Botanical Inventory of the Cordillera del Cóndor Region of Ecuador and Peru

Project Activitiess and Findings, 2004-2007

The U.S. National Science Foundation provided financial support to Missouri Botanical Garden (MO), for the project, "**Botanical Inventory of the Cordillera del Cóndor Region of Ecuador and Peru",** for a three-year period, 2004-2007, through NSF project No, 0346679, with David Neill as Principal Investigator. This project was a collaborative effort with Ecuadorian and Peruvian institutions and botanists: the Herbario Nacional del Ecuador (QCNE), the herbarium of the Universidad Nacional de Loja (LOJA) in southern Ecuador, and the herbarium of the Universidad Nacional de Trujillo (HUT) in northern Peru. This report is a summary of the project activities and findings, and includes introductory background information on the flora of the Cordillera del Cóndor region.

Background: The Cordillera del Cóndor

The Cordillera del Cóndor region is an eastern outlier of the main Andean chain that extends about 150 km from north to south, rises to a maximum elevation of about 2900 m, and forms part of the international border between Ecuador and Peru. The Cóndor forms part of the discontinuous chain of .sub-Andean cordilleras. that are situated between the Eastern Cordillera of the Andes and the Amazon lowlands, parallel to the main Andean chain but attaining more modest elevations and separated from the main Eastern Cordillera by lower elevation valleys. Besides the Cóndor, some of the other sub-Andean cordilleras include the Galeras and Cutucú ranges in Ecuador and the Cordillera Azul and Yanachaga ranges in Peru. Whereas the main Eastern Cordillera is comprised mostly of metamorphic and volcanic rocks, the sub-Andean cordilleras are made up principally of Mesozoic and early Tertiary sediments . sandstones and limestones . deposited at the western margin of South America prior to the rise of the Andes and uplifted concurrently

with the main Andes, largely in the past several million years. Intrusive igneous formations, often bearing deposits of gold, copper, and other minerals, also form part of the Cóndor and the other sub-Andean cordilleras.

The sub-Andean cordilleras, situated at the interface between the Andes and the Amazon, are certainly among the most biologically diverse and least known areas on Earth. These low mountain ranges, extending through more than 10 degrees of latitude, have not been conceptualized heretofore as a coherent biogeographical unit; rather, each separate sub-Andean cordillera has been associated, biogeographically, with the main Eastern Cordillera range at its latitude (e.g., the .ecoregions. of Dinerstein et al., 1995). However, on the basis of botanical surveys in several of the sub-Andean cordilleras that we and others have carried out in recent years, we suggest that these mountain ranges have in common geological and floristic features that set them apart both from the Amazon lowlands and from the main Andean chain, and we further suggest that the sub-Andean cordilleras merit consideration collectively as a distinct biogeographic region. This new understanding of the sub-Andean cordilleras has bearing on the interpretation of the evolutionary history of South America and also on conservation planning for the region.

Recent botanical fieldwork in Ecuador and Peru has revealed a fascinating and unexpected biogeographical connection between the sub-Andean cordilleras and the Guayana Shield in northeastern South America. A number of plant genera once thought to be endemic to the sandstone mesas or .tepuis. of the Guayana region have been found to occur as disjuncts on the sandstone portions of the sub-Andean cordilleras, but not elsewhere in the Andean region (Berry et al., 1995). With each season of fieldwork, additional disjunct Guayana taxa are being discovered in the Cordillera del Cóndor and other sub-Andean cordilleras. These disjunct genera include *Stenopadus* (Asteraceae), *Digomphia* (Bignoniaceae), *Everardia* (Cyperaceae), *Euceraea* (Flacourtiaceae), *Phainantha* (Melastomataceae), *Pterozonium* (Pteridaceae), *Perissocarpa* (Ochnaceae), *Retiniphyllum* (Rubiaceae), *Bonnetia* (Theaceae), and *Aratitiyopea* (Xyridaceae).

The Cordillera del Cóndor region may well have the "richest flora of any similar-sized area anywhere in the New World" (Schulenberg & Awbrey, 1997), and it almost certainly has one of the highest concentrations of vascular plant species yet unknown to science of any place on Earth. We estimate the flora of the Cóndor to exceed 4,000 species of vascular plants (about 1,900 species have been identified from collections made to date) and 300-400 species of bryophytes. Building on prior floristic fieldwork in the Cóndor region since 1990, we propose a comprehensive, three-year botanical inventory in the Cóndor region, using geological information and satellite imagery to guide further fieldwork.

For over 160 years, the Ecuador-Peru border in the Cóndor region was in dispute, leading to armed conflict between the two countries in 1941, 1981, and 1995. Following the 1995 border conflict, the two countries began diplomatic negotiations, resulting in a peace treaty in 1998 that established the precise location of the international border.

Although the western slopes of the Cordillera del Cóndor in Ecuador have been partially deforested for establishment of cattle pastures, the core area of the region is largely intact. However, the prospect of environmental degradation and habitat loss resulting from large-scale mining is an imminent threat. The igneous formations of the Cóndor are rich in minerals, particularly gold and copper. Small-scale gold extraction by individual miners using traditional methods has been carried out in parts of the Cóndor for decades. Large mining concessions have been granted by the governments of both Ecuador and Peru, and proposals for large open-pit copper mines in the

heart of the Cóndor range have been put forth. The specter of mining is the greatest challenge faced by the conservation initiatives in the region.

Study area and geological background

The Cordillera del Cóndor region as we define it for this project comprises an area of about 1.1 million hectares (11,000 km²), including about 700,000 ha in southeastern Ecuador and 400,00 ha in adjacent northern Peru, from ca. 3°00.S to 4°30.S and 78°00.W to 79°00.W. In Ecuador, the study area includes all territory east of the Río Zamora and south of the Río Santiago in Morona-Santiago and Zamora-Chinchipe provinces, the entire watersheds of the Río Coangos in the northern portion, and the Río Nangaritza in the southern portion. In Peru, the study area includes the upper watersheds of the Río Cenepa and Río Comainas and the upper elevation areas adjacent to the Peru-Ecuador border; the area forms part of Condorcanqui province, Amazonas department. The lower portion of the Río Cenepa south of 4°00.S is not included in the present project. Comprehensive botanical inventories have already been carried out in the lower Cenepa region and adjacent areas of the middle Río Marañón and lower Río Santiago, southeast of the Cóndor region; Rodolfo Vásquez and colleagues at Missouri Botanical Garden are preparing a flora of the lower Cenepa region.

The geological composition of the Cordillera del Cóndor region is an important key to understanding its unique floristic composition and its putative biogeographic links to the Guayana Shield region. The marine and epicontinental sedimentary formations in this sub-Andean region were deposited at the western margin of South America during the Mesozoic and early Tertiary, prior to the Andean uplift; the sediments were derived from erosion of the ancient Guayana and Brazilian shields (Campbell, 1971). The sedimentary strata exposed in the Cóndor region range in age from the lower Jurassic Santiago formation, with limestones and volcanic intercalations, to the Paleocene-lower Eocene Tena formation, formed of reddish clays. Of particular interest for this study are the mid-Cretaceous (Aptian-Albian) sandstone Hollin formation and the stratum above it, the limestone Napo formation. The western portion of the region is comprised of the massive granitic Zamora batholith. The strata were uplifted to their present elevations with the Andean orogeny of the Eastern Cordillera, since the late Miocene, with most of the uplift since the Pliocene, in the past 5 Ma (Gregory-Wodzicki, 2000).

The Hollin sandstone is comprised of coarse- to medium-grained quartzite similar to the massive Guayana Shield sandstone formations, from which it is ultimately derived. The formation is about 150 m thick and is exposed in only about 6% of the Cóndor region in fragments ranging from less than 100 ha to over 20,000 ha in size. The sandstone fragments are dispersed throughout the region as an archipelago of different-sized islands in a matrix of non-sandstone substrates that form clay soils. The sandstone areas are typically flat-topped mesas with nearly vertical sides, and are easily detected in satellite imagery. As a result of the variation in uplift throughout the region, the sandstone mesas range in elevation from heights near the base of the Cordillera del Cóndor to their highest peaks at 2,900 m.

Substrate heterogeneity, vegetation and floristic composition

Environmental heterogeneity associated with differences in geological substrate and soil is a topic that has interested botanists for generations in many regions of the world (Kruckeberg, 2002). In lowland Amazonian Peru, floristic differences in areas of white sand vs. lateritic clays have been documented and patterns of beta-diversity associated with edaphic heterogeneity contribute substantially to the overall species richness of the region (Tuomisto et al., 1995; Vásquez & Phillips, 2000).

Soils derived from sandstone are generally known to be highly acidic and very poor in nitrogen, phosphorous and other nutrients; sandstone and podzolized white-sand vegetation is typically stunted and sclerophyllous, and frequently a thick peat layer is formed atop the oligotrophic substrate (Anderson, 1981; Duienvorden & Lips, 1995). The dissolved humic acids in water draining sand and sandstone substrates impart the coloration of .black-water. streams and rivers. These characteristics of sandstone vegetation are observed in the Cordillera del Cóndor region as well.

The botanical inventory work carried out in the Cóndor region to date has revealed readily observable differences in the structure and floristic composition of the vegetation on sandstone vs. adjacent non-sandstone substrates, but these differences have not yet been documented in a systematic way. At 1,000 m elevation, forest on sandstone is very dense with narrow-trunked, pole-size trees and a canopy 10 m tall or less, whereas forest on non-sandstone is much less dense with larger trees and a canopy height of 25 m or more. At 2,000 m elevation, the sandstone vegetation is a dwarf, very dense scrub with canopy of about 5 m, whereas on non-sandstone a more typical Andean cloud forest occurs with a 20 m tall canopy. Many of the species that occur on sandstone appear to be strongly restricted to that substrate type, including the Guyana disjuncts (see below), but some species evidently lack such substrate specificity, occurring on sandstone as well as on soils derived from limestone and igneous rocks. Among the principal objectives of this project is to document patterns of substrate specificity for the Cóndor region flora and interpret such patterns in terms of taxonomic relationships, life forms, and vegetation types. Some of the sandstone-restricted species in the Cordillera del Cóndor are also, it appears, very narrow endemics and may be found on only one or a few of the sandstone .tepuis. in this highly fragmented habitat. For instance, three species of *Weinmannia* (Cunoniaceae) with a dwarf, shrubby habit and very reduced, sclerophyllous leaves have been described from recent collections on different tepuis, all in similar scrub vegetation at about 2,000 m, but all three are known only from single populations despite searches for them in similar habitats on other tepuis in the region Rogers 2002a, b). These observations remain merely anecdotal, however, until a more thorough and systematic floristic survey on different sandstone fragments can be conducted throughout the Cóndor region.
Substrate specificity of saxicolous bryophytes has not been systematically documented in tropical montane regions, but initial observations in the Cóndor region suggest that the patterns of occurrence of mosses and hepatics growing on bare rock surfaces do show differences between sandstone, limestone, and igneous substrates, just as do vascular plants.

Guayana disjunct taxa in the Cóndor region

One of the conceptual issues in biogeography that this project will address is the presence of plant genera in the Cordillera del Cóndor region that are disjunct from the highlands of the Guayana Shield, thousands of km to the northeast. The evolutionary and biogeographical history of these disjunctions is as yet unknown, in the absence of explicit phylogenies for the taxa in question. Some of the relevant facts can aid in formulation of hypotheses of the origin of these disjunct distributions:

- In the Cóndor region, the Guayana disjuncts are found exclusively on sandstone substrate.
- The Guayana disjuncts form a minor component of the vegetation in the Cóndor region, where they occur in forests or scrub dominated by Andean taxa.
- The Guayana disjuncts in the Cóndor region (11 genera recorded to date) are only a small

subset of the diverse endemic flora (135 endemic genera) of the Guayana shield (Berry et al. [1995] listed 138 endemic genera, but three are now known as sub-Andean disjuncts).

- Most of the disjunct genera are more diverse in the Guayana region, with up to 15 species occurring there and only one or two disjunct species in the Cóndor region and other sub-Andean sandstone cordilleras.

- The available habitat of sandstone substrate in the Guayana highlands region is much older than that in the Cóndor and other sub-Andean cordilleras. The Roraima sandstones of the Guayana Shield are Precambrian marine deposits 1600 Ma old, ca. 3000 m thick, and uplifted to their present position beginning about 90 Ma in the mid-Cretaceous (Huber, 1995; Givnish et al. 2001). The Hollin sandstone in the Cordillera del Cóndor was deposited (from erosion of the original Guayana Shield sandstones) in the mid-Cretaceous (ca. 120 Ma), is only about 150 m thick, and was uplifted to its present elevation since the late Miocene but mostly in the past 10 Ma (Campbell, 1971; Gregory-Wodzicki 2000).

