LAND UNIT SURVEY OF THE PESCADO RIVER AREA

NW ARGENTINA

(including maps in scale 1: 68.000)

by

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February 1989

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This thesis is produced as a partial fulfillment of the requirements of the Master of Science degree in Rural and Land Ecology Survey at the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.

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This study was sponsored by the Consejo Nacional de Investigaciones Científicas y Técnicas de Argentina (CONICET).

To Cristina,
my family and
family in law.

ABSTRACT

Zuviría, M. de, 1989: Land unit survey of the Pescado river area, NW Argentina. M.Sc thesis, International Institute for Aerospace Survey and Earth Sciences (ITC),Enschede: 108 pages, 25 tables, 87 references, 22 appendices (including 5 maps 1: 68.000, 1 Landsat TM FCC image, 1 Landsat TM thermography, 1 stereogram and 8 photos), English abstract.

The land survey of an area of 176 km2 located in NW Argentina with potential climatic suitability for coffee was carried out following the land unit approach.

Geomorphology, geology (stratigraphy and lithology), topoclimate (temperature, precipitation, solar radiation, water balance, catabatic flux and Landsat TM thermal data), soil and land cover data (floristic composition and aerial cover per layer) were analyzed by means of remote sensing and field data and a classification for each of these land attributes was performed.

These information was used to elaborate through the ILWIS Geo-Information System the land unit map 1:68.000 of the study area and also a terrain (including drainage) and floristic community map of the area were obtained at the same scale.

On basis of the land ecological information the land suitability for coffee was determined following the FAO framework.

ACKNOWLEDGEMENTS

I wish to express my thanks to all those who contributed to the completion of this study. Special mention is made of the following.

Prof. Dr. Izak S. Zonneveld (ITC), Chairman of the Board, for his general advise during the whole study.

Dr. Hein van Gils (ITC), Supervisor, for his help before and during the fieldwork, for the carefull correction of this thesis and for his general guidance.

Prof.Dr. Karl F. Schreiber, External Examiner, University of Muenster, West Germany, for his general advise and support of this study.

Dr. Willem van Wijngaarden (ITC), for his help in the analysis of the vegetation data.

Dr. Domingo Jakúlica (Salta, Argentina), for his assistance during the fieldwork and his help in the identification of rock types found within the study area.

Dr. Eduardo F. Gallardo and other members of the geological team of Yacimientos Petrolíferos Fiscales (YPF), Province of Salta Division, for their help in the identification of parent materials and in some practical aspects of fieldwork.

Ir. Sikke A. Hempenius (ITC), for his advise on thermal data acquisition.

Dr. Massimo Menenti, ICW, Wageningen, for his help in thermal data analysis.

Mr. Robinson Ruiz,for his practical suggestions on cartographic aspects of the study.

Agr. Eng.Hugo Villota (IGAC, Colombia), for his help in the interpretation of the aerial photographs and in the design of the cross section of the terrain.

Agr. Eng. Juan J. Burgos and Dr. Osvaldo F. Canziani, Director and Sub-Director, respectively, of the Centro de Investigaciones Biometeorológicas (CIBIOM) del CONICET of Buenos Aires, Argentina, for their help in the preparation of the research proposal and support of this study.

Ph.D. Carlos Valenzuela, for his help during the mapping stage through ILWIS and general advise.

Lic. Dante J. Bedendo (INTA, Argentina), for his help in the soil classification.

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CHAPTER 1: INTRODUCTION

1.1 Research objectives and location of the area of study

The main objective of the study was to carry out the semi-detailed land ecological survey by means of field and remote sensing data of an area of 176 km2, located in the north of the Province of Salta, in the extreme NW of the Argentine Republic, between 22°37′ and 22°42′S, and 64°27′ and 64°37′W bounding with the Bolivian Republic and including part of the course of the Pescado river (Appendix A).

The area was chosen for its potential climatic suitability for coffee (Burgos, Cagliolo and Santos, 1951; Küper and Camargo, 1977; Zuviría, 1986) and previous studies on their topoclimate were carried out (Zuviría & Burgos, 1986; Zuviría, 1987)aiming to assess different methods for delineating free-frost areas. It was concluded in the last study that the density of Ficus maroma, a tree species abundant in the study area, gives the best indication on topoclimate but no floristic studies were done.

The analysis of the land ecological, including geomorphological, geological (stratigraphy and lithology), topoclimatological, hydrological, edaphic and land cover data was carried out following the land unit approach (Zonneveld, 1979). These results provided the necessary data base for the land suitability for coffee evaluation, done according to FAO (1977; 1984).

1.2 Description of the area of study

The area forms part of the mountain chains called "Sierras y Estribaciones Subandinas" (CNRB,1973) while the altitude ranges between 450 and 1850 m and the rainfall fluctuates between 1000 and more than 2000 mm/year (Bianchi,1981),

The climate of the zone can be classified as humid mesothermal without or with little water deficiency (Burgos and Vidal,1951), but one should be aware of the fact that in the area of study at short distances strong variations of the main climatic parameters in relation with the topography occur frequently (CNRB,1973; Zuviría and Burgos,1986).

The main land cover is a thick forest called "Selva montana"(Cabrera,1976; Hueck, 1981) and the most representative tree-species are Ficus maroma, Inga marginata, Phoebe porphyria, Rhamnus polymorphus, Cedrela angustifolia and Blepharocalyx gigantea. Even when the most valuable tree timber species have been taken from the area close to the road, (Appendix V, photo 1) most of the surface remains under the (semi-)natural forest type.This can be explained by the fact that the area is almost uninhabited, due to reasons of a socio-economical character (land tenure, deficient infrastructure, government policies, etc), and therefore, only small patches with coffee, horticulture and maize were found within the study zone. The area was formerly inhabited by natives according to the artifacts found by Dr. Jakúlica close to the Pescado river, but their culture is still under study.

1.3 Data base

Terrain and vegetation features were analyzed on the basis of the previous reports (CNRB, 1973; Serraiotto, 1977; Méndez et al,1979; CCHRB, 1980), cartographic data (topographic chart scale 1: 20.000, CARTA), and topoclimate studies (Zuviría & Burgos, 1986; Zuviría, 1987), and through the interpretation of 10 black and white air photos at a scale of about 1: 70.000 (IGM, 3A-206:9606-7, 3A-208:9558-61, 3A-210: 9547-50, taken in August 1966) covering the whole area of study, and with the aid of 17 others of low quality at a scale of 1: 20.000 (CARTA, August 1966), partially covering the area of interest, and one LANDSAT 5 TM CCT (path 231,row 76, quadrant 2, taken on 25 July 1986 at 09:45 AM).

C H A P T E R 2: M E T H O D S

2.1 Introduction

The survey was carried out following the 'land-unit approach' (Zonneveld,1979,Ch.V, and 1988b,Ch.29; Gils, 1981), aiming primarily at the understanding of the landscape as a integrated entity.

Main characteristics of the approach are:

-the emphasis on the use of aerial photographs and/or other remote sensing imagery.

-using aerial photographs and / or other remote sensing products before the actual fieldwork, thus providing a base for a sampling strategy;

-its 'holistic' nature, i.e. the land is considered to be a fully integrated (holistic) entity, that can and should be studied as a whole.

Not all literature cited may be generally available in Argentina. Researchers there, dealing with similar projects may be interested in the methods used in this survey. The next section (2.2) gives therefore an outline of the procedure followed. As for the topoclimate part of the survey, a more detailed description of methods is given separately (section 2.3).

2.2 Description of the survey procedure in steps

The following description is derived from Zonneveld (1979 & 1988a and b). To the general paraphrase of each step annotations are added, dealing specifically with the present study.

a. Study of reference material

General and local literature, topographical charts and existing vegetation, soils, geology and topoclimate maps were studied. This step was continued throughout the survey.

References to the most important literature on the area and the existing maps are given in the other chapters, dealing with specific aspects of the areas's landscape. Two bibliographies of value for any student of the area are CNRB (1973) and CCHRB (1980).

b. First glance to the aerial photographs

This action was done in order to establish a rough subdivision of the area into major units, to become familiar with the photo-features and to compile the preliminary photo-interpretation legend.

For this study, two sets of aerial photographs and one Landsat TM CCT were available. All of them were taken in winter season (dry season) and are refered in section 1.3.

c. Preliminary field inspection

Since the author had been in the study area carrying out other surveys using the refered aerial photographs, this step was not necessary for this study.

d. Preliminary photo-interpretation

Photo-features were studied and linked to land-features and areas with relevant similarities in photo/land-features were delineated. This step resulted in the preliminary 'photo-interpretation map' with its legend defined in terms of photo-features with a hypothetical relation to land-features.Photo-features analyzed include tone, texture, shape, size, spatial pattern and location.

In this case,the procedure began by drawing the topographic base map in scale 1: 20.000 on the basis of a photocopy of the topographic chart at the same scale, taking an equi-distance among contour lines of 50 m (the original one was 10 m). Then the analysis began with the tracing of the drainage and water divides in the base map and photographs 1: 70.000 and 1: 20.000, and continued with the delineation in the photographs of the preliminary 'terrain-units'. Then, this information was transfered to a photo-reduction of the topo-graphic base map and the preliminary terrain map in scale 1: 50.000 was obtained. For this, the features used were: drainage pattern (density and type), shape and size (height, internal relief and slope steepness were specially considered). In addition to this, a false colour composite Landsat TM image (refered in 1.3) 1: 75.000 was obtained by combining bands 4,5 and 2, and was used as an aid for mapping the preliminary 'terrain units'.

The photo-interpretation led to the preliminary 'terrain map' and not to the preliminary 'land-unit' map because of the fact that vegetation boundaries could not be depicted in the aerial photographs at any scale.Even when it was possible to distinguish in some spots in the photographs 1: 20.000 the location of Ficus maroma,a tree species abundant in the study area, their distribution could not be mapped due to the low quality of these photographs, the general homogeneity of the vegetation and the shadow's hiding effect.

The topoclimatic analysis of the catabatic fluxes was done following the methodology proposed by Enders (1979) and applied on a pilot area in the study one (Zuviría and Burgos, 1986). Cold air fluxes were estimated for each preliminary 'terrain-unit' (see section 2.3).

Digital values of the Landsat CCT available for this study (refered in 1.3) were calculated for all bands within each preliminary 'terrain unit' and digital data or 'intensity levels' of the thermal channel (band 6) were classified with the ERDAS system following the 'bitslicing' methodology (Hem-penius, 1985) aiming to obtain surface temperature values of different preliminary 'terrain units'. Temperature values (T) and their standard deviation were calculated from band 6 'intensity levels' (L) for each preliminary 'terrain unit' by using the calibration formula given by Anuta (1984) for Landsat 4:

$$T\ (°C) = -12{,}5809 + 0{,}2917\ L - 0{,}000233\ L^2$$

According to Hempenius (1985), it is likely that the 'intensity level to temperature' conversion of the band 6 sensor of Landsat 5 TM can be done with the formula given for Landsat 4 TM. A pseudocolour photographic product of band 6 was obtained in scale 1: 75.000 for making a visual interpretatation of the temperature differences found within the study area.

Then, the fieldwork sampling strategy was selected and the sample points were located in the aerial photographs. The number of sample points depends on several factors such as internal variation of the 'preliminary units', time, funds and (most of all) the quality of the preliminary photo-interpretation (Zonneveld, 1988b). In this case, it was decided to describe 96 sample points. Due to time constraints and the need of a higher density of sample points in units of higher internal complexity, the stratified clustered preferential strategy was chosen for distributing the samples in the area (Zonneveld et al,1988c). No sample points were located within the floodplain of the Bermejo and Pescado river (terrain unit A1) due to their nule usefulness for coffee or any other crop.

e. Fieldwork

The fieldwork was carried out between June and August 1988. It comprised sampling in the spots selected on the basis of the preliminary map, literature searching and gathering of additional information through contact with local experts. A field guide was employed who proved to be very skilfull in orientating in the field and was extremely proficient in recognizing tree and shrub species.

'Sampling', i.e. the description of the various aspects of the landscape, the so-called 'land attributes' (geology, terrain, soil, vegetation and land use; Zonneveld, 1979) was done using 'ITC relevé sheets' for the data recording (Appendix K). Due to the fact that within the tropical forest under study no floristic types had already been distinguished and considering that the possibilities of finding a field guide able to recognize at least the woody species seemed to be scarce in the beginning of the survey,structural/physiognomic survey methodologies were analyzed (Küchler, 1988) and as a result a pro-forma designed by Webb, Tracey & Williams (1976) was brought to the field for selecting on the spot the vegetation attributes to be described. Finally, as a field guide able to recognize most of the woody species was available the floristic approach was carried out using, as mentioned, ITC relevé sheets.

Due to accessibility problems, the location of some points was changed in the field, and the final number of samples was reduced to 67 mainly due to the difficulty of finding an appropiate field-guide for a longer period. In Appendix C the location of the sample points are given.

The attributes of the landscape described in the field were vegetation, soil, lithology and terrain, each requiring its own approach.

As for vegetation, a 'plot' was described at each sample point.Emphasize was putted in selecting a plot as homogeneous as possible regarding its terrain characteristics and large enough to contain a reasonable reflection of its floristic composition. The size of the plots was 500 m2 while the shape was rectangular (20m x 25m). Both parameters were selected following the guidelines given by Matteucci and Colma (1982, Ch.2), Gauch (1975, Ch.2) and Zonneveld and Küchler (1988b, Ch.5).

Within each plot floristic composition and vegetation structure were described systematically. As for structure, cover of five layers and litter was estimated in percentage. The height limits of each layer were established on base of the observations done during the field inspection carried out in the first two days and taking into account the height limits of the different strata mentioned by Meyer (1963) and Cabrera (1976) for the forest under study. However, after ten relevés it was decided to modify the chosen height limits and it was considered better to do not use these first ten relevés for the further structure analysis, not only because of the different height limits of the layers but also due to the scarce field experience of the author in estimating aerial cover in the field. The final height limits of the five layers and the name given to each layer are presented in table 1.

Table 1: Height limits and name of the vegetation layers

LAYER	HEIGHT (m)	NAME
1	> 18	high tree layer
2	8 - 18	low tree layer
3	3,5 - 8	high shrub layer
4	1,5 - 3,5	low shrub layer
5	0,1 - 1,5	herb layer

The density of the following 'special growth-forms' (Küchler, 1988, Ch.4A) was estimated in each plot: bamboos, climbers (lianas), epiphytic bryoids (epiphytic lichens and mosses), epiphytes (only flowering plants) and ferns.

As for the floristics, all shrubby and tree species found within the plots were identified (a list of them is given in Appendix O) with the help of the key and species description given by Digilio and Legname (1966) and Legname (1982) for NW Argentina, but most of the none woody species were not identified. For the tree and tree-like species, the density of each species was taken (as number of individuals per plot with a diameter at brest height over 4cm), and for the few other ones a combined scale of cover/density recommended by Zonneveld (1988b,Ch.5) was used (table 2). For practical reasons (e.g. to allow computer processing) the density values per plot were reduced to a 9 point scale as indicated in the species-to-relevé matrix (table 15).

Table 2: Combined scale of cover/abundance
(from Zonneveld, 1988b,Ch.5)

r	Cover	<	5%	rare
p	"	<	5%	few
a	"	<	5%	rather numerous (abundant)
m	"	<	5%	numerous (many)
1	"	approximately	10%	(number irrelevant)
2	"	"	20%	(" ")
3	"	"	30%	(" ")
etc				

As for the study of soils, pH, texture and colour of the various horizons, effective depth (= depth up to which it was possible to auger) and surface stoniness were described systematically according to FAO (1977). Soil data were collected augering up to 1,00 m depth. Systematic data on erosional features like soil accumulation behind trees and existence and type of gullies, terracettes and landslides were taken. The topographic position was indicated and altitude, slope type, steepness and exposure were measured. Rock samples were taken of all the units to be identified by Dr. Jakúlica.

f. Data classification and data correlation

For each land attribute, a classification system was worked out. Landform and lithology were integrated in an existing terrain typification (Villota, 1983). Soils were tentatively classified at the suborder level according to USDA (Soil Survey Staff, 1975; ISM, 1983) on base of the auger survey. A definitive classification could not be performed due to the lack of modal profiles descriptions and analytical data. Soil main suborders were used to characterize terrain units (Appendix M). Soil parameters measured in the field were ranged into arbitrary categories.

The vegetation was classified in two ways: according to its structure and floristic composition.

The structure classification was performed by clustering the relevés according to their recorded values of aerial cover per layer (Gils & Wijngaarden, 1984;Ellenberg & Müller-Dombois, 1974) with the aid of the PADI and MAINFLEX computer programs.

The floristic classification was done by grouping the floristic data of all plots by means of a 'species-to-sample plot matrix' (a statistical matrix method in which data is manipulated by hand or by computer) (Jongman, 1987) aiming to isolate groups of species that show similar distributions among the relevés under comparison (='socio-logical', 'ecological' or 'socio-ecological' groups) and also to isolate those relevés that have similar species composition (='vegetation types' or 'communities') by placing them side by side in the matrix.This procedure is one of the keystones of the French - Swiss approach of vegetation description (Müller-Dombois & Ellenberg, 1974, Ch.9) and its final result is the 'classified species-to-relevé matrix' on which sociological plant species groups and plant communities, as well as some environmental variables, are indicated. Most of the mentioned manipulations were done by computer, using the PADI, QUICKTAB and MAINFLEX programs, but it has to be stated that the outcome (i.e.the classified species-to-relevé matrix) was strongly influenced by the decisions taken by the author during the execution of the program.

In the beginning, the statistical ordering of data was done, without using any guiding principle. Then, as after adding to the heading of the species-to-relevé matrix values of some environmental parameters became clear that altitude and slope exposure were correlated with the floristic vegetation types, these were taken into account for deciding the final location of those relevés with a doubtful position between two floristic types.

Floristic vegetation types are described as 'plant communities' (Zonneveld, 1988b) even when, however, few species others than tree or tree-like were included on the relevés. This could limit up to some extent the strict validity of the 'communities' here obtained. The idea behind defining 'communities' is that they give, in general, a more consistent indication of the environment than individual species (Zonneveld, op.cit) being therefore more suitable for characterizing the land ecological.

The relationships among terrain units, soil parameters (pH, texture and colour of top horizon, surface stoniness and effective depth), altitude, slope exposure and steepness, vegetation floristics and structure were analyzed matching this information in tables and matrices.

An additional analysis of vegetation-environment relationships was also performed by canonical correspondence analysis (CANOCO program), a computer analysis technique in which the ordination axes are constrained to be linear combinations of environmental variables (Ter Braak,1987; Jongman, Ter Braak & Tongeren, 1987, Ch.5).

Deciduousness was analyzed per community and structural type because of its obvious ecological significance as an adaptation to seasonal drought (Eiten, 1968; Küchler, 1988, Ch.4A). Only two categories were selected: evergreen and deciduous, the last one including the various irregular forms of deciduousness. The number of species and number of woody individuals per relevé were also analyzed per community and structural type in tables (Appendices P and R).

Colour combinations in scale 1: 75.000 of different bands of the Landsat TM scene available for this study were obtained. After comparing them, the bands 4,5,7 false colour composite (FCC) image was selected to be included in this report (Appendix G) instead of the bands 4, 5, 2 FCC image previously obtained (mentioned in step d), for showing up better than all others not only the terrain characteristics, but also some vegetation differences.

Temperature values obtained from Landsat TM band 6 were analyzed in relation with terrain parameters and vegetation structure. General principles on thermographies were taken from Sabins (1987), Lillesand & Kiefer (1987) and Menenti et al (1986).

Topoclimates were analyzed in relation with terrain units and vegetation communities. Some methodological aspects of the topoclimate survey are given in section 2.3.

Finally, the 'annotated map' (a photo-interpretation map on which at each sample point the structural and floristic classification symbols were indicated; Zonneveld,1988b) was produced.

g. Final terrain map

In this step, a re-interpretation of the photographs and other imagery was done and the final terrain map with its legend was built up. In this case, the original photo-interpretation lines were slightly modified, but the field information on vegetation proved to be very useful for the further characterization of 'land-units' (step h).

h. Drawing of the final land-unit map

In this study,the 'land-unit' map (Appendix G) was obtained by taking the boundaries of the terrain map and overlying them with the vegetation communities boundaries, depicted by taking contour lines and slope exposures, as resulting from the analysis of communities-environment relationships. This procedure was done by using the ILWIS software (Meijerink et al, 1987 and 1988). Also the terrain (including drainage), vegetation,topography and relevés location maps were obtained through ILWIS (Appendices B, C, D and F). The information on vegetation structure was matched with the land-units and used for their characterization.

The procedure followed at ILWIS began by digitizing (that is, determining X and Y coordinates values of points, lines or areas depicted in maps) the topographic and terrain maps, drainage lines and water divides, roads and relevé location. Then, editing operations for verifying the digital data against the original maps and subsequently correction of error were done, and the original data were transformed from vector to raster format. After that, the mentioned thematic maps were obtained and, finally, the land-unit map was produced as mentioned and the surface occupied by each unit was estimated using the 'Crosstable' program (Appendix U).

i. Coffee suitability evaluation

In this step each 'land-unit' was linked to specific coffee requirements and the 'coffee suitability cross table' was produced. For this, land-units were evaluated according to FAO (1976 and 1984) and León & Forero (1982) taking the vegetation communities and catabatic flux as indicating climatic conditions and slope steepness in relation with erosion hazard as the relevant land qualities.

j. Reporting and reproduction

2.3 Topoclimatic survey methods

The variations of the relevant climatic parameters of the area of interest were previously studied (Zuviría & Burgos, 1986 and Zuviría, 1987).

In the first study, a laboratory methodology partially based on Enders (1979) was adaptated and implemented for this data-scarce area. From the analysis of topography and the measured climatic data, the monthly mean temperature for different elevations was calculated, global solar radiation, annual precipitation and cold air drainage charts were elaborated and the monthly water balances were estimated at different points.

In the second study, the validity of the mentioned methodology was assessed. For this, daily minimum and maximum temperature was measured in eleven stations installed in the area of study for two weeks in the winter. As these values include also the frost registered on July 22, 1986, a comparison was made between the minimum temperature expected according to the model and the recorded values. In addition to this, the distribution of Ficus maroma, an indicative species of frost absence or low frequency (Ibarguren,1979; Jakúlica,1983), was analyzed as well as its relationship with the recorded temperature values.

As both studies were published in spanish, some references will be given in relation with particular methodological aspects of them.

The calculation of the monthly average air temperature at different altitudes was done following the methodology developed by De Fina & Sabella (1959) for areas with scarce meteorological data. Temperature records were available from Orán (357 m), Aguas Blancas (405 m), Alarache (1000 m), Balapuca (615 m), Arasayal (570 m) and Colonia Santa Rosa (320 m) (Appendix A).

The annual rainfall presented a close correlation with the altitude and a regression formula was supplied for calculating the rainfall at different altitudes within the study area. The values received by sloping surfaces were calculated by multiplying the rainfall on a flat surface by the cosine of the sloping angle.

The solar global radiation was estimated using the model proposed by Klein (1977) for tilted surfaces. The declination was estimated as suggested by Kondratyev (1969) and an average atmospheric transmission coefficient of 0,5 was taken according to Alanís et al (1976).

The calculation of the monthly water balance of flat surfaces located at different altitudes was done according to Thornthwaite & Mather (1955), taking a water holding capacity of 150 mm,as suggested by Küper & Camargo (1977) for the area of study. The potential evapotranspiration (PET) was estimated with the formula given by Thornthwaite (1948).

As the calculation of the monthly water balance of tilted surfaces at different altitudes is not possible with the Thornthwaite formula, a new procedure was proposed. First,the monthly average temperature, vapour pressure,wind velocity and cloudiness of the city of Orán (405 m; Appendix A) were taken for the period 1961-1970 (Servicio Meteorológico Nacional, 1981). Then, with these values, others tabulated, the global radiation estimated with the mentioned procedure for a flat surface, and taking and albedo of 10%, the daily and monthly PET of a flat surface located in Orán, at an altitude of 405 m, covered by forest and with the mentioned water holding capacity, was calculated applying the formula given by Penman (op.cit). Then, using the nomogram given by Frère (1972), it was possible to estimate the percentual variation of these values of PET when modifying the global radiation, resulting from taking different values of slope steepness and exposure. These percentual values were used for estimating the PET of tilted surfaces located in the study area by multiplying them by the PET ones obtained for flat surfaces in the area of interest by applying the mentioned Thornthwaite formula. Finally, the water balances were estimated using these values.

The catabatic fluxes (cold air fluxes) were estimated according to Enders (1979), and the validity of these results could be mostly verified in field. The same procedure (section 2.2.d) was applied in this study for the part of the study area that was not previously analyzed and, therefore, will be explained with more detail. The influence of relief on catabatic flux was analyzed taking into consideration the flux produced by terrain irradiation and neglecting the possible influence of gradient winds. The method begins by overlying a transparent grid to the topographic map (in this case it was used the map in scale 1: 20.000 and a grid of 0,5 x 0,5 cm = 1 ha). Then, the calculation begins in the cell (= grid element) that contains the highest point. This cell is surrounded by other eight ones with equal or less elevation, and produces a cold air flux which direction will be determined by the cell(s) that show(s) the higher elevation difference in relation with the first one, among which the flux value will be distributed. If, e.g., from the eight mentioned cells four were showing less and the same elevation in relation with the initial one, and this one were producing one relative cold air flux unit, this value would be divided among these four cells, corresponding then to add 0,25 units to the values produced by these cells. This procedure is repeated for the next cells (in fact, for simplifying the estimations, the elevation value registered in the upper corner of each cell was the one considered for the whole cell) until the lowest cells are reached. It was considered that equal surfaces produce equal cold air masses. In reality, differences will exist due to the soil surface and/or land cover. A cell with a slope steepness less than 5% produces one relative cold air flux unit, and for others with higher steepness this value is increased in relation with the slope angle.

