Land Use Zoning based on a World Soils and Terrain Digital Database study to Conserve the Brazil-nut forests in Bolivia's Amazonia.

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ABSTRACT

Botanists have long recognized the western Amazon forests as the "center of origin" of Brazil-nut (Bertholletia Excelsa) and many other tree-crop species. As increasingly large areas of these forests in Bolivia's Amazonian Pando Department were being destroyed in the early 1990s for cattle ranching, a land resource study following the World Soils and Terrain Digital Database approach was commissioned to provide a basis for zoning the region to conserve the Brazil-nut forests. It was found that the soils of the Pando have low fertility levels and would be incapable of supporting forests were it not for the nutrient-cycling phenomenon. This finding was supported by the study of many representative soil profiles. Local experience confirmed that the forests of the region regenerate very slowly following clearing. The soils are patently unsuitable for agricultural "colonization". Complementary forest inventory studies confirmed that the forests often have very high concentrations of Brazil-nut trees and could support a more intensive extractive activity. In order to arrest the destruction of the native forests, a Regional Land Use Zoning map was drawn up in consultation with other specialists and local people. Unfortunately little attention has been paid to the latter to date, and forest clearing continues at an ever-accelerating pace. It is evident that the zoning recommendations must be implemented if one of the Amazon's biological treasure troves is to be conserved for the future benefit of mankind.

Zonificação de Uso de Terra baseado em um Estudo de Solos e Terrenos para Conservação de Florestas de Castanha na Amazônia Boliviana.

RESUMO

E bem reconhecido por cientistas botânicos que as florestas ocidentais da Amazônia são o "centro de origem" da castanha (Excelsa de Bertholletia) e de muitas outras espécies de árvores produtivas. Nos anos 90, um estudo dos recursos de solos e terrenos (utilizando a metodologia do World Soils and Terrain Digital Database) foi comissionado para fornecer uma base para a zonificação da região cujo objetivo era ajudar na preservação das florestas de castanha no Departamento. Verificou-se que os solos do Pando têm níveis baixos da fertilidade e seriam incapazes de acomodar florestas se não fosse pelo fenômeno da reciclagem de nutrientes que ocorre nessa região. Estes resultados foram obtidos pelo estudo de muitos perfis representativos dos solos da região. A experiência dos nativos da região confirmou que a regeneração de florestas é muito lenta após deforestamento. Os resultados também indicam que os solos não são apropriados para a "colonização" agrícola. Estudos complementares de inventários florestais confirmaram que as florestas freqüentemente têm concentrações muito elevadas de árvores de castanha e poderiam suportar uma atividade extrativa mais intensa. Para diminuir a destruição das florestas nativas, um mapa regional de zonifacação do uso da terra foi criado em consulta com outros especialistas e pessoas nativas da região. Infelizmente, pouca atenção foi dada ao mapa nos últimos anos e o deforestamento continua em um ritmo acelerado. As recomendações de zonificação feita nos anos 90 ainda são válidas e estas devem ser implementadas para diminuir o impacto de deforestmento nos recursos biológicos de uma das regiões mais valiosas da Amazônia Boliviana. Tal implementação contribuiria para geração de benefícios para o futuro da humanidade.

INTRODUCTION

Forests rich in Brazil-nut (Bertholletia excelsa) and rubber (Hevia brasiliensis) cover a large part of Bolivia's Amazonian Pando Department. This region which extends over about 6,319,000 ha, is an integral part of the "center of origin" of Brazil-nut, rubber, cacao (Theobroma cacao) and other tree species, of incalculable genetic value (Purseglove, 1968, Dias et al. 2003 and many other authors). Until relatively recent times, the forests of this region were virtually untouched in contrast with the neighboring Amazon territories of Brazil, where forest removal for pasture production has proceeded apace over the past forty-odd years. However, with the collapse of the Bolivian rubber tapping industry in the mid-1980s and the rapid build-up of demographic and migratory pressures following the construction of roads to connect the region with the highlands, felling for timber and forest clearing for cattle ranching has taken a serious toll of what was one of the most spectacular forest regions of south-western Amazonia (Cochrane, 1973). The senior author was impressed in the early 1970s by the fact that he often found native cacao growing in the forests well away from rivers on very poor soils and associated with high Brazil-nut tree populations; he stated bluntly that it would be a crime to fell and burn these forests which he likened to a tropical "Garden of Eden".

Between 1992 and 1994, in view of the then evident increasing rate of the destruction of the forests in the Pando, a Dutch Government financed land resource survey of the region was carried out to detail how the region might best be zoned to ensure its future prosperity (Cochrane et al. 1994a). Figure 1 locates the region of study.

[Insert Figure 1 about here]

The Pando Department extends from Peru in the west and is frontiered with Brazil to the north and east. To the south, and more so to the south-east, it merges with the wet-land Mojos savannas, locally called "pampas". Several major rivers dissect it. From the border with Peru in the west, the Madre de Dios river runs eastwards until it joins the northward flowing Beni river near the township of Riberalta. Further to the north, the Orthon with its major tributaries, the Madidi and Tahuamanu rivers, also flows approximately eastwards until it merges with the Beni river. Along the frontier with Brazil, first the Acre, and then the Abuna rivers channel eastwards. The latter meets the north running Mamore river, which merges with the Beni river a little north of the historic "rubber boom" township of Cachuela Esperanza, where rapids impede navigation. There are wide seasonal fluctuations in the volume of water flow in all these rivers, resulting in considerable differences in water levels. The latter are often in excess of 15m, with the consequent seasonal flooding of their younger alluvial deposits.

The land resource survey followed on from, and complemented an earlier World Bank sponsored project to study the Brazil-nut and rubber region of north-eastern Bolivia (Cochrane et al. 1992). It was considered that the sustained development of the Pando Department would be enhanced and its forest resources preserved and properly managed, through the preparation of a "Regional Land Use Zoning (LUZ), Map and Plan", and its subsequent implementation.

Previous Knowledge of the Region

The FAO-UNESCO Soil Map of the World (1971, 1974), indicates that the soils of the region are low fertility Ferralsols (Oxisols) and Acrisols (Ultisols), which support a fragile tropical forest ecosystem. A more detailed appraisal of the study region was carried out by Cochrane (1973), but without the aid of modern satellite imagery and remote sensing techniques. He found that many of the soils in the region were highly weathered and of low natural fertility. Further work using satellite imagery confirmed the earlier findings (Cochrane et al., 1985).

More recently, Cochrane et al. (1992), carried out a study of the land use potential of the Brazil-nut region of Northern Bolivia, following the provisional World Soils and Terrain Digital Database SOTER methodology as detailed by ISRIC (1991). This latter study delineated land units of the Pando Department and provided details of the inherently fragile nature of the soils of the region. It emphasized the very real hazards of indiscriminate land usage in terms of the medium and long term productivity and prosperity of the region.

Localized studies of limited areas of the region included the work of: Iriate et al. (1976) between Riberalta and Guayaramerin; Carrera (1976) near Riberalta; Sainz et al. (1984) in the vicinity of Porvenir in the Nicolas Suarez Province; Iporre (1984) in VacaDiez Province; Macias (1984) north of Chive near the border with Peru; Iporre (1985) in the vicinity of Santa Rosa de Abuna; Macias (1985) in the northern Ballivian Province; the

Servicio Nacional de Aerofotogrametria, SNA (1978) in north-western Pando; studies by C0NET (consultants, 1978a, b) in the Cobija-Puerto Heath region; CONSA and HARZA (consultants, 1983) in the immediate Puerto Heath region; and the study of Salm and Marconi eds. (1992) over the Manuripi -Heath National Amazonian Reserve.

It is of significance that not one of the foregoing studies identified any substantial areas of fertile soils that are not subjected to seasonal flooding and, or have poor drainage conditions. They paint a picture of inherently poor soils supporting fragile forest ecosystems dependent on the nutrient cycling phenomenon of tropical forests.

Objective

The objective of this report is to summarize and draw attention to the findings of the land resource study of the Pando Department of Bolivia, and specially the resultant Regional Land Use Zoning (LUZ), Map and Plan (Cochrane et al. 1994a). Unfortunately, to date very little if any attention has been paid to the recomendations of the latter and the destruction of the Brazil-nut forests continues at an ever-accelerating pace.