Given this background, the most reasonable hypothesis for the disjunct distribution of the sandstone-restricted taxa between the Guayana region and the Cordillera del Cóndor and other sub-Andean cordilleras is that the plants migrated to the Cóndor region by occasional long-distance dispersal in relatively recent times, following evolution and diversification *in situ* in the Guayana region over much longer periods.

On the other hand, there may be cases where plant taxa have migrated in the opposite direction, from the Andean region to the Guayana highlands, and then diversified in the latter region. Such a pattern was suggested by Struwe et al. (2002) for *Symbolanthus* (Gentianaceae), which is diverse in the Guayana region, less diverse in the tropical Andes, but for which several new, undescribedspecies have been found recently by the PI that grow abundantly in the Cóndor region (L. Struwe, pers. comm. 2002).

The question of the Guayana disjuncts in the sandstone sub-Andean cordilleras of Ecuador and Peru is an intriguing facet of South American biogeography that warrants further attention. The Present floristic survey project will help shed more light on this issue by revealing in more detail the distribution patterns of the Guayana disjuncts, and by providing plant material to researchers for molecular phylogenetic studies of the taxa in question.

Botanical exploration in the Cordillera del Cóndor region prior to 2004

The PI, with Ecuadorian colleagues from QCNE, initiated botanical inventories in 1990 in the southern portion of the Cordillera del Cóndor region, the Nangaritza watershed. The initial collecting efforts in 1990-91 yielded more than 30 species new to science that have been published to date, as well as the first evidence of the occurrence of Guayana disjunct taxa such as *Stenopadus* and *Phainantha* on the sandstone mesas of the Cóndor region. Two expeditions sponsored by Conservation International.s Rapid Inventory Program (RAP) surveyed animals as well as plants: in Ecuador in 1993, with Alwyn Gentry (MO) as lead botanist, in the Nangaritza and Coangos valleys and atop the central Cóndor crest; and in Peru in 1994, with Robin Foster (F) as lead botanist, in the upper Comaina watershed and atop the sandstone mesa of Machinaza (reported in Schulenberg & Awbrey, 1997). The first Co-PI of the proposed project carried out further botanical exploration in the upper Nangaritza basin in 1994, finding the disjunct Guayana fern genus *Pterozonium*.

For the remainder of the 1990s, further explorations were not possible because of the border conflict between Ecuador and Peru in the Cóndor region. The tensions between the two countries over the border exploded into battle in early 1995. The fighting was concentrated in the upper Cenepa valley and lasted about 2 months before a ceasefire was agreed upon. During the battle, thousands of lethal land mines were placed by both the Ecuadorian and Peruvian armies in the upper Cenepa valley and along portions of the crest of the Cóndor. After several years of negotiations mediated by the U.S. and other Latin American countries, Ecuador and Peru signed a peace treaty in 1998 that established the precise location of the international border in the Cordillera del Cóndor.

The PI, joined by Ecuadorian colleagues from QCNE, Ecuadorian post-graduate students, and native Shuar parabiologists, reinitiated botanical inventory work in the Cóndor region during 2000-2002 with support from the National Geographic Society. Botanical collections were made in a series of field trips in the northern (Coangos), central (Quimi-Tundayme), and southern (Nanguipa) portions of the Cóndor region in Ecuador. Concurrently, botanists from the University of Loja herbarium (LOJA) carried out botanical inventory work in the Nangaritza watershed. These collections resulted in discoveries of numerous species new to science, most of which are sandstone endemics and several of which have been published; e.g., *Weinmannia auriformis* Z.S. Rogers (Cunoniaceae) and *Maxillaria jostii* Dodson (Orchidaceae). The recent fieldwork has also added to the list of Guayana disjunct taxa on the sandstone mesas of the Cóndor region; e.g., *Digomphia* (Bignoniaceae), *Everardia* (Cyperaceae), and *Retiniphyllum* (Rubiaceae).

The .**Checklist of the Flora of the Cordillera del Cóndor Region, Ecuador**. is available online at MBG.s Web site, http://mobot.mobot.org/W3T/Search/Ecuador/projscdc.html. This is a dynamic checklist, which is linked to the TROPICOS database, http://mobot.mobot.org/W3T/Search/vast.html. Each time that a specimen is identified and the information is updated in the main TROPICOS database, the Cóndor checklist is also updated to include that species. Images of plants taken in the field are also available on the TROPICOS database, indexed by the name of the species. Photographs of unidentified species are indexed by genus.

Objectives of the Cordillera del Cóndor Project: 2004-2007

The principal objective of this project was to carry out a comprehensive inventory of the vascular plants and bryophytes of the Cordillera del Cóndor region of southeastern Ecuador and adjacent northern Perú. Because we had previously, carried out some floristic inventory fieldwork in this region, intermittently from 1990 to 2003, and also had obtained the data sets of other botanical inventories made in the region by other botanists, we knew that the Cordillera del Cóndor had some areas of nutrient-poor, highly acidic sandstone geological formations, and that plants growing on these sandstone areas included species with phytogeographical affinities to the flora of the Guayana highlands of northeastern south America, as well as some locally endemic taxa. We also were aware from the outset that the flora on the sandstone plateaus of the Cordillera del Cóndor is markedly distinct, as a general pattern, from the floristic elements occurring on the adjacent non-sandstone formations (limestones, igneous and metamorphic rock types) in the same region.

From the beginning of the project, we intended to concentrate on sampling the flora of the sandstone areas of the Cordillera del Cóndor, where the most distinctive and biogeographically interesting floristic elements were likely to occur. By studying the available cartography and satellite imagery of the Cordillera del Cóndor before initiating the fieldwork for this project, we

realized that, due to variations in tectonic uplift and erosion of the Cretaceous Hollín Formation that forms the sandstone layer in the region, the sandstone plateaus occur in fragments ranging from a few hectares to more than 20,000 hectares in area, and at elevations from less than 300 m to over 2900 m. The sandstone plateaus are also situated at varying distances from one another, and due to orographic precipitation and "rain shadow" effects, also differ to some degree in annual weather patterns and moisture regimes.

Therefore, we expected that the floristic inventory of the sandstone plateaus of the Cordillera del Cóndor could best be carried out as an exercise in "island biogeography", considering the sandstone fragments of varying size, elevation, climate and distance from one another as "habitat islands" surrounded by a matrix of very different vegetation on non-sandstone geological formations. Our objective in planning the botanical inventory program, was to sample as many as possible areas of sandstone of different sizes, elevations and aspects. Another objective was to carry out quantitative studies of the forest vegetation in a series of one-hectare plots to determine levels of beta-diversity between forest stands on adjacent sandston vs. non-sandstone substrates.

In actual practice, our botanical inventory activities were subject to some constraints in time, resources, and logistical considerations. We intended originally to carry out fieldwork on the eastern slopes of the Cordillera del Cóndor in the Río Cenepa watershed of Amazonas department, Peru. On the eastern slopes, we would expect rainfall to be higher than on the western slopes, and the flora would vary accordingly. Constraints in logistics, travel costs and difficulties in obtaining permission from local indigenous communities in the Río Cenepa region precluded us from conducting fieldwork in that region. In Peru, instead, fieldwork was carried out on the drier western slopes of the Cordillera, in Cajamarca province, and also on the western slopes for the total 150-km length of the Cordillera in Ecuador. We were not able to reach the highest sandstone plateau on the summit of Cerro Plateado at 2900 m elevation near the just inside Ecuador's southeasternmost border with Peru. Nevertheless, we covered as much ground as possible during the three years of fieldwork, and amassed a considerable number of plant collections that begin to reveal the phytogeographic patterns of the flora of the Cordillera del Cóndor region.

Vascular plant collections

Prior to the initiation of this project in 2004, there were approximately 9,000 vascular plant collections recorded from the Cordillera del Cóndor region, 5,500 from Ecuador and 4,500 from Perú. About half of these prior collections were made by the PI and his Ecuadorian colleagues during 2000-2003, after the 1998 peace treaty between Ecuador and Peru resolved the border conflict between the two countries that impeded field work during most of the 1990s.

The botanists associated with the project supported by NSF during 2004-2007 made approximately 13,000 collections of vascular plants in the Cordillera del Condor region, including about 11,000 from Ecuador and 2,000 from Peru, bringing the total number of vascular plant collections to about 22,000 for the region. The precise numbers of collections have not yet been determined since those made during the final 9 months of the project are still being entered into the TROPICOS botanical database administered by Missouri Botanical Garden. The first set of specimens has been given to the principal herbaria in the host countries: the National Herbarium of Ecuador (QCNE) in Quito and the Universidad Mayor San Marcos (USM) in Lima. Duplicate collections have been sent to Missouri Botanical Garden (MO); shipments are pending for collections made during the final 9 months of the project.

In addition to the fertile collections, about 2,000 sterile vouchers were made from the marked and tagged trees ≥10 cm DBH in the six one-hectare tree plots. These sterile vouchers are housed at the

QCNE herbarium in Quito, and with a few exceptions, will not be distributed to other herbaria. When the sterile vouchers are determined to species, and if no fertile collections were obtained from the same one-hectare plot, just one voucher per species per plot is entered in the TROPICOS botanical database, so as to provide a vouchered site record for that species for purposes of distribution records and biogeographical analyses.

Principal localities for botanical inventories

Ecuador

Cerro Kaputna area 03°01'S 77°55'W 270-550 m

Cerro Kaputna is the north-westernmost outlier of the Cordillera del Cóndor, located on the south bank of the Río Santiago at the point where this large river makes an abrupt turn to the south and enters Peru; the Santiago continues south to its union with the Río Marañón. Cerro Kaputna is composed of both limestone as well as sandstone Cretaceous sedimentary rocks. Most of the sandstone outcrops that we have encountered in the Cordilera del Cóndor are above 1000 m elevation, but this area contains the lowest-elevation sandstone outcrops in the region, below 500 m. At these low-elevation sandstone outcrops, floristic elements occur that are typical of white-sand areas of lowland Amazonia but are not found on the higher elevation sandstone fragments; examples the understory herb *Rapatea muaju* (Rapateaceae) and the understory tree *Dolichodelphys chlorocrater* (Rubiaceae).

Rio Coangos area 03°02'S 78°13'W 400-1200 m

This is the northernmost portion of the Cordillera del Cóndor region. A north-south trending tectonic graben separates the Cordillera del Cóndor proper from the parallel ridge to the east, the Cordillera de Huaracayo, and in the rift valley between the two cordilleras, the Río Coangos flows north, in Ecuadorian territory, into the Río Santiago, and the Río Cenepa flows south, in Peruvian territory, into the Río Marañón. The entire Coangos watershed is inhabited by Shuar communities, and we carried out floristic inventories during 2005 in several of these. The dendrology course in September 2005 was held in two Shuar communities, Kuankus and Yunkumas, and the first two one-hectare forest inventory plots were established: one on non-sandstone substrate at 670 m elevation, and a second plot on the sandstone plateau of Cerro Chuank Naint at 1150 m.

Río Quimi area 03°34'S 78°27'W 900-1900 m

The Río Quimi is a "black-water" river that drains the largest area of sandstone in the Cordillera del Cóndor, and is a tributary of the Río Zamora in the central portion of the Cóndor region. The sandstone plateau at the crest of the cordillera in this region covers more thatn 20,000 hectares, at elevations of about 1800-2000 m, and forms the international border between Ecuador and Peru. In 2006 the entire sandstone plateau was designated as two protected areas by the Ministry of Environment of Ecuador. The western slopes of the Cordillera below the sandstone plateau, however, do not have formal protection. The granite batholith below the sandstone contains a very substantial deposit of copper, and the Canadian-based mining company, Corriente Resources, Inc., owns the mining concession and has applied for a permit to open a large open-pit copper mine that will extract the mineral over a period of 20 years. During our field work in this region, we stayed as guests at the copper company field camp, and a large proportion of the botanical inventories were carried out in this area. The fourth and final dendrology course, and the sixth and final one-hectare forest plot inventoy, were carried out in this area in April 2007.

Rìo Yacuambi area 03°46'S 78°53'W 900-2600 m

This area is actually not within the Cordillera del Cóndor, but rather is part of the eastern slopes of the Eastern Cordillera of the Andes, in Zamora-Chinchipe province, west of the Río Zamora that nominally forms the western boundary of the project study area. We included botanical inventories in this area in part because we realized to our surprise that there are sandstone fragments in this area, outside of the Cóndor and attached to the main Andean range. The clue to this was the "black-water" river, the Río Kiim, that drains this area and is a tributary of the Río Yacuambi. The area includes a 30,000-hectare forest reserve that belongs to three Shuar communities. The Shuar parabiologists carried out botanical inventories in this region during 3 one-month periods, and documented a number of species that are restricted to sandstone substrates and serve as "sandstone indicators" such as *Centronia laurifolia* (Melastomataceae).