In general the fluxes are following the drainage and terrain and that makes it easier to map them. They were therefore calculated for each terrain unit and ranged into categories of catabatic relative units.

C H A P T E R 3: T O P O C L I M A T E

3.1. Introduction

Climatological data for the Pescado area are scarce, however, their topoclimates have been studied by modeling (Zuviría & Burgos, 1986; Zuviría, 1987). The results will be used for estimating the variability of the main climatic parameters within the area of study.

The following sections present the available data and applies correlations between topographic and climatological parameters for extrapolation.In Chapter 6,the climatological information will be matched with the information on vegetation and finally will be used for a suitability assessment for coffee.

3.2 Temperature

The monthly average temperatures in the study area, estimated by Zuviría & Burgos (1986), are shown in table 3.

Table 3: Monthly mean temperature (°C) estimated for different altitudes in the Pescado river area. (Source: Zuviría & Burgos, 1986)

ALTITUDE	500	600	700	800	1000	1200	1400	1700
January	25,8	25,4	24,9	24,4	23,4	22,4	21,4	20,0
February	24,6	24,2	23,7	23,2	22,3	21,4	20,4	19,0
March	22,9	22,5	22,1	21,6	20,7	19,9	19,0	17,7
April	19,3	18,9	18,5	18,1	17,2	16,3	15,5	14,2
May	18,0	17,6	17,2	16,8	15,9	15,1	14,3	13,0
June	15,4	15,0	14,6	14,2	13,4	12,7	11,9	10,8
July	14,4	14,0	13,6	13,2	12,4	11,7	10,9	9,8
August	16,1	15,7	15,3	14,9	14,0	13,2	12,4	11,1
September	19,9	19,4	19,0	18,6	17,7	16,9	16,0	14,8
October	22,1	21,6	21,1	20,7	19,7	18,7	17,8	16,3
November	24,1	23,7	23,2	22,7	21,8	20,9	19,9	18,5
December	25,2	24,7	24,2	23,7	22,7	21,8	20,8	19,3
Annual	20,6	20,2	19,8	19,3	18,4	17,6	16,7	15,4

3.3 Precipitation

Precipitation in NW Argentina has a strongly seasonal character (Schwerdtfeger, 1954; Woelken, 1954; Bianchi, 1981) showing a long dry period. 84% of the annual rainfall is registered in the warm semester October-April (Burgos et al, 1951; Hoffman, 1971).

Precipitation increases in this period due to the shifting of the subtropical anticyclonic strip, located at 25°S in winter, to farther 30°S in summer, and also because of the action of a low pressure center, called 'baja térmica', that develops in this period in the 'llanura chaqueña', located at the east of the study area.

The study area shows orographic precipitation which could be more abundant in slopes facing to the east (Bianchi,1981). In the west of the study area the ridge 'Las Pavas' is found (Appendix C) and it probably has a strong orographic precitation affecting the survey area.

The monthly mean precipitation was estimated in the study area for flat surfaces at different altitudes by Zuviría & Burgos (1986), as shown in table 4.

Table 4: Monthly mean precipitation (mm) estimated for flat surfaces at different altitudes in the Pescado area (Source: Zuviría & Burgos, 1986)

ALTITUDE	500	600	700	800	1000	1200	1400	1700
January	257	288	320	351	414	477	539	602
February	234	263	292	320	378	435	492	550
March	253	284	315	346	407	469	531	593
April	109	123	136	149	176	203	230	256
May	30	34	38	41	49	56	64	71
June	18	21	23	25	30	34	39	43
July	9	10	11	13	15	17	19	22
August	9	10	11	13	15	17	19	22
September	22	25	28	31	36	42	47	52
October	49	55	61	67	79	90	102	114
November	108	121	134	148	174	200	227	253
December	216	242	269	295	348	401	453	506
Annual mean	1314	1476	1638	1799	2121	2441	2762	3084

The precipitation received by surfaces with sloping angles of 10%, 30%, 60% and 100% is respectively 99%, 96%, 86% and 71% of the value estimated for the flat surface at the same altitude.

3.4 Solar Radiation

Solar energy and water are the two main climatic parameters. Their local and temporal variation, in conjunction with terrain parameters as topography, vegetation and soils leads to the formation of different topoclimates. In mountaineous or hilly areas, like the study area, solar radiation is the most important and active factor in the heat balance and topoclimate (Geiger, 1969).

The global variation through the year for a flat surface and the percentages of these values received by different slopes are shown in table 5.

Table 5: Solar global radiation (Rg) received by a flat surface (B= 0) located in the study area in the most representative day of each month, in MJ/m2/day,and by slopes of different angle (B) and exposure, given as a percentage of the value obtained for the flat surface. Terrestrial shadows were not considered in the calculations and a value of 0,5 was taken for the mean atmospheric transparence (Kt) for all months. Eastern and western slopes were considered symetrical.
B = slope angle (%) N, E, S = slope exposures
(Source: Zuviría & Burgos, 1986)

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
B = 0	22	20	18	15	12	11	11	13	16	19	21	21
B=15N	96	99	104	110	116	119	118	112	106	101	97	95
B=30N	91	97	106	117	129	135	132	122	110	100	92	89
B=60N	79	89	104	124	144	155	150	132	111	93	81	76
B=15E	99	100	100	100	100	100	100	100	100	99	99	99
B=30E	98	98	98	99	99	99	99	99	98	98	98	98
B=60E	93	94	94	95	96	96	96	95	95	94	93	93
B=15S	102	99	94	88	83	79	81	86	92	97	101	103
B=30S	102	96	86	75	65	59	61	71	82	92	100	104
B=60S	99	87	70	51	35	26	30	44	63	81	96	104

The difference between southern slopes, cooler and wetter,and northern slopes, warmer and dryer, is shown in table 5. However, differences in vegetation were found between eastern and western slopes, receiving both, according to these estimations, the same precipitation and radiation. According to Geiger(1950) differences in temperature and moisture between eastern and western slopes have to be expected. In the morning due to the higher humidity of the shallow soil and air layer, the sun radiates the eastern slopes where most of this energy is used for the water evaporation. During the day, because of the effect of the rising temperature and the short-wave radiation received, the top soil layer gets dry. In consequence, in the afternoon, when the sun radiates the western slopes they warm up more than the eastern ones,because their moisture was diminishing during the day. Therefore, the western slopes may present higher soil and air temperatures and less soil moisture than the eastern slopes,but it is expected that these contrasts may be reduced by the forest cover of the slopes.

3.5 Water balance

Water balances for the study area were previously estimated (Zuviría & Burgos, op.cit) following the explained procedure (see section 2.4). The altitudinal belt in which coffee could be croped ranges in the study area from 500 to 900 m and slopes steeper than 40% are not suitable for coffee or any other crop due to the high erosion hazard (Küper & Camargo, 1977; Del Frari, 1980). Therefore, only water balances for flat and sloping surfaces between 575 and 875 m are shown in table 6.

Table 6: Monthly water balances (Thornthwaite & Mather method) calculated for flat terrain and slopes with different exposures sloping 60%, located at 575 m and 875 m.
(Source: Zuviría & Burgos,1986)

B = sloping angle (%) N,S,E,W = slope exposure
PET, AET = potential and actual evapotranspiration
WR = water reserve WR var. = water reserve variation
A = annual R = rainfall

ALTITUDE = 575 m

B = 0%	J	F	M	A	M	J	J	A	S	O	N	D	A
R	285	260	280	122	33	20	11	10	25	53	119	240	1458
PET	143	113	100	62	52	34	31	41	69	94	117	137	993
WR	150	150	150	150	132	120	105	85	63	48	50	150	113
WR var.	0	0	0	0	-18	-12	-15	-20	-22	-15	2	100	0
AET	143	113	100	62	51	32	26	30	47	68	117	137	926
Deficit	0	0	0	0	1	2	5	11	22	26	0	0	67
Excess	142	147	180	60	0	0	0	0	0	0	0	3	532

ALTITUDE = 575 m

B= 60%S	J	F	M	A	M	J	J	A	S	O	N	D	A
R	245	223	240	105	28	17	9	9	21	45	102	206	1250
PET	141	97	68	29	15	9	9	15	45	77	112	142	759
WR	150	150	150	150	150	150	150	144	122	99	92	150	138
WR var.	0	0	0	0	0	0	0	-6	-22	-23	-7	58	0
AET	141	97	68	29	15	9	9	15	43	68	109	142	745
Deficit	0	0	0	0	0	0	0	0	2	9	3	0	14
Excess	104	126	172	76	13	8	0	0	0	0	0	6	505

ALTITUDE = 575 m

B= 60%N	J	F	M	A	M	J	J	A	S	O	N	D	A
R	245	223	240	105	28	17	9	9	21	45	102	206	1250
PET	112	100	104	78	79	56	51	56	76	88	96	105	1001
WR	150	150	150	150	106	82	61	45	31	23	29	130	92
WR var.	20	0	0	0	-44	-24	-21	-16	-14	-8	6	101	0
AET	112	100	104	78	72	41	30	25	35	53	96	105	851
Deficit	0	0	0	0	7	15	21	31	41	35	0	0	150
Excess	113	123	136	27	0	0	0	0	0	0	0	0	399

ALTITUDE = 575 m

B=60%E-W	J	F	M	A	M	J	J	A	S	O	N	D	A
R	245	223	240	105	28	17	9	9	21	45	102	206	1250
PET	133	105	94	59	49	32	29	39	66	88	109	128	931
WR	150	150	150	150	130	118	103	84	62	46	44	122	109
WR var.	28	0	0	0	-20	-12	-15	-19	-22	-16	-2	78	0
AET	133	105	94	59	48	29	24	28	43	61	104	128	856
Deficit	0	0	0	0	1	3	5	11	23	27	5	0	75
Excess	84	118	146	46	0	0	0	0	0	0	0	0	394

ALTITUDE = 875 m

B = 0%	J	F	M	A	M	J	J	A	S	O	N	D	A
R	376	344	370	161	44	27	14	13	33	70	157	317	1926
PET	127	102	92	57	49	33	30	39	64	84	106	122	905
WR	150	150	150	150	145	139	125	105	85	77	128	150	130
WR var.	0	0	0	0	-5	-6	-14	-20	-20	-8	51	22	0
AET	127	102	92	57	49	33	28	33	53	78	106	122	880
Deficit	0	0	0	0	0	0	2	6	11	6	0	0	25
Excess	249	242	278	104	0	0	0	0	0	0	0	173	1046

ALTITUDE = 875 m

B= 60%S	J	F	M	A	M	J	J	A	S	O	N	D	A
R	323	295	317	138	38	23	12	11	28	60	135	272	1652
PET	126	88	63	27	14	8	8	15	42	69	102	127	689
WR	150	150	150	150	150	150	150	146	133	125	150	150	146
WR var.	0	0	0	0	0	0	0	-4	-13	-8	25	0	0
AET	126	88	63	27	14	8	8	15	41	68	102	127	687
Deficit	0	0	0	0	0	0	0	0	1	1	0	0	2
Excess	197	207	254	111	24	15	4	0	0	0	8	145	965

ALTITUDE = 875 m

B= 60%N	J	F	M	A	M	J	J	A	S	O	N	D	A
R	323	295	317	138	38	23	12	11	28	60	135	272	1652
PET	99	90	96	72	75	55	49	53	71	79	87	93	919
WR	150	150	150	150	117	94	73	55	41	36	84	150	104
WR var.	0	0	0	0	-33	-23	-21	-18	-14	-5	48	66	0
AET	99	90	96	72	71	46	33	29	42	65	87	93	823
Deficit	0	0	0	0	4	9	16	24	29	14	0	0	96
Excess	224	205	221	66	0	0	0	0	0	0	0	113	829

ALTITUDE = 875 m

B=60%E-W	J	F	M	A	M	J	J	A	S	O	N	D	A
R	323	295	317	138	38	23	12	11	28	60	135	272	1652
PET	118	95	87	54	47	31	28	37	61	79	99	114	850
WR	150	150	150	150	141	134	120	101	80	71	107	150	125
WR var.	0	0	0	0	-9	-7	-14	-19	-21	-9	36	43	0
AET	118	95	87	54	47	30	26	30	49	69	99	114	818
Deficit	0	0	0	0	0	1	2	7	12	10	0	0	32
Excess	205	200	230	84	0	0	0	0	0	0	0	115	834

The water availability resulting from the water balances is taken into account in the further suitability for coffee evaluation (Chapter 8).

3.6 Catabatic flux

The process that leads to the development of winter frosts in NW Argentina is characterized by the action of a polar cold front in this region (Burgos et al, 1951; Burgos, 1963). In the study area, frosts take place due to the combined action of the mentioned front and catabatic fluxes produced as a consequence of the nocturnal cooling produced by the emission of long wave radiation from the surface. The frost hazard as depending on the dynamics and intensity of cold air fluxes, determined in this area by topography, is estimated here.

The influence of relief on cold air movement was analyzed following the methodology described in section 2.3, considering only the catabatic flux produced by radiation without taking into account the possible influence of gradient winds.

The cold air fluxes were estimated for each terrain unit and the results are shown in table 7.

Table 7: Maximum values of catabatic flux (in relative units) estimated for each terrain unit.

Terrain unit symbol	Maximum catabatic flux (relative values)
M1	400
H1	100
H21	50
H22	150
H3	200
F11	50
F12	600
F2	800
A1	800
A2	800

Most of the catabatic fluxes are concentrated in different parts of units A1, A2, F2 and F12 (table 7).

3.7 Landsat 5 TM thermal data

The surface temperature values obtained from Landsat TM band 6 data (section 1.3) and their respective colours in the thermography enclosed (Appendix I) are presented in table 8.

Table 8: Frequency distribution of surface temperature values of a subframe of 350 rows x 619 columns obtained from Landsat TM band 6 data (section 1.3) covering the study area, with pixel frequency, pixel percentage, cumulative pixel frequency, cumulative percentage and colours assigned to the different temperature values in the thermography enclosed (Appendix I).

F = frequency CF = cumulative frequency
P = percentage CP = cumulative percentage

T (°C)	F	P	CF	CP	COLOUR ASSIGNED
15,5	10	0,00	10	0,00	BLACK
15,7	41	0,02	51	0,03	BLACK
16,0	152	0,07	203	0,10	BLACK
16,2	465	0,21	668	0,31	MAGENTA
16,5	1266	0,58	1934	0,89	MAGENTA
16,7	2580	1,19	4514	2,08	MAGENTA
16,9	3513	1,62	8027	3,70	BLUE
17,2	4330	2,00	12357	5,70	BLUE
17,4	5417	2,50	17774	8,20	BLUE
17,6	9333	4,31	27107	12,51	CYAN
17,9	14664	6,77	41771	19,28	CYAN
18,1	24503	11,31	66274	30,59	GREEN
18,4	33144	15,30	99418	45,89	GREEN
18,6	35762	16,51	135180	62,40	GREEN
18,8	28586	13,19	163766	75,59	DARK GREEN
19,1	21001	9,69	184767	85,28	DARK GREEN
19,3	13961	6,44	198728	91,72	DARK GREEN
19,5	7912	3,65	206640	95,37	RED
19,8	4967	2,29	211607	97,66	RED
20,0	2806	1,30	214413	98,96	RED
20,2	1368	0,63	215781	99,59	BLACK
20,5	594	0,27	216375	99,86	BLACK
20,7	142	0,07	216517	99,93	BLACK
20,9	53	0,02	216570	99,95	BLACK
21,2	23	0,01	216593	99,96	BLACK
21,4	25	0,01	216618	99,97	BLACK
21,6	10	0,00	216628	99,98	BLACK
21,9	19	0,01	216647	99,99	BLACK
22,1	3	0,00	216650	100,00	BLACK

The analysis of these values in relation with other terrain parameters (Appendix M) show that internal relief (Meijerink et al, 1988) is associated with temperature variations within each terrain unit. This parameter was included in table 9, as well as the temperature values.

Table 9: Mean surface temperature values and standard deviations calculated from Landsat TM band 6 data (section 1.3)for different terrain units and internal relief.

TERRAIN UNIT	SURFACE MEAN (° C)	TEMPERATURE STANDARD DEVIATION	INTERNAL RELIEF (m)
M1	18,1	1,8	150-400
H1	18,7	0,7	75-200
H21	18,4	0,2	0-30
H22	18,4	0,3	30-100
H3	18,9	0,4	30-150
F11	19,1	0,2	0-30
F12	18,7	0,3	30-100
F2	18,5	0,2	0-30
A1	20,0	0,2	-
A2	18,8	0,1	-

As it can be seen in the Landsat TM band 6 slicing enclosed (Appendix I; colour-temperature relations are given in table 8) and in table 9, terrain unit M1 presented the lowest mean temperature.According to the temperature and precipitation relation with altitude (sections 3.2 and 3.3) this was expected due to the higher mean altitude and precipitation of this unit. Lagouarde (1983) analyzed the effect of topography on thermal images in a mountaineous forest area finding a linear relation between surface temperature, given by a diurnal HCMM thermography, and altitude. The effect of water content in humid areas was analyzed by Nieuwenhuis and Menenti (1986) who related increasings in evapotranspiration with decreasings in surface temperature. The highest mean temperatures were presented by the unit A1, mainly composed by sandy river deposits, possibly dry when thermal data were recorded (dry season). This was also expected due to the thermal properties of dry sand in comparison with the rest of the study area covered by forest. For a wet land surface (here the forest) the net radiation energy is used mainly as latent heat for vaporization. In dryer surfaces like the sandy river deposits in the study area, latent flux decreases resulting in a rise of the sensible heat and, therefore, in a higher surface temperature (Menenti, 1984; Niewenhuis, 1986).

The mean temperatures of the other units were relatively uniform (18,4 to 19,1°C). As the altitude and the cover were not very different among this units, the differences were probably due to the combined effect of slope exposure (observed by Lagouarde, 1983) and vegetation structure (no references were found on thermal differences related with differences on forests structure). The slope exposure effect can be clearly seen in the thermography enclosed (Appendix I) in terrain unit H1. The eastern slopes, facing towards the sun in the morning (data were recorded at 9:45 AM) are warmer than the western slopes, mostly in the shadow during the first hours after sunrise (7:40 AM approximately). Terrain units F11, F12 and H3 show higher mean values than units H21 and H22. This could be explained because of the fact that the first group of units present more slope exposures to the east than the second. Also, vegetation structure analysis (Chapter 6) reveals that both groups of terrain units differ in structure. The mean percentual values of aerial cover per layer of structural types A, F, H (associated with terrain units F11, F12 and H3), B, C, and J (associated with terrain unit H22) are presented in table 10.

Table 10: Mean aerial cover (%) per layer for vegetation structural types A, B, C, F, H and J. N = number of layer

LAYER N	LAYER (m)	MEAN AERIAL COVER (%) Type A	Type F	Type H	Type B	Type C	Type J
1	+18	23	30	30	35	42	10
2	8-18	30	30	30	25	35	35
3	3,5-8	30	32	30	35	30	40
4	1,5-3,5	30	40	60	30	32	25
5	0,1-1,5	62	75	35	55	30	37
Total		175	207	185	180	167	147

At the time of the day on which data were recorded (09:45 AM), the temperature in the crown space (first and second layer) is higher than in the lower layers and a vigorous turbulence between upper and lower vegetation layers may be beginning to be produced (Geiger, 1950). Additive cover values of the two lower layers (4 and 5) are lower in structural types B, C and J than in types A, F and H (85, 62 and 62 for types B, C and J, and 92, 115 and 95 for types A, F and H). These results suggest that conditions for a higher heat exchanging between upper (warmer) and lower (colder) layers are better presented in structural types B, C and J than in types A, F and H, where the higher thickness of the lower layers would act as a barrier for the heat exchange. This could be one reason for explaining the mean lower temperature values found in terrain unit H22 in comparison with terrain units F11, F12 and H3. However, field temperature measurements in the different vegetation layers are necessary for assessing the validity of this hypothesis.

The relatively low mean values shown by terrain unit F2 could be explained due to their low topographic possition associated with areas receiving shadows from their surroundings. The role of vegetation structure is difficult to analyze because, on one hand, types I and G are characteristic of this terrain unit and also of terrain unit A2, showing both units different mean temperatures and, on the other hand, types I and G show a very different proportion of emergent trees being, however, very homogeneous the temperature within both terrain units.

The internal relief is correlated with the standard deviation (SD) of temperature values within different terrain units (table 9). The highest SD presented by terrain unit M1 is associated with their high internal relief (also with altitudinal differences). In the thermography enclosed (Appendix I) temperature differences between darker and lighted slopes are sharper in this terrain unit than in all others. In the same way, terrain units H1, H3, H22, F12, H21, F11, F2 and A2 show a respectively decreasing internal relief correlated with decreasing temperature SD values.

Therefore, temperature homogeneity within terrain units is a parameter that correlates with internal relief.

C H A P T E R 4: T E R R A I N

4.1 Introduction

Terrain analysis is linked to geology and geomorphology, being considered as "a study which (genetically) describes the landforms and processes which led to their formation, and investigates the interrelationships of this forms and processes in their spatial arrangement over time" (Van Zuidam, 1986).

As mentioned (section 2.2), the photo-interpretation was done on base of terrain differences. A physiographic map in scale 1: 500.000 (CNRB, 1973) and one in scale 1: 250.000 of the north of the Province of Salta (Zuviría, 1986) were taken as a general guide for elaborating the terrain map of the study area in scale 1: 68.000 (Appendix D).

Geology (stratigraphy and lithology) and geomorphology (landforms) were analyzed on the basis of the terrain map scale 1: 68.000 and a cross section (Appendix E). For illustrating the terrain units description, a Landsat 5 TM FCC (bands 4, 5, 7) image, a Landsat 5 TM band 6 slicing and a stereogram, all in scale 1: 75.000, are included (Appendices H, I and J).

The legend of the terrain map is presented in table 11 and includes in the heading hierarchical levels of terrain units and the selected guiding principles, mainly taken from Villota (1983).

A separate description on geological aspects of the units is presented in the following section showing the stratigraphy and lithology of the rock types occuring in the study area. In section 4.3 the terrain units description is given.

Table 11: Legend of the terrain map of the Pescado river area.

* Vd = valley density, S = slope steepness
IR = internal relief (= average of the height differences in meters between local drainage divides or hilltops and the valley bottoms within a terrain unit; Meijerink, 1988)

TERRAIN HIERARCHICAL LEVELS			SYMBOL
Main Landscape	Landscape	Sub-landscape	
GUIDING PRINCIPLES			
spatial relation (Vd,IR,S)* and main origin	morphology (external & internal) lithology and geologic formation	modifications due to geomorphologic active processes	
Structural-denudational mountains	broad anticlinal crest in devonian to carboniferous quartzitic sandstones		M1
Structural-denudational hills	narrow anticlinal crest in late tertiary red & yellow sandstones and till		H1
	Hogbacks in late tertiary red & yellow sandstones and tuff	moderat.dissected	H21
		very dissected	H22
	Denudational hills in early tertiary/plio-quaternary conglomerates		H3
Colluvio-alluvial footslopes	Mud flow deposits from quartzitic sandstones	terraced fans	F11
		ravines and slopes complexes	F12
	Colluvial footslopes and colluvio-alluvial valley fills		F2
Alluvial plains of braided-meandering rivers	floodplain		A1
	depositional terraces		A2

4.2 Geology: Stratigraphy and Lithology

A general outline on the geology of NW Argentina can be found in Méndez et al (1979, including a map in scale 1: 400.000) and Aceñolaza & Toselli (1981). A geological history of the study region was given by Serraioto (1977) who carried out a survey in scale 1: 100.000 of an area adjacent to the study one. The latter study as well as the 'cross section' of the area given by Jakúlica (1951) were taken into account for our survey. A scheme on the geology of the study area is presented in table 12.

Table 12: Geology: stratigraphy and lithology

STRATIGRAPHY	LITHOLOGY	TERR.UNITS
Carboniferous to devonian (Group 'Picachos')	quartzitic sandstones	M1
Late tertiary (Group 'Orán', fraction 'arenoconglomerádica')	red & yellow sandstones with till and tuff inclusions	H1,H21,H22
Early tertiary to plio-quaternary (Group 'Orán', fraction'conglomerádica')	conglomerates	H3
Quaternary deposits	unconsolidated materials	F11,F12,F2 A1, A2

The morphology of the area is characterized by strongly folding and faulting which resulted in a tectonically complex scheme. Fractures and folded structures show a strike approximately NNE - SSW. The most important structures (see Appendices D and E) within the study area are the broad and asymetrical anticline of "Sierra de las Pavas" (terrain unit M1), a mountaineous ridge in carboniferous to devonian sandstones,and the narrow and symetrical anticline of the "Serranía del Divisadero"(terrain unit H1), a less developed ridge in late tertiary red and yellow sandstones with some till inclusions.