MATERIALS AND METHODS

The Pando land resource study followed the World Soils and Terrain Digital Database SOTER, methodology (ISRIC-FAO-UNESCO-ISSS, 1993), which was complemented with additional forestry and socio-economic studies. The SOTER methodology identifies and maps areas of land with "distinctive, often repetitive patterns of land form, lithology, surface form, slope, parent materials and soil". Effectively, SOTER Units delineate areas of similar landscape where the same type of farming or forestry management might succeed. Consequently their careful description is fundamental to land use planning and agrotechnology transfer. The mapping of the SOTER Units covered the region with an average precision approximating a scale of 1:500,000. The work was carried out as an integral part of the world-wide SOTER initiative. The methodology was similar to that summarized by Cochrane and Cochrane (2002, 2006) and the system was set up from the outset of the work.

The World Soils and Terrain Digital Database, SOTER.

Prior to the definitive delineation of the SOTER Units, the SOTER land resource database file set detailed in the SOTER procedures manual (FAO-ISRIC-UNEP-ISSS, 1993), was organized into a relational database management system RDBMS. The set of files was originally designed for use with dBase 4+, but with some minor modifications were transposed for use with Paradox 4+. These files can be imported into Microsoft Access and most other database management software. The database was in fact the first SOTER database to be setup up in the entire world in accordance with the 1993 standards.

The objective of the SOTER database file set, apart from standardizing the way land is described, is to transcribe the point soil profile data and in-field observations to a spatial basis in terms of land units, the larger of which may be mapped. Consequently, an additional file "PROF.GRP" (soil profile groups), was added to the SOTER database file set to group similar soils to facilitate the statistical analysis of the variation over an area of terrain of their attributes, especially their chemical and nutrient properties.

Architecture of the Computerized System

The architecture of the computerized system has been recorded by Cochrane et al. (1994b), and was basically similar to that since summarized by Cochrane and Cochrane (2002, 2006) in their work in Brazil's western Amazonian State of Rondonia. The system used inexpensive, commercially available software packages that are backed with strong support organizations providing regular updates and improvements to their programs. It permits the interlinkage of the relational database management of the SOTER file set with Geographic Information System GIS, software for map making, spatial analysis and satellite image interpretation, together with interlinkage with specialized forestry and other databases.

It should be emphasized that the design of the SOTER database file system is open-ended, and facilitates the integration of other types of databases including more detailed farming, forestry and socio-economic data. Soil profile data per se', was integrated with the system via the FAO-ISRIC Soil Database SDB2 Version (1991) software.

Agricultural climate studies

From the outset of the study an examination and analysis of the available meteorological data was made. In the past a considerable amount of climatic work had been carried out for the region by Hargreaves and his co-workers (Hargreaves, 1977; Hancock et al, 1979; Hargreaves et al, 1978); Cochrane et al. (1985) and Povoa (1988).

Meteorological data sets from 5 meteorological stations, Cobija, Guayaramerim, Puerto Maldonaldo (in neighboring Peru), Riberalta and Rurrenabaque were compiled as an integral part of the SOTER database. The data was analyzed following the approach of Hargreaves and his co-workers, and included monthly averages of: a) mean temperature in degrees Celsius, b) percentage of possible sunshine, c) mean solar radiation in Langleys per day, d) mean precipitation in mm, e) potential evapotranspiration PETH, in mm, f) precipitation deficit in mm, g) dependable precipitation at 75% probability level PD75 and h) Hargreaves'(1972), "Moisture Availability Index, MAI"; MAI = PD75/PETH. Hargreaves' methodology for calculating potential evapotranspiration was chosen as it gives a good correlation with the measured lysimeter data collected under the control of the American Society of Agricultural Engineers ASAE (Hargreaves, 1977, 1989).

Satellite imagery preparation and field work

Collateral with the climate studies, composite, geographically corrected satellite imagery, using bands 3, 4 and 5 of the Thematic Mapper (TM) 1:250,000 imagery was compiled for the region. This imagery was carefully examined, and an initial, very provisional delineation of the SOTER Units was drawn-up to help plan the field work.

Field studies were carried out to describe the region's terrain and soil characteristics, record representative soil profile descriptions and collect their horizon samples for laboratory analysis. Four major field expeditions were carried out during 1992 and three in 1993; these were complemented with several smaller expeditions. Aerial reconnaissance completed the task of examining the most inaccessible parts of the region, and helped with the extrapolation of the on-ground studies. The latter was carried out by the senior author piloting his Piper PA-18, Short Take off and Landing STOL, aircraft, specially adapted for aerial reconnaissance work. The more recent qualitative assessment of forest clearing in the region was also carried out using the same aircraft.

The major expeditions followed the regions of influence of the Beni, Acre, Orthon, and Madre de Dios rivers, and transected the region from west to east and north to south. Soils were studied and representative profiles recorded and sampled along many transects, mainly following exiting bush trails both by on foot and by motor cycles. Hand-carried Geographic Positing System GPS, equipment was used to locate the position of sample sites and the study transects, and to identify these on the satellite imagery.

Soil Analysis and the Soil Profile Database

The soil profile samples taken during the course of the field work were analyzed in the "Centro de Investigaciones en Agricultura Tropical - British Tropical Agricultural Mission (CIAT-BTAM)" soils laboratory in Santa Cruz, under the supervision of the senior author. The methodology used for the analysis is detailed by Cochrane and Barber (1993); it is comparable to that of the International Soil Reference and Information Center ISRIC (van Reeuwijk ed. 1987). The quality of the analyses in the CIAT-BTAM soils laboratory at the time they were carried out, was monitored bi-annually by the international system set-up by ISRIC for comparing soil analyses world-wide, and supported by the University of Wageningen, Holland and found to be satisfactory.

The soil profile descriptions were standardized according to the FAO guidelines (FAO, 1990a). Following field work and laboratory analyses, the descriptions of the soil profiles and their sample analyses were digitized using the FAO-ISRIC Soil (profile) Database program SDB2 Version (1991). This facilitated the storage, retrieval and examination of that data.

The Vegetation Database

The native vegetation of the region was described in terms of the physiognomic classes used by UNESCO (1973), with the modifications partly based on Eyre's (1968) descriptions for tropical forests, and partly according to the authors' examinations, as summarized in Table 1. An evaluation of the economic value of the forests was prepared as a complementary activity to the studies (ZONISIG, 1996-97).

[insert Table 1 about here]

Deforestation

During the course of the study, a quantitative assessment of the extent of forest clearing was recorded in the database. This was followed up in 2005 by the senior author who carried out an aerial reconnaissance of the Pando by flying his Piper PA-16 aircraft over a series of transects, to make a qualitative estimate of the expansion of forest clearing. Furthermore, recent work carried out by Steininger et al. (2000a, 2000b), Rojas et al.(2003), and satellite image interpretation carried out by the Museo Noel Kempf Mercado de Historia Natural in Santa Cruz, Bolivia, provide further quantification of recent forest clearings in Pando and specially around the capital city of Cobija.

Map Making, Digitization and the Report

With the successive completion of the climate studies, field work, the laboratory analysis of soil sample data, the vegetation work and the subsequent compilation and analysis of the SOTER database of the region, definitive SOTER Units and in some cases their subdivided “Terrain Components”, were delineated directly onto the 1:250,000 satellite imagery and digitized using Geographic Information System GIS, software. The IDRISI software developed by Eastman (1992) was chosen for this purpose; it was the GIS software being used by the United Nations Environmental Program UNEP, at the time of the study. Input of the mapped information into the IDRISI system was carried out using the IDRISI ancillary program TOSCA (Jones, 1991); the latter has long since been superseded by much more sophisticated programs. A small 12 inch digitizing tablet “Summasketch II”, was used for digitizing the SOTER Unit map. Once transferred to IDRISI, the mapped SOTER Units were subjected to the ample spatial analysis procedures of that system, and formed the basis for computer generated thematic maps. IDRISI provides for the export of map information in a variety of formats compatible with all the major GIS, commercially available software including Arc Info and ERDAS. In fact, several of the map files were subsequently prepared in those formats.

Thematic maps

The digitized SOTER Unit map facilitated the production of thematic maps, by assigning desired parameters to the Terrain Components. Where only a SOTER Unit could be mapped, this was assigned the principal property of its largest Terrain Component. The mapped units so classified, were grouped by the Geographic Information System GIS, software program to form the thematic map. It should be observed that the resulting maps are comparable to most thematic maps, including soil maps produced using more traditional methods, as the latter invariably represent generalizations caused by scale considerations. In examining and interpreting maps, scale limitations are often ignored.

Personal Computer (PC), Users Packet

The report on the land resources of the Pando Department, the many files that summarize the soils and terrain information gathered during the course of the survey work, together with the SOTER Unit map and a series of thematic map files, were recorded as an integral Personal Computer (PC), Users Packet. The latter was appended to the final hard copy report on the land resources of the region.