Upper Río Nangaritza area 04°14'S 78°39'W 900-1700 m

The upper watershed of the Río Nangaritza, in Zamora-Chinchipe province, drains a large area that includes sandstone plateaus as well as some limestone outcrops, and this area was a major focus of our botanical inventory activities. Much of the area is formally designated as the "Upper Nangaritza Protection Forest", excluding the settled areas where farms and pastures in along the main river have been settled by three ethnic groups – the indigenous Shuar, and the native Saraguro and non-indigenous mesizo communities who migrated to the region from the Andean region of Ecuaodr. Two of the four dendrology courses were held at the community of Las Orquídeas, at the end of the gravel road that in the upper Nangaritza valley. Three of the six one-hectare forest inventory plots were established in this area, on the sloping sandstone plateau southwest of Las Orquideas, in a formally protected area the "Las Orquídeas Tepui Reserve" that is administered by the community.

Río Vergel area 04°41'S 78°57'W 1800-2300 m

Within Ecuador, this is the southernmost portion of the Cordillera del Cóndor and is part of the watershed of the Río Chinchipe, a major tributary of the Río Marañón. At the boundary between the upper Río Nangaritza watershed and the Río Vergel watershed is the highest summit in the Cordillera del Cóndor, Cerro Plateado at 2900 m, which is capped by a sandstone plateau. We believe that this summit is the only area where herbaceous páramo vegetation occurs on sandstone in Ecuador; however, due to the remoteness and difficult access of Cerro Plateado, we were not able to include this site in the floristic inventory work during this project. Three field trips were made to lower areas in the Río Vergel watershed. This region remains rather poorly sampled, however, and merits further floristic inventory work in the future.

Peru

Río Chirinos area 05°06'S 78°57'W 800-2200 m

South of the Ecuador-Peru border, the main ridge of the Cordillera del Cóndor continues in a south-trending direction, and forms the boundary between the Peruvian departments of Cajamarca and Amazonas, until the range ends at the Río Marañón, southeast of the city of Jaén, Peru. The northern portion of the main Cóndor ridge in Peru is within the watershed of the Río Chirinos, a tributary of the Río Chinchipe. This area was the focus of floristic inventories carried out by the Peruvian forester-botanist, Juan Perea, during 2006-2007.

Cordillera Huarango area 05°12'S 78°42'W 1000-2300 m

In Peru, the ridge that forms the boundary between Cajamarca and Amazonas departments, east of the Rìo Chinchipe, is known as the "Cordillera Huarango", although structurally it is the southernmost extension of the Cordillera del Cóndor. This area was the focus of floristic

inventories by the Peruvian botanist, Eric Rodríguez of the Universidad Nacional de Trujillo, during two expeditions in July 2005 and April 2006.

Bryophyte collections

Inventories and collections of the bryophytes in the Cordillera del Cóndor region were made by MBG curator Steven Churchill, assisted by Edison Jaramillo, an undergraduate student from the Universidad Central del Ecuador, during November-December 2005. They carried out collections in the upper Río Nangaritza area and the the Rió Quimi area, in the central and southern portions of the Cóndor region in Ecuador. These inventories are complemented by earlier collections made by bryologists from the the National Herbarium of Ecuador during 2002-2003 in the northern portions of the Cóndor. Steven Churchill identified the bryophyte collections and compiled a list of the mosses recorded from the Cordillera del Cóndor. A full set of the bryophyte collections was given to the National Herbarium of Ecuador in Quito.

Dendrology Courses

Dendrology is a branch of systematic botany with practical applications: the term applies especially to the identification of living trees in the forest, rather than from dried herbarium specimens, using in part the vegetative characters of leaves, bark, exudates, tree archictecture, etc., to identify standing forest trees to family or genus level, when flowers or fruits are not available for examination by the student. Dendrology is a considerable challenge in species-rich Neotropical forests. David Neill, the Principal Investigator, has taught dendrology courses in Amazonian Ecuador since the mid-1980s on an annual basis, and also on some occasions in Ecuador. The dendrology course programs include discussion of tropical forest ecology, animal-plant interactions and the history of economic uses of trees throughout the New World tropics, but especially the Amazon basin and the Andes.

This project was the first time that dendrology courses were held in the Cordillera del Cóndor region, where the forest composition and structure are quite distinct from the forests typical of lowland Amazonian Ecuador. Besides the classroom lectures and field practice in tree identification, the dendrology courses involved the participants in a research activity that added to their learning experience: all participants aided in the establishment of one or two one-hectare forest inventory plots during each course. In each plot, all trees with a diameter at breast height (DBH) of 10 cm or greater, are measured, marked with permanent aluminum tags, and identified. Voucher specimens are collected from at least one tree of each species in the plot, and for the trees that cannot be identified to species on sight.

Three dendrology courses were originally scheduled for this project, to be held in the northern, central and southern sections of the Cordillera del Cóndor, with one course during each year of the

project. The courses were originally planned for groups of twelve university-level students at each course: six from Ecuador and six from Peru. We actually held four courses, not three, and each course included 25 to 60 students, so we were able to reach a much larger audience of students than originally planned – a total of 170 students in the four courses. The participating students included practicing foresters and rural community members who are involved in forest management and conservation, as well as university-level biology students. Each course was 15-20 days in duration in the field, with post-field work to identify plant specimens from the course in the herbaria of Quito and Loja.

Dendrology Course # 1 September 2005

The first dendrology course was held at the indigenous Shuar communities of Kuankus and Yunkumas, in the Río Coangos watershed in the northernmost section of the Cordillera del Cóndor in Morona-Santiago province. The site is a five-hour hike from the nearest roadhead, crossing footbridges over the Río Santiago and Río Zamora. The participants included six university students from Ecuador and six from Peru, as well as 15 indigenous Shuar from local communities who are engaged in forest management activities with the Shuar Federation. There were also six instructors and assistant instructors on the course, led by the project's Principal Investigator. The entire group set up two one-hectare plots, on non-sandstone substrate at Kuankus at 670 m elevation, and on the sandstone plateau of Yunkumas at 1150 m elevation. The latter site involved a further 5-hour hike to the top of the plateau where the entire group camped out for a week in order to complete the tree plot inventory. Following the field work, most of the participants travelled to Quito and participated in the identification of the tree specimens at the National Herbarium of Ecuador.

Dendrology Course # 2 May 2006

The second dendrology course was held at the Cabañas Yankuam eco-tourist lodge, on the banks of the upper Río Nangaritza in the southern portion of the Cordillera del Cóndor, in Zamora-Chinchipe province, Ecuador,near the *mestizo* village of Las Orquídeas. On this occasion, the entire group of 60 students were from the 4th-year botany class at the Universidad Central del Ecuador in Quito. The course was organized by their botany professor, Mercedes Asanza, and taught by David Neill. In addition to attending the dendrology lectures and field activities, each student carried out an individual research project with two days of field work, on different aspects of the flora at this site. The students prepared posters and oral presentations of their research projects, which were presented in a symposium at the biology school of the Universidad Central del Ecuador.

The participants in the second dendrology course established two one-hectare plots in the "Tepui Conservation Area" that is administered by the village association of Las Orquídeas: one plot on a slope just above the Río Nangaritza and below the sandstone plateau at 920 m elevation, and a second one-hectare plot at 1120 m elevation atop the sloping sandstone plateau.

Dendrology Course # 3 November 2006

The third dendrology course, like the first one, included university students from Ecuador and Peru – six students from each country – as well as 15 participants from local communities in the region, indigenous Shuar as well as non-indigenous *mestizos*, who are engaged in forest management and conservation activities in the Cordillera del Cóndor region. The course was hosted by the *mestizo*

village of Las Orquídeas, on the upper Río Nangaritza in Zamora-Chinchipe province. Dendrology class lectures were held in the village two-room schoolhouse. This group established a third one-hectare forest inventory plot in the "Tepui Conservation Area" on the sandstone plateau above Las Orquideas, at 1620 m elevation on the upper portion of the sloping plateau. The group also revised and completed the tree inventories in the two tree plots at Las Orquídeas by the participants in the second dendrology course.

Dendrology Course # 4 April 2007

The fourth and final dendrology course, like the second course, was comprised mostly of 4th year botany students from Mercedes Asanza´s class at the Universidad Central del Ecuador, at total of 35 students. This course was held in the central portion of the Cordillera del Cóndor, in the Río Quimi watershed, in northernmost Zamora-Chinchipe province. The course was generously hosted at the field camp of EcuaCorriente. S.A., an Ecuadorian copper-mining company that is a subsidiary of a Canadian company, Corriente Resources, Inc., The company has plans to develop a large open-pit copper mine at the site, on the granitic rock below the sandstone plateau that, in this region, forms the crest of the Cordillera del Cóndor at 1800-200 m and delineates the international boundary between Ecuador and Peru.

As in the second dendrology course, the 4th year students from the Universidad Central del Ecuador each conducted a 2-day individual research project on different aspects of the flora in the area, besides participating in the dendrology lectures and practicums. The group established the sixth and final one-hectare forest inventory plot of the NSF-supported project, along a ridge at 1200 m elevation above the copper company field camp.

Establishment of one-hectare tree inventory plots

The original proposed for this project submitted to and approved by NSF included the establishment of six one-hectare permanent forest inventory plots in the Cordillera del Condor, including all trees and lianas ≥ 10 cm DBH and applying the standard methodology for such plots (Phillips et al., 200). The plots were to be established in pairs, with one forest plot on sandstone substrate at each of three sites in the northern, central and southern portions of the Cordillera del Cóndor in Ecuador, and a second plot at each site on non-sandstone substrate, as close as feasible to the "sandstone" plot.

The fieldwork for the one-hectare forest inventory plots was carried out by the students and instructors on each of the dendrology courses in the Cordilera del Cóndor that were an integral part of this project. The plan called for the participants in each of the three dendrology courses to establish two one-hectare tree plots on nearby areas of contrasting sandstone and non-sandstone substrates.

The first pair of plots was established according this plan, during the first dendrology course in the northern portion of the Cordillera del Cóndor, on land belonging to the Shuar communities of Kuankus and Yunkumas. The layout of the remaining four tree plots, however, deviated from the original plan. Tree plots 3, 4 and 5 are arranged along an altitudinal transect of the sloping sandstone plateau at Las Orquídeas, west of the Río Nangaritza in the southern portion of the Cordillera del Cóndor plot. The sixth plot is located, by itself, on a ridge below the sandstone plateau in the Río Quimi watershed, in the central portion of the Cordillera del Cóndor.

1**. Kuankus Plot** 03°02’55” S 78°13’41” W 670 m
This plot is located on non-sandstone substrate with clay soil, on land belonging to the Shuar community of Kuankus. In floristic composition and structure, the forest at this site is very similar to a typical *terra firme* forest type that occurs in large areas of Amazonian Ecuador.

2. Yunkumas Plot 03°03’34” S 78°14’45” W 1150 m
This plot is located just 2.5 km distant and 500 m higher in elevation than the Yunkumas plot, but on top of the sandstone plateau known to the Shuar in this region as Cerro Yuank Naint, the “Mountain of the Vultures”. The forest composition and structure are very distinct from the Kuankus plot, with some of the dominant species that are restricted to sandstone-derived soils, and much shorter in stature with much less biomass than the Kuankus plot.

3. Nangaritza River Slope Plot 04°15’01” S 78°39’36” W 920 m
This plot is located on a steep slope just above the west bank of the Río Nangaritza. It is situated below the sandstone plateau of the Hollin Formation, but because the sandstone has eroded down onto the slopes below, the soil has a high sand content and the forest has many tree species that are typically restricted to the sandstone formation.

4. Nangaritza Lower Sandstone Plateau Plot 04°15’08” S 78°39’53” W 1120 m
This plot is located just one km west of and 200 m higher than Plot # 3, but it is located on a nearly level site atop the sandstone plateau in the area of Las Orquídeas. The forest canopy is very uneven and the basal area and biomass of the forest is much lower than in Plot # 3. Some tree species are shared between Plots 3 and 4, but most of the dominant species are different between the two plots.

5. Nangaritza Upper Sandstone Plateau Plot 04°15’32” S 78°41’04” W 1620 m
This one-hectare tree plot is located about 4 km west of, and 500 higher elevation, than plot 4, near the upper edge of the sloping sandstone plateau west of the Río Nangaritza above the village of Las Orquídeas. Nearly all of the dominant tree species in the plot are different from those in Plots 3 and 4 on the same altitudinal transect.

6. Wawaime Plot 03°33’41” S 78°26’14” W 1100 m
This tree plot is located in the Río Quimi watershed in the central portion of the Cordilellera del Cóndor. It is the only one among the six plots established in this project that is not laid out in a 100 m x 100 m square pattern; it is a rectangular plot, 250 m x 40 m and includes part of a ridge line, a steep slope and gully below the ridge. It is located several hundred meters below the sandstone plateau in this area, but the soil along the ridge has sand eroded from the plateau above, with tree species typical of the sandstone substrate. The gully bottom has species more typical of the terra firme forests in lowland Amazonian Ecuador.