In the eastern footslope of "Sierra de las Pavas", a group of Quaternary deposits can be found,consisting mainly of mud flows, colluvial footslopes and colluvio-alluvial valley fills (terrain units F11, F12, F2, A1 and A2) differing in their drainage pattern and slope characteristics. These deposits are partly overlaid on the early tertiary to plio-quaternary denudational hills (terrain unit H3), both of them bounding at the west with the "Sierra de las Pavas" following aproximately a fault line, hidden in some places by the mud flows and footslope deposits. These hills and deposits are bounding at the east, following another fault line, with a group of structural-denudational low hills developed in late tertiary red and yellow sandstones with tuff lenses (terrain units H21 and H22). These low hills are bounding at the east with the "Serranía del Divisadero" (terrain unit H1). Both fault lines, the main structures and strata are represented in the cross section (Appendix E), showing their relation with terrain units.

4.3 Terrain unit description

Each terrain unit (Table 9) was characterized and described in terms of stratigraphy, lithology, elevation, slope steepness, drainage pattern (type and density) and internal relief. These characteristics are summarized in appendices M and N (see also Appendices H and J)

Digital values of the Landsat TM CCT refered in section 1.3 were calculated for each terrain unit. The variation found among units for most bands was not enough to perform a classification. Only band 6 values (presented in section 3.7 and Appendix M) were taken for the terrain units characterization. Landsat digital values are shown in table 13.

Table 13: Landsat TM (path 231, row 76, 25/7/86) digital values (mean = X, and standard deviation = SD) of bands 1, 2, 3, 4, 5, and 7 for the different terrain units. Band 6 values are given in °C.

TERRAIN UNIT	BAND 1		BAND 2		BAND 3		BAND 4		BAND 5		BAND 6		BAND 7	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
M1	47,5	3	17,2	3	15,7	3	47,4	21	38,7	18	18,8	1,8	12,1	6
H1	49,0	3	17,6	3	16,2	3	38,7	18	36,1	19	18,7	0,8	12,1	6
H21	49,3	2	17,7	1	16,4	1	39,3	7	37,2	7	18,4	0,2	11,7	2
H22	49,8	2	18,3	2	16,6	2	45,4	16	39,6	15	18,4	0,3	12,5	5
H3	48,3	2	16,9	2	15,2	2	43,4	13	35,4	11	18,9	0,4	10,9	3
F11	49,2	1	17,8	1	16,1	1	49,6	6	42,8	5	19,1	0,2	13,1	2
F12	49,0	2	17,9	2	16,1	2	48,2	14	40,1	12	18,7	0,3	12,2	3
F2	49,8	2	18,2	1	16,6	2	45,4	6	38,6	5	18,5	0,2	12,2	2
A1	75,1	12	33,7	7	41,9	10	41,0	5	70,8	12	20,0	0,2	39,7	10
A2	49,4	2	17,5	1	15,6	1	46,6	3	36,5	3	18,8	0,1	11,1	2

M1:

This unit, found in the west of the study area, is composed by a portion of the "Sierra de las Pavas", a mountaineous anticlinal ridge developed in carboniferous to devonian quartzitic sandstones (Appendix V, photos 2 and 8).

The altitude ranges from 600 to 1850 m and the internal relief is very high (150 to 400 m). The slope steepness is in general higher than 55% (in many places higher than 100%), being less steep (21 to 55%) in some places.

The drainage pattern is trellis to subparalell, being their density (= rate of dissection) coarse to medium, and it is mainly determined by a complex system of joints and faults. The orientation of their elements is in general NNE -SSW, NW-SE and W-E.

H1:

This unit is located in the east of the area and it is composed by a portion of the "Serranía del Divisadero", a hilly anticlinal ridge developed in red and yellow late tertiary sandstones and till (Appendix V, photo 8).
The altitude varies between 450 and 860 m and the internal relief is moderate to high (75 to 200 m). The slope steepness is in most of the unit higher than 55%.
The drainage pattern is subparalell to dendritic and their density is fine being brooks and streams generally W-E oriented, perpendicular to the axis of the anticline (N-S).

H21:

This unit occupies two small areas in the east of the study one close to the "Serranía del Divisadero". Even when it is difficult to establish with certainty the processes that led to the development of this unit, it was considered as belonging to the hogbacks in late tertiary red and yellow sandstones and tuff after checking the rock type in the field, but presenting a lower dissection than terrain unit H22.
The altitude varies between 490 and 660 m while the internal relief is low (0 to 30 m). This unit presents a generally flat surface tilting to the east with a steepness between 3 and 20%.
The drainage is subparalell with a very coarse density.

H22:

This unit is located in the central-east part of the area and it is composed by hogbacks in early tertiary red and yellow sandstones and tuff.
The altitude varies from 500 to 750 m while slope steepness is between 21 and 140%. The internal relief is intermediate to moderate (30 to 100 m).
The drainage is dendritic having a fine density.

H3:
--

This unit is located in the central-south part of the area and it is composed by denudational hills developed in early tertiary to plio - quaternary conglomerates. This materials were possibly deposited as a consequence of the uplift and subsequently erosion of the block on which the "Sierra de las Pavas" is developed. This unit is bounding in some places with the mentioned ridge but in many areas the conglomerates were covered by mud flows coming from higher places and footslope deposits represented by units F11, F12 and part of F2.
The altitude varies between 600 to 1000 m and slope steepness is between 14 and 140%. The internal relief is intermediate to moderate (30 to 150 m) and the drainage pattern is dendritic-pectinate with very fine density.

F11:

This unit occupies five small areas in the centre of the study area and it is composed of terraced fans originated by quaternary mud flow deposits from quartzitic sandstones. Even when the quick growing of vegetation over this young deposits hides their origin in the field, they were easy to identify in the aerial photos and satellite images due to their particular shape and related scars pointing to the place from which they came loose. The confirmation of this was given in the field by the presence of rocks and blocks of different sizes in quartzitic sandstones found everywhere within this unit.

The altitude ranges from 700 to 1050 m and the internal relief is low (0 to 30 m). This unit presents a relatively flat surface tilting to the south-east or south with a steepness between 3 and 20%.

The drainage pattern is subparalell with a very coarse density.

F12:

This unit is located in the central-north part of the study area and it is composed by a complex of ravines and slopes originating from the dissection of quaternary quartzitic sandstones mud flow deposits. This hypothesis, elaborated on base of the landforms analysis by photo-interpretation, was confirmated in the field by the presence of blocks and rocks of different sizes in quartzitic sand-stones found everywhere within the unit.

The altitude ranges from 550 to 1050 m and the internal relief is intermediate to moderate (30 to 100 m). Slope steepness varies from 14 to 55% and the drainage pattern is dendritic to subparalell with a fine density.

F2:
--

This unit is composed of colluvial footslopes and colluvio -alluvial valley fills distributed along the whole area of study.

The altitude varies from 550 to 900 m and the internal relief is low (0 to 30 m). Slope steepness was between 0 to 20% and the drainage pattern is paralell to subparalell with a very coarse density.

A1:
--

This unit is composed of the floodplain of the Pescado and Bermejo rivers, the most important ones within the study area (Appendix V, photo 8).

The altitude varies from 450 to 600 m and the internal relief is flat. Slope steepness was very low (0 to 2%) and the drainage pattern is braided to meandering. These individual characteristics can be considered as'depositional drainage patterns' according to Van der Weg (1967).

No relevés were done in this unit because it is not suitable for coffee or any other crop.

A2:
--

This unit is composed of different levels of depositional terraces found in the alluvial plain of the Pescado and Bermejo rivers (Appendix V, photo 8).

The altitude of the terraces ranges between 500 and 610 m and the internal relief is flat. Slope steepness was very low, between 0 and 7%. It was not observed any drainage pattern.

C H A P T E R 5: S O I L

5.1 Introduction

The soils of the area were surveyed and classified at the exploratory level by CNRB (1973) as lithosols with an ustic moisture regime associated to bedrock exposures of the different parent materials. Lithosols are considered there as shallow soils with a thin A horizon overlying consolidated rocks of different origin and mineralogical composition. Lithosols are approximately equivalent to lithic Orthents (Soil Survey Staff, 1975).

Data analysis shows that the soils within the study area are very uniform, being tentatively classified as Entisols and Inceptisols (section 5.3). The most typical profiles, using the horizon symbols given by FAO (1977), are A - R and A - C - R. In many plots an O horizon of variable thickness (1 to 5 cm) is also found and the organic matter content is always high in the A horizon decreasing in depth. The texture on top horizon ranges from loamy, loamy sand and sandy loam to sandy. Drainage is always well and soil reaction (pH) at 20 cm depth is always acid, between 4,5 and 7,0. Surface stoniness is very variable, between 0 and 20%, and rock outcrops were observed in some spots. Effective depth presents a wide range, from 10 to 100 cm. The colour of top horizon is always yellow - red hue (Munsell, 1975) and the most typical colours are dark reddish brown, dark brown, reddish brown and dark yellowish brown.

Erosion hazard is classified in relation with texture and slope steepness as very high to high (CNRB,1973), being the main part of the study area under active moderate erosion. In the field, even with slope steepness of 4%, signs of sheet and gully geological erosion were observed, like soil accumulation behind old trees and vegetated gullies. In steeper slopes, in addition to the mentioned erosion signs, terracettes and micro- and macro-landslides were observed in many places.

The results of the soil parameters variability analysis are presented in section 5.2 and in section 5.3 a tentative classification of the soils of the area is performed at a subgroup level. Main soil data of each relevé are presented in Appendix L.

5.2 Soil parameters-environment relationships

Soil parameters are in general hardly related with terrain or vegetation characteristics. Soil reaction (pH) mean value is in all terrain units between 5,5 and 6,0 (Appendix M). Surface stoninesses of al least 1% is found in every terrain unit. Dark reddish brown colour of top horizon is found in all terrain units, however, dark yellowish brown colour is exclusively found in Quaternary deposits (terrain units F12, F2 and A2). Effective depth is the only soil parameter that shows some relation with other land characteristics.

5.3 Soil classification

The classification of each relevé is given in table 14.

Table 14: Soil classification of relevés at a suborder level and effective depth range (cm) of each soil type.

Soil Suborder	Symbol	Relevés Number	Effective depth
Orthent	Eo	4,8,9,13,15,16,18,21,24, 25,26,34,36,37,39,43,45, 47,58,65,66,67	60-99
Lithic Orthent	lEo	2,3,5,19,20,23,28,29,30, 31,32,35,40,49,50,51,55, 56,57,59	10-50
Psamment	Ep	17,22,46,48,52,53,54,64	60-99
Andept	Ia	14	90-99
Umbrept	Iu	1,6,7,11,12,38,44,60,61	70-99
Ochrept	Io	10,27,33,41,42,62,63	50-99

Soils are classified as Entisols, including Orthents, Lithic Orthents and Psamments, when no horizon differentiation is found, and as Inceptisols, including Umbrepts, Ochrepts and Andepts, when a horizon differentiation in texture, colour and/or soil reaction (pH), is observed.

Entisols are classified as Psamments and Orthents. Orthents with a lithic contact at less than 50 cm depth are defined as lithic Orthents.

Inceptisols are classified as Umbrepts and Ochrepts and only one soil developed on volcanic ashes is classified as Andept.

As can be seen in tables 15 and 16, lithic Orthents are associated to effective depths between 10 and 50 cm.

CHAPTER 6: VEGETATION

6.1 Introduction

The study area is located in the tropical and subtropical rain-forests of South-America of the phytogeographical Province of "Las Yungas" (Cabrera, 1976). This Province is found in a narrow strip following the "Cordillera de los Andes" from Argentina to Colombia. The study area is located in the"Tucumanish-bolivianisches Waldgebiet" Region (Hueck, 1981).

The available vegetation descriptions of this Region are based mostly on the structure (physiognomy) of the vegetation, qualified by dominant species, as in the Bolivian part of the Region (Coro, 1983) and in the high Bermejo river catchment area, in the study area (Movia, 1972).

The Argentinian part of this Region is divided into three Districts (Cabrera, 1976) being the study area in the "Distrito de las Selvas Montanas", found between 550 and 1600-1800 m in the study Region (Movia, 1972; Cabrera, op. cit). This District was studied by Meyer (1963) in the southest part of this Region. He differentiated two Sub-Districts: the basal or lower, between 450 and 900 m, and the higher, between 900 and 1300 m. Cabrera (op.cit) stated that only after defining communities in relation with altitudinal layers, slope steepness, exposure and latitude it will be possible to divide this District into Sub-Districts.

Based on the altitudinal range of the study area, between 450 and 1850 m, it could be predicted that part of the two other Districts of the "Tucumanish-bolivianisches Wald-gebiet" Region ("Distrito de los bosques montanos" and "Distrito de las Selvas de Transición", Cabrera, op.cit) occur within the study area. However, their characteristic species were not observed in the field neither by the author nor by Dr. Jakúlica (pers.comm.).

The upper limit of the "Distrito de las Selvas Montanas" is quite variable in the "Tucumanish-bolivianishes Wald-gebiet", being for Meyer (op.cit) 1300 m in Tucumán and 1500-1600 m in Salta, for Coro (op.cit) 1400 m, for Cabrera (op.cit) 1600 m and for Movia (op.cit) 1800 m. Because of the fact that the "Sierra de las Pavas" (Appendix C) conforms an isolated mountaineous ridge in a hilly area, rainfall is higher here than in the surrounding areas (Chapter 3) while reaching to the West the mountaineous chains of the "Cordillera de los Andes" rainfall diminishes at altitudes higher than 1300-1400 m (Bianchi, 1981) having a close relation with vegetation changes (Gerold,1987). The higher precipitation in the study area will therefore determine the existence of the forest. These environmental characteristics of isolated mountains can be related also with vegetation changes at different altitudes than in surrounding mountaineous areas (Zonneveld & Surasana, 1988).

The results of the floristic composition and vegetation structure analysis are presented separately in sections 6.2

Table 15: Classified species-to-relevé matrix. For species indicated with a star (*), values refer to estimated cover/density (see table 1) and for others to counted number of individuals with a diameter at brest height higher than 4 cm per releve. These last values were transformed to a 1 to 9 scale as follows:

Field value :	1	2	3	4	5-6	7-9	10-14	15-25	25-50
Matrix value:	1	2	3	4	5	6	7	8	9

R E L E V E N U M B E R			3333 7698	3343 3504	662251050221 107601519988	1052240155502 0673598258634	21331634054524 06209217736228	46050141506612 56291534443731	644614 512474
A L T I T U D E (m x 100)			1111 4433	1111 2222	998888777777	7777777777777	66666666666666	66666666666666	555555
S L O P E E X P O S U R E			SSSE WEWE	NSSS WSEE	SSSSSSNNNNSS EESEEEWWWWWW	SSSSSEEEENNNN SSEEEEEEEEEEN	NNWSSSSSSOOOOO WWWWWWWWSOOOOO	OSSSSSSSSSENNN OEEEEEEEEEEEEN	NSSOOS WWSOOE
S L O P E A N G L E (%)			9478 9050	8675 0050	61 431666451 528551500004	1192 551 7763 4090450465050	9979952 95000356812236	194 277 67 09293504420044	89 809924
T E R R A I N U N I T			MMMM 1111	MMMM 1111	MMMMMFHMHFFF 111111312112 2 222	FFMHFFHFHMHHH 1113212231333 21 12	HHHHHHFFFAAAFF 31233212222222 2 22	HHFFFHHHFFHHFF 22121112222222 222 2 1 22	HHHFFH 222222 122 1
S T R U C T U R A L T Y P E			KKBL	KDDD	EKKAAD I CHF	EFGH GFAH H	ALHADAHI IGIII	CC B EGDE BJIA	EBJIIA
	a	Cyathea o'donelliana	71						
		Cordyline dracaenoides	11					.	
	b	Blepharocalyx gigantea	9972	215					
S		Miconia molybdea	1187	5889	6 12415 5	7 1 6	5 3 1 3	124 3 1	1
		Phoebe porphyria	66	2561	56656146 253	25356652263 5	22555657361667	1 2824 1517236	233765
O	c	Athyana wienmannifolia	51	12 6	21 11 121	33 13633	2 11 451	44 311 4143 5	5336 4
		Acreugenia pungens	13		2 21	1 5 5315	41 211 315 1	64 2561521	324 4
		Prunus tucumanensis	1 1	13	2 2	3 1154 3333	3 53 1 3 1	42 1213511222	312122
C		Cedrela angustifolia	6 12		1 1 1 1	2 1		111 1 1 12	
	d	Aegiphyla saltensis	4		12 5	21		11 1 1	
I		Tipuana tipu	1		4	2		7	13
		Parapiptadenia excelsa	1					1	1
O		Inga marginata		634	86657337 17	2 7115 3525 1	27 4754 83336	24 5133 6 1	24 462
		Rhamnus polymorphus		3	24 161 122	3 32234211	71 547 3 7	66 35136342	6652 5
		Urera baccifera		2 1	1152 1 2654	2214 1 1 15	21653113 11	11113114 3	11
L		Piper tucumanum		1 2	44561135 15	571 333 1	12 25 8 518	1 2416 1 15	3
		Pteris spp. *		++	1+5 3 .3	+13+ 42 +	.+ 1 +..	3+ 1 61 3.	..25.
		Chusquea lorentziana *		++12	21 4..	64. 453 .45	31 6 1 2	22 6 + 11	5
O	e	Chrysophyllum gonocarpum		52	13 431	1 11 331 5	1 214 12 34	32 11 4 14 3	3122 4
		Heliconia subulata *		+	. .+ ..	+. ++ .1 . .	. +. 1. .+	++ .. + .	. +.
		Pogonopus tubulosus		2	22 111 51	214 6 5 1	3 1	1 1	2 1
G		Tabebuia lapacho		12 3	111 3	2 5 2 11	21 4 3	53 2 11	12
		Ruprechtia laxiflora		1		1 1 2 1	3 1 1 1	112211	1
		Cordia trichotoma		2	2	1 1 2	151 122 2	1 1	1 2
I		Cocoloba tiliaceas		2				1	
		Urera caracasana			7 5225	5 33 25 54 4	133 1 221 13	1 41112 11 2	53544
C		Solanum riparium			1	11 13 1	2 2 51 1 22	111 1	1 2 21
		Chrysophyllum marginatum			1 1 1	1 1	1 3 1 1	1 1 1 25 1	112431
	f	Anadenanthera collubrina			2 11		32 3	1 6 1 1 1	1 1
A		Pisonia zapallo			1 3	1 1	1	1 14 1	12
		Phyllostylon rhamnoides			2			2	1
		Myroxylon peruiferum			2	2 1 1	1 3		1
L		Ficus maroma			3 141 11	1 21 32 1	1 1 23 1	1 1	
		Lonchocarpus lilloi			2 11	11 11 1	11 1 1	1 111	
		Nectandra pichurium			1			5 1	
		Acreugenia mato			1	2			
		Eugenia pseudomato				11	1		
		Celtis pallida			1 1	1 1		1	
G	g	Fagara nigrescens			1		1	1	
		Canna compacta *				+ .	.	. .	
		Sambucus peruviana				1	6		
R		Amburana cearensis				1			
		Acanthosyris falcata				1			
		Calycophyllum multiflorum						1	
O		Schinus meyeri			1				
		Phitecellobium grisebachianum			1	1 2 1 1		1 1 5 1	1 1
U		Astronium urundeuva				1		3 1 3	
	h	Celtis spinosa				1		1 1	
		Stenocalyx uniflorus				1 1		31 121 322	3 2 56
P		Terminalia triflora		1		1 14 11		1 1 1 13	12 1
		Cassia carnaval					1 1	1 1	
S		Rollinia occidentalis					5 1	2	4
	i	Piper elongatum						1	1
#		Gleditsia amorphoides							1 1
		Allophyllus edulis					2		1
		Dunalia breviflora					1		
C O M M U N I T Y #			1	2	3	4	5	6	7

: see references in next page

Table 15: Classified species-to-relevé matrix references

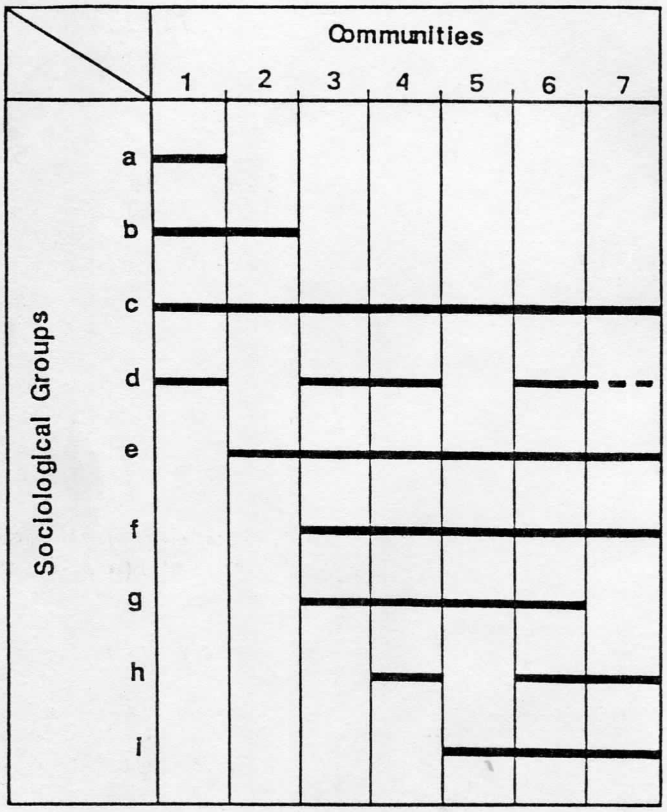
FLORISTIC COMMUNITIES

Symbol	Name	Sociological groups
1	Cordyline dracaenoides Blepharocalyx gigantea	a + b + c + d
2	Blepharocalyx gigantea Chusquea lorentziana	b + c + e
3	Ficus maroma Miconia molybdea	c + d + e + f + g
4	Ficus maroma Terminalia triflora	c + d + e + f + g + h
5	Acreugenia pungens Cordia trichotoma	c + e + f + g + i
6	Acreugenia pungens Stenocalyx uniflorus	c + d + e + f + g + h + i
7	Chrysophyllum gonocarpum Stenocalyx uniflorus	c + d + e + f + h + i

SOCIOLOGICAL PLANT SPECIES GROUPS

Symbol	Name	Communities
a	Cordyline dracaenoides	1
b	Blepharocalyx gigantea	1 - 2
c	Phoebe porphiria	1 - 2 - 3 - 4 - 5 - 6 - 7
d	Cedrela angustifolia	1 - 3 - 4 - 6 - 7
e	Inga marginata	2 - 3 - 4 - 5 - 6 - 7
f	Urera caracasana	3 - 4 - 5 - 6 - 7
g	Ficus maroma	3 - 4 - 5 - 6
h	Terminalia triflora	4 - 6 - 7
i	Rollinia occidentalis	5 - 6 - 7

Table 16: Bar diagram of floristic communities (1 to 7) versus sociological plant species groups (a to i).



|——| : occurs with high frequency

|- - -| : occurs with low frequency

| | : absent

and 6.3 showing there their respective relationships with environmental parameters. In section 6.4 both floristic and structure results are compared and their respective usefullness for characterizing the land units is assessed.

6.2 Floristic composition

The classified species-to-relevé matrix is presented in table 15, showing the plant communities and sociological plant species groups and including in the heading altitude, slope angle, slope exposure and vegetation structural type for each relevé.

In table 16 a bar diagram is shown, derived from the species-to-relevé matrix. In Appendix O a list of the woody species found within the study area is presented.

Sparce riverine shrublands were observed in the flood-plain of the Pescado and Bermejo rivers (terrain unit A1), however, no relevés were made there because of them are unsuitable for any agricultural land use (Chapter 2). The dominant woody species in these shrublands are Tessaria integrifolia (bobo, pájaro bobo) and Salix humboldtiana (sauce criollo) and various grasses. For practical reasons, the vegetation of these floodplains is refered in maps and tables as community 8.

As can be seen in the species-to-relevé matrix the seven communities show a close relation with altitude and slope exposure and some relation with terrain units and structural types (see also Appendices N and T). The soil parameters are relatively homogeneous among the communities (Appendix P).

The growth-forms density is also homogeneous in all communities being climbers (lianas), epiphytic bryoids (epiphytic lichens and mosses), epiphytes (only flowering plants) and ferns abundant everywhere in the study area. Only community 1 shows a higher density of epiphytic bryoids (Appendix V, photos 3, 4 and 5). Bamboo density is variable (see in the table 15 density values of Chusquea lorentziana, the only bamboo species in the study area) but their presence is related with the altitudinal ranges between 500 and 1280 m. The mean species diversity (number of recorded species per relevé) is estimated for each community (Appendix P) and, as it relates with altitude and slope exposure, it is discussed on each community later. The number of woody individuals per plot is estimated for each community and structural type (Appendices P and R) but as no significative differences are found, except for community 1, it is only discussed there. The mean proportion of evergreen species is estimated for each community and no significative differences are found. As it was expected to find a higher proportion of evergreen species in community 1 according to the results obtained by Meyer (1963) for the 'higher Sub-District', this parameter is only discussed on community 1.

In the species-to-relevé matrix some relevés could have been classified into more than one community. The criteria for the location assignment of these relevés was to analyze, when available, additional floristic information taken on the spot and the values of the environmental parameters included in the heading of the species-to-relevé matrix.

For example, relevé 61 could have been placed in communities 3 or 2. Reasons for placing it in community 2 were the absence in the plot and in their surroundings of Blepharocalyx gigantea (in relevé 34 this species was found close to the plot), the presence of Cedrela angustifolia and the high abundance of Inga marginata. When no floristic reasons were found for placing one relevé in one out of two communities, the environmental parameters were taken as a guide. This was the reason for placing relevé 59 in community 6 and not in 7.

