such as habitat selection and reproductive behavior, are mainly a reflection of cultural interference in the so-called pristine or natural páramo. After three years of observation and experimentation, it was clear to me that this bird, considered a signature species associated with the páramo's lacustrine environments, responded to the vagrant movement of cattle in their roaming about the páramo pastures (Sarmiento 1988). Feral and domesticated free-ranging cattle that have intruded into Cotopaxi National Park have generated a robust community of scarabs and other beetles—the main food source for Andean lapwings—in their scat. Because the flocks followed the dung sites distributed by the vagility of cattle, I later concluded that people, rather than nature, appear to have been responsible for the evolving biogeography of the Andean lapwing.

Furthermore, this bird—once believed emblematic of the Andes—was also collected in the lowlands of Limoncocha in the Ecuadorian Amazon and in the piedmont at Chalpi toward the lowland coastal plains, presenting a paradox of biogeography, because neither site is in the mountains. The lapwing's presence in folk ethnobiology and its spiritual significance for the Kichwa and other indigenous groups, especially the Puruha around Cacha, presented a paradox in cultural geography, for neither group depicted this bird in its cosmology. Thus the enigmatic status of the Andean lapwing has questioned old notions of páramo life and other principles of applied montology in the Neotropics.

A FOREIGN WORD HINTS OF CULTURE

I have argued elsewhere that the very name “Andes” is a proxy for the cultural nature of the mountains in South America (Sarmiento 2001b). Local inhabitants did not have a name for the mountain chain, only for individual peaks or specific hills named with the Kichwa suffix *urcu*. This condition remains rather common among mountain people. For instance, the Nepalese do not have a name for the cordillera of the Himalayas, only for special mountains, such as Sagarmatha; the Sami do not have a name for the Scandinavian Alps, only for certain mountains, such as Kiruna-*vara*; the Mapuche in southern Patagonia still do not use a name for the entire cordillera, only for special peaks.

So, unlike prevalent but mistaken notions about the etymology of Andes as referring to the Inca territory of Antisuyo or to the copper mines of Anta, the name “Andes” refers to the main cultural attribute of the echelon-like structures, terraces, or scaffolding that are known in Spanish as *andenerías*, systems of *andenes*. These structures impressed the Spaniards, who wrote in Castellan shorthand (omitting the last syllable and changing the *n* to an *s* to make the word plural) to document their discoveries. In summary, “La Cordillera de los Andenes,” lacking a proper name, became known in Europe for its main attributes—terraces and walkways on its steep slopes—as “La Cordillera de los Andes.” The name “Andes” was shortened by the few people who could read then and became the name for the entire mountain chain. Thus the cultural nature of the neotropical mountains has been recognized since the first colonial contact.

In addition, as I proposed above, the lack of a vernacular descriptor for the highland grasslands can be taken as evidence of the modernity of this landscape feature. The word “páramo” is taken to refer to the meteorological condition of cloudiness and cold rain, or it may describe the state of being cold and wet, instead of the actual plant formation (Luteyn 1999). One version is that the Spanish word *páramo* has obscure origins in a paleo-Iberian language that described the rather desolated, windswept highlands of the northern massif in Spain. Others suggest that the Latin etymology can be traced to *para moor*, referring to a site adjacent to a wetland or to a swampy, grassy habitat.

Moreover, a descriptor for “elfin forest” is missing in the vernacular language. The use of the Kichwa word *yunga* or the Hispanicized *yungilla* is a reference to the warm, forested slopes of the eastern flank of the Andes. In the Carchi and Imbabura lexicon, however, is the word *chaparro*, borrowed from the Mexican Spanish for “of small stature” but mostly denoting a place for gathering fuelwood in the nearby forests (Sarmiento 2001a).

HUMAN MONTOLOGY

The human-induced and human-driven dynamics of the Andean tree line in highland Ecuador are documented here by both direct and indirect evidence. With corroboration to characterize two Andean tree lines instead of only one, which is traditional for mountains in temperate latitudes, the inclusion of human impact as the driver of Tropandean landscape change deserves increased recognition from mountain scholars.

The new discipline of montology merits an in-depth review. Its tenets have so far emphasized only temperate and northern latitudes. The efforts of Alexander von Humboldt and Carl Troll made tropical mountains known to the world of geographers. In fact, Tropandean landscapes should be considered the birthplace of ecology, although the intricate patterns of Andean tree lines have not been conducive to inclusion of the human dimension (Sarmiento 1995b, 1997c, 1999; Sarmiento, Romero, and Messerli 1999). The anthropogenic nature of highland grasslands is important to the definition of needed potential management practices and conservation priorities for páramos in Ecuador (Figure 6). The much-needed preservation and strict protection of the remnant shreds of Andean forests should be considered a highest priority in scenarios for sustainable mountain development in the region. Precautionary measures need to be included in the policymaking process that affects water-supply and watershed management for the ever-thirsty, growing Andean cities. The role of TMCFS as “water towers” can no longer be conceived only as an imaginative educational campaign; it must be a priority for national security and strategic long-term environmental planning. The old approach of protecting “pristine” páramos from human interference, known as the “Yellowstone Model,” should give way to the new approach of conserving living landscapes, known as the “Green Mountains Model.”

Generalizations of yesteryear, especially about tropical mountains, should be avoided in light of the changing paradigms, modern technologies, and sophisti-

cated tools that are available to restore degraded mountains into healthy, forested ones (Myster and Sarmiento 1998; Zimmerer and Young 1998). Restoration of TMCFS is a priority if we are to halt the destruction of the mountain system and the continuation of the sandwich-like scenario of the moving Andean tree lines (Sarmiento 1995c, 2000b). If the movement of agricultural and grazing frontiers can be stopped by reworking the degraded grassland sites instead of by opening up new, fresh forest floors, a better prospect for mountain development is envisaged, securing soil fertility, water catchment, culture maintenance, food security, and biodiversity conservation (Hamilton 1996). Let there be an organized effort to reforest the highlands and to re-create the neotropical forests that once existed!

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