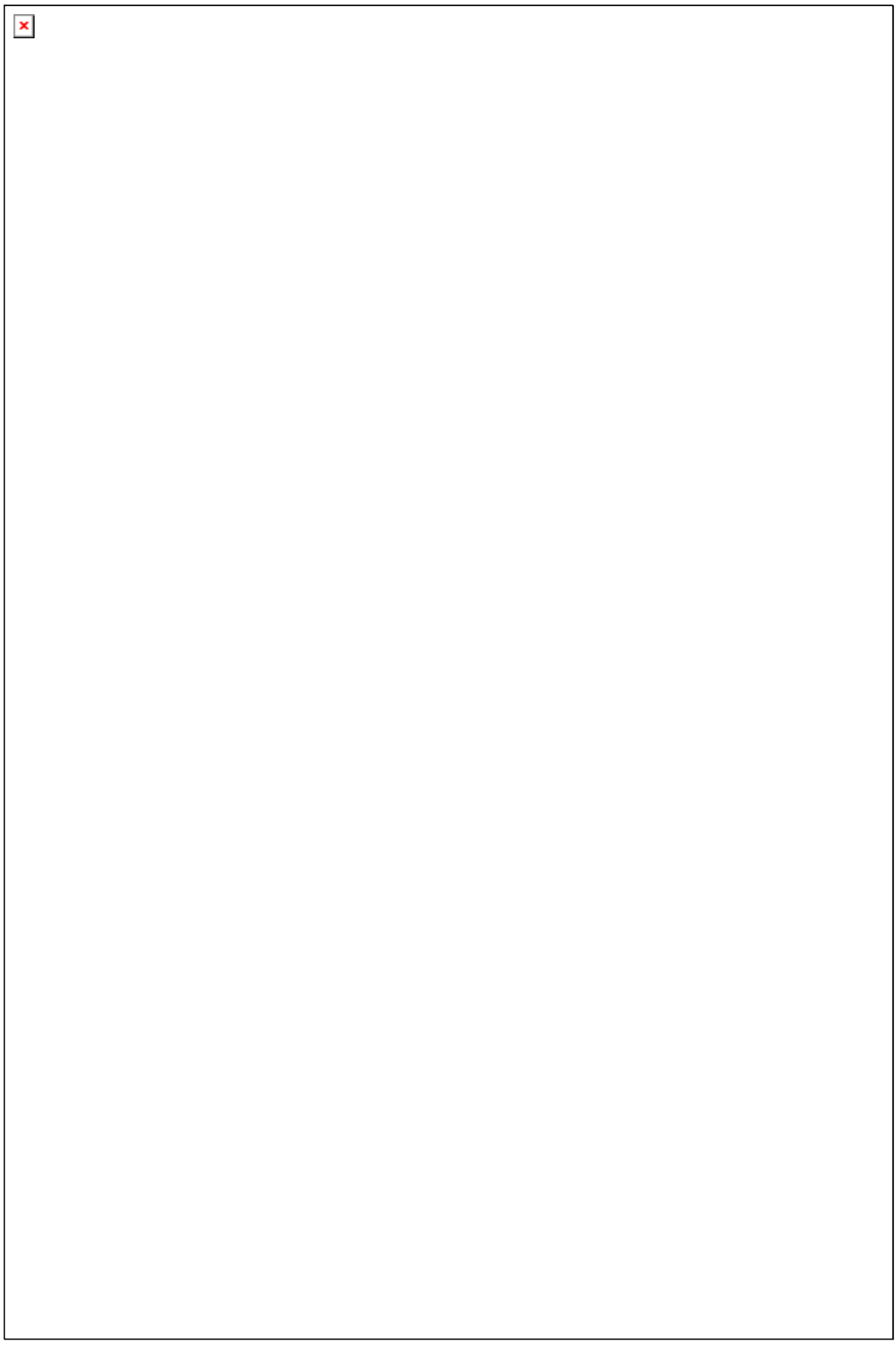
Cartography and GIS studies of the Cordillera del Cóndor region

This project included development of a Geographic Information System (GIS) for the Cordillera del Cóndor region of Ecuador and Peru. One major objective is to study the distribution of plant species with respect to environmental variables within the region such as geological substrate, soils, slope, and precipitation. Another objective is to classify and map the vegetation types in the region based on remote sensing data as well as ground truthing.

The base map of the Cordillera del Cóndor region was developed by the technical staff of the Ecuador Conservation Data Center in Quito, headed by geographer Pablo Almeida, using ArcGIS software. The available data layers include geology and vegetation, the "digital elevation model" of the topography of the region, and the botanical data from TROPICOS, Missouri Botanical Garden´s TROPICOS database.

One product of the Cordillera del Cóndor flora project will be the availability of the GIS map of the region online, using an internet map server, along with the botanical information from TROPICOS, that will allow the user to plot species distributions within the region and analyze distributions with respect to several environmental variables. This feature has not yet been put online, but is expected to be available to the public in late 2007.

A copy of the base map for the Cordillera del Cóndor region is shown on the following page.



Botanical Inventory of the Cordillera del Cóndor Project -- Participants

Senior Personnel

Neill, David
David Neill, the Principal Investigator on this project, devoted at least part of every month to the Cordillera del Cóndor project from January 2005 to April 2007. During this time he supervised the field work of the three Ecuadorian botanists and three Shuar parabiologists who participated in the floristic inventory activities of the project. He also served as the principal instructor for the four dendrology courses, held during September 2005, May and November 2006, and April 2007, and supervised the fieldwork for the six one-hectare forest inventory plots that were sampled by the course participants. He also supervised the data entry of the more than 10,000 plant collections made during the course of this project into TROPICOS, Missouri Botanical Garden's online botanical database.

Together with Carmen Ulloa of Missorui Botanical Garden, Neill published in 2006, in the MBG journal Novon, a new species of Melastomataceae, *Phainantha shuariorum*, endemic to the Cordillera del Cóndor and a generic-level disjunct from the highland sandstone plateaus of the Guayana Shield; the specific epithet is dedicated to the Shuar ethnic group in whose territory the species is found. Neill is currently preparing for publication, additional new species of trees based on recent collections from the Cordillera del Cóndor region, in several different families including *Clethra* (Clethraceae), *Lozania* (Lacistemataceae), *Dacryodes* (Burseraceae) and *Parkia* (Fabaceae). Neill is also preparing a publication on the forests of the Cordillera del Cóndor, based largely on the six one-hectare forest inventory plots, and a separate paper on the biogeographical patterns in the flora of the region, dealing especially with the endemisms and Guayana Shield disjunctions of the plants recorded from the sandstone plateaus of the Cóndor.

Neill also has collaborated extensively, throughout the period of the NSF project, with the Ministry of Environment of Ecuador, with local Shuar and *mestizo* community groups, and with industry representatives including the Corriente Resources copper mining firm, to assist in planning for protected areas and other conservation measures in the Cordillera del Cóndor region. This work will continue in future years as the management plans for the newly declared protected areas in the region begin to be designed and implemented. Partly through Neill's collaboration with the Ministry of the Environment, the majority of the sandstone plateaus of the Cordillera del Cóndor, with their unique flora and vegetation, are now within formally designated protected areas.

van der Werff, Henk
Henk van der Werff, the first CoPrincipal Investigator, carried out field work in the Cordillera del Cóndor on two trips to Ecuador, during October-November 2004 and October-November 2006. He was accompanied in the field on both occasions by Wilson Quizhpe, an Ecuadorian botanist from Loja who worked on the project, and by Bruce Gray from the CSIRO herbarium in Queensland, Australia. During these two field trips about 1500 collections were made from three principal areas in the Cordillera del Cóndor region: the Río Quimi area in the north, the Río Nangaritza area farther south, and the Río Vergel area in the southernmost part of the Cóndor region within Ecuador.

Both van der Werff and Gray are specialists in systematics of Lauraceae, of which many species are canopy trees, difficult to collect, and poorly represented in herbaria, so their fieldwork concentrated

on collecting Lauraceae and other canopy trees in flower or fruit. During the first field trip in 2004, they made a total of 76 fertile collections of Lauraceae, an unusually high proportion for any collecting foray in the Neotropics. A number of these are species new to science, that van der Werff is currently preparing for publication, as well as other species newly reported for Ecuador, previously known only from Peru.

In November 2006, van der Werff's field work in the Nangaritza area coincided with the third dendrology course led by David Neill in the same area, so van der Werff presented a "guest lecture" to the 40 students in the course on the systematics of Lauraceae.

Churchill, Steven

Steven Churchill, a bryologist with Missouri Botanical Garden based in Santa Cruz, Bolivia, is an expert on the moss flora of the Andes, a topic on which he has authored and co-authored a number of publication. Churchill`s participation was essential to the inclusion of bryophytes in the floristic inventory of the Cordillera del Cóndor. He carried out fieldwork to collect bryophytes during October-December 2005. He was accompanied in the field by an Ecuadorian undergraduate student beginning to work on bryophytes, Edison Jaramillo. They made collections in the Río Quimi and upper Río Nangaritza areas of the Cóndor region in Ecuador.

Churchill also examined the bryophyte collections at the National Herbarium of Ecuador (QCNE) and made many determinations of specimens housed there, including numerous collections made in previous years by bryologists and students in the Cordillera del Cóndor region. Churchill later worked further on the determinations of bryophytes from the Cóndor region, with the duplicate specimens that were sent to Missouri Botanical Garden. He compiled a preliminary checklist of the mosses of the Cordillera del Cóndor.

Croat, Thomas

Thomas Croat is a Senior Curator at Missouri Botanical Garden whose research interests center on the systematics of Araceae in the Neotropics. He is currently working on the Araceae treatment for the 'Flora of Ecuador', a series edited in Sweden and published in Denmark. The Catalogue of Vascular Plants of Ecuador (1999) listed 404 species of Araceae for the country, but Croat has estimated (pers. comm.. to David Neill) that about 1,000 additional, undescribed species of Araceae occur in Ecuador.

Tom Croat has made many collecting trips to Ecuador over the past several decades, and during the current project, he made collections during July-August 2004 and April 2006; both trips included fieldwork in the Cordillera del Cóndor as well as other regions of Ecuador. His fieldwork was not supported by the grant from NSF, but by grants from the National Geographic Society and private donors. His collections, however, are included in the online database of the flora of the Cordillera del Cóndor on Missouri Botanical Garden`s TROPICOS web site.

Asanza, Mercedes

Mercedes Asanza, an Ecuadorian botanist, is a professor of botany at the Universidad Central del Ecuador, in Quito. She is also the spouse of David Neill, the PI on this project. Each year, she organizes a field course on the flora of Ecuador for her 4th-year botany students. During the project in the Cordillera del Cóndor supported by NSF, the majority of the participants in the second and fourth dendrology courses (May 2006 and April 2007) were Mercedes Asanza's 4th-year students from the Universidad Central. On each of these field courses, the students carried out and reported on individual research projects dealing with plants, besides attending the dendrology lectures and field exercises and participating in the one-hectare forest inventory plot field work. Each year, the

students made public presentations of their research projects in a symposium at the Universidad Central in Quito.

Mercedes Asanza's research interests are in Pteridophytes, and she made collections of ferns while in the field in the Cordillera del Cóndor on several occasions.

Mercedes Asanza also helped with logistical and administrative support for the duration of the three years of the project, as well as the accounting of the project for the expenses incurred in Ecuador.

Gray, Bruce
Bruce Gray is a plant systematist with CSIRO, the Australian scientific research agency, based in Queensland, Australia. His research interests center systematics of Lauraceae, an interest he shares with Henk van der Werff of Missouri Botanical Garden, and the two have frequently collaborated on fieldwork in various regions of the world.

Gray participated in the floristic inventory of the Cordillera del Cóndor, accompanying Henk van der Werff, in October-November 2004 and October-November 2006. He is an expert at collecting herbarium specimens from tropical trees that attain heights of 30 m or more, using a slingshot to shoot a line over the topmost branches of canopy and emergent trees, and then pull the line to break a branch with fertile specimens. He used this technique to great effect on his two trips to Ecuador. He also taught these techniques to the Ecuadorian botanists in the field and presented them with the equipment after each of his field trips.

Manzanares, José
José Manzanares is a Spanish botanist and horticulturist who has resided in Quito, Ecuador for more than 25 years, and has become the foremost authority on the systematics of Bromeliaceae in Ecuador. He has published two volumes of his projected four-volume, profusely illustrated systematic treatment, titled "Jewels of the Jungle: Bromeliaceae of Ecuador". The second volume, published in 2005, on subfamily Pitcarinioideae, included 14 species of *Pitcarirnia* new to science of which 5 species were recent collections from the Cordillera del Cóndor. As part of the project, José Manzanares spent a month in the herbarium at Missouri Botanical Garden in June 2005, to work on specimen identifications and manuscripts for the subsequent volumes of his opus on the Bromeliaceae of Ecuador.