The species-to-relevé matrix shows a clear difference among communities 1, 2, 3-5, 4-6, and 7.Differences between communities 3 and 5 and between 4 and 6 are less clear and will have to be assessed in further studies. It is interesting that these two pairs of floristically related communities (3-5 and 4-6) show similar environmental conditions and values of species diversity per plot (table 17 and Appendices P and Q), but are differing in altitude, vegetation structure and associated terrain units (Appendices P and N).

Many species proposed by Meyer (op.cit) as exclusive of the "lower or basal Sub-District", between 450 and 900 m in Tucumán, were found only in communities 3, 4, 5, 6 and 7, between 450 and 1000 m in the study area, like Solanum riparium,Chrysophyllum marginatum, Anadenanthera collubrina, Pisonia zapallo and Stenocalyx uniflorus (four of these species belong to sociological group f). Blepharocalyx gigantea was observed by Meyer exclusively in the "higher Sub-District" and we only found it in communities 1 and 2 between 1000 and 1850 m with very high density values, especially in community 1. On the other hand, various species given by Meyer as exclusive for the "higher Sub-District", between 900 and 1300 m in Tucumán, were found everywhere within the study area, like Tipuana tipu and Miconia molybdea (this last species was, nevertheless, more abundant in communities 1 and 2, between 1000 and 1350 m). Two Mirtaceae belonging to sociological group g, Acreugenia mato and Eugenia pseudo-mato, were exclusive of the "higher Sub-District" in Tucumán,between 900 and 1300 m, while they were found in the study area in communities 3, 4, 5 and 6, between 600 and 1000 m. Chusquea lorentziana, a bamboo species, was found in Tucumán only in the "higher Sub-District" while it was observed in the study area in communities 2, 3, 4, 5, 6 and 7, between 550 and 1280 m.

The vegetation community map of the study area in scale 1: 68.000, produced taking contour lines and slope exposures as boundaries among communities, is presented in Appendix F. Because of this, these boundaries have to be considered as preliminar limits that may have to be adjusted in further studies. Vegetation communities distribution is also indicated in the terrain cross section (Appendix E).

Floristic communities are described and their relationships with vegetation structural types and location are indicated for each community.

1. Community of Cordyline dracaenoides & Blepharocalyx gigantea

Sociological species groups: a, b, c and d.

This community is found in the higher part of the "Sierra de las Pavas" between 1300 and 1850 m. As can be seen in the FCC Landsat image (Appendix H), the floristically defined boundary at 1300 m has a close relation with a colour change in the image (compare Appendices F and G) resulting from a lower reflectance on band 4 in this community.

This community is characterized by a high to very high density of Blepharocalyx gigantea, a tree species with a height between 14 and 18 m (Appendix V, photo 5), and by the presence of Cyathea o'donelliana, a tree-fern (Appendix V, photo 6) and Cordyline dracaenoides, a palm-like species.

While the density of the mentioned species decrease, in the lower parts of this community, it is observed a density increase of Miconia molybdea, a shrub between 3 and 8 m height, associated with the presence of two other tree species of sociological species group c, Phoebe porphyria and Athyana wienmannifolia (table 15).

The structure varies in relation with the mentioned floristic changes. In the spots with a high density of Blepharocalyx gigantea structural type K is the most representative one (Appendix S). It shows a thick low tree layer with scarce emergents, a thick herb layer and a semi-open high and low shrub layers. Spots showing a higher density of Miconia molybdea present a thick low and high shrub layer, a semiopen low tree layer with some emergent specimens of Phoebe porphyria and a thick herb layer (structural type L). An intermediate situation is also observed (structural type A) in spots presenting an intermediate to low cover of low trees, high shrubs and low shrubs, with also some emergent trees and a thick herb layer.

Even when it is not shown by the cover values per layer, the vegetation is in general less thick in this community than in all the others, possibly in relation with the cooler climate in this community. The mean value of species found per relevé is the lowest one in the study area (Appendix P). As this "higher Sub-District"is bounding at higher altitudes with the "Distrito de los Bosques Montanos" (Cabrera, 1976) characterized by single - species forests, the species diversity could be considered as a parameter related with mean temperatures, lower in these single-species forests and higher in the communities found at lower altitudes in the study area, characterized by higher species diversity values. The number of woody individuals per plot is slightly higher in this community than in the others (Appendix P), possibly because very big trees were not found within the relevés in this community.

This community presents a higher density of epiphytic bryoids (lichens and mosses) than all others (Appendix V, photo 5), probably,as suggested by Meyer (1963) for Tucumán, in relation with the higher rainfall and the almost permanent presence of a misty belt surrounding the mountain covered by this community. This was also observed for this "higher Sub - District" (Meyer, 1963) by Hueck (1956) who differentiated physiognomically the higher and lower Sub-Districts of Meyer, only by their density of epiphytic bryoids. As mentioned before in this section, Chusquea lorentziana, the only bamboo species in the study area was observed in all the other communities except in this.

As expected from Meyer (1963) almost all the abundant species in this community are evergreen, except Cedrela angustifolia, which is a semi-deciduous species (Appendix P).

2. Community of Blepharocalyx gigantea & Chusquea lorentziana

Sociological species groups: b, c and d.

This community is found in the "Sierra de las Pavas" between 1000 and 1300 m.

It is characterized by a very high density of Miconia molybdea, a shrub dominating at a medium height between 7 and 10 m (it was shorter in community 1) in this community, by a medium to high density of Blepharocalyx gigantea,Phoebe porphyria, Inga marginata, Athyana wienmannifolia, and by the presence of Chusquea lorentziana in all relevés.

This community shows a close relation with structural type D (Appendix S), presenting a medium cover in the herb stratum, a medium to low cover in the high and low shrubby strata, a high cover in the low tree layer and a very low cover in the higher layer. The species diversity mean value (Appendix P) is intermediate between the values of community 1 and the others, possibly in relation with the altitudinal range in which is found this community, as commented for community 1.

3. Community of Ficus maroma and Miconia molybdea

Sociological species groups: c, d, e, f and g.

This community is found between 650 and 1000 m, only in NW and SW exposures between 650 and 750 m and at any exposure between 750 and 1000 m.

It is characterized by a high density of Phoebe porphyria, a variable density of other tree species, and a high density of low trees or high shrubs like Miconia molybdea, Inga marginata, Urera baccifera, Piper tucumanum and Pogonopus tubulosus. Ficus maroma, a tree species with a crown diameter reaching up to 40 m, if present occupies most of the high and low tree layers giving a particular physiognomy to communities 3 and 4 (Appendix V, photos 3, 4, 7 and 8).

The vegetation structure is very heterogeneous between 650 and 750 m (structural types C, F, H and I are found) but the relevés between 750 and 1000 m are characterized by structural type K when Miconia molybdea is found (the same as for community 1) and by structural type A when this species is absent (Appendix R). The species diversity mean value (Appendix P) is between the values presented by communities 1, 2 and communities 4, 6 and 7, possibly in relation with the altitudinal range of this community, as commented for community 1.

4. Community of Ficus maroma and Terminalia triflora

Sociological species groups: c, d, e, f, g and h.

This community is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

It is characterized by the same sociological groups as community 3 plus group h. However, from the analysis of the species-to-relevé matrix other differences appear. Miconia molybdea is found in less constance than in community 3 and Myrtaceae grow in importance in this community (see Acreugenia pungens and Stenocalyx uniflorus specially) being also abundant in communities 5,6 and 7. Chusquea lorentziana, a bamboo species, was found in this community presenting cover values between 40 and 60%, higher than in other communities. Ficus maroma characterizes this community as well as community 3, but presents here higher cover values in the high tree strata.

Vegetation structural types G, F and H (Appendix S) are the most representative for this community. Structural type G shows relation with spots on which Ficus maroma and Terminalia triflora are found together. Structural type F is similar to G, but the proportion of emergent trees, high in G, is intermediate in F. Type H is associated, the same as in community 5, with high densities of Chusquea lorentziana and/or low shrubs, which result in high cover values in the low shrub stratum and medium to low values in all the other layers. The species diversity mean value (Appendix P) is between the values presented by communities 1,2,3 and communities 6 and 7, possibly in relation with the mean temperatures, as commented for community 1.

5. Community of Acreugenia pungens and Cordia trichotoma

Sociological species groups: c, e, f, g and i.

This community is found between 550 and 650 m in SW, W and NW slope exposures.

It is characterized by the abundance of Acreugenia pungens, the presence of Cordia trichotoma and the general high density of low shrubs like Urera baccifera,Urera caracassana, Solanum riparium, Piper tucumanum and others. Ficus maroma is found specially in the part of the community close to the Pescado river.

Vegetation structural types H, A and I are the most representative for this community (Appendix S) and are characterized by showing a medium to high cover in the low shrub and herb layers and a low cover in the other layers.

The mean species diversity value (Appendix P) is lower than expected according to the altitudinal range in which this community is found, but it is possible that environmental differences between west and east exposures could be also related with species diversity, as suggested by comparing the values from communities 3 and 5 versus communities 4 and 6.

6. Community of Acreugenia pungens and Stenocalyx uniflorus

Sociological species groups: c, d, e, f, g, h and i.

This community is found between 550 and 650 m in NE, E and SE slope exposures.

It is characterized by a high abundance of two Myrtaceae, Acreugenia pungens and Stenocalyx uniflorus. Even when it differs from community 4 only by the presence of sociological group i, there are other differences. Ficus maroma and Chusquea lorentziana (species groups g and e) show in general lower density in community 6 than in 4 and Stenocalyx uniflorus (species group h) is more abundant in community 6.

The structure is also different than in community 4. The most representative structural types are B, C and E (Appendix S). The first two types have in general a medium to low cover in all layers and type E is characterized by a very thick low tree layer. The species diversity mean value (Appendix P) is between the values of communities 1, 2, 3, 4, 5 and community 7, possibly in relation with the altitudinal range in which this community is found, as commented in community 1.

7. Community of Chrysophyllum gonocarpum & Stenocalyx uniflorus

Sociological species groups: c, (d), e, f, h and i.

This community is found between 450 and 550 m.

It is characterized by the presence of Chrysophyllum gonocarpum, C. marginatum, the abundance of the Myrtaceae characterizing community 6 and the high density of low shrubs. Ficus maroma is not found in this community and Chusquea lorentziana frequency is low.

The most representative vegetation structural type is I (Appendix S) with a high low shrub and herb layer cover and a medium to low cover in the other layers. The species diversity mean value (Appendix P) is the highest one, possibly in relation with the altitudinal range in which this community is found, as commented in community 1.

6.3 Structure

Vegetation structure is analyzed in terms of percentage of aerial cover per layer (Chapter 2). For this, the five following strata were distinguished in the field (table 1):

1) High tree stratum (+ 18,0 m)

This layer is occupied by the emergent trees reaching a mean height between 20 and 25 m. The main tree species here are Cedrela angustifolia, Phoebe porphyria, Ficus maroma, Tipuana tipu (Appendix V, photo 7), Lonchocarpus lilloi, Anadenanthera collubrina, Myroxylon peruiferum and Astronium urundeuva.

2) Low tree stratum (8,0 - 18,0 m)

This stratum is occupied by trees reaching a mean height between 10 and 15 m.The main species found in the field are Blepharocalyx gigantea , Phoebe porphyria, Ficus maroma, Tipuana tipu, Parapiptadenia excelsa, Chrysophyllum gonocarpum, Athyana wienmannifolia, Tabebuia lapacho, Ruprechtia laxiflora, Cordia trichotoma , Anadenanthera collubrina, Myroxylon peruiferum , Inga marginata , Miconia molybdea, Acreugenia pungens, Pisonia zapallo,Phyllostylon rhamnoides, Nectandra pichurium, Phitecellobium grisebachianum, Astronium urundeuva and Terminalia triflora.

3) High shrub stratum (3,5 - 8,0 m)

This stratum is occupied by woody species with a mean height between 4 and 7 m. The main species here are Inga marginata, Miconia molybdea, Prunus tucumanensis, Chusquea lorentziana,Rhamnus polymorphus,Urera baccifera,U.caracasana Piper tucumanum, Chrysophyllum gonocarpum, C. marginatum, Pogonopus tubulosus, Cordia trichotoma, Solanum riparium, Pisonia zapallo, Phyllostylon rhamnoides, Nectandra pichurium, Acreugenia mato, Phitecellobium grisebachianum and Stenocalyx uniflorus.

4) Low shrub stratum (1,5 - 3,5 m)

This stratum is occupied by woody species and sometimes also by herbs growing higher than 1,5 m. The main species found in the field here are Aegiphyla saltensis, Chusquea lorentziana, Rhamnus polymorphus, Urera baccifera, Urera caracasana, Piper tucumanum, Pogonopus tubulosus and Solanum riparium.

5) Herb stratum (0,1 - 1,5 m)

This stratum is mainly occupied by herbs and some low shrubs and,as commented before (Chapter 2),most of the herbs were not identified on the field. Some of the main species in this stratum are Chusquea lorentziana, Canna compacta, Pteris spp and Heliconia subulata.

The structure data recorded in the field are presented in Appendix L as well as their classification.Twelve structural types are distinguished (Appendix S) and their characteristics are shown in Appendix R. The structural types do not present any clear relation with slope exposure, species diversity, soil reaction (pH), soil colour and texture of top horizon and surface stoniness. However, the structural types are related with terrain units (Appendix N, tables 17, 18 and 20).

Structural types K, E and D are almost exclusively found in the mountaineous area (terrain unit M1). These types are characterized by presenting a high low tree and herb cover, a low proportion of emergents and a medium to low high and low shrubby cover (table 18).

Structural type A is found in the lower mountaineous area (terrain unit M1) and in the bounding hills (terrain units F12 and H3) while types F and H are found in this hilly area. Structural types A, F and H are characterized by presenting an homogeneous medium to low cover in the high and low tree and high shrubby layers. The herb cover is high and the low shrub cover is medium in types A and F while the herb cover is medium and the low shrub cover is high in type H.

Structural types B, C and J are found in the hilly area mainly represented by terrain unit H22. These types are characterized by presenting a medium to low cover in all strata being the proportion of emergents higher than in the mentioned types (table 18).

Structural types G and I are found in valley fills and depositional terraces (terrain units F2 and A2). These types are characterized by presenting a high low shrub and herb cover, a medium to low high shrub and low tree cover and a very high (type G) or low (type I) proportion of emergents.

Each type is described in terms of their mean aerial cover per layer (table 17) and the mentioned relationships between structural types and terrain units are shown in table 18.

Table 17: Mean aerial cover per layer (%) and total cover for the different structural types.

Layer	Height (m)	STRUCTURAL TYPE A	B	C	D	E	F	G	H	I	J	K	L
1	+18	23	35	42	8	10	30	62	30	10	10	5	8
2	8-18	30	25	35	60	62	30	22	30	30	35	60	25
3	3,5-8	30	35	30	28	31	32	24	30	25	40	17	65
4	1,5-3,5	30	30	32	28	43	40	48	60	63	25	25	64
5	0,1-1,5	62	55	30	50	59	75	75	35	71	37	79	75
Total cover		175	180	167	174	205	207	231	185	199	147	186	237

Table 18: Mean aerial cover (%) per layer for groups of structural types related with terrain units.
* only for structural type A.
** only for structural type H.
(see layers height values in table 17)

LAYER	TERRAIN UNIT					
	M1	M1*, H3, F12**		H22	F2, A2	
	STRUCTURAL TYPE					
	K, D, E	A, F	H	B, C, J	G	I
1	5 - 10	25 - 30	30	35 - 42	62	10
2	60 - 62	30	30	25 - 35	22	30
3	17 - 31	30 - 32	30	30 - 40	24	25
4	28 - 43	30 - 40	60	25 - 32	48	63
5	60 - 80	62 - 75	35	30 - 55	75	71

STRUCTURAL TYPE A:

This type is characterized by showing an almost uniform cover in the high and low tree and shrub layers (between 23 and 30%) and a high cover (62%) in the herb layer (table 19 and Appendix S).

It is found between 550 and 750 m in slopes with a steepness between 4 and 100% (Appendix R).

STRUCTURAL TYPE B:

This type is characterized by presenting a relatively uniform cover in the high and low tree and shrub layers (between 25 and 35%), the same as in type A, but the proportion of high trees is higher and the proportion of herbs (55%) is slightly lower than in type A.

It is found between 530 and 580 m in slopes with a steepness between 60 and 80%.

STRUCTURAL TYPE C:

This type is characterized by showing a very uniform cover in the low tree, high and low shruby and herb layer (between 30 and 35%) and a slightly higher cover of emergents (42%).

It is found between 590 and 660 m in slopes with a steepness between 10 and 100%.

STRUCTURAL TYPE D:

This type is characterized by presenting a low proportion of emergents (8%), a high cover in the low tree layer (60%), a medium to low cover in the high and low shrub layers (28%) and a medium cover of herbs (50%).

It is found between 560 and 770 m and also between 1200 and 1250 m in slopes with a steepness between 4 and 90%.

STRUCTURAL TYPE E:

This type is similar to type D, and it is characterized by a low proportion of emergents (10%), a high cover in the low tree layer (62%), a medium cover of the high and low shruby layers (31 and 43% respectively) and a medium to high herbs cover (59%).

It is found between 550 and 720 m, in SE slopes with a steepness between 65 and 100%.

STRUCTURAL TYPE F:

This type presents a very uniform cover of high and low trees and high shrubs, between 30 and 32%, a slightly higher cover of low shrubs (40%) and a high cover of herbs (75%).

It is found between 650 and 750 m in slopes with a steepness between 14 and 75%.

STRUCTURAL TYPE G:

This type shows a high cover of high trees (62%), a low cover of low trees and high shrubs (22 to 24%), a medium cover of low shrubs (48%) and a high cover of herbs (75%).

It is found between 570 and 670 m, in SE and E slopes with a steepness between 2 and 14%.

STRUCTURAL TYPE H:

This type presents a very uniform cover of high and low trees, high shrubs and herbs (30 to 35%) and a high cover of low shrubs (60%).

It is found between 640 and 720 m in slopes with a steepness between 25 and 70%.

STRUCTURAL TYPE I:

This type shows a low proportion of emergents (10%) a medium to low cover in the low tree and high shrub strata (25 to 30%) and a high low shrubs and herbs cover (63 to 71%).

It is found between 510 and 620 m in slopes with a steepness between 0 and 6%.

STRUCTURAL TYPE J:

This type presents a low proportion of emergents (10%) a medium cover of low trees, high shrubs and herbs (35 to 40%) and a medium to low cover of low shrubs (25%).

It is found between 530 and 580 m in slopes with a steepness between 70 and 100%.

STRUCTURAL TYPE K:

This type presents a very low proportion of emergents (5%), a high cover of low trees (60%), a medium to low high and low shrubs cover (17 to 25%) and a very high cover of herbs (79%).

It is found between 800 and 1450 m in slopes with a steepness between 8 and 100%.

STRUCTURAL TYPE L:

This type shows a low cover of high trees (8%), a medium to low cover of low trees (25%) and a high cover in the high and low shrub and herb layers (64 to 75%).

This type is found in only two relevés presenting a very different altitude and slope steepness. Therefore, it will not be used for characterizing land-units.

6.4 Comparison of vegetation structure and floristic classifications

The value of combining structure and floristic composition is great as they are both the most secure basis of all subsequent knowledge of habitat (Zonneveld & Küchler, 1988b, Ch.5). However, a structural vegetation type does not necessarily correspond to a floristic one (Gils & Wijngaarden, 1984; Zonneveld & Küchler, op.cit) and they can relate with different environmental factors (Van der Meulen & Gils, 1983).

In this study, from the structure and floristic data analysis the following conclusions are derived:

1) The relation of floristic communities with terrain units is low, except for communities 1 ,2 (exclusively found in terrain unit M1) and 8 (exclusively found in terrain unit A1).

2) Floristic communities show a close relationship with altitude and slope exposure (Appendices P and Q) and do not present so much relation with other terrain or soil parameter.

3) Floristic communities present a variable association with structural types (Appendices N, P and R), as summarized in table 19.

Table 19: Floristic communities most representative structural types.
(1) = percentage on which the given structural types are found among the relevés made on each community.

Floristic community	Most representative structural types	(1) %
1	K	50
2	D	75
3	A - K	40
4	H - G - F	78
5	I - A - H	77
6	B - E - C	64
7	I	33

From the analysis of table 19, it can be concluded that communities 2, 4, 5 and 6 show a good association with structural types. Community 1 shows also some association with structural type K, and this association is less clear for communities 3 and 7.

4) Structural types are related with terrain, as shown in table 20. However, as only two relevés were made in terrain units F11 and H1 and three in terrain unit H21, and the structure was not homogeneous within these units, the recorded data are not enough to characterize the vegetation structure in the mentioned terrain units.

Table 20: Terrain units most representative structural types
(1) = percentage on which the given structural types are found among the relevés made on each terrain unit.

Terrain unit	Most representative structural types	(1) %
M1	K - E - D - A	81
H1	-	-
H21	-	-
H22	B - C - J	75
H3	A - F - H	86
F11	-	-
F12	H	50
F2	I - G	67
A2	I	67

5) Vegetation structure and floristic composition are related with different land ecological factors. Floristic composition is related with altitude and slope exposure while structure is associated with terrain units (tables 15 and 18).

CHAPTER 7: LAND UNITS

7.1 Introduction

The land unit map of the study area is presented in Appendix F. The symbols used for each land unit indicate a terrain unit combined with a floristic community.For example, land unit M1/1 represents the area of the terrain unit M1 in which floristic community 1 is found. The area occupied by each land unit is given in Appendix U.

The legend of the land unit map is presented in table 21, and includes in the heading the hierarchical levels of land units (Zonneveld, 1979), their equivalents terrain units hierarchies (table 11) and the guiding principles used for defining them in this study.

Land units are characterized at the land facet level in terms of main origin, spatial relation (valley density, internal relief and slope steepness), morphology, lithology, geological formation and modifications due to geomorphologic active processes (table 21). Land facets are described in terms of calculated maximum cold air flux accumulation, temperature values taken from Landsat TM band 6 (mean and standard deviation), main soil subgroups, soil texture and colour of top horizon, soil reaction (pH), surface stoniness, soil drainage, erosion processes and vegetation structural types. These characteristics are presented in Appendix M. Stratigraphy, lithology, altitude, slope steepness, drainage pattern (type and density) and internal relief are shown there (see also Chapter 4).

The only soil parameter that shows some relation with other land characteristics is effective depth.This parameter is related with slope steepness, land facets and soil subgroups. The effective depth is generally higher than 50 cm in slopes with a steepness between 0 and 20% while it varies between 10 and 100 cm in slopes steeper than 20%. It is higher than 50 cm in land facets H1, H21, H22, F2 and A2, variable between 10 and 100 cm in land facets M1,F11 and F12 and in land facet H3 it is always lower than 50 cm (table 22). The effective depth is between 10 and 50 cm in lithic Orthent (table 14) and higher than 50 cm in the other subgroups. In table 22 are presented the main soil suborders and soil effective depth of each land facet. Lithic Orthent is characteristic of land facet H3 and is found in different proportions in land facets M1, F11 and F12 in steep slopes. In other land facets deeper Inceptisols and Entisols are found. Psamments are found in slopes steepness between 0 and 10% associated to sandy alluvial deposits in old river terraces (land facet A2 and part of F2).

Land units are characterized at the ecotope level in terms of floristic communities. Ecotopes are described in terms of vegetation communities, altitude, slope exposure, annual mean temperature and annual mean precipitation.

For some ecotopes, soil effective depth, main soil subgroups and structural types are also given.

Table 21: Legend of the land unit map of the Pescado area, NW Argentina. Ecotopes occupying less than 5% of the area of their respective land facet are not included (Appendix U).
Vd = valley density
IR = internal relief
S = slope steepness
* see references for communities in Appendix F.

L A N D U N I T H I E R A R C H I C A L L E V E L S				SYMBOL
MAIN LANDSCAPE	LAND SYSTEM	LAND FACET	ECOTOPE	
T E R R A I N U N I T H I E R A R C H I C A L L E V E L S				
MAIN LANDSCAPE	LANDSCAPE	SUB-LANDSCAPE	_	
G U I D I N G P R I N C I P L E S				
spatial relation (Vd, IR, and S) and main origin	morphology (external and internal), lithology and geologic formation	modifications due to geomorphologic active processes	floristic composition *	
Structural-denudational mountains	Broad anticlinal crest in devonian to carboniferous quartzitic sandstones		community 1	M1/1
			community 2	M1/2
			community 3	M1/3
Structural-denudational hills	Narrow anticlinal crest in late tertiary red and yellow sandstones and till		community 3	H1/3
			community 4	H1/4
			community 5	H1/5
			community 6	H1/6
			community 7	H1/7
	Hogbacks in late tertiary red and yellow sandstones and tuff	moderately dissected	community 5	H21/5
			community 6	H21/6
			community 7	H21/7
		very dissected	community 3	H22/3
			community 4	H22/4
			community 5	H22/5
			community 6	H22/6
			community 7	H22/7
	Denudational hills in early tertiary to plio-quaternary conglomerates		community 3	H3/3
			community 4	H3/4
Colluvio-alluvial footslopes	Mud flow deposits from quartzitic sandstones	terraced fans	community 3	F11/3
			community 4	F11/4
		ravines and slopes complexes	community 3	F12/3
			community 4	F12/4
	Colluvial footslopes & colluvio-alluvial valley fills		community 3	F2/3
			community 4	F2/4
			community 5	F2/5
			community 6	F2/6
			community 7	F2/7
Alluvial plains of braided-meandering rivers	floodplain		community 8	A1/8
	depositional terraces		community 5	A2/5
			community 7	A2/7

Table 22: Main soil subgroups and soil effective depth (cm) on each land facet.