RESULTS AND DISCUSSION

The printed report on the region (Cochrane et al. 1994a), was complemented with a digital copy recorded in Microsoft Word format together with the Personal Computer PC Users' packet. The latter was organized into three sections: Section 1, SOTER database files; Section 2, IDRISI map files and Section 3, FAO-ISRIC SDB2 (soil profile) database. The vegetation and other data were compiled as separate but interconnectable files. This enabled the speedy compilation of accurate statistical information about climate, landscapes, soils, vegetation and land use. The SOTER Unit map that was delineated on the satellite image maps at the scale of 1:250,000, was recorded in Section 2 along with the Regional Land Use Map and a series of thematic maps. Details of the PC User's packet have been summarized by Cochrane et al. (1994b); it provides easy access to all information recorded and analyzed for the convenience of future investigations.

Agricultural Climate

Analysis of the meteorological data supported the findings of Cochrane et al. (1985) that the major determinant of the climate of this area of the Amazon is the seasonal migratory movements of the low pressure Equatorial Trough EqT, often referred to as the Inter-tropical Convergence Zone. The position of the EqT follows the seasonal march of the sun, but lags behind by about 2 months. During the southern hemisphere summer a continental heat low pressure zone develops over northern Argentina, Paraguay, and southern Bolivia which influences the EqT movement, and results in high instability and heavy rains throughout the region in the December to March period.

In contrast with the warm northerly air masses, invasions of cold polar air masses are common during the drier winter months and produce marked and rapid drops in temperature as the cold front passes northward. These cool winds, referred to as "surazos" in Bolivia, may last from 3 to 8 days or, in exceptional cases, up to 15 days. Temperatures may drop to as low as 6 degrees Centigrade in a matter of a few hours. The passage of the cold front is often accompanied by rain squalls and marked atmospheric turbulence, especially during the April to August period.

The seasons

Hargreaves (1972) formulated the “Moisture Adequacy Index (MAI), at the 75% probability level of precipitation occurrence” to identify dry and wet seasons based on soil water adequacies. He showed that there is a good relationship between MAI and crop production when soil moisture is adequate for a week or more and recommended a MAI level "less than 0.34" to define a dry month. Conversely, a wet month is defined as one with a MAI greater than 0.33, bearing in mind that this level may be too low for soils with very low moisture-holding capacities. The MAI indices show that the region has a distinct dry season, ranging from 3 to 5 months; the dry season is more pronounced in the eastern part of the region. Annual rainfall distribution is higher in the western sector of the region, about 1,800mm, and grades to about 1,600mm in the east.

There is little doubt that the seasonal characteristic of the climate would facilitate the nutrient cycling phenomenon of these forests, with the rapid decomposition and incorporation of dry leaf litter into the soil with the start of the rainy season. Further, the “nitrogen flush” effect (Hardy, 1946; Cochrane and Souza, 1985), would facilitate the adequate movement of nutrients to the root zone of the forest vegetation, apart from supplying nitrogen per se’.

Land form, Lithology and Hydrology

The region is essentially a dissected plains area. To the west it was found to be slightly higher, with a median altitude a little in excess of 150m; Quaternary fluvial sandstone-mud stone mixed and often compacted sediments overlie Tertiary mixed sediments (Leyton and Pacheco, 1989). These appear to have been uplifted in relatively recent times, and subjected to more intensive natural erosion, resulting in strong peneplanation and significant areas of small hills. The higher formation gradually and unevenly slopes towards the east. About midway across the region, median altitudes fall to less than 150m; here the lithology is probably almost exclusively of Quaternary fluvial origin, and peneplanation much less pronounced.

There is an evident relationship between the direction of flow of the major rivers of the region, and its over-all geology and land-form. The northward flow of the Beni and Mamore rivers approximately coincides with the influence of the Brazilian Pre-Cambrian shield formation (Ahlfeld and Branisa, 1960), which underlies the Quaternary fluvial sediments of the eastern segment of the region. Protuberances of the Brazilian Shield, including small hills formed from granites and gneiss, may be seen near Cachuela Esperanza and northwards to the border with Brazil. The rapids along the Beni and Mamore rivers from Cachuela Esperanza northwards, are a direct consequence of the Shield formation, and indicate the shallowness of the formation along the border region with Brazil. Extensive areas of low-lying, seasonally water-logged lands are found in this area, possibly reflecting the underlying influence of impermeable Shield materials, although more probably a result of the effect of the Shield in "damming" surface and ground water flows.

To emphasize the diversity of the lands of the region, a landscape map was generated by subdividing the land-form map according to overall soil drainage conditions and native forest versus savanna vegetative cover, Figure 2. It was seen that significant proportion of the region has soil drainage problems in addition to the generally recognized flooding problems; a third of the land surface is affected by these two problems.

[insert Figure 2 about here]

Soils

During the course of the field work, over 360 soil profiles were dug, examined and samples collected for subsequent laboratory analyses. The information was stored in the database. The final database consisted of over 400 soil profile descriptions and their analyses, 40 of which were recorded from previous studies. Figure 3 illustrates the location of these samples.

[Insert Figure 3 about here]

Following analyses, the soils of the Pando Department were mapped and classified according to both the FAO-UNESCO revised legend (1990b), and the United States Department of Agriculture's Soil Taxonomy classification (1987). It was found that 82% of the soils classify as Ferrasols or Lixisols according to the FAO system and 58 %, classify as Oxisols and 24% as Ultisols, according to Soil Taxonomy. This indicates that the majority of the soils of the region are highly weathered and poorly supplied with plant nutrients.

It may be observed that in contrast with traditional soil mapping, the SOTER methodology facilitates a much more in-depth examination of soils and their properties. The subdivision and description of SOTER Units into “Terrain Components” and the latter in terms of soil units bridges the gap between the mapped SOTER Units and soils.

Soil Physical Characteristics

The examination of soils according to their physical properties facilitate the evaluation of their susceptibility to erosion and their suitability for agricultural and tree crop production from a physical standpoint. It was found that over 30% of the region is covered by steeply sloping lands that are very susceptible to erosion; only their existing forest cover protects these lands from severe soil loss. In fact, many of the hilly lands are doubly susceptible to erosion, as their soils have a distinct textural change. These are Ultisols with light textured topsoil horizons over heavier textured subsoil horizons. Even on relatively gentle sloping sites, those soils are susceptible to erosion, as may be witnessed by the many eroded areas of lands cleared of their forests for cattle production in the vicinity of Cobija. Apart from erosion hazard, in the words of the late F. Hardy (Pers. comm. with senior author, 1960), it is necessary to study the "root room" of a soil, or its many other physical characteristics as a plant growth environment. This was carried out during the in-field examination of the soil profiles.

Soil drainage and flooding problems

From the database it was estimated that approximately 32%, or 2,024,000 ha of the region is covered by soils that are either poorly drained and, or, are subject to annual flooding. In fact, 825,700 ha of the non-flooded soils have drainage problems, as seen on the landscape map of the region, Figure 2. The latter problem is area specific and predominates in several SOTER units. Clearly the magnitude of the flooding and especially the soil drainage problems imposes a severe limitation on land usage throughout the region.

Soil moisture holding capacities

The soil textural characteristics of the region have been recorded in the database. Although a lesser proportion of the region, approximately 34%, has light textured soils or soils with lighter textured topsoils, it should be noted that the heavier (clay) textured soils have high Al-Fe sesquioxide levels which reduces their capacity to withhold soil moisture, and so they tend to act more like light textured soils in this respect (Cochrane et al. 1985).

Coarse soil materials

Hardened plinthite or laterite was seen occasionally, generally in geomorphically predictable positions in the landscape, particularly on the edges of the peneplains. It was found that only a few of the SOTER Units contain shallow soils where plinthite, and or hardened plinthite may be a serious limiting factor to plant growth. The problem was prevalent in the minor area of savanna soils. A more common problem with the soils of the region, is the presence of gravel size laterite particles and, or Fe-Mn concretionary materials which would make cultivation difficult.

Soil Chemical Characteristics

Soil analyses were carried out on most of the profile samples collected during the field expeditions; a lesser amount of analyses have been recorded in the literature. This data was summarized as database files in Section 1, SOTER files of the PC User's packet, and in Section 3 of the same packet as an integral part of the FAO-ISRIC SDB2 Version Soil (profile) Database. While the soil chemical properties varied between the SOTER Units, these were more marked between the well drained and the poorly drained and, or seasonally flooded soils.