Vásquez, Rodolfo
Rodolfo Vásquez is a Peruvian botanist and forester, and is the head of Missouri Botanical Garden`s program in Peru, currently based in the town of Oxapampa in the Selva Central region of Peru. Although he carried out field work in the Cordillera del Cóndor region and the Río Cenepa region of Peru during the 1990s, Rodolfo did not personally participate in the fieldwork in this project. He served as liaison for the project activities in Peru, supervised the field work of the Peruvian botanists, Juan Perea and Eric Rodriguez, who conducted the botanical inventories in the Peruvian portion of the Cordillera del Cóndor, and obtained the required research and collecting permits from the Peruvian agency, INRENA, that issues the permits.

Graduate Student

Quizhpe, Wilson
Wilson Quizhpe, a native of Loja, Ecuador, is a professional forester and graduate of the University Nacional de Loja. He served as the major liaison between the project and the Loja university

herbarium, and the project's principal contact with the regional office of the Ministry of Environment in Loja, which has jurisdiction over the Cordillera del Cóndor region. Wilson participated on a full-time basis with the project from November 2004 to April 2007 and made about 2,000 plant collections during this period, mostly in the central and southern portions of the of region in Zamora-Chinchipe region. Wilson has been accepted into the graduate program of the Universidad de Alicante in Valencia, Spain, and his MS thesis (and possibly later, a doctoral dissertation) will be a study of the forest flora and vegetation of the Río Quimi watershed in the central portion of the Cordillera del Cóndor. He visited Missouri Botanical Garden, together with the Principal Investigator and three other Ecuadorian botanists, during July-August 2006 and worked on the species descriptions for his study of the tree flora of the Río Qumi watershed.

Undergraduate Student

Katan, Tuntiak
Tuntiak Katan is a Shuar student in the Applied Ecology program at the Universidad San Francisco de Quito, and completed his third year of studies in the June 2007. He will be the first Shuar in history to complete a university degree in biology. Tuntiak was one of the four Shuar high school graduates who participated in the conservation biology training program with Missouri Botanical Garden and the Wildlife Conservation Society in 2002-2004.

Jaramillo, Edison
Edison Jaramillo was a student in the biology department of the Universidad Central del Ecuador. He acquired an interest in bryophytes, and in this project, he collected bryophytes in the Cordillera del Cóndor as a field assistant with Steven Churchill, during November-December 2005. Following this learning experience, he completed his undergraduate thesis, a survey of the mosses at the Yanacocha biological station in the eastern Andes of Napo province in northern Ecuador.

Technician, Programmer

Almeida, Pablo
Pablo Almeida, an Ecuadorian geographer, is a specialist in Geographic Information System (GIS) technology, and is Director of the Conservation Data Center of Ecuador, a non-governmental organization associated with the Jatun Sacha Foundation and based in Quito. Under contract with Missouri Botanical Garden, Pablo Almeida and his technical staff prepared the base maps for the Cordillera del Cóndor flora project, using ArcGIS and other cartographic software. The cartography was compiled using digitized topographic maps at 1:50,000 and 1:100,000 scale from Ecuador and Peru, and from these the GIS team developed a Digital Elevation Model at 30-m scale. For Ecuador, the cartography also includes geologic and vegetation layers. The map will be used for online presentation of the Cordillera del Cóndor floristic database using the internet map server system at Missouri Botanical Garden. This feature has not yet been implemented.

Other participants

Kakejai, Camilo
Camilo Kajekai is a Shuar "para-biologist" and graduate of the training program in conservation biology for ethnic Shuar and Awá high-school graduates, held by Missouri Botanical Garden and the Wildlife Conservation Society during 2002-2004. He participated in the project from September 2005 to April 2007 as a plant collector, and made more than 1,000 collections. With his knowledge of the Shuar names of many plants as well as the Latin binomials of the same plants, his

contribution to the project was very significant. He also helped as participating instructor in the dendrology courses and helped the dendrology students with the one-hectare tree plot inventories. Many of his plant collections in the Cordillera del Cóndor were made in his home community, Kaputna, at the northwestern limit of the region, and included low-elevation species not found elsewhere in the study area.

Wisum, Abel
Abel Wisum is a Shuar "para-biologist" and graduate of the training program in conservation biology for ethnic Shuar and Awá high-school graduates, held by Missouri Botanical Garden and the Wildlife Conservation Society during 2002-2004. He participated in the floristic inventories of the Cordillera del Cóndor during several periods: September-December 2005, March-September 2006, and January-April 2007. Some of his plant collections were made outside of the study area, near his home in the Shuar community of Tumpaim in the heart of the Cordillera de Cutucú, the sub-Andean range north of the Cordillera del Cóndor, and these collections allow for comparisons of the flora between the two adjacent cordilleras.

Morales, Carlos
Carlos Morales, an Ecuadorian botanist and graduate of the Universidad Central del Ecuador, participated in the floristic inventory of the Cordillera del Cóndor on this project from June 2005 to December 2006. He generally worked in the field collecting with Diego Reyes, in the northern sector of the Cordillera del Cóndor in Morona-Santiago province. He also participated as assistant instructor on the four dendrology courses led by the PI from September 2005 to April 2007. In July and August 2006, he traveled with the David Neill and three other Ecuadorian botanists to Missouri Botanical Garden, where they worked on processing and identifying the specimens collected through June 2005 in the Cordillera del Cóndor.

Reyes, Diego
Diego Reyes, an Ecuadorian botanist and graduate of the Universidad Central del Ecuador, was a student on the first dendrology course in September 2005, and subsequently participated as a plant collector on the project from March to December, 2006. He worked alongside Carlos Morales in the floristic inventories in the northern portion of the Cordillera del Cóndor. Diego Reyes visited the herbarium of Missouri Botanical Garden during July-August 2006 and helped to process the project collections at MO. Like the other Ecuadorian botanists who visited MO at that time, he also made use of the library and herbarium facilities to advance his knowledge of floristic taxonomy and to plan future research endeavors.

Rodríguez, Eric
Eric Rodríguez is a Peruvian botanist based at the herbarium of the Universidad Nacional de Trujillo, in the coastal city of Trujillo, where he is collections manager of the university herbarium. He has many years of experience of fieldwork in the Andes and the coastal regions of northern Peru. The Universidad Nacional de Trujillo was the principal Peruvian institution that participated in the NSF-supported project for the floristic study of the Cordillera del Cóndor, and Eric served as the principal Peruvian counterpart for this project. With some students and other faculty members from his university, he made two plant collecting trips, in July 2005 and April 2006, to the southernmost spur of the Cordillera del Cóndor. This ridge, that forms the boundary between Cajamarca and Amazonas departments, is generally known in Peru as the Cordillera Huarango. Eric Rodriguez was participated as an assistant instructor in the first dendrology course, held in Ecuador in September 2005, and led the contingent of six Peruvian students to that participated in the field course.

Perea, Juan

Juan Perea is a Peruvian forester and botanist; he is a native of the city of Iquitos in lowland Amazonian Peru and a graduate the Universidad Nacional de la Amazonia Peruana in that city. He has participated as a field botanist with Missouri Botanical Garden`s programs in Peru for several years. He was one of six Peruvian students on the first dendrology course sponsored by the NSF project, in Ecuador in September 2005. Subsequently, he was contracted as a plant collector for the NSF project and carried out floristic inventories in the Río Chirinos watershed, in the northernmost part of the Cordillera del Cóndor within Peru, from April to December, 2006.

Botanical Inventory of the Cordillera del Cóndor Region of Ecuador and Peru

Project Findings 2004-2007

Introduction: The "Lost World" of the Cordillera del Cóndor

The region of isolated sandstone table mountains of the Guayana Highlands in southern Venezuela and adjacent countries – the biogeographical "Pantepui" is sometimes known popularly as the "Lost World", because it was the remote and mysterious setting of Arthur Conan Doyle's novel (1912) of that name, in which scientists discovered dinosaurs and other prehistoric animals roaming the heights of the *tepuis*. Floristically, the Pantepui region is known among botanists as somewhat of a world apart due to the large number of endemic taxa that have evolved there over long periods of time on the ancient erosion surfaces of the sandstone tepuis. In the Guayana highlands 23 endemic genera and over 1,000 endemic species have been recorded, and 138 endemic genera in the larger region of the Guayana Shield as a whole (Berry *et al.* 1995; Berry & Riina 2005, Rull 2007).

Prior to the present floristic inventory project, it was also known that there are a number of genera that are "almost endemic" to the Guayana Shield except for one or more outliers in other regions (Berry *et al.* 1995). Most, or perhaps all of these outlier taxa are restricted to nutrient-poor sandstone or lowland white sand areas outside of the Guayana Shield. When we initiated the

project, five of these "sandstone outlier" genera had been reported from the Cordillera del Cóndor region: *Bonnetia* (Bonnetiaceae), *Everardia* (Cyperaceae), *Phainantha* (Melastomataceae) *Pterzonium* (Pteridaceae) and *Stenopadus* (Asteraceae). During the course of the fieldwork in the Cordillera del Cóndor, we have recorded several other genera, not previously known from the region that are additional "Guayana Shield outliers"; these include *Digomphia* (Bignoniaceae) and *Retiniphyllum* (Rubiaceae). Some taxa in the Cordillera del Cóndor are apparently species-level disjuncts from the tepuis of the Guayana highlands, including *Retiniphyllum tepuiense* and *Podocarpus tepuiensis*; these are not recorded from anywhere outside of the Pantepui region except for the populations on the sandstone summits of the Cordillera del Cóndor, more than 2,000 distant from Pantepui

We also have registered a number of other genera that were previously not known from Ecuador; most of these latter occur on the scattered patches of white sand in lowland Amazonia. Among these genera recently discovered in the Cordillera del Cóndor that are new to Ecuador are *Krukoviella* (Ochnaceae), *Hortia* (Rutaceae) and *Sterigmapetalum* (Rhizophoraceae)

Our collections in the region have also turned up a number of species new to science; these include locally endemic tree species that are restricted to the sandstone forests of the Cordillera del Cóndor, within genera that are common in the Amazon and the Andes; among these are yet-undescribed taxa of *Clethra* (Clethraceae), *Compsoneura* (Myristicacae) *Dacryodes* (Burseraceae), *Lozania* (Lacistematacae), *Talauma* (Magnoliaceae).

What is most surprising to us is that our quantitative forest inventories on the sandstone plateaus of the Cordillera del Cóndor indicate that many of the tree species in the region that are new to science or new records for Ecuador are among the most abundant and dominant species in our one-hectare tree plots. The forest vegetation on sandstone substrate in the Cordillera del Cóndor, in terms of floristic composition, structure and dynamics, is utterly unlike any forest type that has been known previously from Ecuador. On the other hand, the forests on non-sandstone substrates in the Cóndor range are very similar to the forest stands that are known from the adjacent eastern slopes of the Andes and the piedmont lowlands of Amazonian Ecuador.

We are convinced that our fieldwork in the Cordillera del Cóndor to date has barely scratched the surface, in terms of a comprehensive inventory of the floristic diversity of this region. Many of the newly discovered taxa are apparently locally endemic to one or a few of the numerous sandstone plateaus and fragmented outcrops in the region, and only a comparative few of the numerous sandstone areas, of different sizes and at different elevations, have been visited as yet by botanists. We have observed many species of trees and shrubs in the field that we are confident are undescribed and new to science, but repeated visits to the same localities will be required to acquire sufficient flowering and fruiting specimens sufficient for formal taxonomic descriptions of these new taxa. In short, terms of its floristic diversity the Cordillera del Cóndor region of Ecuador and Peru remains a "Lost World" that is still in the initial stages of discovery.

New generic records and other novelties in the flora of the Cordillera del Cóndor

In the following section we illustrate and briefly describe some of the botanical novelties and new floristic records for Ecuador that we have found in the Cordillera del Cóndor in the project supported by the National Science Foundation.