Land facet	Main soil suborders	Soil effective depth
M1	Eo - lEo - Iu - Io	10 - 100
H1	Eo	100 - 100
H21	Ia - Iu - Eo	80 - 100
H22	Io - Eo	50 - 100
H3	lEo	10 - 50
F11	lEo - Iu	20 - 90
F12	lEo - Iu - Io	15 - 100
F2	Eo - Ep - Iu	70 - 100
A2	Ep	60 - 80

7.2 Land unit description

The land unit description follows bellow:

LAND FACET M1:

In all this land unit signs of sheet and gully geological erosion are found, such as high soil accumulation behind trees and vegetated gullies and also terracettes, micro- and macro-landslides are present everywhere.

The maximum catabatic flux value obtained within this unit is 400 RU (= relative units) and, as can be seen in the Landsat thermography (Appendix I), the lowest mean temperature values are found in this unit, in relation with their higher altitude values (see section 3.7). The standard deviation of the temperature values is the highest one in the study area, in relation with the pronounced internal relief of this unit (section 3.7 and Appendix M).

The more abundant soil subgroups in this unit are Orthents (40%), lithic Orthents (30%), Umbrepts (18%) and Ochrepts (12%). The percentage given for each soil type is the proportion of all relevés of a land facet belonging to this type.

The texture on the top horizon is loamy sand to sandy loam and the colour is dark brown to dark reddish brown. Drainage is well and pH at 20 cm depth is between 5,0 and 6,5. Surface stoniness is between 3 and 20% and some rock outcrops were observed. The effective soil depth presents a wide range. It is between 10 and 40 cm in lithic Orthents, between 40 and 100 cm in Orthents, and 100 cm in Umbrepts and Ochrepts.

The main vegetation structural types are K, E, D and A (table 18).

Ecotope M1/1:

This ecotope is characterized by floristic community 1 (Cordyline dracaenoides - Blepharocalyx gigantea) and it is found between 1300 and 1850 m at all slope exposures.

The main soil type is Orthent and the effective soil depth is between 50 and 100 cm. The annual mean temperature is between 15,0 and 17,1°C (Chapter 3) while the annual mean precipitation is between 2600 and 3200 mm.

The main structural type in this unit is K, characterized by showing a very low proportion of emergents, a dense low tree cover, a medium dense to sparce high and low shrubby cover and a very dense herb cover.

Ecotope M1/2:

This ecotope is characterized by floristic community 2 (Blepharocalyx gigantea - Chusquea lorentziana) and it is found between 1000 and 1300 m at all slope exposures.

The main soil type is lithic Orthent, being Orthent and Ochrept also found. The effective depth is variable between 30 and 100 cm.The annual mean temperature is between 17,1 and 18,4°C while the annual mean precipitation is between 2100 and 2600 mm.

The main structural type in this ecotope is D, characterized by presenting a low proportion of emergents, a dense low tree cover, a medium dense to sparce cover in the high and low shrubby layers, and a medium herb cover.

Ecotope M1/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 1000 m, only in NW and SW slope exposures between 650 and 750 m and at any slope exposure between 750 and 1000 m.

The main soil types are lithic Orthent and Umbrept. The effective soil depth is variable between 30 and 90 cm. The annual mean temperature is between 18,4 and 20,0 °C while the annual mean precipitation is between 1550 and 2120 mm.

The main structural types in this ecotope are K and A. The first is described for the ecotope M1/1 and the second one is characterized by showing a medium dense to sparce high and low tree and high and low shrubby layers cover and a high herb cover.

LAND FACET H1:

In all this land unit signs of active sheet erosion and landslides of all sizes were found.

The maximum catabatic flux value is low (100 RU) and the mean temperature given by Landsat thermography (Appendix I) is higher than in the previous land facet as expected because of the lower altitude of this land facet.Temperature differences between eastern and western slopes within this unit as well as standard deviations are lower than in M1 in relation with the lower internal relief of this unit (section 3.7 and Appendix M).

The only soil subgroup found within this unit is Orthent (Chapter 5). The texture on the top horizon is loamy to loamy sand and the colour is dark reddish brown. Drainage is well and pH at 20 cm depth is the parameter with a wider range, varying between 4,5 and 6,5. Surface stoniness is between 3 and 10% and effective soil depth is 100 cm.

Data on vegetation structure are very heterogeneous to arrive at any conclusion.

Even when only ecotopes H1/5 and H1/6 were identified in the field within this unit, according to the vegetation-environment analysis (Chapter 6), also ecotopes H1/3, H1/4 and H1/7 should be found within this unit. As the very steep relief and the landslides found everywhere make this unit unsuitable for coffee or any other crop of this unit, few relevés were done here.

Ecotope H1/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 860 m, only in NW and SW exposures between 650 and 750 and at all exposures between 750 and 860 m.

The annual mean temperature is between 19,0 and 20,0°C and the annual mean precipitation is between 1550 and 1900 mm.

Ecotope H1/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

Ecotope H1/5:

This ecotope is characterized by floristic community 5 (Acreugenia pungens - Cordia trichotoma) and it is found between 550 and 650 m in SW, W and NW slope exposures.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H1/6:

This ecotope is characterized by floristic community 6 (Acreugenia pungens - Stenocalyx uniflorus) and it is found between 550 and 650 m in NE, E and SE slope exposures.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H1/7:

This ecotope is characterized by floristic community 7 (Chrysophyllum gonocarpum - Stenocalyx uniflorus) and it is found between 450 and 550 m at any slope exposure.

The annual mean temperature is between 20,4 and 20,8°C and the annual mean precipitation is between 1230 and 1400 mm.

LAND FACET H21:

Even in places with a slope angle of 4% signs of sheet and gully erosion (soil accumulation behind old trees, vegetated gullies up to 1 m width) were found, while in steeper spots terracettes and micro-landslides were also observed.

The maximum catabatic flux value is low (50 RU). The mean temperature value taken from Landsat thermography (Appendix I) is low possibly in relation with the low altitude of this unit. The standard deviation of these temperature values is also low due to the low internal relief (section 3.7 and Appendix M).

The soil subgroups in this unit are Andept, Umbrept and Orthent. The texture on the top horizon is loamy to loamy sand and the colours are dark brown, dark reddish brown and reddish brown. pH at 20 cm depth is between 5,0 and 5,5 and surface stoniness is always less than 1%. Drainage is well and the effective soil depth is higher than 80 cm.

Vegetation structural types E, D and A are found in this unit. Type A is described for ecotope M1/3 and types E and D are characterized by presenting a low proportion of emergent trees, a dense low tree cover, a medium dense to sparce high and low shrubby cover and a medium dense to high herb cover.

Ecotope H21/5:

This ecotope is characterized by floristic community 5 (Acreugenia pungens - Cordia trichotoma) and it is found between 550 and 650 m in SW, W and NW slope exposures and in flat terrain.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H21/6:

This ecotope is characterized by floristic community 6 (Acreugenia pungens - Stenocalyx uniflorus) and it is found between 550 and 650 m in NE, E and SE slope exposures.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H21/7:

This ecotope is characterized by floristic community 7 (Chrysophyllum gonocarpum - Stenocalyx uniflorus) and it is found between 490 and 550 m at any slope exposure.

The annual mean temperature is between 20,4 and 20,6°C and the annual mean precipitation is between 1300 and 1400 mm.

LAND FACET H22:

All the unit shows geological sheet and gully erosion. Landslides are so common here that the shape of the slopes is often given by their scars.

The maximum catabatic flux value is 100 RU. The temperature mean value taken from Landsat thermography (Appendix I) is low, possibly due to the altitude, slope exposure and main vegetation structure, and the standard deviation of these values is intermediate in relation with the relief intensity of this unit (section 3.7 and Appendix M).

The soil subgroups found in the unit are Orthents (50%), lithic Orthents (10%) and Ochrepts (40%). The texture on the top horizon is loamy sand to sandy loam and the colours vary from dark reddish brown to strong brown. pH at 20 cm depth is between 5,5 and 6,5 and surface stoniness is between 0 and 5%. The minimum effective depth is generally higher than 50 cm but shallow soils (lithic Orthents) are also found as well as some rock outcrops.

Structural types B,C and J are almost exclusively found in this unit. These types present a medium dense to sparce cover in all strata showing some differences in the percentages of emergent trees and herbs.

Ecotope H22/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 750 m in NW and SW slope exposures.

The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

Ecotope H22/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

Ecotope H22/5:

This ecotope is characterized by floristic community 5 (Acreugenia pungens - Cordia trichotoma) and it is found between 550 and 650 m in SW, W and NW slope exposures and in flat terrain.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H22/6:

This ecotope is characterized by floristic community 6 (Acreugenia pungens - Stenocalyx uniflorus) and it is found between 550 and 650 m in NE, E and SE slope exposures.

The main soil subgroup in this unit is Orthent and soil effective depth is generally higher than 70 cm. The annual mean temperature is between 20,0 and 20,4°C while the annual mean precipitation is between 1400 and 1550 mm.

Ecotope H22/7:

This ecotope is characterized by floristic community 7 (Chrysophyllum gonocarpum - Stenocalyx uniflorus) and it is found between 500 and 550 m at any slope exposure.

The main soil subgroup in this unit is Ochrept and soil effective depth is higher than 80 cm. The annual mean temperature is between 20,4 and 20,6°C and the annual mean precipitation is between 1300 and 1400 mm.

LAND FACET H3:

This unit shows geological sheet and gully erosion and landslides are found everywhere. However, narrow 'U' shaped valleys less steep than the rest of the unit are also found. In one of the valleys a small and recent coffee plantation was found.

The maximum cold air accumulation is 200 RU. Temperature values shown by Landsat thermography (Appendix I) are high possible due to the effect of slope exposure and vegetation structure characteristics and their standard deviation is intermediate to high in relation with the internal relief of this unit (section 3.7 and Appendix M).

The main soil type in the unit is lithic Orthent. The texture on the top horizon is in general sandy loam and the dominant colours are dark reddish brown to dark brown. Drainage is well and pH at 20 cm depth is between 5,0 and 6,0. Surface stoniness varies between 1 and 15% and the soil effective depth is between 10 and 50 cm.

The main structural types are A,F and H. Types A and F are characterized by a medium dense to sparce tree and shrubby cover and a medium dense (type A) to dense (type F) herb cover. Type H is very different and also characterizes the F11 land facet. It shows a medium dense to sparce tree, high shrub and herb cover and a medium dense to dense low shrub cover.

Ecotope H3/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 1000 m, only in NW and SW slope exposures between 650 and 750 m and at any exposure between 750 and 1000 m.

The annual mean temperature is between 18,4 and 20,0°C and the annual mean precipitation is between 1550 and 2120 mm.

Ecotope H3/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

The main soil subgroup is lithic Orthent and soil effective depth is generally between 10 and 35 cm. The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

LAND FACET F11:

This land unit presents geological sheet and gully erosion everywhere and in steeper places also terracettes and micro-landslides were observed in association with shallow soils (Lithic Orthents).

The maximum cold air accumulation is 50 RU.The temperature values derived from Landsat thermography (Appendix I) are very high and uniform within the unit (section 3.7 and Appendix M).

The main soil types are Umbrepts and lithic Orthents. The texture of the top horizon is sandy loam and the colour is dark reddish brown.Drainage is in general well and the pH at 20 cm depth is between 5,0 and 5,5. Surface stoniness is between 5 and 10% and minimum effective depth is between 20 and 90 cm, the lower values related with lithic Orthents and steepness values higher than 20%, and the deeper soils are associated with Umbrepts and steepness values lower than 20%.

The main vegetation structural type in this unit and also in the land facet F12 is H. It is characterized by a medium dense to sparce cover in all strata except in the low shrub layer, being there medium dense.

Ecotope F11/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 700 and 1000 m, only in NW and SW slope exposures between 700 and 750 m and at any exposure between 750 and 1000 m.

The annual mean temperature is between 18,4 and 19,8°C and the annual mean precipitation is between 1640 and 2100 mm.

Ecotope F11/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 700 and 750 m mainly in S, SE, E and NE slope exposures.

The annual mean temperature is between 19,5 and 19,8°C and the annual mean precipitation is between 1640 and 1720 mm.

LAND FACET F12:

In this land unit signs of sheet and gully erosion have been observed everywhere and landslides and terracettes are found in many places.

The maximum cold air flux values are very high (600 RU). The temperature values derived from Landsat thermography (Appendix I) are relatively high and their standard deviation is intermediate to low due to the internal relief characteristics of this unit (section 3.7 and Appendix M).

The main soil types in the unit are lithic Orthents (55%), Umbrepts (30%) and Ochrepts (15%). The texture on the top horizon is loamy to sandy loam and the dominant colours are dark reddish brown and dark yellowish brown. The pH at 20 cm depth is between 5,0 and 6,5 and drainage is in general well. Surface stoniness is between 3 and 10% and minimum effective soil depth is between 15 and 50 cm in lithic Orthents and between 75 and 100 cm in Inceptisols. Lithic Orthents are found in slopes steeper than 25% while Inceptisols occur in slopes with less than 23% of steepness.

Vegetation structural type H is the most characteristic for this land facet as well as for land facet F11. This type shows a medium dense to sparce cover in all strata except in the low shrub layer, being there medium dense.

Ecotope F12/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 1000 m, only in NW and SW slope exposures between 650 and 750 m and at any exposure between 750 and 1000 m.

The annual mean temperature is between 18,4 and 20,0°C and the annual mean precipitation is between 1550 and 2120 mm.

Ecotope F12/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

LAND FACET F2:

This land unit shows geological sheet erosion in some places.

The cold air flux accumulation is very high in many parts of this unit reaching values up to 800 RU. The temperature values derived from Landsat thermography (Appendix I) are in general medium to low in comparison with other units (section 3.7 and Appendix M)

The main soil types in the unit are Orthents (46%), Psamments (38%) and Umbrepts (16%). The texture on top horizon is in general sandy loam to sandy and the dominant colours are dark reddish brown, dark brown and dark yellowish brown. pH at 20 cm depth is between 5,0 and 7,0 and drainage is in general well. Surface stoniness is between 0 and 5% and the effective soil depth is higher than 70 cm.

Vegetation structural types G and I are the most representative for this unit and also for the land facet A2. Type G is characterized by having a medium to high cover of emergent trees, a medium to low cover of low trees and high shrubs, a medium cover of low shrubs and a high cover of herbs. Type I shows a low proportion of emergents and a medium to low cover of low trees and high shrubs, and a medium to high cover of low shrubs and herbs.

Ecotope F2/3:

This ecotope is characterized by floristic community 3 (Ficus maroma - Miconia molybdea) and it is found between 650 and 950 m, only in NW and SW slope exposures between 650 and 750 m and at any exposure between 750 and 950 m.

The annual mean temperature is between 18,6 and 20,0°C and the annual mean precipitation is between 1550 and 1930 mm.

Ecotope F2/4:

This ecotope is characterized by floristic community 4 (Ficus maroma - Terminalia triflora) and it is found between 650 and 750 m mainly in S, SE, E and NE slope exposures.

The annual mean temperature is between 19,5 and 20,0°C and the annual mean precipitation is between 1550 and 1720 mm.

Ecotope F2/5:

This ecotope is characterized by floristic community 5 (Acreugenia pungens - Cordia trichotoma) and it is found between 550 and 650 m in SW, W and NW slope exposures and in flat terrain.

The annual mean temperature is between 20,0 and 20,4°C and the annual mean precipitation is between 1400 and 1550 mm.

Ecotope F2/6:

This ecotope is characterized by floristic community 6 (Acreugenia pungens - Stenocalyx uniflorus) and it is found between 550 and 650 m in NE, E and SE slope exposures.

The annual mean temperature is between 20,0 and 20,4°C and the anual mean precipitation is between 1400 and 1550 mm.

Ecotope F2/7:

This ecotope is characterized by floristic community 7 (Chrysophyllum gonocarpum - Stenocalyx uniflorus) and it is found between 450 and 550 m at any slope exposure.

The annual mean temperature is between 20,4 and 20,8°C and the annual mean precipitation is between 1230 and 1470 mm.

LAND FACET A1:

In this land unit no relevés were done because it is not suitable for coffee or any other crop. It does not exist a soil layer and in most of the unit it does not exist any aerial cover other than some sparce grasses and herbs, and some spots of riverine shrublands. This vegetation is refered as community 8.

The cold air accumulation reachs in this unit 800 RU. The temperature values derived from Landsat thermography (Appendix I) are the highest within the study area due to the thermal properties of dry sand, covering most of this unit (section 3.7 and Appendix M).

Ecotope A1/8:

This ecotope is characterized by floristic community 8 and it is found between 450 and 600 m.

The annual mean temperature is between 20,2 and 20,8°C and the annual mean precipitation is between 1230 and 1470 mm.

LAND FACET A2:

This unit does not show any erosion sign.

The maximum cold air flux value is 800 RU. The temperature values derived from Landsat thermography (Appendix I) are medium to high in comparison with other units (section 3.7 and Appendix M).

The only soil subgroup in this unit is Psamment, characterized by presenting a thin top layer developed over old river sandy deposits. The texture on this top layer is loamy sand to sandy and the colours observed are dark reddish brown to dark yellowish brown. pH at 20 cm depth is between 5,0 to 7,0 and surface stoniness is between 0 and 1%. Drainage is well and the effective soil depth is between 60 and 80 cm.

The vegetation structural types observed in this unit are I and G, the same as in land facet F2.

Ecotope A2/5:

This ecotope is characterized by floristic community 5 (Acreugenia pungens - Cordia trichotoma) and it is found between 550 and 610 m.

The annual mean temperature is between 20,2 and 20,4°C and the annual mean precipitation is between 1400 and 1500 mm.

Ecotope A2/7:

This ecotope is characterized by floristic community 7 (Chrysophyllum gonocarpum - Stenocalyx uniflorus) and it is found between 450 and 550 m.

The annual mean temperature is between 20,4 and 20,8°C and the annual mean precipitation is between 1230 and 1470 mm.

CHAPTER 8: LAND EVALUATION FOR COFFEE

8.1 Introduction

The requirements for Coffea arabica, the coffee species in NW Argentina (Küper & Camargo, 1977), are described. For this the 'land qualities', 'land characteristics' (FAO, 1976; León & Forero, 1982) and called parameters by Küper & Camargo (1977) that define such this suitability in the Province of Salta, are presented in section 8.2. The 'land qualities' are rated and land suitability classes are defined on base of these ratings (section 8.3). The land unit suitability for coffee evaluation and the surface suitable for coffee calculation are presented in section 8.4 Land units are considered at the ecotope level (Chapter 7) in the land evaluation.

8.2 Coffee requirements in terms of land qualities and land characteristics in the Province of Salta

Latitude: It may be lower than 22°37'(Küper & Camargo, 1977) As the study area is located at the north of the Tropic of Capricorn (22°37'; Appendix A), this quality can be omitted in the land evaluation.

Altitude: Coffee grows in the Province of Salta between 500 and 900-1000 m (Küper & Camargo, 1977). The altitude in the study area ranges between 450 and 1850 m, being related to Climate (Chapter 3). Coffee requires (Küper & Camargo, 1977) an annual mean temperature between 18,0 and 22,0 °C and an annual rainfall higher than 1400 mm for a high density coffee plantation and between 1000 and 1400 mm for a low density one. As can be seen in tables 3 and 4, the part of the study area between 550 and 1000 m satisfies the requirements of a high density coffee plantation while the area between 450 and 550 m satisfies the requirements for a low density one.The part of the area between 1000 and 1850 m is not suitable for coffee in relation with their annual temperature mean values.

Therefore,in the further coffee suitability evaluation the land quality climate is related to altitudinal ranges. Altitudes higher than 1000 are considered not suitable, between 550 and 1000 m are considered highly suitable while between 450 and 550 m are considered moderately suitable.

Slope steepness: Slopes with a steepness between 0 and 40% are suitable for coffee (Küper & Camargo, 1977). This land characteristic is related to the resistance to soil erosion. Signs of geological sheet and gully erosion where observed everywhere within the study area. Mass movements as terracettes and micro- and macro-landslides were found in slopes steeper than 55%. The main textural classes found in the study area are highly susceptible to erosion (Foster et al,1985) and the rainfall erosivity in NW Argentina is high

(Spescha,1987). Therefore, slope steepness higher than 40% is considered as not suitable for coffee and a steepness between 20 and 40% is considered moderately suitable for coffee. Our arguments may be supported by the Federación Nacional de Cafeteros de Colombia (1975) recommendation of not to crop coffee in slopes steeper than 40% in Colombia, where similar soil and rainfall conditions occur.

Soil reaction (pH): For coffee soil pH is preferably between 5,0 and 6,5 , but a pH between 4,5 and 7,0 is tolerated (Küper & Camargo, 1977). The soils of the study area present a pH between 4,5 and 7,0.Therefore this land characteristic is not considered in the further evaluation.

Texture of the top soil horizon: Coffee requires a medium, neither very heavy nor very loose, texture. Loamy and related textural classes are the best ones (Küper & Camargo, 1977).As the main textural classes of top horizon within the study area are loamy, loamy sand and sandy loam, this land characteristic is not considered in the further evaluation.

Fertility: Coffee requires a high fertility (Fed.Nac.Caf. Col.1979).Even when the soils of the study area could be possibly defficient in Phosphorus, Nitrogen and Potasium, fertilization can be done economically (Kuper & Camargo, op. cit). Therefore, this land quality is omitted in the land evaluation.

Moisture availability: Coffea arabica tolerates an annual water deficit of 150 mm and requires a minimum surplus of 100 mm (Küper & Camargo, 1977). In the study area, every point between 500 and 1000 m sloping 60% or less to any orientation fulfills this condition (table 6). However, in coffee plantations close to the study area found on slopes facing the north, signs of water deficiency were observed. This could be interpreted better if following the criterium given by Burgos & Forte Lay (1983) two drought levels are taken, one absolute coincident with wilt point (WP), considered by Zuviría & Burgos (1986) as equal to 40% of field capacity (FC) in the study area. Then, if FC = 150 mm, WP = 0,4 x 150 mm = 60 mm. The second level stands for a conditional drought (CD) that would take place when reaching 50% of the available water in a situation of high atmospheric demand, being here CD = WP + 0,5 (FC - WP) = 60 + 0,5 (150 - 60) = 105 mm. Therefore, as shown in table 6, the permanent wilting condition is sustained for a long period on slopes at 575 m sloping 60% to the north which can represent important losses in a non-irrigated coffee plantation.On northern slopes at 875 m the situation is less critical. In flat terrain and eastern and western slopes the conditional drought situation is common during the dry period and it can turn critical only ocassionally. On southern slopes it is difficult to reach even a conditional drought situation and are the ones with less water limitations.In addition to this, as a water holding capacity of 150 mm is taken for calculating the water balances, the droughts will be more severe in shallow soils, presenting a lower water holding capacity.

Because of the fact that within each land unit are found northern and southern exposures, presenting the highest moisture availability differences, slope exposure will not be taken into account for rating this land quality. Moisture availability is considered in the land evaluation in relation with the soil effective depth. According to Küper & Camargo (1977) coffee preferably grows in the study area in soils deeper than 50 cm, but if the soil is between 30 and 50 cm it is possible to crop coffee expecting some moisture availability limitations. Therefore It is considered in the further coffee suitability evaluation that soil effective depths higher than 50 cm are highly suitable for coffee, effective depths between 30 and 50 cm are moderately suitable for coffee and effective depths lower than 30 cm are not suitable for coffee.

However, the relation between moisture availability, altitude, slope angle and slope exposure shown by the water balances will have to be taken into account for locating the coffee plantations in the land-units presenting at least a moderate suitability for coffee.

Frost hazard: Floristic composition and catabatic flux are the land characteristics used in diagnosing the frost hazard.

Coffee requires absolute minimum temperatures higher than 0 °C (Fed.Nac.Caf.Col., 1979). In the study area with frost frequences of 1 in 10 years or lower coffee is economic (Jakúlica, 1983).

The presence of Ficus maroma indicates frost absence (Jakúlica, per.comm; Ibarguren et al, 1983). Zuviría (1987) related the density of Ficus maroma to frost hazard. This species at high densities is the best indication of frost absence in the study area. In the further coffee suitability evaluation it is considered that floristic communities 3 and 4, with a high density of Ficus maroma indicate absence or very low frost frequency; floristic communities 5 and 6, having a lower density of Ficus maroma, indicate a medium frost frequency, while floristic communities 1, 2 and 7, where Ficus maroma is absent, indicate high frost frequency.

Catabatic flux were calculated for part of the study area (Zuviría & Burgos, 1986) and the relative values obtained related to frost hazard (Zuviría, 1987). In the coffee evaluation it is considered that catabatic flux values higher than 400 relative units (Chapter 3) indicate a high frost frequency while lower values indicate a medium to nule frost hazard.