The Fertility of the Flat, Well-drained Lands fFree From Flooding

The following is a brief overview of the major soil chemical properties affecting plant nutrition, or the "fertility", of the non-flooded, adequately drained, flattish (less than 8% slopes), lands of the region, which might be considered for possible agricultural and, or pastoral production, according to their physical characteristics. Lands so defined, cover approx. 52% of the total study area or 3,308,762 ha out of the total area of the department, of approx. 6,318,900 ha. The information has been drawn from the SOTER database, and is summarized in Table 2.

[insert Table 2 about here]

Soil acidity or pH

About 79% of the topsoils and 70% of the subsoils have low pH levels (less than 5.4, regarded as strong acid conditions), which could affect the availability of some essential plant elements, and would provide the necessary soil solution environment for Al toxicity problems (Cochrane et al., 1980).

Carbon levels

As indicated by Table 2, the carbon (C), levels, which are used to indicate soil organic matter contents, are in the medium range in the topsoils but very low in the subsoils. The soil organic matter levels are intimately linked to soil fertility and evidence the nutrient cycling phenomenon of the forest lands.

Phosphorus

The available phosphorus (P), levels of the topsoils are predominantly in the lower medium range, and unlikely to sustain crop growth for any length of time with deforestation.

Exchangeable cations; calcium, magnesium, potassium and sodium

With the exception of the very low sodium levels, the topsoils have exchangeable cation levels in the medium to low range. Subsoil levels are low; levels follow the organic matter pattern, which indicates that soil fertility is largely dependent on the carbon cycle of the forest cover.

Effective cation exchange capacity

The effective cation exchange capacity of the soils, even of their topsoils are predominantly low; 70% are rated as low. This follows as they have been formed in strongly weathered parent materials; they have an inferior capacity to hold and supply nutrients for crop growth. Anion exchange capacity levels were not measured for these soils, although it is likely that such could play an important role in the retention of plant nutrients, especially with respect to nitrogen cycling. (Cochrane and Souza, 1985).

Aluminum toxicity

Table 2 shows that 70% of the topsoils and 77% of the subsoils of these lands have high percent aluminum Al, saturation levels of their effective cation exchange capacities. As most of the soils have low pH levels (less than 5.4, a condition permitting the solution of toxic Al hydroxides), they have potentially toxic conditions for many of the higher yielding tropical crops with low tolerances to high soil Al levels. Very substantial applications of lime (1 to several tons per ha) would be needed to overcome this condition for many tropical crops (Cochrane et al. 1980).

Other plant nutrients

Sulphur and trace element analyses were not carried out. However, it is probable that sulphur levels follow the organic matter levels, and that deficiencies could develop following deforestation. Further, it is quite possible that trace element deficiencies including zinc and possibly boron could occur in these soils.

Native Vegetation

The native vegetation of the region was described in terms of the physiognomic classes used by UNESCO (1973), with the modifications as shown in Table 1. The location of the several major formations illustrated by Figure 4. The evaluation of the economic value of the forests was prepared as an essential complementary activity of the studies (ZONISIG, 1996).

[Insert Figure 4 about here]

Tropical Semi-evergreen Seasonal Forests predominate through the region, with hydroseres found as inclusions on poorly drained or flooded lands. The forests on the well drained lands have emergents forming an open upper story canopy that ranges from 35 to 50m in height, depending on the specific land areas. Many of these emergents loose their leaves during the latter part of the wet season (August -September). In terms of non-timber products, it was seen that it is rich source of both Brazil nuts and rubber, which curiously, are often seen growing virtually side by side. Native cacao is also common, especially in the more western parts of the region.

An interesting finding from the complementary forestry inventory studies was that there was a much higher proportion of Brazil-nut tress in these forests than previously thought. Brazil-nut tree populations in some areas of the forests were the highest recorded for the Amazon as a whole (ZONISIG, 1996). This finding indicated that much less than half of the Brazil-nuts of the region were being harvested. The latter activity could readily be expanded.

Savannas

Some minor areas of mainly poorly drained savanna lands are found in the south-eastern areas of the region, about 19,000ha in all. The boundary between the forests and savannas is quite abrupt, with transitions occurring over distances of 100-200m or less, which reflect the radical changes in both soil physical and sometimes chemical conditions, as seen elsewhere in the sub-continent (Cochrane, 1989).

Deforestation

Deforestation, especially in the vicinity of Cobija, has increased dramatically in recent years. Between 1986 and 1990, satellite imagery showed that the area cleared in the vicinity of Cobija alone, increased by 56%; 27,680 ha to 43,080 ha (Cochrane et al. 1994a). Throughout the region as a whole, it was estimated that over 50,000ha of this once majestic forest had been cleared for cattle ranching by 1990 and over 80,000ha seriously degraded by timber extraction and other activities.

The 2005 aerial inspection of the region by the senior author indicated that forest clearing is accelerating fast; many more hectares of forest have either been completely cleared or seriously degraded since the early 1990s. As a rough estimate, at least 200,000ha of the forests have now been cleared for cattle raising and twice as much again seriously degraded by timber extraction in the region of Cobija, the capital of the

Department. Figure 5 illustrates the expansion of anthropogenic areas in the north western part of Pando satellite interpretations presented by Killeen et al. (2007 under review).

[insert Figure 5 about here]

It may be noted that the rate of deforestation in all Bolivia has increased from approximately 50,000 hectares per year in the 1960’s to over 200,000 hectares per year in the 1990’s (Steininger et al. 2000a, 2000b, and Rojas et al. 2003). In the Pando department, deforestation rates were approximately 10,000 ha per year from 1991 to 2001. Based on aerial observations in 2005, the rate of deforestation appears to have increased substantially.

Land Use

The use of the land as seen in 1992 was classified for the region according to the SOTER Land Use Classes, which were adapted from Remmelzwaal (1990). From an analysis of the database it was seen that 5,042,600 ha, were being used for Brazil-nut collection and rubber tapping with varying degrees of selective felling for the extraction of timber. Of this area 3,643,961 ha were being used for Brazil-nut collection. The remainder was used virtually solely for rubber tapping in the past; with the collapse in the price of natural rubber in the mid 1980s, only a small amount of the rubber in the region was being tapped. Further, it was evident from the ancillary forest inventory work (ZONISIG-DHV-ITC, 1996, 1997), that only a lesser part of the total Brazil-nut production of the forests was being collected.

Other minor uses of the land include: extensive ranching on the natural pampas found in the south-east sector of the region (19,000 ha), some slightly more intensive ranching mainly in the vicinity of Cobija (about 51,000 ha), shifting agriculture for local food supplies (approximately 116,000 ha affected throughout the department, about 66% of which is reverting back to forests at varies stages of regeneration), and a more extensive area of lands suitable only for hunting and fishing. Figure 6 illustrates the land use of the Pando.

[insert Figure 6 about here]

Land Use Zoning

A Land Use Zoning LUZ, map Figure 7, together with a report was prepared as an integral part of the land resource study (Cochrane et al. 1994a), to guide the rational use of the natural resources of the Pando Department and the conservation of its forest resources. The land use zones were defined and delineated as a result of interdisciplinary findings and discussions with the foresters who carried out the forestry inventory work, sociologists, economists and local authorities. They demarcate land use categories that would lead to the sustained development of the region in an environmentally, ecologically sound manner. The zones take into account what is possible with regard to land use and forest management in the light of their land resources and socio-economic circumstances. The objective was to provide a framework for the development of the region without destroying its unique Amazonian Brazl-nut forests.

[insert Figure 7 about here]

As shown on the Land Use Zoning map, eight land use zones were delineated:

1. Settlement areas

The survey indicated that the soil resources of the department, although varied, are generally poor and have severe limitations for agricultural usage. Consequently, the choice of settlement areas for agricultural activities were qualified from the outset by emphasizing that these have been delineated for non-intensive agricultural systems, and only as a response to the sociological realities of the recent migration movements within the region toward its capital city, Cobija. Clearing the forests lands for ranching has led to degraded and unproductive pasture lands. Burnt Brazil-nut trees standing alone in eroded pastures barely supporting one head of cattle per 5 to 8ha, is a typical current scenario. In fact, one Brazil-nut tree surviving in a pasture near Cobija, was found to have a diameter of 210cm at chest level, and although severely damaged by fire, was still producing nuts as seen by Photo Plate 1.