***Retiniphylllum tepuiense* (Rubiaceae) –** We have collected this handsome flowering shrub at several sites in the "dwarf scrub forest" atop the isolated sandstone plateaus – the "*tepuis*" – of the Cordillera del Cóndor, at about 1200 m elevation. This is an example of a plant species with a disjunct distribution between the Guayana highlands of southern Venezuela and the Cordillera del Cóndor of southeastern Ecuador, a distance of more than 2,000 km. Before our discovery, *Retiniphyllum tepuiense* was known only from the "tepuis" of the Guayana region of Venezuela. Our collections are also the first record of the genus *Retiniphyllum* for Ecuador. Most species of this genus are found exclusively lowland white sand substrate in the Guayana Shield, or on the small patches of white sand that are scattered throughout Amazonia, below 500 m elevation; only a few species, like this one, occur on sandstone at higher elevations. In Peru, different species of *Retiniphyllum* are known from Amazonian lowland white sand vegetation, but this type of habitat has never been detected anywhere in Ecuador

***Hortia* cf. *brasiliensis* (Rutaceae)**

In November 2006, during our forest plot inventory of the 3rd Cordillera del Cóndor dendrology course, we found a tree in flower in the forest on the sandstone plateau at Las Orquídeas that we had never seen before in 22 years of research in Ecuador, and initially we had no idea of the taxonomic placement of the tree – neither the genus nor the botanical family to which it belonged.. The tree, with its "candelabra"-type branching form, its large leaves clustered at the ends of the branches, and its large flat-topped inflorescence with brilliant pink flowers, had us "stumped" and piqued our scientific curiosity. Back in Loja, where we were able to consult the botanical literature available in the herbarium library and over the Internet, we determined that the unknown tree was a species of *Hortia*, in the citrus family, Rutaceae. This genus, *Hortia*, had never before been reported in Ecuador or Peru, but a half-dozen species were previously known from various regions of South America, including the Guayana Shield of southeastern Venezuela, the forests of coastal Brazil and the *cerrado* savannas of central Brazil, as well as one species in the Chocó region of Pacific coastal Colombia and adjacent Panama. Just three *Hortia* trees were recorded in the uppermost one-hectare tree plot on the sandstone plateau at Las Orquídeas. This species may be *Hortia brasiliensis*, in which case it has an interesting disjunct distribution between the Atlantic coastal forests of Brazil, the Cordillera del Cóndor in Ecuador and the western cordillera of the Andes in the Chocó region of Colombia – but not, in this case, in the Guayana highlands.

***Krukoviella disticha* (Ochnaceae)**

Krukoviella disticha, the sole species of this monotypic genus, was collected in flower during 2005-2006 at several localities in the Rio Nangaritza and Rio Quimi watersheds.
This species is known from a rather small number of collections. It was first collected by Richard Spruce in the Tarapoto area of lowland Amazonian Peru in the 1860s, and subsequently by B.A. Krukoff in the 1930s in western Amazonian Brazil. It is probably restricted in lowland Amazonia to white sand fragments, but the information on these older collections do not indicate the soil type or substrate. In the 1990s several collections were made on sandstone fragments in the Rio Cenepa region of Amazaons, Peru, on sandstone outcrops. Our recent collections in Ecuador at 900-1100 m extend the elevational range of this plant considerably upwards. Although it has sometimes been described in the literature as a tree or shrub, the Ecuadorian populations are definitely lianas.

***Humiriastrum mapiriense* (Humiriaceae)**

A significant number of the trees, shrubs and other plants that we are documenting in the floristic inventory of the Cordillera del Cóndor region are species that are either new records for Ecuador, or are new to science. One tree that we collected in flower and fruit at several sites in the Cordillera del Cóndor during 2005 and 2006, we immediately recognized to be a species in the Humiriaceae, a family of about 50 species of trees in tropical America that are known for their slow growth and very hard, heavy durable wood and hard durable fruits that last for a long time after falling to the forest floor. Once we had the flowering and fruiting specimens before us in the herbarium of Missouri Botanical Garden, and after studying the pertinent taxonomic literature and viewing the specimens in St. Louis as well as the images over the Internet of the type specimens of various species of Humiriaceae at the New York Botanical Garden and at the U.S. National Herbarium of the Smithsonian Institution, we determined that the Humiriaceae tree we found to be rather common on the sandstone plateaus of the Cordillera del Cóndor is *Humiriastrum mapiriense*, a species that was previously known from only a few collections in the Mapiri region of Bolivia, on the eastern slopes of the Andes. This species is locally dominant in the 3rd tree inventory plot at Las Orquídeas, the uppermost plot on the sandstone plateau at 1620 m elevation. Another species of Humiriaceae, *Humiria balsamifera*, is the dominant species in the mid-elevation tree plot at Las Orquídeas, at 1120 m elevation; although it is so very common locally, *Humiria balsamifera* had never been reported or collected previously in Ecuador.

***Podocarpus tepuiensis* (Podocarpaceae) –**

Podocarpus, the only arborescent genus of Gymnosperms native to the tropical Andes, includes at least 7 species known from Ecuador and Peru. Generally, *Podocarpus* in Andean forests do not occur in pure or dense stands, but are usually in relatively species-rich, mixed forests along with numerous other genera of Angiosperms. In the highest of our one-hectare forest inventory plots at 1600 m elevation on a sandstone plateau in the Cordillera del Cóndor, we found a species of *Podocarpus* that we had not seen before in Andean Ecuador, and that was one of the dominant species in the plot with a number of large, canopy-emergent trees in a single hectare of forest. The herbarium material was determined by the taxonomic specialist as *Podocarpus tepuiensis,* a species known previously only from the sandsone tepuis of the Guayana highlands, so this is evidently another species-level disjunct between the Pantepui region and the Cordillera del Cóndor.

***Pitcairnia neillii* (Bromeliaceae)**

The *tepuis* of the Guayana highlands have extensive areas on the summits of the sandstone table mountains with open, herbaceous vegetation growing on bare rock or with a very thin layer of soil. The floras of these herbaceous meadows on theVenezuelan tepuis have very high levels of endemism. On the sandstone mesas of the Cordillera del Cóndor, in contrast, we have as yet seen very few areas of open, herbaceous vegetation – the Cóndor uplands are covered almost entirely with closed-canopy forests or very dense shrubby vegetation. We have encountered a few areas with patches of herbaceous vegetation on bare rock, in patches of less than a hectare each. Among the locally endemic herbacecous plants in these patches is *Pitcarnia neillii*, described and published in 2005 by the Spanish taxonomist José Manzares in the second volume of this project 4-volume treatise on the Bromeliaceae of Ecuador. Four additional new species of *Pitcairnia* from the Cordillera del Cóndor were described in the same publication. We have now found several populations of *P. neillii*, in patches of a few to several dozen plants, on bare sandstone outcrops in the northern and central sections of the Cóndor.

***Phainantha shuariorum* (Melastomataceae)**

Four species of the genus *Phainantha*, all of them endemic to the Pantepui region of the Guayana highlands, were known before we began floristic inventories in the Cordillera del Cóndor. We first collected this fifth species of *Phainantha* in the Cóndor in 1990, but sufficient flowering material for the taxonomic description of the new species was not encountered until 2004. *Phainantha shuariorum*, published by Carmen Ulloa and the project PI David Neill in 2006, is a semi-woody vine with an unusual habit that climbs and clings to tree trunks,by means of adventitious roots at the nodes, in the sandstone forests of the Cóndor at 1000-1500 m elevation. The specific epithet commemorates the Shuar indigenous group, in whose territory occur most of the populations of *P. shuariorum*.

***Stenospermation arborescens* (Araceae)**

The arborescent habit of *Stenospermation arborescens*, with an erect semi-woody trunk up to 2 m high, is very unusual for the genus and for Araceae in general, which are almost entirely herbaceous. This species is quite common in the low, dense shrubby vegetation on Cordillera del Cóndor sandstone plateaus at 1800-2000 m elevation. The species was previously known from a single locality in the Cordillera de Cutucú, the sub-Andean mountain range north of the Cóndor and north of the Río Santiago in Morona-Santiago province, that also has areas of sandstone. The flora of the Cordillera de Cutucú is now much more poorly known than that of the Cóndor, but undoubtedly the two ranges share many locally endemic taxa.

Quantitative Forest Inventories in the Cordillera del Cóndor:

One-hectare Permanent Plots

The original proposal for this project submitted to and approved by NSF included the establishment of six one-hectare permanent forest inventory plots in the Cordillera del Condor, including all trees and lianas ≥ 10 cm DBH and applying the standard methodology for such plots (Phillips et al., 200). The plots were to be established in pairs, with one forest plot on sandstone substrate at each of three sites in the northern, central and southern portions of the Cordillera del Cóndor in Ecuador, and a second plot at each site on non-sandstone substrate, as close as feasible to the "sandstone" plot.

The fieldwork for the one-hectare forest inventory plots was carried out by the students and instructors on each of the dendrology courses in the Cordilera del Cóndor that were an integral part of this project. The plan called for the participants in each of the three dendrology courses to establish two one-hectare tree plots on nearby areas of contrasting sandstone and non-sandstone substrates.

The first pair of plots was established according this plan, during the first dendrology course in the northern portion of the Cordillera del Cóndor, on land belonging to the Shuar communities of Kuankus and Yunkumas. The layout of the remaining four tree plots, however, deviated from the original plan. Tree plots 3, 4 and 5 are arranged along an altitudinal transect of the sloping sandstone plateau at Las Orquídeas, west of the Río Nangaritza in the southern portion of the Cordillera del Cóndor plot. The sixth plot is located, by itself, on a ridge below the sandstone plateau in the Río Quimi watershed, in the central portion of the Cordillera del Cóndor. Soil samples were collected at all plots and analyzed at the laboratory of Agro-Bio-Chem S.A. in Quito Ecuador.

The summary data for each of the six one-hectare tree plots are presented in the tables on the following pages. The data include the location of each plot, a brief description of the terrain and geologic substrate, the number of individuals, approximate number of species, and total basal area of the trees in each plot. The soils data in these summary charts include just the pH and the soil texture – proportion of sand, silt and clay. The tables list the 15 "most important" species recorded in each plot (in some cases, a genus is listed that includes several different species, not separated in these tables). The maximum diameter attained by each species in the plot is indicated, as well as the sum basal area and number of individuals of each listed species. The "Relative Density" is the proportion proportional number of individuals of each species, with respect to the total number of trees in the plot, on a scale of 0-100, and the "Relative Dominance" is the proportional basal for each species. We use the term "Relative Importance" for the combined values of Relative Density and Relative Dominance for each species, also fitted to a scale of 0-100. Since standing dead trees were so prominent in many of these plots, we include the values for total number of standing dead trees (not identified to family or taxon) in each plot.

In Ecuador, more than 70 one-hectare tree inventory plots have been established by several research teams in the past several decades, using the same methodology that we used for the six plots in the Cordillera del Cóndor. None of the previously established plots in Ecuador have been sampled on sandstone or lowland white sand substrates.

Our results for the Cordillera del Cóndor demonstrate clearly that the sandstone forests of this region are very different in species composition, structure and dynamics, to any forest stand that has been sampled elsewhere in Ecuador. They also have very little in common with the tree plots that have been sampled in the lowland white sand areas near Iquitos, Peru (Vásquez & Phillips, 2000).

Three of the six plots in this study are located atop sandstone plateaus, and two are situated below the sandstone, but have a relatively high proportion of sand in the soil, derived from erosion of the sandstone above down onto the ridges and slopes below. Only the Kuankus plot is relatively distant from any sandstone source; this is also the lowest elevation plot at 670 m. The floristic composition and structure of the Kuankus plot is very similar to plots that we have surveyed in terra firme areas of lowland Amazonian Ecuador on lateritic clay soils. In fact, all of the tree species in the Kunankus plot are also known from the Jatun Sacha Biological Station, at 400 m in the piedmont zone of the Río Napo basin, 300 km to the north in Napo province.

The remaining five plots have very different tree species compositions from any other sites we have known in Ecuador. A significant number of the most common trees in these plots are either species new to science, or species that are not known from anywhere else in Ecuador. For example, two species of Humiriaceae are among the dominants in the middle and upper plots at the Nangaritza site, which are separated by just 4 km distance and 500 m elevation, but one species *Humiria balsamifera*, occurs only in the mid-elevation plot and the other, *Humiriastrum mapiriense*, only in the upper plot. Both species are new records for Ecuador. Elsewhere in Ecuador, we have seen Humiriaceae only rarely as minor components in the forests. In the mid-elevation Nangaritza plot, *Digomphia densicoma* (Bignoniaceae) is among the top five species in abundance and basal area; but the genus *Digomphia*, before this study, was considered endemic to the Guiana Shield (Berry *et al*., 1995).

Additional species that are dominant in the sandstone-area tree plots but are recorded in Ecuador only from the Cordillera del Cóndor include *Bonnetia paniculata* (Bonnetiaceae), *Roucheria grandiflora* (Linaceae), *Pagamea dudleyi* (Rubiaceae), *Schefflera harmsii* (Araliaceae), *Centronia laurifolia* (Melastomataceae), *Podocarpus tepuiensis* (Podocarpaceae) and *Ternstroemia circumscissilis* (Theaceae).

Species that, we are reasonably certain, are new to science are also common in the tree plots. These include undescribed species of *Dacryodes* (Burseraceae), *Compsoneura* (Myristicaceae), *Tovomita* (Clusiaceae), *Byrsonima* (Malpighiaceae).

Chrysophyllum sanguineolentum (Sapotaceae) has the top position in "Relative Importance" in two plots, second in importance in one plot, and fourth in another plot. This species is not restricted to white sand or sandstone, and is widespread in lowland Amazonia as well as the Guayana Shield region. There are several recognized subspecies of this taxon, however, and the one in our plots (probably subsp. *balata*) may be sandstone-restricted.
Regarding the long-term dynamics of the sandstone forests in the Cordillera del Cóndor, we do not yet have any direct measure of forest dynamics, but one feature that we noted in these forests is very significant. We observed virtually no tree falls or tree-fall gaps in these forests. On the other hand, there are great numbers of "standing dead" trees in each one-hectare plot. It appears to us that, because the roots of adjacent trees are so intimately intertwined, forming the dense root mat with humus that make a sponge-like layer atop the sandstone, and the roots penetrate very little into the sandstone substrate, the trees that die virtually never topple over; their roots remain intertwined with their neighors, and the dead trees simple decompose in place, erect, over a number of years.