However, even when in the alluvial plain of the Pescado river, located in the south of the study area, severe frosts should occur according to the catabatic flux model and communities 5 and 6 occur there, frost were not observed in that area in the last 38 years (Jakúlica, 1983). These fact, observed in other rivers of the region by Jakúlica (op.cit), was explained by Zuviría (1987). While crossing through mountaineous ridges in the area the rivers become narrow determining the existence of deep valleys locally called 'angostos'. Through them a strong breeze blows downstream between midnight and early morning during the whole year accompained by a misty airmass in close contact with the water of these rivers, that sweeps away the cold air along the shore.When reaching the footslope area the rivers become wider ending the 'angostos' and the mist is dispersed over the adjoining areas. This misty air retains the outgoing long-wave radiation during the night, producing a 'green house' effect (Geiger, 1950), keeping the temperature two or three degrees higher than in other areas at the same altitude with the same vegetation cover. It was observed in the field a higher density of Ficus maroma in the area close to the Pescado river than in all the other areas occupied by floristic communities 5 and 6.

Therefore, frost hazard is considered very low or nule in land-unit A2/5 and in the part of land-units F2/5 and F2/6 close to the Pescado river.

As frost hazard is estimated for each 'land facet' (=terrain unit; Appendix M) it is considered that cold air flux accumulation in land units F2/3 and F2/4 is very low, according to the cold air flux map covering part of the study area made by Zuviría & Burgos (1986) including 'frost bags' and 'frost pockets' (Mahrt, 1986).

8.3 Land quality rating

The land qualities considered in the coffee suitability evaluation and their rate, established according to the considerations presented in section 8.2, are indicated in table 23.

The symbols proposed by FAO (1976; 1984) for representing land qualities rate and land suitability classes are not used in this evaluation.It is considered better to represent land qualities by capital letters, their rate by arabic numbers and land suitability classes by roman numbers. This is prefered for avoiding confusion in the final land unit suitability table (table 25) between the arabic numbers representing in the FAO system both land qualities rate and land suitability classes. Also, the addition of capital letters for representing land qualities in this study enables to add in the final land suitability class the capital(s) representing the most limiting quality(ies).

Table 23: Land quality rating

LAND QUALITY: CLIMATE

DEGREE	LAND CHARACTERISTIC Altitude (m)
C1	550 - 1000
C2	450 - 550
C3	> 1000

LAND QUALITY: EROSION HAZARD

DEGREE	LAND CHARACTERISTIC Slope steepness (%)
E1	0 - 20
E2	20 - 40
E3	> 40

LAND QUALITY: MOISTURE AVAILABILITY

DEGREE	LAND CHARACTERISTIC soil effective depth (cm)
M1	> 50
M2	30 - 50
M3	< 30

LAND QUALITY: FROST HAZARD

DEGREE	LAND CHARACTERISTIC	
	Catabatic flux (RU)	Floristic communities
F1	< 400	3 and 4
F2	< 400	5 and 6
F3	> 400	1, 2 and 7

Three overall coffee suitability classes are considered:

Class I : Highly suitable: no limitations for coffee.

Class II : Moderately suitable: moderate limitations for coffee, as moderate erosion hazard, low to medium frost hazard or moderate water availability.

Class III: Not suitable: severe limitations for coffee like high erosion hazard, high frost hazard or low water availability.

The land suitability classes are defined on base of the individual land qualities rating (table 23) in table 24.

Table 24: Conversion table. Overall land suitability classes as defined by combinning individual land quality ratings.

LAND SUITABILITY CLASS	LAND QUALITY			
	Climate	Erosion hazard	Moisture availability	Frost hazard
I	C1	E1	M1	F1
II	C2	E2	M2	F2
III	C3	E3	M3	F3

8.4 Land evaluation for coffee suitability

In the land-unit suitability for coffee ecotopes occupying less than 5% of the surface of their respective land facet are not considered (Appendix U). The surface occupied by these ecotopes is considered as belonging to the other ecotopes of the same land facet. The results are presented in table 25.

Table 25: Land unit suitability classes for coffee.
Class I = highly suitable
Class II = moderately suitable
Class III = not suitable

* C = climate E = erosion hazard
M = moisture availability F = frost hazard
LQ = limiting land quality(ies) is(are) added by capital letters to suitability classes.

LAND UNIT	LAND QUALITY C	E	M	F	SUITABILITY CLASS	LQ	AREA (km.2)
M1/1	C3	E3	M1/3	F3	III	C E F	7,7
M1/2	C3	E3	M1/3	F3	III	C E F	10,9
M1/3	C1	E3	M1/3	F1	III	E	8,4
H1/3	C1	E3	M1	F1	III	E	1,5
H1/4	C1	E3	M1	F1	III	E	0,5
H1/5	C1	E3	M1	F2	III	E	1,3

H1/6	C1	E3	M1	F2	III	E	1,0
H1/7	C2	E3	M1	F3	III	E F	0,7
H21/5	C1	E1	M1	F2	II	F	0,7
H21/6	C1	E1	M1	F2	II	F	0,3
H21/7	C2	E1	M1	F3	III	F	1,3
H22/3	C1	E2/3	M1	F1	II-III	E	0,9
H22/4	C1	E2/3	M1	F1	II-III	E	1,1
H22/5	C1	E2/3	M1	F2	II-III	E	4,9
H22/6	C1	E2/3	M1	F2	II-III	E	5,3
H22/7	C2	E2/3	M1	F3	III	F	2,5
H3/3	C1	E1/2/3	M2/3	F1	II-III	E M	16,4
H3/4	C1	E1/2/3	M2/3	F1	II-III	E M	6,2
F11/3	C1	E1	M2/3	F1	II-III	M	1,8
F11/4	C1	E1	M2/3	F1	II-III	M	0,3
F12/3	C1	E1/2/3	M1/2/3	F1	I-II-III	E M	12,9
F12/4	C1	E1/2/3	M1/2/3	F1	I-II-III	E M	4,2
F2/3	C1	E1	M1	F1	I		3,3
F2/4	C1	E1	M1	F1	I		4,1
F2/5	C1	E1	M1	F1/3	I-III	F	6,8
F2/6	C1	E1	M1	F1/3	I-III	F	3,3
F2/7	C2	E1	M1	F3	III	F	3,9
A1/8	C1/2	E1	M3	F3	III	F M	2,2
A2/5	C1	E1	M1	F1	I		1,7
A2/7	C1	E1	M1	F3	III	F	0,4

The area occupied by each land suitability class is approximately:

Class I = 20 km.2 (17% of the study area)
Class II = 25 km.2 (22% of the study area)
Class III = 70 km.2 (61% of the study area)

Therefore, 17% of the study area is highly suitable for coffee, while 22% is moderately suitable and 61% is not suitable for this land utilization type.

CHAPTER 9: CONCLUSIONS

The major aim of this study, the characterization of the land ecological conditions of the Pescado river area, was achieved.

The land unit approach adopted in this study enabled to work out a classification system for soil, topoclimate, geology (stratigraphy and lithology), geomorphology, floristic composition and vegetation structure, and to integrate this information in a systematical way in the final land unit map.The simultaneous collection of various land data at the same spot was fundamental for the relationship analysis among different land attributes and the characterization of land units. Therefore, this study may serve as a base for further thematic or land ecological studies in the area around the survey area.

A land evaluation for coffee was performed on basis of the land unit map. The role played by vegetation communities for indicating and rating frost hazard proved to be essential in the land evaluation.

The identification of seven floristically defined communities may be considered as a significant contribution to the ecology of the tropical rainforest of Latin America where floristic studies are scarce.

Floristic composition of vegetation and vegetation structure are related with different environmental factors. Floristic communities are related with altitude (correlated with temperature and precipitation) and slope exposure while vegetation structural types are related with terrain units. Therefore,it is recommended to include both floristic composition and structure data in any land ecological study.

The surface temperature values derived from the Landsat TM thermography used in this study are related with terrain units and vegetation structural types.Thermal data are therefore a tool for vegetation structure analysis of forest areas.

CHAPTER 10: BIBLIOGRAPHY

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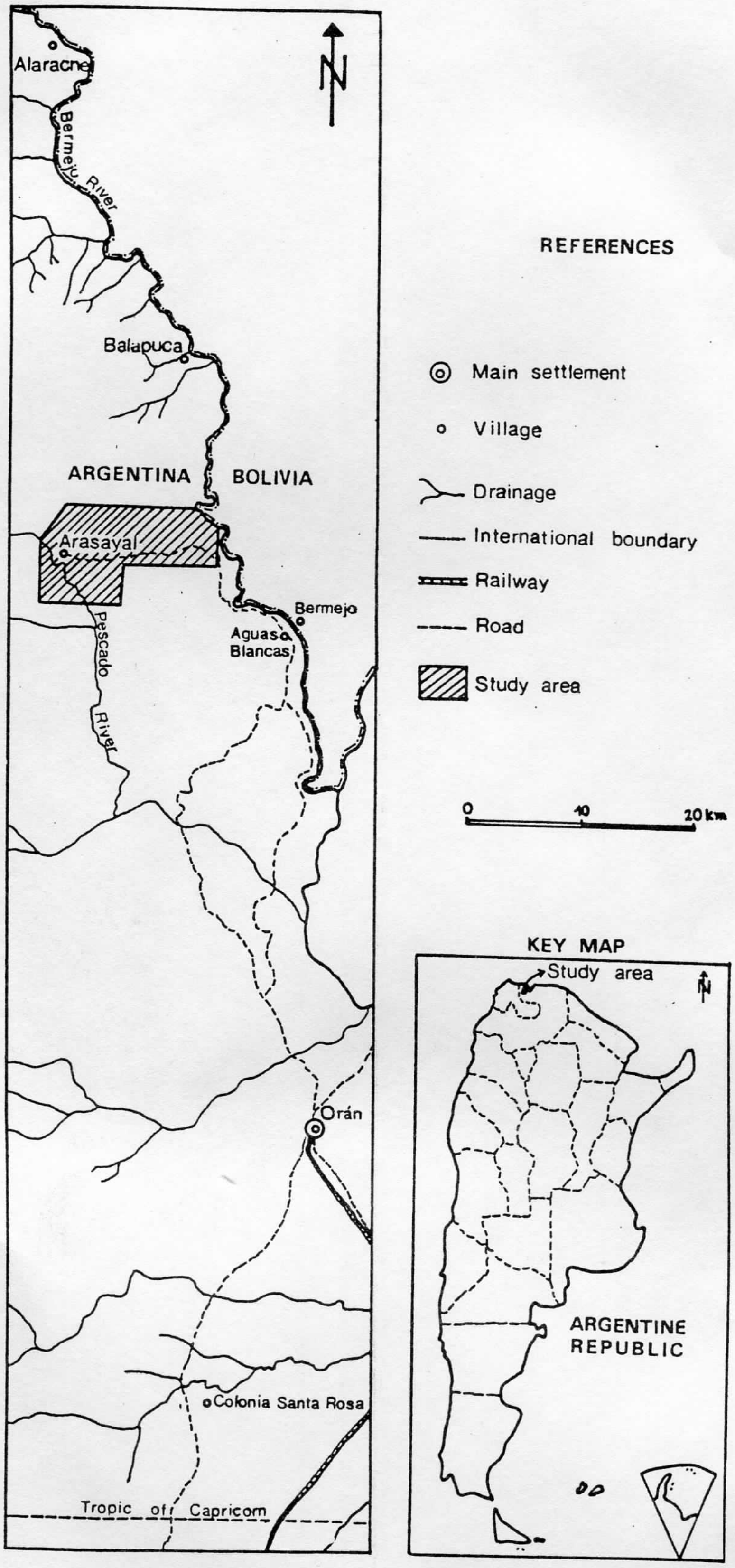
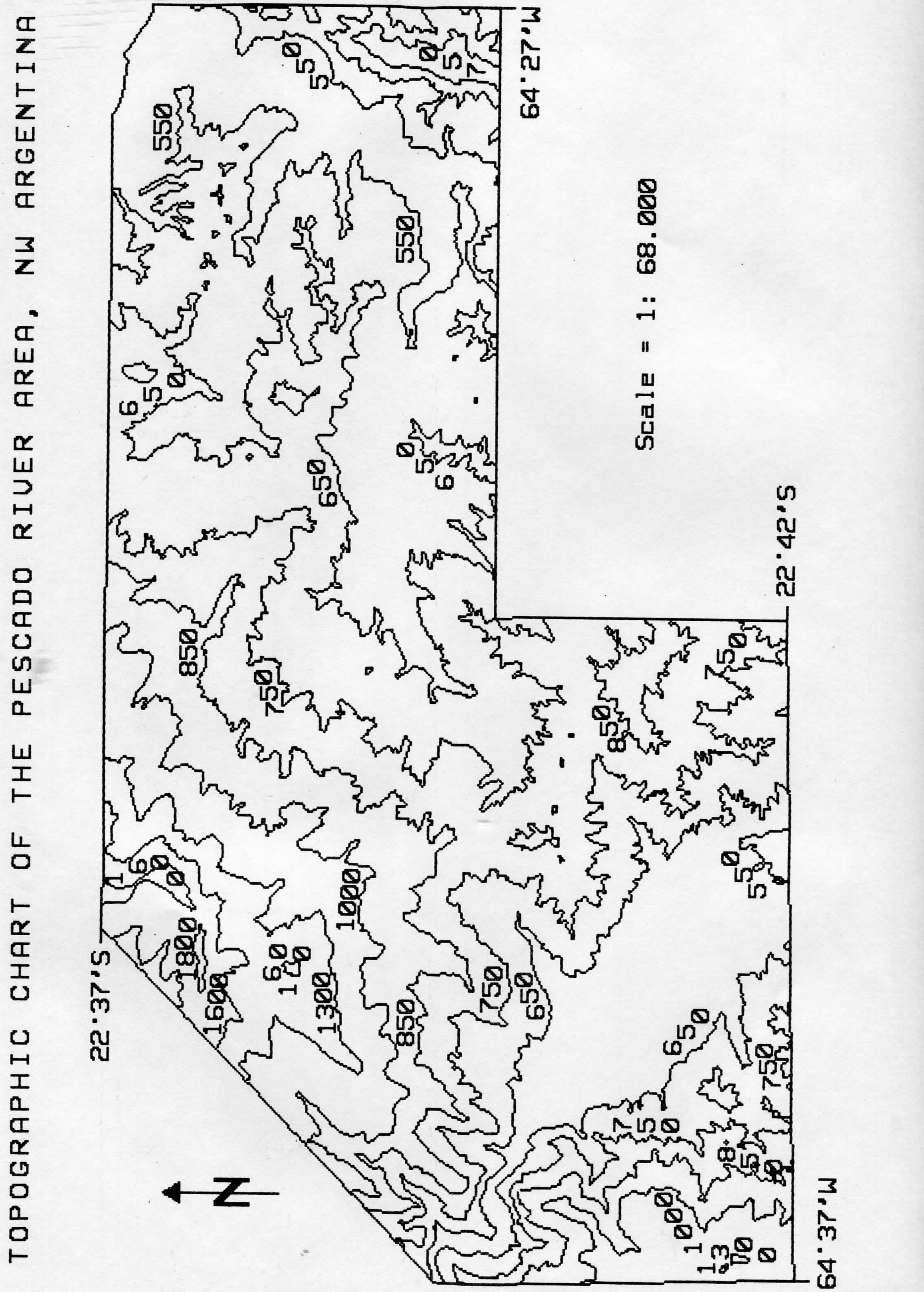
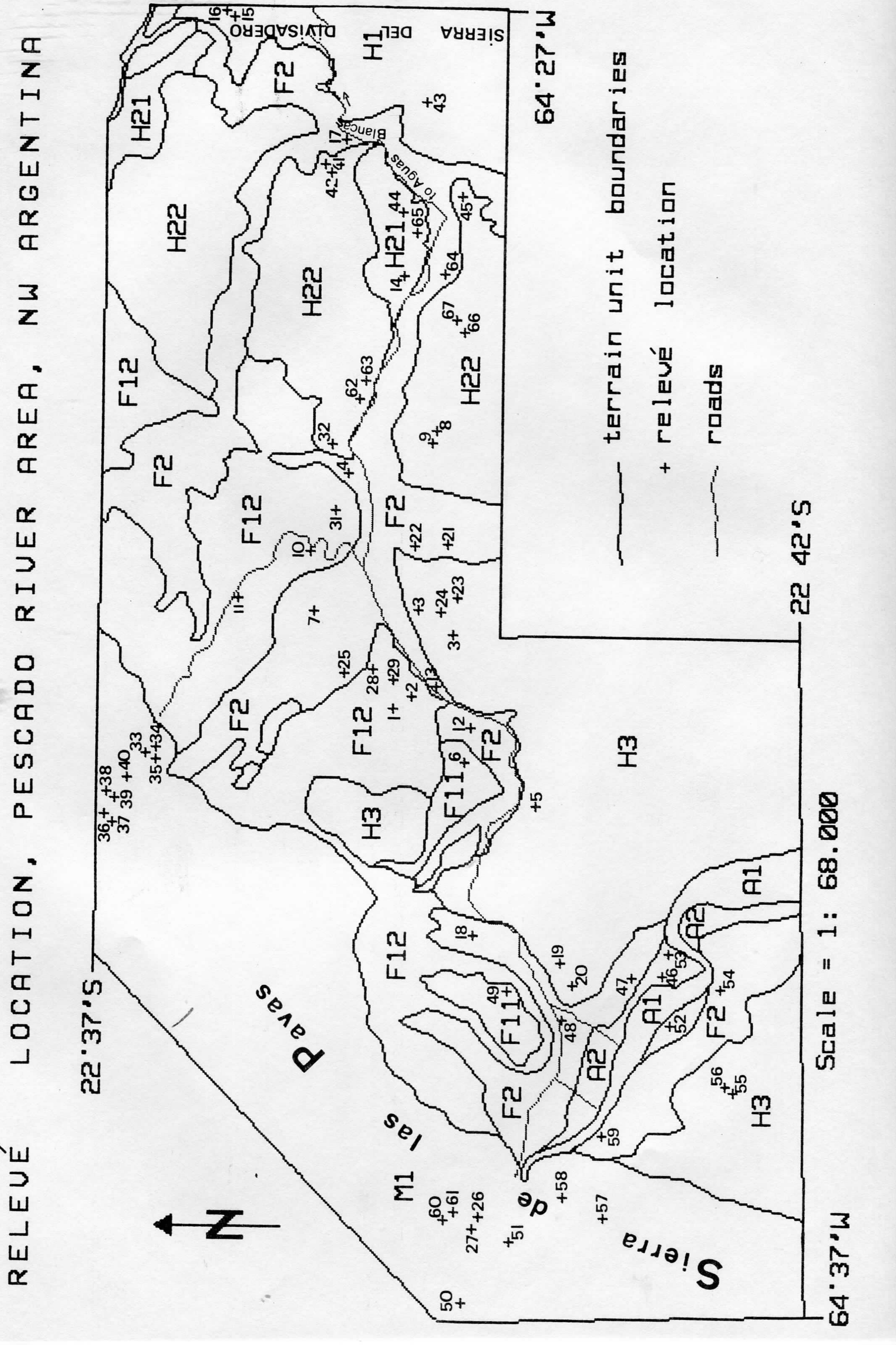
APPENDIX A: Location map



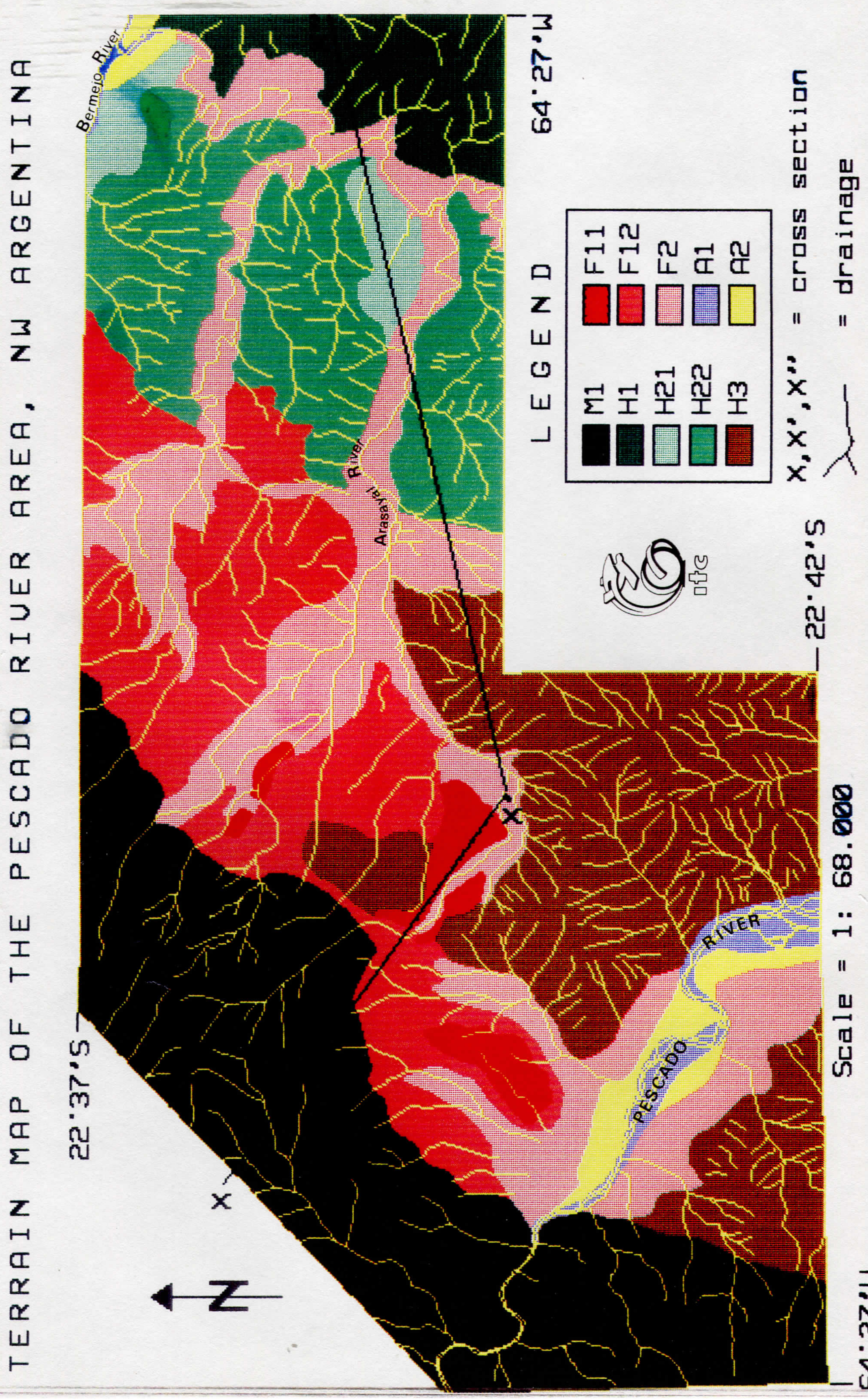
APPENDIX B: Topographic map of the Pescado river area, NW Argentina
(Source: CARTA, 1966, original in scale 1: 20.000)



APPENDIX C: Relevés location map (for terrain references, see Appendix D) of the Pescado area, NW Argentina



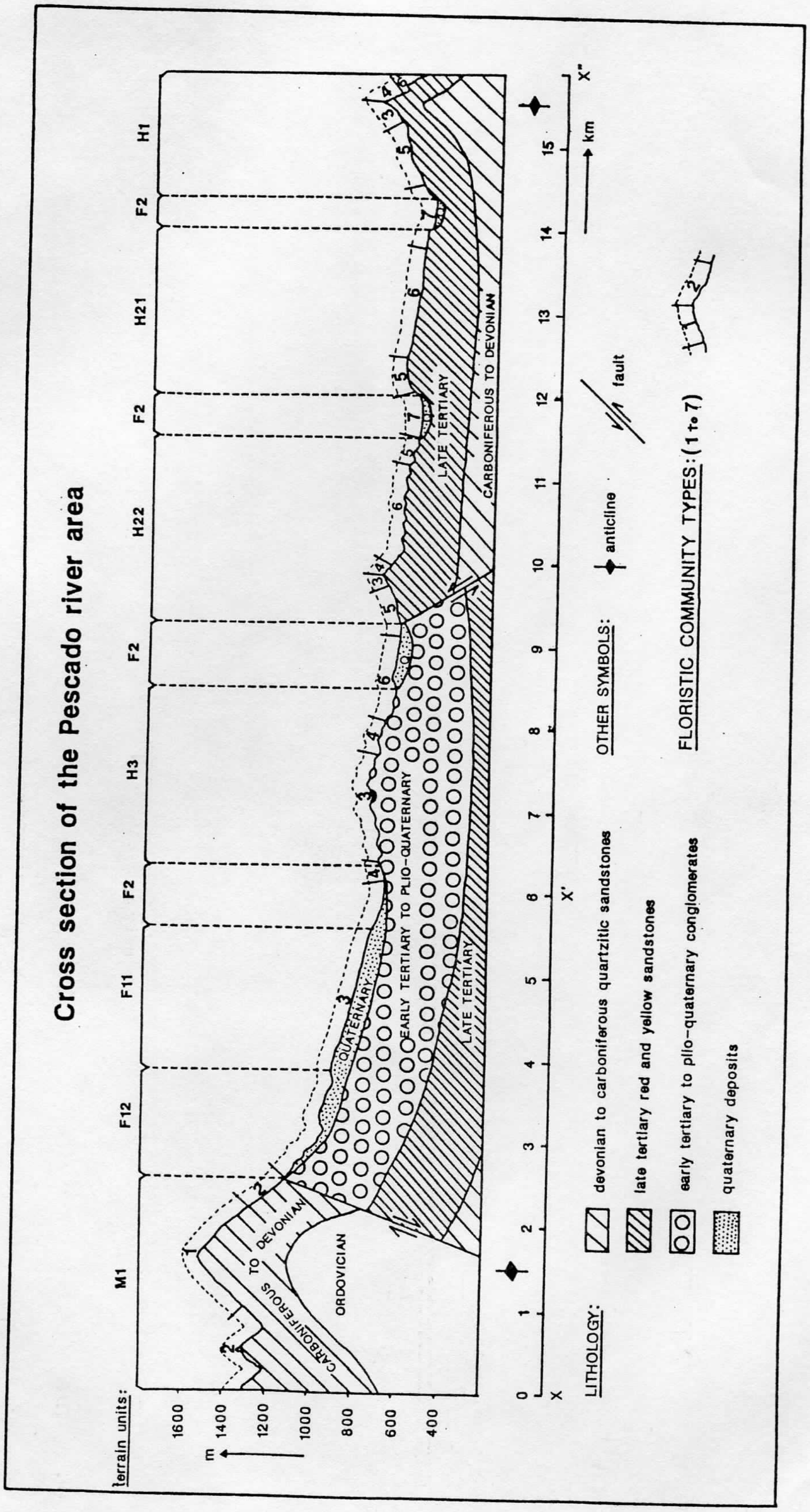
APPENDIX D: Terrain map of the Pescado river area, NW Argentina