[insert Photo Plate 1 about here]

The areas zoned for settlement were not designated for "colonization" by people from the highlands of Bolivia or elsewhere. Agricultural colonies invariably expand and the resultant land clearing would only speed the destruction of the natural resources of the Pando. Much better soil resources exist in other parts of the country for colonization (Cochrane 1973).

2. Extensive ranching on native savannas

Minor areas of natural wetland savannas mosaic with the forested lands in the south-eastern quadrant of the region and were zoned for extensive ranching. Local experience shows that the native pastures of these lands support about one head of cattle per 7 to 10ha.

3. Native forest reserves for flora

The area zoned as a native forest reserve for the conservation of native flora covers an area with a very low rural population. It includes the major physiognomic forest types of the region that range from low to tall semi-evergreen seasonal to almost evergreen forests, along with their hydroseres.

Although relatively little is known about these forests, they may well prove to be invaluable in the years to come in terms of their genetic diversity within species. It is very interesting to see Brazil-nut trees, rubber and native cacao growing in close proximity one to another on some of the soils of the several SOTER units of the zone. These remote forests are an original part of the “center of origin” of the latter trees and probably many other species. They are unique to western Amazonia, and should be preserved for future generations. Settlement and lumber extraction should be completely prohibited.

4. Native forest reserves for fauna

Two areas were chosen as forest reserves for fauna, where hunting for animals should be prohibited:

a) An area in the north-eastern Pando department which is difficult to penetrate due to seasonal flooding or semi-flooding of a high proportion of its landscape which covers approximately 281,000ha. This area is virtually unpopulated by human beings, mainly because of its poorly drained soils. From all accounts it has a high feline and reptilian population together with a rich diversity of many other animal species, not only on the ground and in its streams but also living in or on its forest cover including monkeys and birds (Rumiz & Aguilar 2001). The area should also be treated as a floristic reserve, especially for palms and water tolerant plant species.

b) An area of 115,000ha in the north-western corner of the Pando department which is hilly and would otherwise be categorized as a critical watershed region. This area has been zoned primarily as a non-human primate reserve, as it is the natural habitat of at least one rare species of monkey that could easily become extinct if care is not taken for its preservation.

Soil-wise, the area is inherently poor, mainly consisting of nutrient-poor Ultisols, which would be subject to a severe water erosion hazard should its forest cover be removed. Consequently, it is axiomatic that no timber removal should take place in the region.

5. Extractive reserves

Over 43% of the area, 2,745,000ha, has been zoned for extractive activities that cause a minimum of damage to the forest ecosystem. Selective extractive activities, but under more closely managed or supervised conditions, are also envisaged for Zones 3, 6, 7 and 8, giving a total of approximately 5,994,000ha in all.

Areas with significant, but still relatively sparse rural populations have been zoned in this land use category. They are found on different landscapes throughout the region, but their soils are uniformly poor. Ferralsols (Oxisols and Ultisols) predominate that have low pHs (mean topsoil pH 5.0); these are poorly supplied with plant nutrients and have high exchangeable aluminum levels (mean topsoil level = 2.0 cmol(+)/kg. Topsoil organic matter levels are moderate (mean topsoil C% = 1.09), and are intimately linked to the little fertility the soils have which is dependent on the forest-soil carbon cycle. Indiscriminate forest removal on these lands, and in fact over most of the region, can only lead to massive soil water erosion and, or soil chemical degradation, as has already occurred in the Cobija region where lands have been cleared for ranching.

The forests covering the zone are seres (intergrades) of tropical semi-evergreen seasonal forests with varying heights and botanical characteristics; however most are naturally endowed with Brazil-nut, rubber and tropical hardwood trees. Properly cared for, they could provide the existing rural population with a reasonable standard of living.

6. Managed forest reserves

An area of approximately 486,000ha along the northern Bolivian border with Brazil, which represents various landscapes found in the region including hills, high peneplains and low peneplains with a complex of soil-forest combinations, was zoned as a reserve for managed forests. The zone is sparsely populated and relatively untouched in-so-far-as timber extraction is concerned. It is currently used for Brazil-nut collection and some rubber tapping. The forests have distinct floristic variations, and are representative of many of the northern forests.

7. Critical watersheds, hilly areas

The hilly area along the eastern portion of the northern border of Pando, which covers approximately 512,000ha, has been zoned as a critical watershed area. The hills of the region are not high, 200 - 250m median elevation, but are characterized by their steep slopes. They have been dissected from their original elevated plane surfaces by natural geological erosion processes over a long time. Ferralsols, mainly Ultisols and some Oxisols, predominate in the region; the Ultisols are highly susceptible to erosion. Soil degradation by water erosion, with its dire consequence of silting up local rivers, can only be avoided by maintaining the present forest cover on these lands.

8. Critical watershed, flooded areas

Most of the alluvial lands along the extensive river systems of the region are subject to severe annual floods, and are quite unsuitable for close settlement. A few minor areas can be found of higher lands not affected, or rarely affected by floods. Hydrologically speaking, the existing flood plains provide expansion zones to ameliorate peak flow rates of rivers, and the flood forest cover of such plays a critical role in reducing water erosion. Without such mechanisms, existing townships sited in riberine areas, would simply be washed away.

SUMMARY AND CONCLUSIONS

Like all previous studies, the survey did not identify any substantial areas of land that could be considered as being "inherently fertile" and suitable for agricultural and, or agro-pastoral purposes. Although it was estimated that 52% of the region has soils with slopes less than 8% that are neither flooded nor poorly drained, this statistic does not take to account other physical let alone nutrient limitations. The analytical data shows that almost all of the latter soils have poor and fragile fertility states. Apart from low nutrient and pH levels, many have potentially severe aluminium toxicity problems. The little fertility they have is intimately linked to the carbon cycle of the forest cover, which has been built up over many years. In short, the findings indicate that forest removal can only lead to the rapid degradation of these lands, as is evident in the Cobija region where lands are being cleared for ranching, as shown on Photo Plate 1. Colonization for agricultural and, or agro-pastoral activities, can only lead to an ever-accelerating pattern of land degradation.

Up until the early 1990s, about 80,000ha of the Pando department, had already been affected by land clearing. Unfortunately deforestation has increased substantially in recent years. The typical forest sound in many parts of the region is no longer the whistle of the "seringeiro" (rubber tapper) birds or the early morning chattering of monkeys, but the high-pitched whine of chain saws.

A World Heritage

The Land Use Zoning LUZ, Map (Figure 7) was drawn up in 1994 on the basis of the research on the soil and forest resources of the Pando Department, to provide a guide for land usage. The region was zoned to take advantage of its native forests for its development. Unfortunately to date, little has been achieved by the local authorities to implement the recommendations of the study.

Fortunately, although deforestation is proceeding at an ever-accelerating pace throughout the region, there is still a high proportion of the native forests physiognomically intact. The areas zoned as natural reserves can still be regarded as areas for the preservation of the region’s typical flora and fauna. These are some of the last remaining relatively intact remnants of the "center of origin" of many of Amazonia’s natural forest trees including Brazil-nuts, rubber and cacao to be found in the southern Amazon. Their unique biodiversity and genetic resources should be preserved as a biological treasure trove for humanity and further forest clearing prohibited. Only responsible conservation measures based on the effective use and preservation of the forests will ensure the future prosperity of the region.

It is in the urgent interest of both Bolivians and the world conservation community as a whole, to see the proper establishment and maintenance of the zoned natural reserves for the preservation of the flora and fauna of the southern Amazon. Serious thought should be given to the creation a “World Heritage Area” for the conservation of these unique forests, for the enjoyment and enlightenment of present and future generations.

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TABLE 1. Regional Native Vegetation Classes. - SOTER Classes Adapted from UNESCO (1973).

FOREST VEGETATION		
Code	**Description**	**Area in ha.**
IA2E	Tropical semi-evergreen seasonal forest, 50-100% of emergents dry season deciduous	
Forests on well drained, non-flooded soils:		
IA2ET	as IA2E, but tall: emergents over 40 m.	1,021,400
IA2EM	as IA2E, but medium: emergents 30 - 40 m.	3,265,400
IA2EL	as IA2E, but low: emergents less than 30 m.	
Forests on imperfectly drained or flooded soils:		
IA2EMG	as IA2E, but medium, drainage imperfect	130,700
IA2ELG	as IA2E, but low, drainage imperfect	569,700
IA2ELH	as IA2E, but low, drainage poor	204,800
IA2EMF	as IA2E, but medium, annually flooded	444,000
IA2ELF	as IA2E, but low, annually flooded	84,800
IAS	Swamp forests: low with graminoid species	579,500
SAVANNA VEGETATION		
Code	**Description**	**Area in ha.**
VB6	Poorly drained savannas	18,600
Total Remaining Native Vegetation:		6,240,000

Note. All estimates include areas taken up by rivers, lagoons and swamps.