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Kuankus Plot

Location: Shuar community of Kuankus, in lower Río Coangos watershed, Limon-Indanza Cantón, Morona-Santiago. Located 2.5 km east of and 450 m lower than Yunkumas plot.

03°02'55"S 78°13'41"W 670 m Plot Shape: 100 m x 100 m

September 2005, Surveyed by participants of 1st dendrology course in Cordillera del Cóndor

Topography and substrate: Terrace above Río Coangos, hilly terrain, well-drained, lateritic clay soil. 500 m below sandstone plateau; no evidence of sand in soil derived from plateau above.

Tall, dense forest with canopy to 35 m; canopy emergents to 50 m.

Soil: pH 4.2; sand 54%, clay 28%, silt 18%

776 trees in plot; 37.2 m², total basal area; ca. 220 species

Family	Taxon	Max Diam (cm)	Species Basal Area	Species Abundance	Relative Density	Relative Dominance	Relative Importance
ARECACEAE	*Wettinia maynensis*	19.9	1.63	128	16.5	4.4	10.4
MYRISTICACEAE	*Otoba glycycarpa*	107.8	3.98	47	6.1	10.7	8.4
BURSERACEAE	*Dacryodes peruviana*	68.7	2.31	44	5.7	6.2	5.9
RUBIACEAE	*Chimarrhis glabriflora*	75.5	1.92	11	1.4	5.2	3.3
LECYTHIDACEAE	*Grias neuberthii*	28.4	0.59	28	3.6	1.6	2.6
MORACEAE	*Ficus* sp.	150.0	1.77	1	0.1	4.7	2.4
(Various families)	(Standing dead trees)	61.0	1.12	12	1.5	3.0	2.3
MYRISTICACEAE	*Virola peruviana*	67.3	1.16	9	1.2	3.1	2.1
EUPHORBIACEAE	*Mabea standleyi*	51.3	0.53	14	1.8	1.4	1.6
MORACEAE	*Brosimum utile*	113.5	1.01	1	0.1	2.7	1.4
ARECACEAE	*Socratea exorrhiza*	35.0	0.29	15	1.9	0.8	1.4
MORACEAE	*Poulsenia armata*	45.0	0.48	9	1.2	1.3	1.2
SAPOTACEAE	*Pouteria durlandii*	69.8	0.72	4	0.5	1.9	1.2
BURSERACEAE	*Protium fimbriatum*	39.0	0.39	10	1.3	1.0	1.2
MORACEAE	*Perebea xanthochyma*	42.0	0.49	6	0.8	1.3	1.1
ULMACEAE	*Celtis schippii*	47.5	0.39	7	0.9	1.1	1.0

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Yunkumas Plot

Location: Shuar community of Yunkumas, in lower Río Coangos watershed, Limon-Indanza Cantón, Morona-Santiago. Located 2.5 km west of and 450 m higher than Kuankus plot.

03°03'45"S 78°14'47"W 1150 m Plot Shape: 100 m x 100 m

September 2005, Surveyed by participants of 1st dendrology course in Cordillera del Cóndor

Topography and substrate: Situated atop Cerro Chuank Naint, a plateau of Hollín sandstone, sloping toward west, undulating terrain, well-drained; plot includes ridge crests and stream valley bottom.

Relatively low, dense forest with canopy to 25 m in stream valleys but only 8 m on upper ridges.

Soil: nearly pure sand derived from crystalline sandstone; pH 3.7; sand 85%, clay 4%, silt 10%

774 trees in plot; 13.4 m², total basal area; ca. 90 species

Family	Taxon	Max Diam (cm)	Species Basal Area (m²)	Species Abundance	Relative Density	Relative Dominance	Relative Importance
SAPOTACEAE	*Chrysophyllum sanguineolentum*	41.5	2.18	85	11.0	16.2	13.6
ARALIACEAE	*Schefflera harmsii*	28.3	1.58	116	15.0	11.7	13.4
ARECACEAE	*Socratea exorrhiza*	16.0	1.05	101	13.0	7.8	10.4
BURSERACEAE	*Dacryodes* "condorensis" sp. nov.	25.8	1.26	72	9.3	9.4	9.3
(Various families)	(Standing dead trees)	29.5	0.68	35	4.5	5.0	4.8
ARECACEAE	*Euterpe precatoria*	18.7	0.45	42	5.4	3.4	4.4
SAPOTACEAE	*Pouteria multiflora*	27.3	0.36	10	1.3	2.7	2.0
LINACEAE	*Roucheria laxiflora*	17.7	0.21	16	2.1	1.6	1.8
MYRISTICACEAE	*Osteophloeum platyspermum*	26.8	0.23	9	1.2	1.7	1.4
FABACEAE	*Macrolobium gracile*	24.0	0.18	10	1.3	1.4	1.3
MELASTOMATACEAE	*Centronia laurifolia*	14.5	0.13	11	1.4	1.0	1.2
THEACEAE	*Ternstroemia circumscissilis*	25.0	0.16	9	1.2	1.2	1.2
MYRISTICACEAE	*Compsoneura* "morona-santiagoensis" sp. nov.	22.2	0.15	7	0.9	1.1	1.0
MELASTOMATACEAE	*Miconia* sp.	16.0	0.09	8	1.0	0.7	0.8
ELAEOCARPACEAE	*Sloanea* sp. nov.	18.5	0.10	7	0.9	0.8	0.8
MYRTACEAE	*Myrcia* sp nov.	25.7	0.12	5	0.6	0.9	0.8

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Nangaritza River Slope Plot

Location: Las Orquídeas Tepuy Reserve, 2 km south of Las Orquídeas village, Nangaritza Cantón, Zamora-Chinchipe province. Slope above west bank of Nangaritza River.

04°15'01"S 78°39'36"W 920 m Plot Shape: 100 m x 100 m

May and November 2006, Surveyed by participants of 2nd and 3rd dendrology courses in Cordillera del Cóndor.

Topography and substrate: Slope above Río Nangaritza, 10% to 60% steep slopes, below the sandstone plateau, but soil with high sand content due to erosion of sand from sandstone formation above.

Tall, dense forest with canopy to 30 m; canopy emergents to 45 m.

Soil: pH 4.5; sand 90%, clay 4%, silt 6%

770 trees in plot; 24.3 m², total basal area; ca. 110 species

Family	Taxon	Max Diam (cm)	Species Basal Area	Species Abundance	Relative Density	Relative Dominance	Relative Importance
SAPOTACEAE	*Chrysophyllum sanguineolentum*	55.0	5.03	128	16.6	20.7	18.7
LAURACEAE	*Nectandra* and *Ocotea* (several species)	39.0	1.89	58	7.5	7.8	7.7
(Various families)	(Standing dead trees)	52.0	1.19	34	4.4	4.9	4.7
APOCYNACEAE	*Aspidosperma* cf. *megalocarpon*	39.8	0.98	25	3.2	4.0	3.6
CLUSIACEAE	*Tovomita* "broadleaf" sp. nov.	56.0	0.88	25	3.2	3.6	3.4
CYATHEACEAE	*Cyathea caracasana*	20.0	0.45	26	3.4	1.8	2.6
RUBIACEAE	*Pagamea dudleyi*	21.4	0.46	24	3.1	1.9	2.5
BURSERACEAE	*Dacryodes peruviana*	53.0	0.72	7	0.9	3.0	1.9
MORACEAE	*Pseudolmedia laevigata*	28.5	0.41	15	1.9	1.7	1.8
MELASTOMATACEAE	*Miconia* (several species)	42.5	0.34	15	1.9	1.4	1.7
CLUSIACEAE	*Clusia* (several species)	31.3	0.40	13	1.7	1.6	1.7
MORACEAE	*Perebea xanthochyma*	31.2	0.37	12	1.6	1.5	1.5
BURSERACEAE	*Dacryodes* "condorensis" sp. nov.	32.8	0.40	10	1.3	1.6	1.5
FABACEAE	*Macrolobium gracile*	33.7	0.35	11	1.4	1.4	1.4
RUBIACEAE	*Ladenbergia stenocarpa*	28.2	0.22	13	1.7	0.9	1.3
EUPHORBIACEAE	*Alchornea grandis*	40.5	0.37	8	1.0	1.5	1.3

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Nangaritza Lower Sandstone Plateau Plot

Location: Las Orquídeas Tepuy Reserve, 2 km south of Las Orquídeas village, Nangaritza Cantón, Zamora-Chinchipe province. Plateau of Hollín Sandstone formation, sloping towards east. One km west of and 200 m higher than the Nangaritza River Slope Plot.

04°15'08"S 78°39'53"W 1120 m Plot Shape: 100 m x 100 m

May and November 2006, Surveyed by participants of 2nd and 3rd dendrology courses in Cordillera del Cóndor.

Topography and substrate: Atop sloping plateau of Hollín sandstone. Lower portion of plateau, 10% slope to nearly level. Sandy soil derived from crystalline quartzite sandstone rock. Dense root mat with humus atop sandstone substrate; tree roots penetrate very little into substrate.

Dense forest with broken, uneven canopy about 10 m tall with emergents to 25 m tall. Many standing dead trees.

Soil: pH 4.4; sand 82%, clay 8%, silt 10%

571 trees in plot; 17.4 m², total basal area; ca. 80 species

Family	Taxon	Max Diam (cm)	Species Basal Area (m^2)	Species Abundance	Relative Density	Relative Dominance	Relative Importance
HUMIRIACEAE	*Humiria balsamifera*	78.0	4.57	70	26.2	12.3	19.2
MELASTOMATACEAE	*Miconia* (several species)	38.0	0.94	54	5.4	9.5	7.4
EUPHORBIACEAE	*Hieronyma* (several species)	22.0	0.68	31	3.9	5.4	4.7
SAPOTACEAE	*Chrysophyllum sanguineolentum*	32.9	0.80	26	4.6	4.6	4.6
BIGNONIACEAE	*Digomphia densicoma*	31.0	0.66	25	3.8	4.4	4.1
PODOCARPACEAE	*Podocarpus sprucei*	55.0	0.90	7	5.2	1.2	3.2
CYRILLACEAE	*Purdiaea nutans*	31.0	0.34	17	2.0	3.0	2.5
CLUSIACEAE	*Clusia* (several species)	34.9	0.30	12	1.7	2.1	1.9
LAURACEAE	*Nectandra* (several species)	24.0	0.24	13	1.4	2.3	1.8
MELASTOMATACEAE	*Graffenrieda* sp.	22.9	0.20	14	1.1	2.5	1.8
FABACEAE	*Macrolobium gracile*	26.7	0.20	10	1.1	1.8	1.4
(Various families)	(Standing dead trees)	37.0	0.11	12	0.6	2.1	1.4
PODOCARPACEAE	*Podocarpus oleifolius*	36.9	0.33	4	1.9	0.7	1.3
MALPIGHIACEAE	*Byrsonima* sp. nov.	27.4	0.20	8	1.1	1.4	1.3
MAGNOLIACEAE	*Talauma* sp. nov.	29.0	0.21	7	1.2	1.2	1.2
BONNETIACEAE	*Bonnetia paniculata*	46.4	0.29	3	1.6	0.5	1.1

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Nangaritza Upper Sandstone Plateau Plot

Location: Las Orquídeas Tepuy Reserve, 4 km southwest of Las Orquídeas village, Nangaritza Cantón, Zamora-Chinchipe province. Near the summit of the sloping Plateau of Hollín Sandstone formation, sloping towards east. Four km west of and 500 m higher than the Nangaritza Lower Sandstone Plateau Plot.

04°15'32"S 78°41'04"W 1620 m Plot Shape: 100 m x 100 m

November 2006, Surveyed by participants of 3rd dendrology course in Cordillera del Cóndor.

Topography and substrate: Atop sloping plateau of Hollín sandstone. Upper, western portion of plateau, near escarpment that forms vertical cliff at western edge of plateau. 20%-30% slopes. Sandy soil derived from crystalline quartzite sandstone rock. Dense root mat with humus atop sandstone substrate; tree roots penetrate very little into substrate.

Dense forest with broken, uneven canopy about 10 m tall with emergents to 25 m tall. Many standing dead trees.