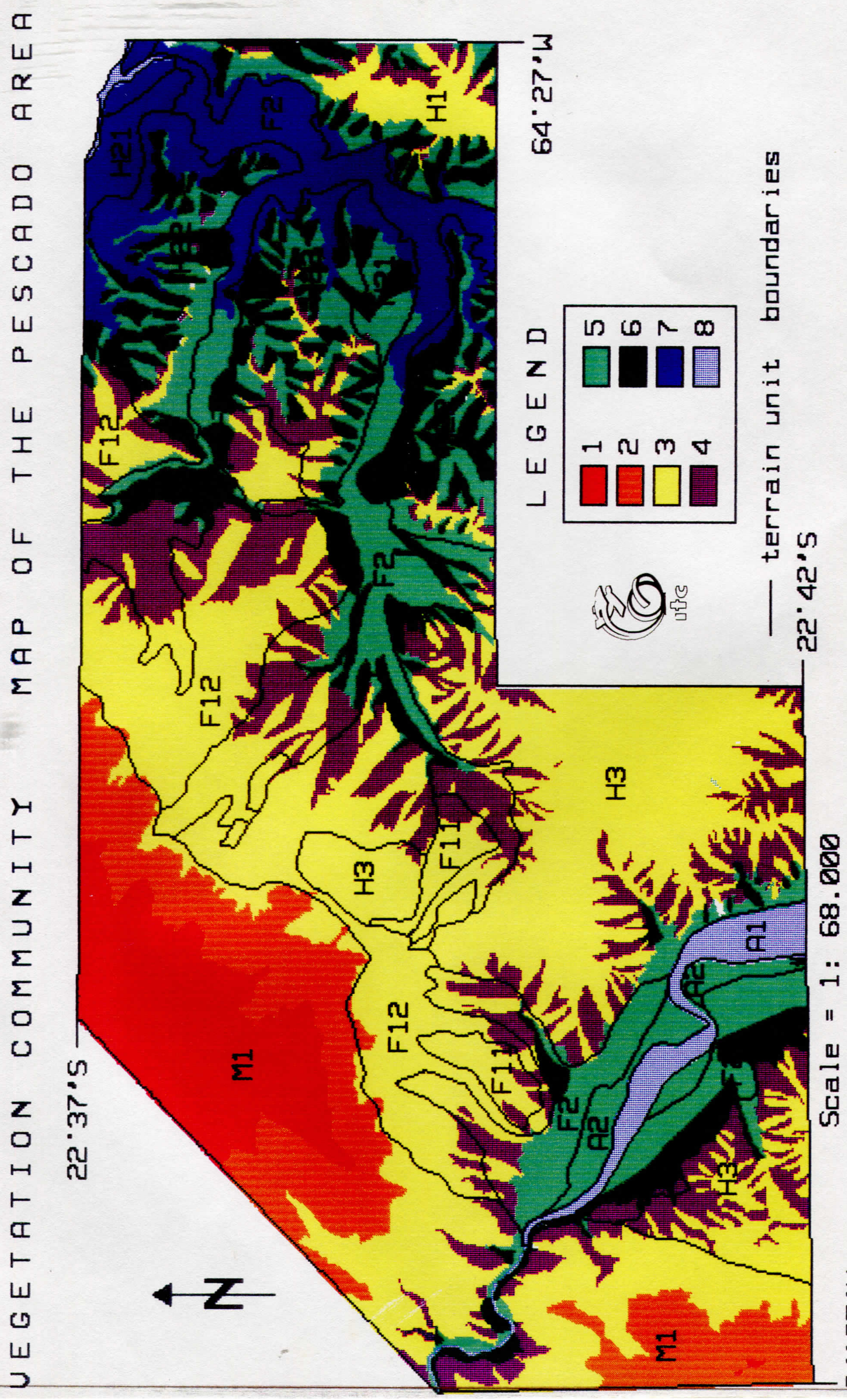
APPENDIX D: Legend of the terrain map of the Pescado river area, NW Argentina.

MAIN LANDSCAPE	LANDSCAPE	SUB-LANDSCAPE	SYMBOL
Structural-denudational mountains	Broad anticlinal crest in devonian to carboniferous quartzitic sandstones		M1
Structural-denudational hills	Narrow anticlinal crest in late tertiary red + yellow sandstones and tills		H1
	Hogbacks in late tertiary red + yellow sandstones and tuff	moderat. dissected	H21
		very dissected	H22
	Denudational hills in early tertiary to plio-quaternary conglomerates		H3
Colluvio-alluvial footslopes	Mud flows deposits from quartzitic sandstones	terraced fans	F11
		ravines and slopes complexes	F12
	Colluvial footslopes and colluvio-alluvial valley fills		F2
Alluvial plains of braided-meandering rivers	floodplain		A1
	depositional terraces		A2

APPENDIX E: Cross section of the Pescado river area, NW Argentina
(see Appendix D)



APPENDIX F: Vegetation community map of the Pescado river area,
---------- NW Argentina.

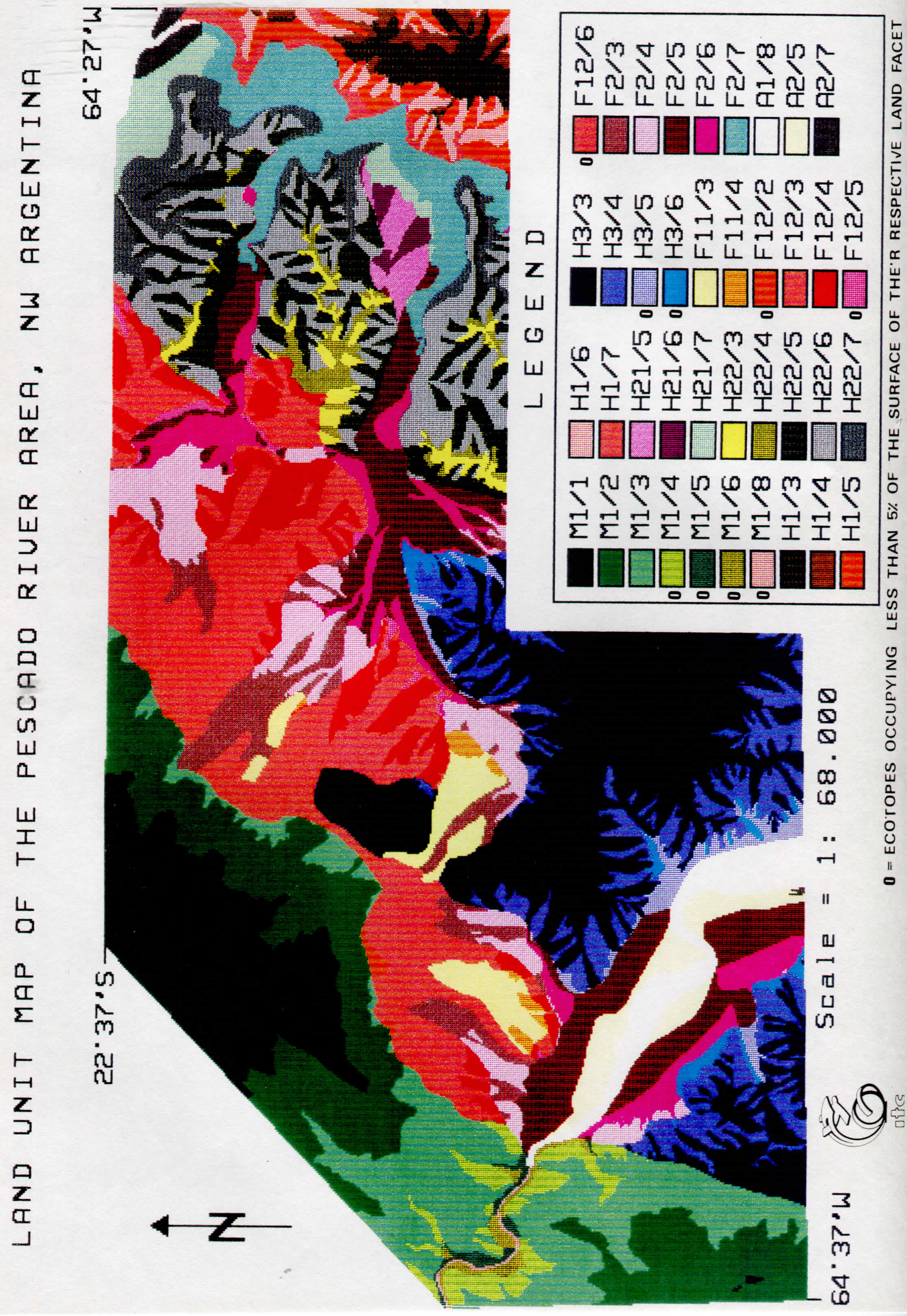


APPENDIX F: Legend of the vegetation community map of the Pescado river area, NW Argentina.

VEGETATION COMMUNITIES

Symbol	Name
1	Cordyline dracaenoides Blepharocalyx gigantea
2	Blepharocalyx gigantea Chusquea lorentziana
3	Ficus maroma Miconia molybdea
4	Ficus maroma Terminalia triflora
5	Acreugenia pungens Cordia trichotoma
6	Acreugenia pungens Stenocalyx uniflorus
7	Chrysophyllum gonocarpum Stenocalyx uniflorus
8	riverine shrubland (see Chapter 6)

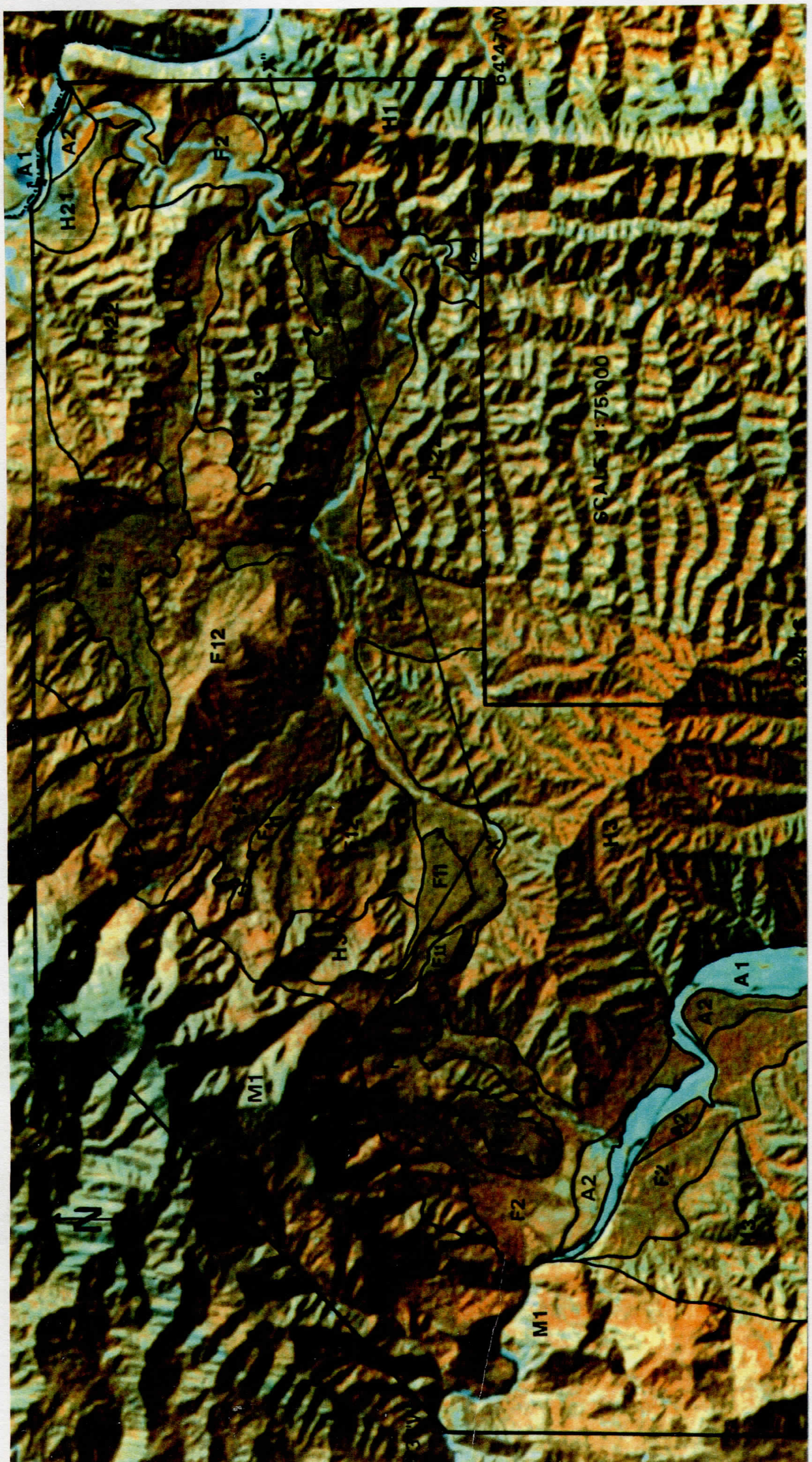
APPENDIX G: Land unit map of the Pescado river area, NW Argentina



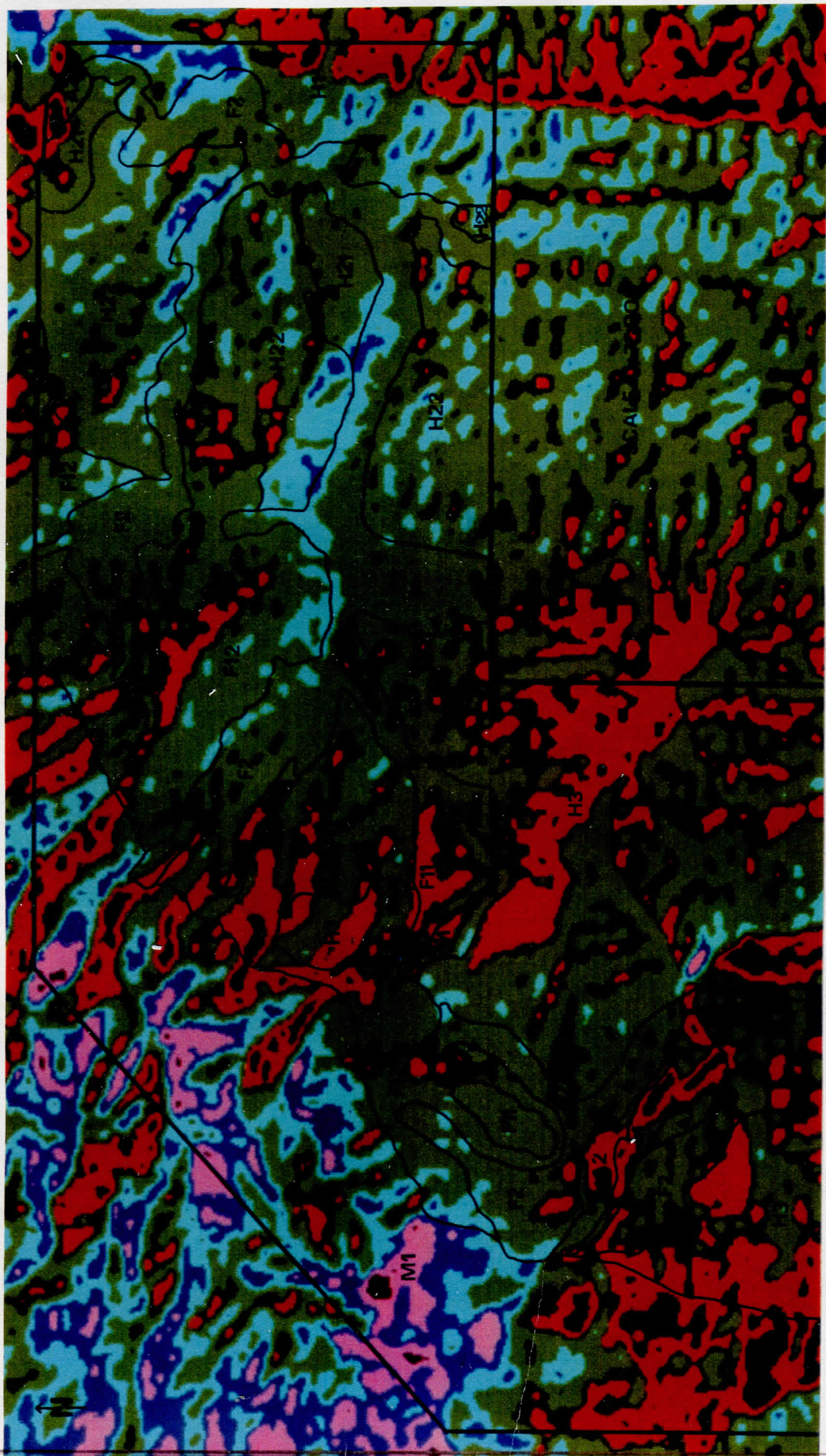
APPENDIX G: Legend of the land unit map of the Pescado river area, NW Argentina.

MAIN LANDSCAPE	LAND SYSTEM	LAND FACET	ECOTOPE	SYMBOL
Structural-denudational mountains	Broad anticlinal crest in devonian to carboniferous quartzitic sandstones		community 1	M1/1
			community 2	M1/2
			community 3	M1/3
Structural-denudational hills	Narrow anticlinal crest in late tertiary red and yellow sandstones and till		community 3	H1/3
			community 4	H1/4
			community 5	H1/5
			community 6	H1/6
			community 7	H1/7
	Hogbacks in late tertiary red and yellow sandstones and tuff	moderately dissected	community 5	H21/5
			community 6	H21/6
			community 7	H21/7
		very dissected	community 3	H22/3
			community 4	H22/4
			community 5	H22/5
			community 6	H22/6
			community 7	H22/7
	Denudational hills in early tertiary to plio-quaternary conglomerates		community 3	H3/3
			community 4	H3/4
Colluvio-alluvial footslopes	Mud flow deposits from quartzitic sandstones	terraced fans	community 3	F11/3
			community 4	F11/4
		ravines and slopes complexes	community 3	F12/3
			community 4	F12/4
	Colluvial footslopes & colluvio-alluvial valley fills		community 3	F2/3
			community 4	F2/4
			community 5	F2/5
			community 6	F2/6
			community 7	F2/7
Alluvial plains of braided-meandering rivers	floodplain		community 8	A1/8
	depositional terraces		community 5	A2/5
			community 7	A2/7

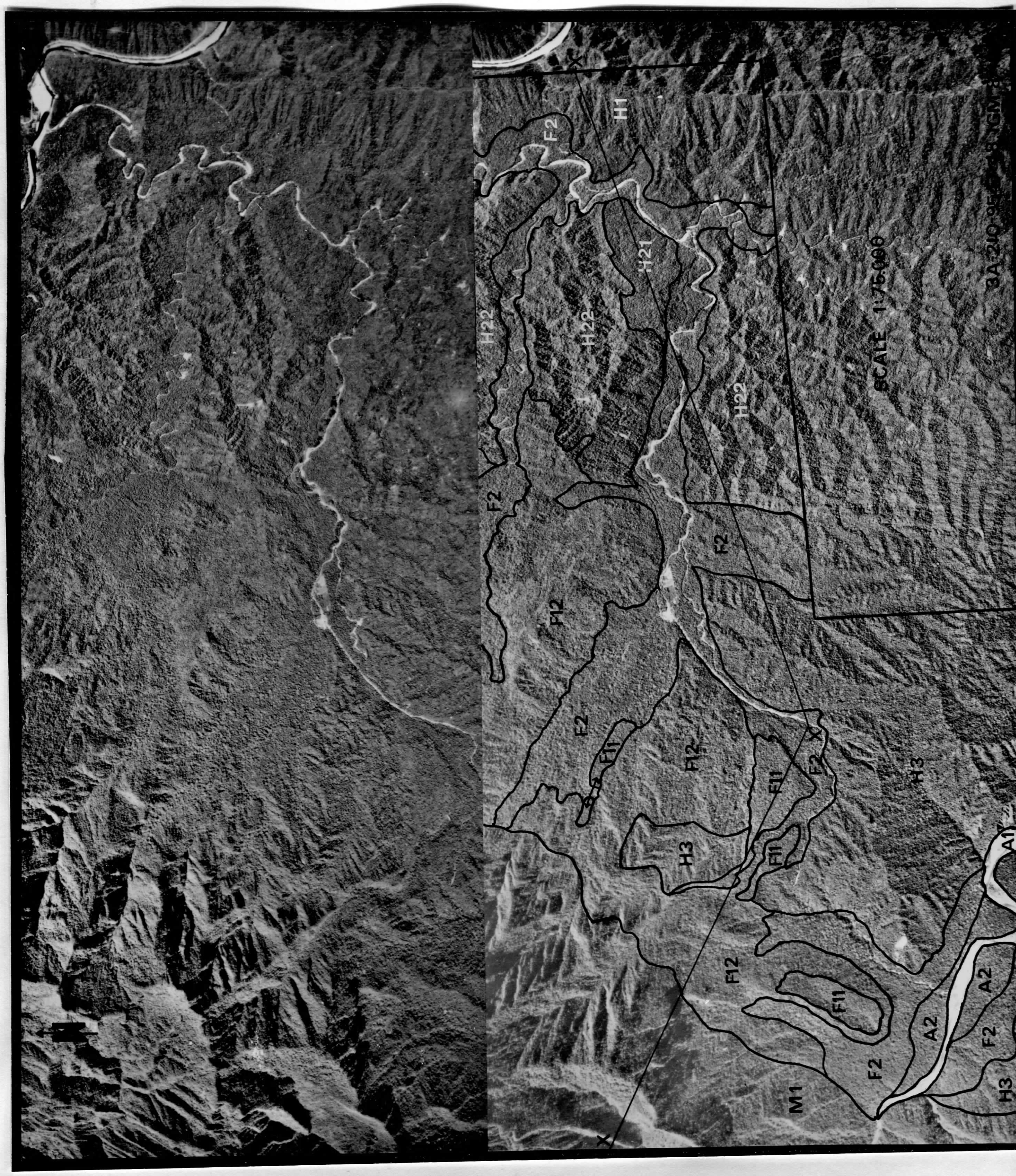
APPENDIX H: Landsat TM FCC image (band 4 = red, band 5 = green, band 7 = blue) of the Pescado river area, NW Argentina (Path231,Row76,25/7/86 9:45AM).



APPENDIX I: Landsat TM band 6 slicing of the Pescado river area, NW Argentina (P231,R76,Q2,25/7/86,9:45AM).
Colour/temperature equivalences are:
black = 15,5-16,0 C and 20,2-22,1 C magenta = 16,2-16,7 C
blue = 16,9-17,4 C cyan = 17,6-17,9 C green = 18,1-18,6 C
dark green = 18,8-19,3 C red =19,5-20,0 C



APPENDIX J: Stereogram of the Pescado river area, NW Argentina.
----------- Source: Instituto Geografico Militar (IGM), photos 3A-210-9547/48, taken on 9/8/1966.



APPENDIX K: ITC relevé data sheet (front)

ITC RELEVÉ DATA SHEET — ITC Vegetation and Agricultural Land Use Survey

PHOTO No. (run, type etc.)	Area, Country, etc.	DATE / / day month year	No.
PRELIMINARY LEGEND SYMBOL:	SIZE SAMPLE m^2	ALTITUDE IN m:	FINAL CLASSIFICATION (not for fielduse)
PRELIMINARY LANDUNIT NAME:	OBSERVER(S):		FINAL MAP SYMBOL

TERRAIN DATA

SITE/ELEMENT	MAPPING UNIT	LANDFORM - (HYDROLOGY)	SYMBOL
ROCK LITHOLOGY:	ROCK LITHOLOGY/GEOLOGICAL FORMATION	SOIL	SYMBOL
LANDFORM/TOPOGRAPHIC POSITION WITHIN MAPPING UNIT	LANDFORM	VEGETATION structure	SYMBOL
SLOPE TYPE straight, concave, convex, irregular	RELIEF TYPE - Very flat - Almost flat (< 2%) - Undulating (3 - 7%) - Rolling (8 -13%) - Hilly (14-20%) - Steeply dissected (21-55%) - Mountaineous (> 55%)	composition	SYMBOL
SLOPE : LENGTH: / EXPOSURE N.NE.E.SE.S.SW.W.NW.	RELIEF INTENSITY	LAND USE	SYMBOL
MICRO-MESORELIEF			

SOIL AND WATER DATA

EROSION TYPE	EROSION RATE	AREA AFFECTED	SOIL DRAINAGE	WATER SOURCE	RUNOFF	FLOODING/PONDING DEPTH	AGENT	FREQUENCY	DURATION
none sheet rill gully eolic	very low low moderate strong severe	<25% 20-50% 50-75% >75%	-excessive -somewhat excessive -well -mod.well -imperfect -poor -very poor	rain run-on aquifer irrigation	very rapid rapid medium slow very slow		none rain run-on river lake sea	...per .....years month week	days weeks months

HORIZON symbol	DEPTH cm	TEXTURE	COLOUR	PH	HCL	MOTTLING	CONSISTENCE	SURFACE SEAL	SURFACE STONINESS/ ROCK OUTCROPS (%)	REMARKS
									effective soil depth (cm)	groundwater depth (cm) .....