TABLE 2. Chemical Properties of the 3,308,782 ha of the Flat, Well-drained, Non-flooded Soils covering the Region.

Property	**Percentages of defined area**		
pH	**Low < 5.4**	**Med 5.4 - 6.5**	**High > 6.5**
topsoil	79	21	0
subsoil	70	30	0
Carbon	**Low < 0.6%**	**Med 0.6 - 3%**	**High > 3%**
topsoil	4	96	0
subsoil	79	21	0
Phosphorus (Olsen)	**Low < 3ppm**	**Med 3 - 6ppm**	**High > 6ppm**
topsoil	48	52	0
subsoil	94	6	0
(Exchangeable cations, cmol(+)/kg)			
Calcium:	**Low < 0.4**	**Med 0.4 – 4**	**High > 4**
topsoil	26	74	0
subsoil	67	33	0
Magnesium:	**Low < 0.2**	**Med 0.2 - 0.8**	**High > 0.8**
topsoil	18	68	14
subsoil	28	76	6
Potasium:	**Low < 0.15**	**Med 0.15- 0.3**	**High > 0.15**
topsoil	32	57	11
subsoil	79	10	11
Sodium:	**Low < 0.1**	**> 0.1**	
topsoil	72	28	
subsoil	78	22	
Aluminium:	**Low < 1**	**Med 1 - 1.5**	**High > 1.5**
topsoil	22	27	51
subsoil	21	20	59
ECEC:	**Low < 4**	**Med 4 - 10**	**High > 10**
topsoil	70	30	0
subsoil	77	23	0
Al Sat. >55% of ECEC: Topsoil 51% Subsoil 70% of area			

Figure Legends

Figure 1. The Amazonian Pando department in northern Bolivia.

Figure 2. Landscape map of Pando showing significant areas with poor soil drainage and flooding problems. (note UTM zone 19S coordinates in metres)

Figure 3. Soil profile survery sampling points in and around Pando plotted over SOTER units.

Figure 4. Native vegetation of Pando as described in terms of the physiognomic classes used by UNESCO (1973) shown in Table 1.

Figure 5. Deforestation around Cobija, the capital city of the Pando, before 1992 and up to 2001, according to satellite image interpretations conducted by the Museo Noel Kempff Mercado de Historia Natural, Santa Cruz, Bolivia.

Figure 6. The use of the land as seen in 1992 and classified for the region according to the SOTER Land Use Classes.

Figure 7. The Land Use Zoning map for the Pando Department of Bolivia

Photo Plate

Photo Plate 1. A solitary Brazilnut tree (2m diameter) in land cleared for cattle ranching near the city of Cobija.

Figure 1. The location of the Amazonian Pando department of northern Bolivia.

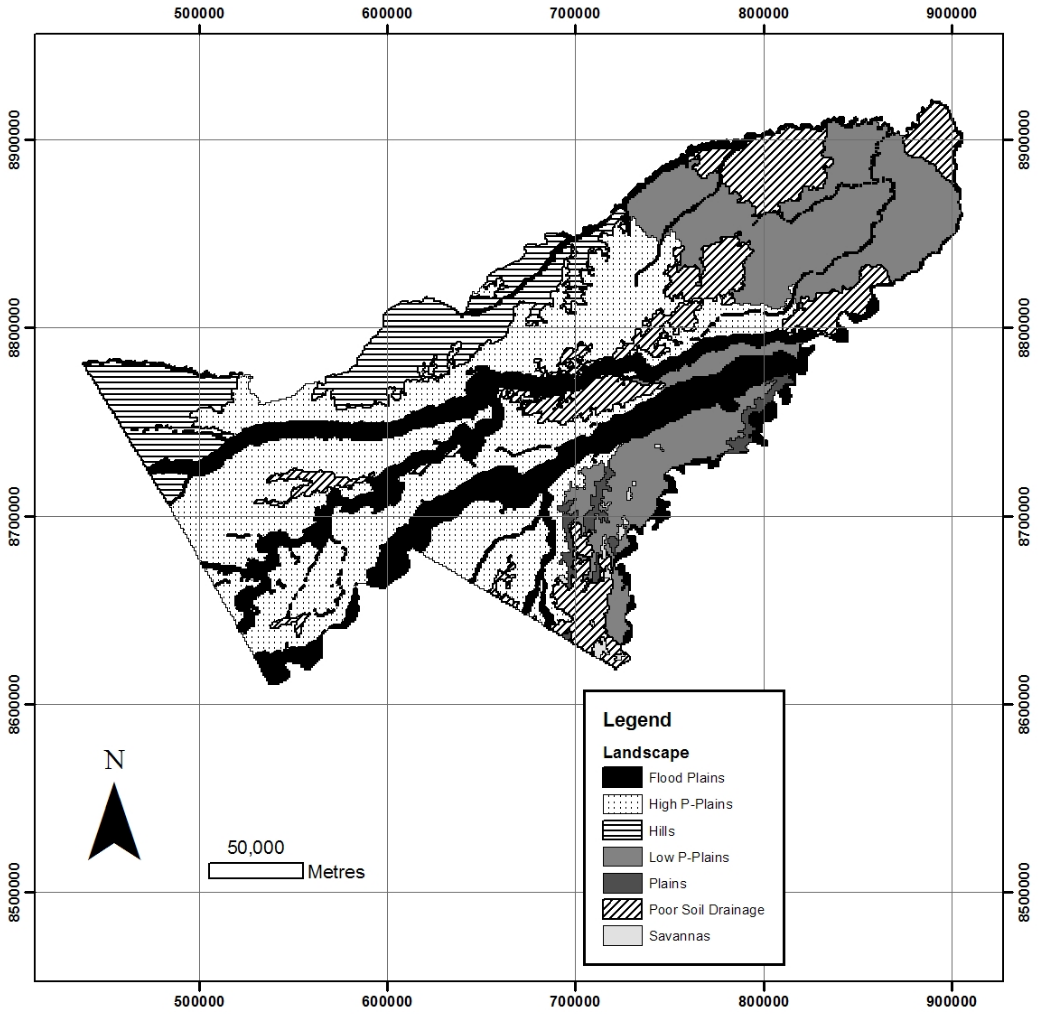

Figure 2. Landscape map of the Pando showing significant areas with poor soil drainage and flooding problems (note: UTM zone 19S coordinates in metres).

