Acta Científica 19(1-3), 3-6, 2005

THE ECOSYSTEMS OF THE LUQUILLO MOUNTAINS

Ariel E. Lugo
International Institute of Tropical Forestry
USDA Forest Service
1201 Ceiba St., Jardín Botánico Sur, Río Piedras, PR 00926-1119

The Luquillo Mountains (LM) in northeastern Puerto Rico, where the El Yunque National Forest is located, have a core of igneous and volcanic rocks with an age of about 146 million years, together with layers of uplifted sedimentary and metamorphed rocks. These mountains are very steep with highly dissected topography and rise abruptly from the coastal plain to an elevation of about 1,000 m (ca. 3,280 feet). The LM are exposed to the trade winds that blow steadily from the Atlantic Ocean. Basic climatic conditions of the mountains are determined by the interaction of their topography and the trade winds as they rise, cool, produce rainfall, and flow over its slopes. The mean annual temperature at lower elevations is about six degrees Celsius (9 Fahrenheit) higher than that on the top of the mountains. On average, annual rainfall triples from the coast to the top of the mountain. The highest rainfall in Puerto Rico falls in the LM, near East Peak with an annual average of over 5 meters (ca. 200 inches). Wind speed, air humidity, and cloudiness also increase with elevation. Clouds form at about 600m (ca. 1,970 feet) elevation, known as the cloud condensation level and it's common to see clouds penetrating and enveloping forests above this elevation.

The LM are also on the path of storms and hurricanes that originate in the Atlantic and move slowly northwestward, and they are also exposed to materials that are transported by wind and clouds from around the globe. Examples of these materials are Saharan dust, pollutants from the burning of fossil fuels in the United States of America and San Juan, greenhouse gases, volcanic ash, and historically, even low levels of radioactive materials produced when atomic bombs were tested in the atmosphere. The LM also have a high diversity of soil types represented by 19 of the Island's 64 soil series. The LM have also attracted humans for millennia making human activity a critical factor in determining the structure, species composition, and function of its ecosystems. The ecosystems of the LM respond and reflect all of the outside influences listed above. These environmental factors interact with the biota as it continues to evolve in the insular context of Puerto Rico.

The ecosystems of the LM form a green tapestry over the landscape that when observed from any lookout appears to be a continuous tapestry of vegetation. This tapestry is composed of a high diversity of species and ecosystem types, each with its own complexity and each interacting with others above, below, and next to it. The heterogeneity of the tapestry is due to the many gradients in the conditions of the mountains as one moves up, down, east, or west within them, and by the constant tearing of the tapestry by disturbances such as hurricanes, landslides, and deforestation, followed by natural repair.

Climatic gradients, varied soils and topography, contrasting wind exposure, and recurrent natural disturbances result in a mosaic of ecosystems on the LM. In different locations within this milieu of conditions, one finds different combinations of species and different ecosystem types. Sometimes the change is gradual and other times the change is abrupt, but continuing change in space and time is a characteristic of the biota in the LM. For example, the distribution of tree species shows a gradual change from the lowlands to the tops of the mountains, with sharp discontinuities at elevations between 600 and 700m (1,970 and 2,297 feet) where the cloud condensation level occurs. The density of epiphytes (or plants that grow on other plants such as mosses, lichens, bromeliads and orchids) increases dramatically above this elevation.

The climatic changes with elevation are related to the change in forest height; forests are taller in the lowlands and decrease in height with elevation. Similarly, there is a transformation in the functioning of ecosystems at the cloud condensation level as forests above this level become "cloud forests" or forested wetlands responding to cloud water and cloud nutrient inputs that transform their soils and soil biota. Above the cloud condensation level, precipitation increases, soils increase in organic matter, decrease in oxygen and the biota changes accordingly both above and below ground. Epiphytes as well as the trees and shrubs supporting them derive nutrients directly from aerial inputs. The density of soil organisms is lower in high elevation forests compared to coastal forests. However, earthworms are more abundant on top of the mountains in the elfin forest than they are at lower elevations. Coincidentally, the low soil oxygen in the elfin forest makes earthworms an important organism in this forest because earthworms burrow and aerate the soil. From east to west, the forest changes because those to the east are exposed to the winds from the Atlantic while the mountain protects those on the west. Thus, the windward forests at high elevations are less diverse, more exposed to the effects of winds, and of shorter stature than the leeward forests.

The ecosystems of the LM also change over time. Hurricanes open forest canopies and stimulate the growth of tree species such as *Cecropia schreberiana*, which rapidly fill the holes in the canopy. Similarly, ferns colonize soils exposed by landslides or road cuts. All these disturbances of the green tapestry occur at different intensities and frequencies and result in ecosystems in different stages of recovery from, or response to, disturbance events. The age of trees reflects these different stages of succession. The oldest trees in the LM range in age between 600 and 1,000 years, and these are the ones that have escaped the frequent hurricanes and human disturbances. Most mature forest trees range in age from 100 to 400 years old. The younger forests that emerged after the abandonment of past human activity in the lowlands or after recent disturbances are less than 100 years old.