Soil: pH 4.6; sand 82%, clay 2%, silt 16%

532 trees in plot; 12.7 m², total basal area; ca. 70 species

Family	Taxon	Max Diam (cm)	Species Basal Area (m^2)	Species Abundance	Relative Density	Relative Dominance	Relative Importance
EUPHORBIACEAE	*Alchornea grandiflora*	39.3	1.01	41	7.98	7.71	7.84
(Various families)	(Standing dead trees)	38.6	0.79	19	6.21	3.57	4.89
PODOCARPACEAE	*Podocarpus tepuiensis*	69.0	0.89	9	7.03	1.69	4.36
HUMIRIACEAE	*Humiriastrum mapiriense*	34.9	0.61	15	4.82	2.82	3.82
ARECACEAE	*Dictyocaryum lamarckianum*	19.6	0.34	16	2.72	3.01	2.87
MALPIGHIACEAE	*Byrsonima* sp. nov.	25.0	0.40	10	3.13	1.88	2.51
ARALIACEAE	*Schefflera harmsii*	24.0	0.25	13	2.01	2.44	2.23
LINACEAE	*Roucheria grandiflora*	18.5	0.19	15	1.52	2.82	2.17
CLUSIACEAE	*Clusia* (several species)	21.1	0.17	12	1.36	2.26	1.81
MELASTOMATACEAE	*Miconia* (several species)	14.5	0.14	13	1.12	2.44	1.78
CLETHRACEAE	*Clethra fimbriata*	27.8	0.21	9	1.62	1.69	1.66
CLUSIACEAE	*Tovomita weddelliana*	12.6	0.15	11	1.22	2.07	1.65
MELASTOMATACEAE	*Graffenrieda*	16.0	0.14	11	1.09	2.07	1.58
FABACEAE	*Dussia sp. nov.*	27.9	0.23	7	1.79	1.32	1.55
FABACEAE	*Ormosia* sp. nov.	28.0	0.16	7	1.30	1.32	1.31

One-hectare Forest Inventory Plots in the Cordillera del Cóndor, Ecuador

Wawaime Plot

Location: EcuaCorriente copper mine site, Río Wawaime watershed (tributary of Río Quimi), El Pangui Cantón, Morona-Santiago. Ridgeline below sandstone plateau.

03°34'22"S 78°26'44"W 1200 m Plot Shape: 250 m x 40 m

April 2007, Surveyed by participants of 4th dendrology course

Topography and substrate: ridge below sandstone plateau with sandy soil from erosion from above (upper half of plot); steeply sloping to bottom of adjacent gully (lower half of plot).

Tall, dense forest with canopy to 25 m; canopy emergents to 40 m.

Soil: pH 4.5-4.6; sand 44-48%

972 trees in plot; 35,92 m², total basal area; approx. 120 species

Family	Taxon	Max Diam (cm)	Species Basal Area (m²)	Species Abundance	Relative Density	Relative Dominance	Relative Importance
ARECACEAE	*Wettinia maynensis*	14.4	2.70	114	11.7	7.5	9.6
SAPOTACEAE	*Chrysophyllum sanguineolentum*	59.5	3.28	45	4.6	9.1	6.9
FABACEAE	*Inga* (several species)	32.9	3.14	41	4.2	8.7	6.5
MYRISTICACEAE	*Osteophloeum platyspermum*	70.5	3.58	29	3.0	10.0	6.5
MORACEAE	*Pseudolmedia laevigata*	49.5	1.65	63	6.5	4.6	5.5
ARECACEAE	*Iriartea deltoidea*	21.1	1.23	59	6.1	3.4	4.7
ARECACEAE	*Euterpe precatoria*	21.6	0.95	63	6.5	2.6	4.6
BURSERACEAE	*Dacryodes* "condorensis" sp. nov.	48.8	1.06	20	2.1	3.0	2.5
(Various families)	(Standing dead trees)	44.2	0.98	22	2.3	2.7	2.5
MORACEAE	*Helicostylis tomentosa*	40.0	0.73	27	2.8	2.0	2.4
EUPHORBIACEAE	*Alchornea* (several species)	47.7	0.90	17	1.7	2.5	2.1
MELASTOMATACEAE	*Miconia* (several species)	36.9	0.53	27	2.8	1.5	2.1
MORACEAE	*Perebea xanthochyma*	38.1	0.65	22	2.3	1.8	2.0
EUPHORBIACEAE	*Hieronyma duquei*	42.5	0.89	14	1.4	2.5	2.0
HUMIRIACEAE	*Vantanea* sp. nov.	75.0	1.00	6	0.6	2.8	1.7
FABACEAE	*Tachigali* sp. nov.	54.6	0.75	12	1.2	2.1	1.7

Checklist of Bryophytes of the Cordillera del Cóndor

This preliminary checklist of the bryophytes of the Cordillera del Cóndor was compiled by Steven Churchill of Missouri Botanical Garden, who is the second Co-Principal Investigator on this project. The checklist is based on collections made by Churchill and his Ecuadorian field assistant, Edison Jaramillo, in October-November 2005, in addition to earlier collections from the Cóndor region by Elsa Toapanta, Carla Cole, and other bryologists, in the bryophyte collection of the National Herbarium of Ecuador (QCNE) in Quito.

MOSSES

BartramiaceaeBreutelia chrysea (Müll. Hal.) A. Jaeger
Leiomela bartramioides (Hook.) Paris
Philonotis hastata (Duby) Wijk & Margad.
Philonotis longiseta (Michx.) E. Britton
Philonotis uncinata (Schwägr.) Brid.

Brachytheciaceae
Meteoridium remotifolium (Müll. Hal.) Manuel
Squamidium leucotrichum (Taylor) Broth.
Squamidium livens (Schwägr.) Broth.
Zelometeorium patulum (Hedw.) Manuel

Bruchiaceae
Trematodon longicollis Michx.

Bryaceae
Bryum alpinum Huds. ex With.
Bryum renauldii Roll ex Renauld & Cardot

Calymperaceae
Syrrhopodon leprieurii Mont.
Syrrhopodon lycopodioides (Sw. ex Brid.) Müll. Hal.
Syrrhopodon prolifer var. *prolifer*
Syrrhopodon rigidus Hook. & Grev.

Dicranaceae
Campylopus lamellinervis (Müll. Hal.) Mitt.
Campylopus richardii Brid.
Campylopus weberbaueri Broth.
Dicranella hilariana (Mont.) Mitt.
Holomitrium antennatum Mitt.
Holomitrium arboreum Mitt.
Leucoloma serrulatum Brid.

Fissidentaceae
Fissidens asplenioides Hedw.
Fissidens scariosus Mitt.
Fissidens serratus Müll. Hal.

Funariaceae
Funaria calvescens Schwägr.

Hypnaceae
Ectropothecium leptochaeton (Schwägr.) W.R. Buck
Mittenothamnium reptans (Hedw.) Cardot
Rhacopilopsis trinitensis (Müll. Hal.) E. Britton & Dixon
Vesicularia vesicularis (Schwägr.) Broth.

Hypopterygiaceae
Hypopterygium tamarisci (Sw.) Brid. ex Müll. Hal.

Leucobryaceae
Leucobryum antillarum Schimp. ex Besch.
Leucobryum giganteum Müll. Hal.
Leucobryum martianum (Hornsch.) Hampe ex Müll. Hal.
Ochrobryum gardneri (Müll. Hal.) Mitt.

Macromitriaceae
Macromitrium …

Meteoriaceae
Meteorium deppei (Hornsch. ex Müll. Hal.) Mitt.
Toloxis imponderosa (Taylor) W.R. Buck
Trachypus bicolor var. *viridulus* (Mitt.) Zanten

Neckeraceae

Isodrepanium lentulum (Wilson) E. Britton
Neckeropsis undulata (Hedw.) Reichardt
Porotrichum filiferum Mitt.

Octoblepharaceae
Octoblepharum cocuiense Mitt.
Octoblepharum pulvinatum (Dozy & Molk.) Mitt.

Phyllogoniaceae
Phyllogonium fulgens (Hedw.) Brid.
Phyllogonium viscosum (P. Beauv.) Mitt.

Pilotrichaceae
Callicostella pallida (Hornsch.) Ångstr.
Cyclodictyon albicans (Hedw.) Kuntze
Hypnella diversifolia (Mitt.) A. Jaeger
Lepidopilum affine Müll. Hal.
Lepidopilum erectiusculum (Taylor) Mitt.
Lepidopilum scabrisetum (Schwägr.) Steere
Pilotrichum fendleri Müll. Hal.
Thamniopsis killipii (R.S. Williams) E.B. Bartram
Thamniopsis pendula (Hook.) M. Fleisch.
Thamniopsis undata (Hedw.) W.R. Buck

Polytrichaceae
Pogonatum tortile (Sw.) Brid.
Polytrichadelphus longisetus (Brid.) Mitt.
Polytrichadelphus sp.1 [margins ca. entire, orange/red spot absent]
Polytrichum juniperinum Hedw.
Steereobryon subulirostrum (Schimp. ex Besch.) G.L. Sm.

Pottiaceae
Barbula indica (Hook.) Spreng. var. *indica*
Barbula indica var. *gregaria* (Mitt.) R.H. Zander

Prionodontaceae
Prionodon densus (Sw. ex Hedw.) Müll. Hal.
Prionodon luteovirens (Taylor) Mitt.

Racopilaceae
Racopilum intermedium Hampe
Racopilum tomentosum (Hedw.) Brid.

Pterobryaceae
Pterobryon densum Hornsch.

Rhizogoniaceae
Pyrrhobryum spiniforme (Hedw.) Mitt.

Sematophyllaceae
Acroporium pungens (Hedw.) Broth.
Sematophyllum cucullatifolium (Hampe) Mitt.
Sematophyllum cf. *erythropodium* Mitt.
Sematophyllum subsimplex (Hedw.) Mitt.
Taxithelium planum (Brid.) Mitt.
Trichosteleum papillosum (Hornsch.) A. Jaeger

Sphagnaceae
Sphagnum magellanicum Brid.

Stereophyllaceae
Pilosium chlorophyllum (Hornsch.) Müll. Hal.

Thuidiaceae
Thuidium tomentosum Schimp.
Thuidium urceolatum Lorentz

HEPATICS

Balantiopsaceae
Isotachis multiceps (Lindenb. & Gottsche) Gottsche
Isotachis serrulata (Sw.) Gottsche

Calypogeiaceae
Mnioloma crenulatum (Bischl.) R.M. Schust. [Calypogeia]

Frullaniaceae

Geocalycaceae
Lophocolea

Herbertaceae

Jungermanniaceae
Anastrophyllum piligerum (Reinw., Blume & Nees) Steph.
Syzygiella concreta (Gottsche) Spruce

Lejeuneaceae
Bryopteris filicina (Sw.) Nees
Omphalanthus filiformis (Sw.) Nees

Lepidoziaceae
Bazzania hookeri (Lindenb.) Trevis.
Micropterygium trachyphyllum Reimers
Telaranea nematodes (Austin) M. Howe

Metzgeriaceae

Pallaviciniaceae
Pallavicinia lyellii (Hook.) Gray

Plagiochilaceae
Plagiochila spp. [4-5 species]

Radulaceae

Trichocoleaceae
Trichocolea paraphyllina (Spruce) Steph.

Environmental impacts and conservation issues in the Cordillera del Cóndor

The Hollín sandstone formation that underlies the plateaus or "*tepuis*" of the Cordillera del Cóndor is composed of nearly pure crystalline silica, and when the vegetation is removed, the sandstone gleams brilliantly white in the sun. In some places in the Cóndor region where the sandstone plateaus are close to roads, the rock is being mined for manufacture of glass, shipped by truck to factories in several Ecuadorian cities. The mining of silica destroys the unique vegetation of the sandstone plateau with its endemic species. While the impact has been limited so far to a few small areas, silica mining, if expanded significantly, could be a serious threat to the endemic plants of the Cordillera del Cóndor outside of the protected areas. Using Geographic Information System technology and satellite imagery along with his fieldwork, we have mapped the sandstone areas of the Cordillera del Cóndor and are working with the Ministry of Environment of Ecuador and several Ecuadorian non-governmental organizations, to help develop a comprehensive conservation plan for the entire Cóndor region.

In 2006, three new protected areas were declared by the Ministry of Environment in the Cóndor region, and the formally protected areas in the Ecuadorian part of the Cordillera del Cóndor now comprise more than 30,000 hectares. Except for the upper Río Nangaritza area, virtually all of the protected areas include only the sandstone plateaus. The western slopes of the Cordillera del Cóndor, with non-sandstone geological substrates and with vegetation types and floristic elements distinct from the sandstone plateaus, are almost all in private hands (although often without full

legal title to the land) and are rapidly being deforested by local residents, to extract timber and establish cattle pastures. Conservation of the western slopes of the Cóndor, if it is to succeed, will require initiatives of the private or non-governmental sector. One initiative is being made by the copper mining company, EcuaCorriente, that is developing plans for a large-scale open-pit copper mine an area of mineral-rich igneous rocks in the Río Quimi area. As compensation for the environmental impact of the copper mine, the company is planning to purchase and conserve an nearby area of intact forest that includes an altitudinal transect from the sandstone plateau summit at 2000 m elevation, down to the river valley bottom at 900 m, thereby protecting a full range of vegetation types on the western slopes of the Cóndor range.

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