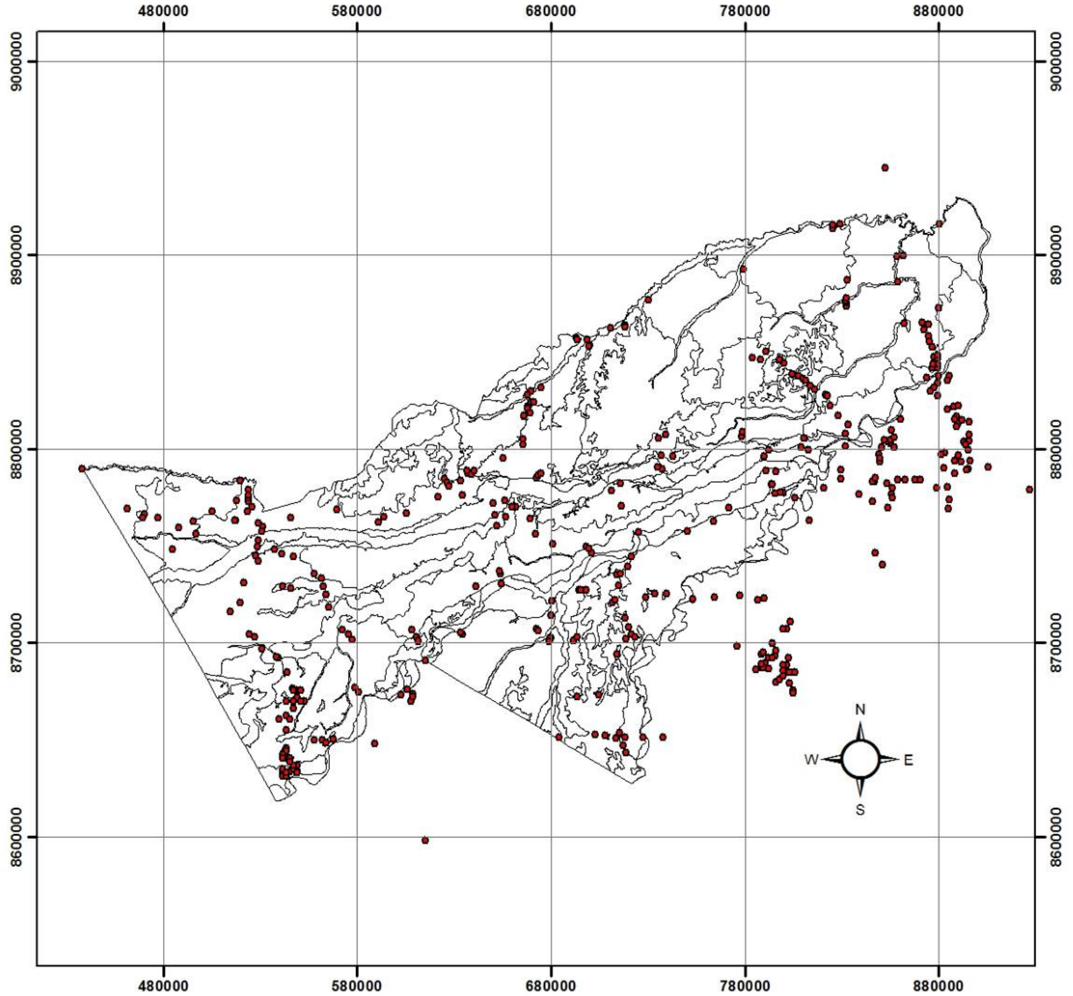

Figure 3. Soil profile survery sampling points in and around Pando plotted over SOTER units.

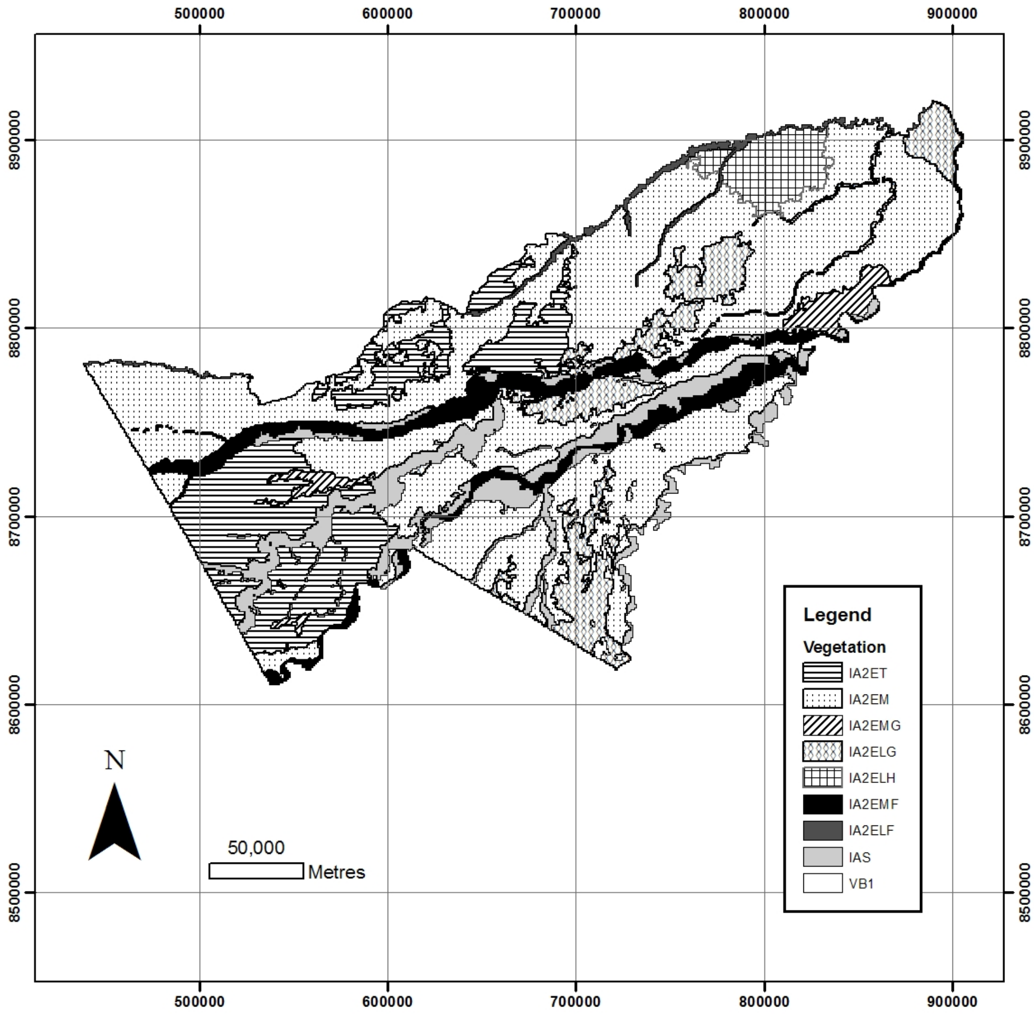

Figure 4. Native vegetation of the Pando as described in terms of the physiognomic classes used by UNESCO (1973) shown in Table 1.

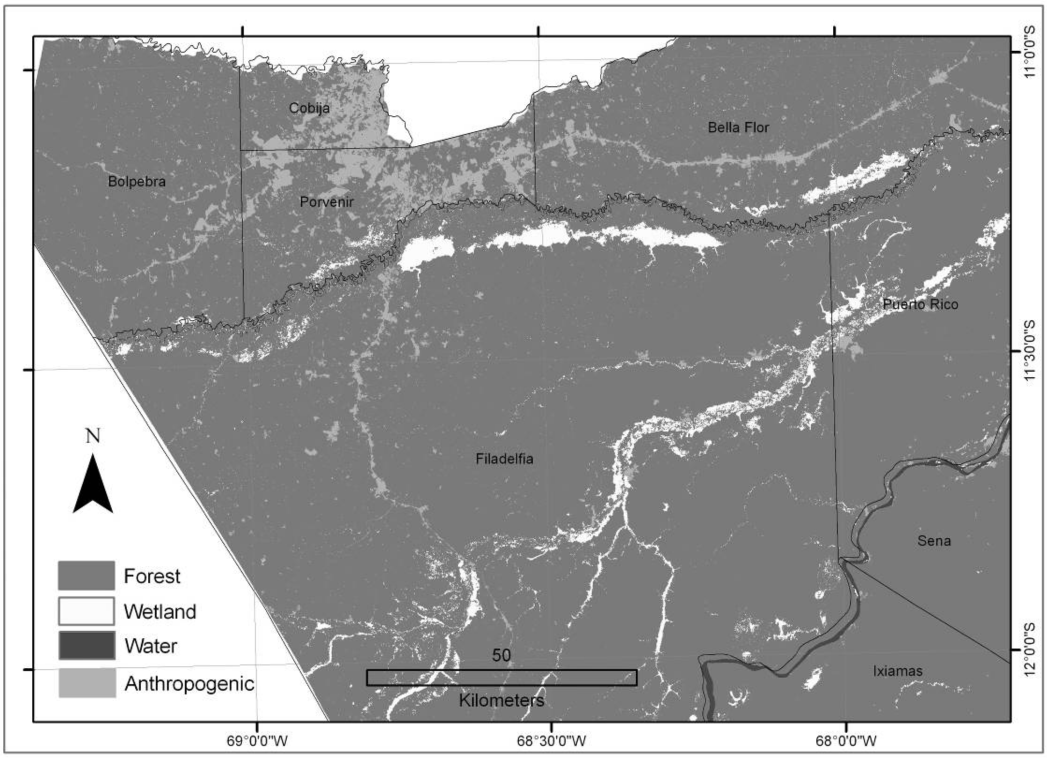

Figure 5. Map of the north western part of Pando showing extent of Anthropogenic areas up to 2005 according to Killeen, et al. (2007 under review).