The types and structure of forests also changes as the species change. For example, the ubiquitous palm forests occur between 300 and 900 m (980 and 2,953 feet) elevation, but their structure and species composition change depending on whether they are windward or leeward, or if they are on river bottoms, ridges, or riparian areas. Tabonuco forests occur below 600 m (1,970 feet) elevation and they also show variability of structure and composition with wind exposure and elevation. Yet, where the tabonuco forests become almost pure stands of tabonuco trees is on the top of ridges, while other species dominate the slopes or the valleys nearby. Colorado forests are found on a particular geology (grandiodorite), a geological formation that weathers rapidly, producing sandy soils. Ferns dominate landslide sites and road cuts, forming unique fern-dominated ecosystems on steep slopes with exposed soils. Because the LM are so wet, many of its forests are wetland forests (even on steep slopes), including the elfin forests, colorado forests, palm forests, and the locally threatened *Pterocarpus* forests. The LM also harbor aquatic ecosystems such as the pools and rapids of its streams, six major river systems, herbaceous wetlands including those on the rock faces of waterfalls, and micro ecosystems in decomposing logs and tanks of bromeliads.

Because the many tree species are arrayed along multiple environmental gradients, it is possible to identify many types of forest. Only when one finds a species dominating a particular location (as tabonuco does on low elevation ridges, palms on high elevation steep slopes, and colorado on granodiorite geology) does it become easy for ecologists to identify a forest type. However, these are usually the exception, because the species composition and order of importance of species along the many gradients of the mountains are always changing, forming an endless number of species combinations. On the mountaintops, for example, the elfin forest occupies a small area, but contains many variants depending on wind exposure, substrate conditions, slope, and geographic location.

Given the environmental milieu, the overall biodiversity in the LM is impressive: 225 tree species, 16 amphibian species, 18 reptile species, 16 mammal species, about 150 resident and migratory bird species, and over 350 mushroom species. The

number of species in groups of organisms such as micro fungi, bacteria, nematodes, arthropods, and other soil groups are unknown but well exceed the number of tree species. The biodiversity of the LM includes 98 rare and endangered plant species and 23 endemic plant species. All this biodiversity occurs on an area no larger than 26,000 ha or 64,250 acres.

The ecosystems of the LM perform many ecological services. They are one of the premier tourist attractions of the Island. They provide recreational opportunities for people of all ages. Each day, humans use about 50 million gallons of water from these mountains. The forests of the LM absorb the energy of hurricanes that pass over them, thus weakening the storm and reducing the impacts of these events to nearby population centers. Trees in the LM include some of the finest tropical hardwoods and are capable of sustaining small wood industries and providing fuel wood, as they did during past centuries. Fungi, bacteria, and soil organisms process enormous amounts of organic matter, a process that is responsible for the clean water, soil formation, and high productivity of the LM. The wildlife of the LM migrates to other regions where they perform important ecological functions. For example, freshwater shrimp reproduce in estuaries and migrate up the rivers and streams. In the process they become part of the coastal food chain including coastal fisheries. Bats, parrots, and other large birds fly long distances pollinating and dispersing plants and consuming large quantities of fruits and insects in lowland ecosystems. Many migratory bird species winter in the LM. Prehistoric stone tools and petroglyphs attest to the fact that humans have lived in and around the LM for millennia and have benefited from its forest products and services, and attributed spiritual value to its mysterious cloud-shrouded appearance.

The presence of humans has had measurable effects on the ecosystems of the LM. Many species have been introduced to the LM. A portion of these species is now naturalized and form part of some of the many ecosystem types in the mountains. Notable among these are the common rat, the beautiful impatiens along the roads, the bamboo, which is a giant grass, and the rose-apple tree. Feral cats, dogs, and mongoose that live near the recreation sites are examples of introduced species considered pests. Recently, an alien giant iguana is rapidly invading the LM. The lowland forests have all been deforested or selectively cut at one time or another, and thus mostly the forests above the cloud condensation level are the ones considered primary or old growth. The daytime heat produced by the ring of urban infrastructure outside the National Forest is affecting the cloud condensation level, and potentially modifying the climate of the LM. Scientists anticipate warmer and drier conditions to prevail over the mountains as a result of increasing rates of urbanization, exacerbating regional drying patterns. Also, because of their geographic position, accumulation of knowledge about its ecosystems, and the close interactions between organisms and the climate parameters that are predicted to change in the future (e.g., air temperature, rainfall, and both frequency and intensity of hurricanes), the LM are a bellwether for monitoring global climate change. The ecosystems of the LM will continue to change and adjust to this new round of human-induced changes, and in so doing will continue to function and be the Island's premier natural wonder.

ACKNOWLEDGMENTS

This work was done in collaboration with the University of Puerto Rico. I thank Fred Scatena, Frank Wadsworth, Oscar Abelleira, Wayne Arendt, Jean Lodge, Jeff Walker, and Mildred Alayón for comments on the manuscript.