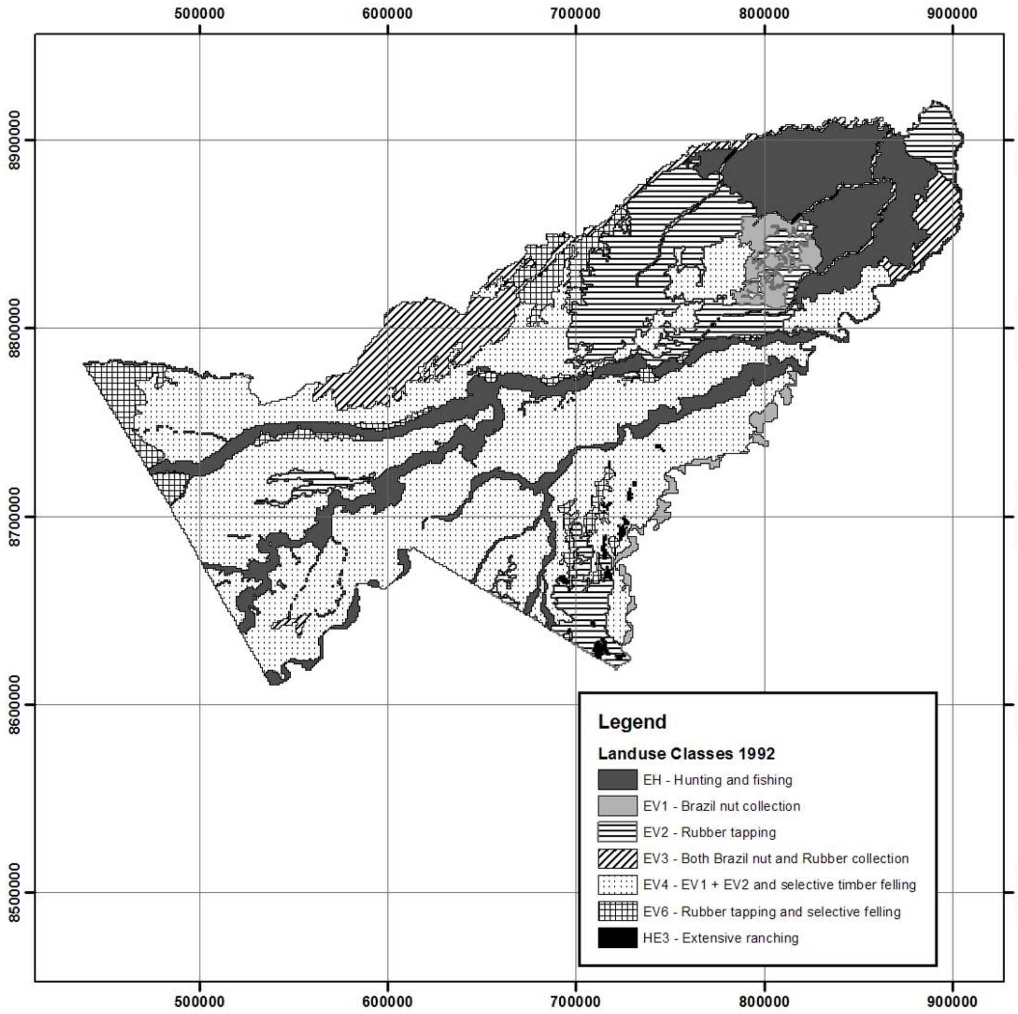

Figure 6. The use of the land as seen in 1992 and classified for the region according to the SOTER Land Use Classes.

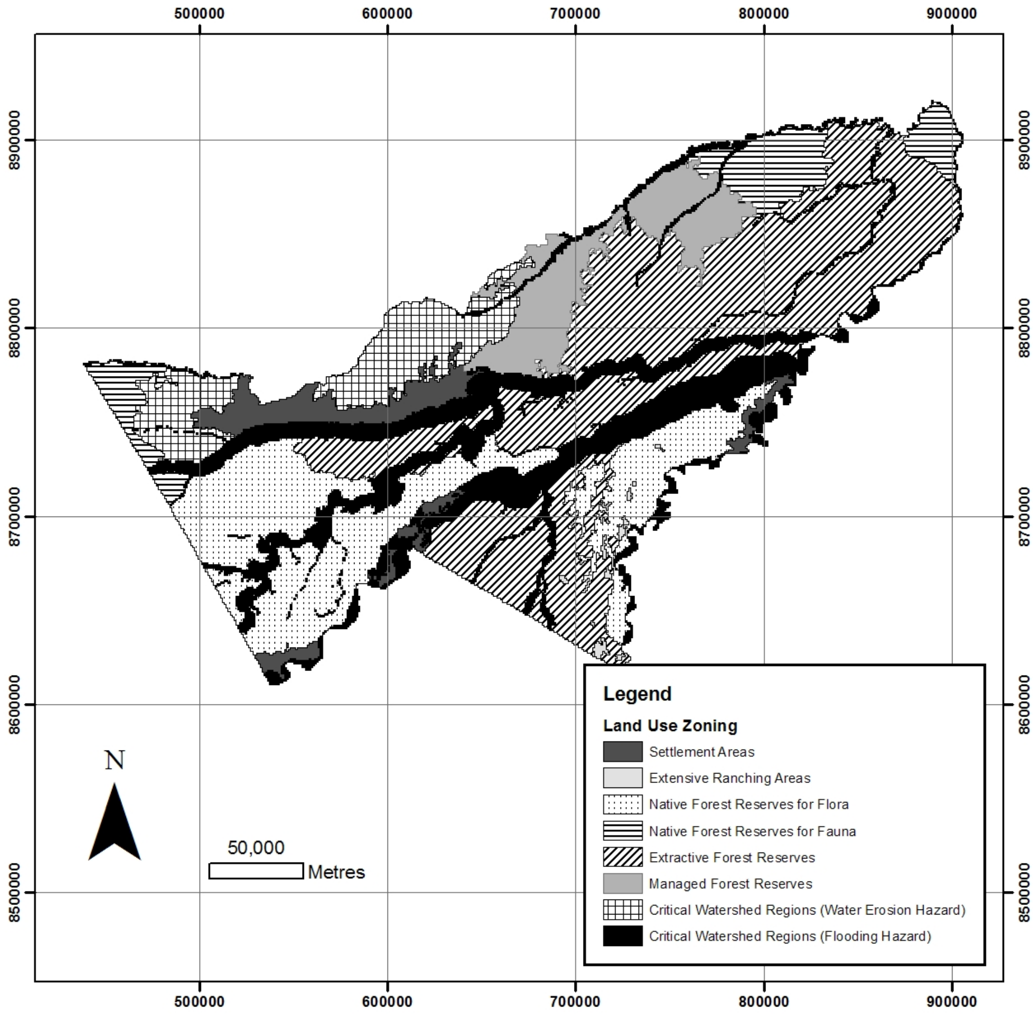

Figure 7. The Land Use Zoning map for the Pando Department of Bolivia.

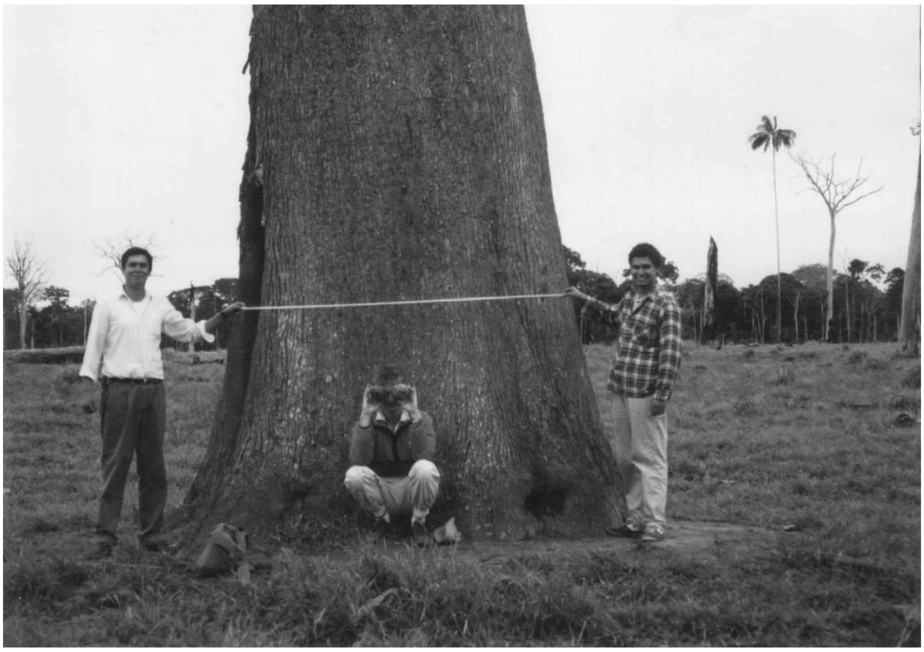

Photo Plate 1. A solitary Brazilnut tree (2m diameter) in land cleared for cattle ranching near the city of Cobija.