PRELIMINARY SOIL CLASSIFICATION

LAND COVER/USE DATA (semi-)natural or planted

SAMPLE PLOT STRATA	HEIGHT	COVER %	DOMINANT SPECIES (for details p.t.o.)	SITE/ELEMENT	MAPPING UNIT
trees				general cover/use type (if complex, estimate % cover of each type)	general cover/use type (if comple , estimate % cover of each type)
shrubs					
herbs					
total real cover %					

PRELIMINARY COVER CLASSIFICATION:
structure:
composition:

LAND USE
type:
field size/shape:

R
3
2
1
B+L+S

0 50 100

APPENDIX K: ITC relevé data sheet (back)

(repeat number here) No.	LIST OF SPECIES					
Litter						

OBSERVATIONS/INTERVIEWS ON VEGETATION, CROPS, ANIMALS AND MANAGEMENT ASPECTS (SAMPLE SITE)

(SEMI-)NATURAL VEGETATION

- burning
- fuel wood collection
- range condition
- grazing traces
- fences
- watering points
- dropping/footmarks/ tracks

CROPS

- planting distance
- stage
- height
- crop condition

Timing

- date of planting
- date of harvesting
- rotation

Mechanisation

Input use

- fertilizer
- pesticides

Yield

(expected) yield in year of survey

- normal yield range

ANIMALS

- type/breed
- number
- estimated body weight
- age/sex
- condition

SAMPLE SIZE:	TOTAL NO. OF TAXA:	

Fresh WEIGHT DATA g/m2

						dry
1	2	3	4	5	a) $\frac{1 \to n}{n}$	c sub.sample
6	7	8	9	10	b. sub.sample	c/b.a=g/m2

APPENDIX L: Main relevés field data and subsequent terrain, vegetation and soil classification.

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	1
Terrain unit	F12	F12	H3	F2	H3	F11	F2	H22	H22	F12	F12	F2	F2	H
Slope exposure	SE	SE	NE	SE	NW	S	S	E	NW	S	SE	E	NE	S
Slope angle (%)	23	42	65	2	65	10	8	50	60	14	11	14	4	
Altitude (m)	635	625	680	605	655	710	650	655	655	720	775	665	625	5
AERIAL COVER (%) LAYER + 18,0m	12	8	12	30	50	80	25	65	40	0	20	67	12	
8,0-18,0m	70	50	70	22	40	12	35	35	30	20	60	17	20	
3,5- 8,0m	82	5	60	40	17	40	70	50	30	60	30	15	25	
1,5- 3,5m	5	85	10	5	17	30	20	17	10	20	20	50	65	
0,1- 1,5m	5	45	3	70	50	5	5	7	20	8	50	99	70	
Total aerial cover (%)	174	193	155	167	174	167	155	174	130	108	180	248	192	
Vegetation structural type	O	O	O	O	O	O	O	O	O	O	D	G	I	
Vegetation community	6	6	4	6	3	4	5	4	3	4	3	4	6	
Number of species per plot	11	12	13	13	11	11	11	11	12	11	15	17	17	
Number of individuals/plot	22	12	21	29	18	14	21	33	18	17	24	27	25	
SOIL pH (at 20 cm depth)	55	52	70	55	60	55	50	65	65	45	50	55	45	
colour of top horizon @	DRB	DRB	DB	DB	DB	DRB	DB	DRB	DRB	DB	DYB	DRB	DB	
surface stoniness (%)	5	18	15	0	5	5	0	0	0	3	0	3	0	
effective depth (cm)	99	15	15	60	15	60	90	99	99	75	90	70	70	
texture of top horizon #	SL	SL	SL	SL	SL	SL	SCL	SL	SL	L	L	SL	SL	
Soil subgroup *	Iu	lEo	lEo	Eo	lEo	Iu	Iu	Eo	Eo	Io	Iu	Iu	Eo	

* soil classification: (Soil Survey Staff, 1975)
Eo = Orthent lEo = lithic Orthent
Ep = Psamment Io = Ochrept
Iu = Umbrept Ia = Andept

textural classes: S=sandy L=loamy SL=sandy loam LS=loamy sand

@ colours of top horizon: (Munsell, 1975)
B = strong brown RB = reddish brown
DRB = dark reddish brown YR = yellowish red
DGB = dark grayish brown DYB = dark yellowish brown
DB = dark brown

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
H21	H1	H1	F2	F2	H3	H3	F2	F2	H3	H3	F2	M1	M1	F12	F12	H3	F12	H22	M1	M1	M1	M1	M1	M1	M1	M1	H22	H22	H1	H21	H22
SE	SE	NW	-	SW	SW	NW	N	-	SE	N	SE	SE	S	SW	NW	SW	SW	W	NW	SE	S	SE	SW	E	SW	SE	SW	S	SE	SE	-
4	75	95	-	14	90	120	4	3	20	30	4	45	8	50	40	90	25	70	80	50	60	40	110	80	75	75	80	+120	70	4	10
565	600	600	515	680	620	630	595	590	670	695	670	770	800	665	660	630	650	640	1170	1205	1200	1450	1440	1340	1350	1250	530	530	600	550	590
3 70 25 50 50	7 70 27 40 60	8 22 70 80 85	7 60 30 80 85	30 30 30 65 80	7 50 30 25 50	15 25 30 25 50	3 20 30 37 55	3 10 20 50 60	40 20 20 32 85	5 30 30 60 50	60 30 25 35 65	20 40 27 40 65	3 60 25 30 75	35 32 50 65 20	40 35 35 30 25	20 15 40 40 70	45 27 22 67 27	20 30 25 45 35	3 52 20 32 75	5 75 25 25 60	2 57 25 20 50	0 57 12 17 75	10 70 15 17 80	10 30 60 47 65	35 30 50 17 60	10 60 30 25 40	35 22 40 40 50	12 35 50 27 35	60 15 35 50 72	20 35 30 20 75	60 25 25 42 32
198	204	215	262	235	162	145	145	143	197	175	215	192	193	202	165	185	188	155	182	190	154	161	192	212	192	165	187	159	232	180	184
D	E	L	I	F	D	A	A	I	F	H	G	A	K	H	C	A	H	H	K	D	D	K	K	L	B	D	B	J	G	A	C
6	6	5	7	3	5	5	6	5	4	4	4	3	3	3	3	5	5	5	2	2	2	1	1	1	1	2	7	7	6	7	6
21	15	18	10	9	14	13	12	10	11	13	14	12	9	17	13	13	9	9	15	8	9	6	6	8	6	9	21	22	20	15	20
36	26	32	33	27	38	41	31	27	25	29	32	39	30	38	35	35	26	23	36	42	36	56	48	31	46	39	38	47	28	43	48
50 DB 0 90 L	45 DRB 3 99 LS	45 DRB 8 99 LS	65 YR - 99 S	55 DRB 5 99 SL	60 DRB 5 50 SL	60 DRB 5 50 SL	60 DRB 1 90 L	70 DYB 1 99 S	75 DRB - 35 SL	50 DRB 5 60 SL	70 DRB 5 80 SL	65 DRB 3 30 L	50 DB 3 30 SL	60 DB 5 50 SL	65 DB 3 35 SL	60 20 -	50 DRB 5 20 L	70 DRB 5 20 SL	65 DB 10 90 SL	65 DB 5 99 SL	70 DB 5 30 SL	50 DB 5 99 LS	50 DB 8 50 LS	55 DRB 5 90 SL	55 DRB 3 50 SL	70 DRB 8 40 SL	50 B 5 80 LS	50 B 5 80 LS	70 DRB 3 99 L	55 DRB 1 90 LS	52 B 0 70 SL
Ia	Eo	Eo	Ep	Eo	lEo	lEo	Eo	Ep	lEo	Eo	Eo	Eo	Io	lEo	lEo	lEo	lEo	lEo	Io	Eo	lEo	Eo	Eo	Iu	Eo	lEo	Io	Io	Eo	Iu	Eo

37	38	39	40	41	42	43	44	45	46	47	48	49
M1	M1	M1	M1	H22	H22	H1	H21	H22	A2	F2	F2	F11
SW	E	SW	SE	SW	S	SE	SE	–	–	SW	–	E
110	80	75	75	80	+120	70	4	10	2	6	6	55
440	1340	1350	1250	530	530	600	550	590	570	590	625	725
10 70 15 17 80	10 30 60 47 65	35 30 50 17 60	10 60 30 25 40	35 22 40 40 50	12 35 50 27 35	60 15 35 50 72	20 35 30 20 75	60 25 25 42 32	65 30 25 55 65	12 20 27 50 80	5 37 20 50 65	30 20 25 60 35
192	212	192	165	187	159	232	180	184	240	189	177	170
K	L	B	D	B	J	G	A	C	G	I	I	H
1	1	1	2	7	7	6	7	6	5	5	5	4
6	8	6	9	21	22	20	15	20	14	8	10	16
48	31	46	39	38	47	28	43	48	42	40	33	37
50 DB 8 50 LS	55 DRB 5 90 SL	55 DRB 3 50 SL	70 DRB 8 40 SL	50 B 5 80 LS	50 B 5 80 LS	70 DRB 3 99 L	55 DRB 1 90 LS	52 B 0 70 SL	70 DRB 1 60 SL	67 DRB 1 90 SL	50 RB 1 80 SL	55 DRB 10 20 –
Eo	Iu	Eo	1Eo	Io	Io	Eo	Iu	Eo	Ep	Eo	Ep	1Eo

50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
M1	M1	A2	A2	F2	H3	H3	M1	M1	F2	M1	M1	H22	H22	F2	H21	H22	H22
SE	NW	–	–	SE	E	NE	SE	NE	SE	SE	SE	SW	E	–	NW	SE	NE
35	60	2	1	4	6	70	+100	75	9	12	65	53	60	9	8	100	70
760	740	580	570	600	675	670	720	750	580	940	925	580	570	540	550	605	580
37 40 22 25 70	15 35 25 50 67	10 30 35 75 60	5 40 22 80 60	10 60 30 40 70	35 25 35 42 80	35 30 20 65 50	10 65 27 35 47	15 35 45 25 60	40 30 30 30 55	10 70 15 25 90	15 55 35 35 70	7 42 35 35 60	25 25 20 35 60	15 30 22 70 80	10 55 40 65 50	35 45 35 30 40	10 35 35 25 40
194	192	210	207	210	217	200	184	180	185	210	210	179	165	217	220	185	145
A	I	I	I	E	F	H	E	A	B	K	E	A	B	I	E	C	J
3	3	5	5	6	4	4	4	4	6	3	3	5	6	7	7	6	6
13	6	10	11	12	16	17	15	13	12	12	11	14	14	12	15	12	16
44	35	37	40	41	40	38	55	40	55	35	44	51	42	42	41	30	31
50 DB 10 45 LS	70 DRB 40 10 –	67 DYB 0 80 LS	50 DYB 0 80 S	65 DRB 1 80 LS	– DYB 1 10 –	60 DYB 20 30 S	60 DGB 20 10 SL	55 DRB 5 70 LS	70 DYB 15 15 S	50 DRB 0 90 LS	50 DRB 0 90 LS	50 RB 3 55 LS	50 RB 1 55 LS	60 B 0 99 LS	50 YR 0 80 SL	60 DYB 0 80 LS	60 DYB 0 80 LS
1Eo	1Eo	Ep	Ep	Ep	1Eo	1Eo	1Eo	Eo	1Eo	Iu	Iu	Io	Io	Ep	Eo	Eo	Eo

APPENDIX M: Terrain unit (=land unit at a land facet level) characteristics

TERRAIN UNIT SYMBOL	SLOPE STEEPNESS (%)	ALTITUDE (m)	DRAINAGE PATTERN TYPE	DENSITY *	INTERNAL RELIEF (m)	CATABATIC FLUX (rel.value)
M1	55-140	600-1850	trellis to subparalell	C-M	150-400	400
H1	55-140	450-860	subparalell to dendritic	F	75-200	100
H21	3-20	490-660	subparalell	VC	0-30	50
H22	21-140	500-750	dendritic	F	30-100	100
H3	14-140	600-1000	dendritic pectinate	VF	30-150	200
F11	8-20	700-1050	subparalell	VC	0-30	50
F12	14-55	550-1050	dendritic to subparalell	F	30-100	600
F2	0-20	450-950	paralell to subparalell	VC	0-30	800
A1	0-2	450-600	braided	F	0	800
A2	0-7	450-610	not visible		0-10	800

TERRAIN UNIT SYMBOL	RELEVES pH (at 20cm)	Surface(%) stoniness	SOIL DATA Effective depth(cm)	Colour ***	MAIN SOIL SUBORDERS **	LANDSAT TM B6 25/7/86 Temperature Mean(C)	SD
M1	5,0-6,5	3-20	10-99	DB-DRB	Eo-lEo-Iu-Io	18,1	1,8
H1	4,5-6,5	3-8	99	DRB	Eo	18,7	0,8
H21	5,0-5,5	0-1	80-99	DB-DRB-RB	Ia-Iu-Eo	18,4	0,2
H22	5,5-6,5	0-5	50-99	DRB-B	Io-Eo	18,4	0,3
H3	5,0-6,0	1-15	10-50	DRB	lEo	18,9	0,4
F11	5,0-5,5	5-10	20-90	DRB	lEo-Iu	19,1	0,2
F12	5,0-6,5	3-10	15-99	DRB-DYB	lEo-Iu-Io	18,7	0,3
F2	5,0-7,0	0-5	70-99	DRB-DB-DYB	Eo-Ep-Iu	18,5	0,2
A1@	-	-	-	-	-	20,0	0,2
A2	5,0-7,0	0-1	60-80	DRB-DYB	Ep	18,8	0,1

TERRAIN UNIT SYMBOL	STRATIGRAPHY AND LITHOLOGY	VEGETATION MAIN COMMUNITIES	STRUCTURAL GROUPS
M1	devonian-carboniferous/quartzitic sandstones	1-2-3	K-E-D-A
H1	late tertiary/red & yellow sandstones + till	3-4-5-6-7	(E-G-L)#
H21	late tertiary/red & yellow sandstones + tuff	5-6-7	(E-D-A)#
H22	late tertiary/red & yellow sandstones + tuff	3-4-5-6-7	B-C-J
H3	early tertiary-plio quaternary/conglomerates	3-4	A-H-F
F11	quaternary/deposits from quartzitic sandstones	3-4	(H)#
F12	quaternary/deposits from quartzitic sandstones	3-4	H
F2	quaternary/colluvium-alluvium (consolidated)	3-4-5-6-7	I-G
A1	quaternary/alluvium (unconsolidated)	8	none
A2	quaternary/alluvium (consolidated)	5-7	I

* C = coarse M = medium F = fine V = very
** Eo = Orthent lEo = lithic Orthent Ep = Psamment
Io = Ochrept Iu = Umbrept Ia = Andept
*** Colours of top horizon: DRB = dark reddish brown
DYB = dark yellowish brown DB = dark brown
B = strong brown RB = reddish brown
# insufficient data @ it does not exist a soil layer

APPENDIX N1: Terrain vs vegetation matrices

Floristic community vs terrain unit matrix

TERRAIN UNITS	FLORISTIC COMMUNITIES 1	2	3	4	6	7	5
M1	X	X	X	X			
F12			X	/	X		/
F11				X			
F2			/	X	X	X	X
H3			/	X			X
H22			/	/	X	X	X
H21					/	X	
H1					X		/
A2							X

Vegetation structural types vs terrain unit matrix

TERRAIN UNITS	VEGETATION STRUCTURAL TYPES K	E	D	A	F	H	B	C	J	I	G	L
M1	X	X	X	X	/		/			/		/
H21		/	/	/								
H3			/	X	X	X						
F12			/			X		/				
H22				/		/	X	X	X			
F2		/		/	/		/			X	X	
A2										X	/	
H1		/									/	/
F11						/						

/ = one relevé   X = more than one relevé

APPENDIX N2: Vegetation structural types vs floristic community matrix.

Floristic community vs vegetation structural types

STRUCTURAL TYPE	FLORISTIC COMMUNITY 1	2	3	4	5	6	7
B	/					X	/
J						/	/
I			/		X	/	X
E			/	/		X	/
C			/			X	
A			X	/	X	/	/
H			/	X	X		
G				X	/	/	
F			/	X			
L	/				/		
D		X	/		/	/	
K	X	/	X				

APPENDIX O: Families and species of shrubs and trees

FILICINEAE
Cyathea o'donelliana E

LILIACAE
Cordyline dracaenoides E

PIPERACEAE
Piper elongatum ('matico') E
Piper tucumanum ('soldado') E

SALICACEAE
Salix humboldtiana ('sauce', 'sauce criollo') D

JUGLANDACEAE
Juglans australis ('nogal criollo') D

ULMACEAE
Celtis pallida ('tala', 'tala pispa', 'talita') E?
Celtis spinosa ('tala') D
Phyllostylon rhamnoides ('palo blanco') D

MORACEAE
Ficus maroma ('maroma', 'gomero', 'aguaray') E
Morus marmolii E?

URTICACEAE
Urera baccifera ('ortiga gigante') D
Urera caracasana ('ortiga del monte') D

SANTALACEAE
Acanthosyris falcata ('sombra de toro hembra') E?

POLIGONACEAE
Cocoloba tiliaceas ('sacha-pera', 'mango del campo') D
Ruprechtia laxiflora ('virarú') E

NICTAGINACEAE
Pisonia zapallo ('zapallo caspi') E

ANONACEAE
Rollinia occidentalis ('chirimoya') E

LAURACEAE
Nectandra pichurium ('laurel blanco') E
Phoebe porphiria ('laurel amarillo') E

ROSACEAE
Prunus tucumanensis ('palo luz') D?

LEGUMINOSAE

Amburana cearensis ('roble criollo') D
Anadenanthera collubrina ('cebil', 'cebil colorado') D
Cassia carnaval ('carnaval') D
Enterolobium contortisiliquum ('timbó', 'oreja de negro') D
Erythrina falcata ('seibo', 'ceibo', 'ceibo salteño') D
Gleditsia amorphoides ('coronillo', 'espina de corona') D?
Inga marginata ('pacay') E
Lonchocarpus lilloi ('quina blanca') E
Miroxylon peruiferum ('quina colorada') E
Parapiptadenia excelsa ('horco-cebil') D
Phitecellobium grisebachianum ('palo barroso') E
Tipuana tipu (tipa blanca) D

RUTACEAE
Fagara nigrescens ('naranjillo') E

MELIACEAE
Cedrela angustifolia ('cedro', 'cedro salteño') D

ANACARDIACEAE
Astronium urundeuva ('urundel') D
Schinus meyeri

SAPINDACEAE
Allophyllus edulis ('chal-chal') E
Athyana wienmannifolia ('quebrachillo') E

RAMNACEAE
Rhamnus polymorphus ('picantillo') E

BOMBACACEAE
Chorisia insignis ('yuchán', 'palo borracho') D

COMBRETACEAE
Terminalia triflora ('lanza amarilla') D

MIRTACEAE
Acreugenia mato ('horco-mato') E
Acreugenia pungens ('mato') E
Blepharocalyx gigantea ('horco-molle') E
Eugenia pseudomato ('guili') E
Gomidesia barituensis E
Stenocalyx uniflorus ('arrayán') E

MELASTOMACEAE
Miconia molybdea E

SAPOTACEAE
Chrysophyllum gonocarpum ('aguay', 'aguay amarillo') E
Chrysophyllum marginatum ('lanza blanca') E

BORRAGINACEAE
Cordia trichotoma ('afata') D

VERBENACEAE
Aegiphila saltensis ('hediondilla blanca') E

SOLANACEAE
Dunalia breviflora ('pucancho') E
Solanum riparium

BIGNONIACEAE
Jacaranda mimosifolia ('tarco', 'jacarandá') D
Tabebuia avellanedae ('lapacho rosado') D
Tabebuia lapacho ('lapacho amarillo') D

RUBIACEAE
Calycophyllum multiflorum ('palo blanco') D
Pogonopus tubulosus ('cascarilla') D

CAPRIFOLIACEAE
Sambucus peruviana ('sauco') D

COMPOSITAE
Tessaria integrifolia ('palo bobo') D

E = evergreen
D = deciduous or semi-deciduous

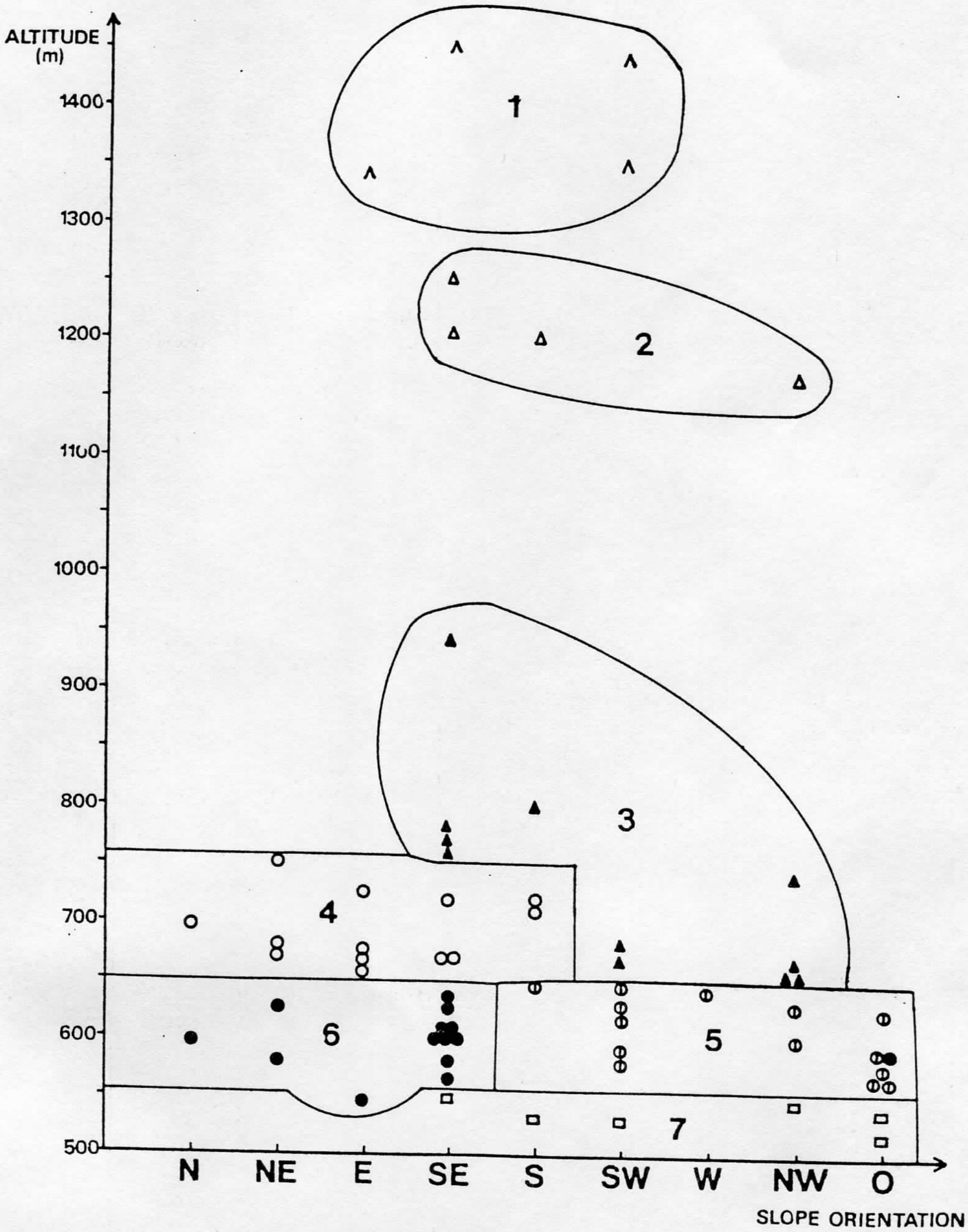
APPENDIX P: Vegetation community characteristics

COMMUNITIES	1	2	3	4	5	6	7
TERRAIN UNITS	M1	M1	M1 F12 (H22,H3 F11,F2)	M1 F11 H3 (F2) (H22)	F2 H22 A2 H3 (H1F11)	H22 H1 F12 F2 (H21)	H21 H22 F2
SLOPE ANGLE (%)	40-110	50-80	8-65	4-100	1-120	2-100	4-120
ALTITUDE (m)	1300-1800	1000-1300	650-750 750-990	650-750	550-650	550-650	450-550
SLOPE EXPOSURE	var.	var.	655-740 NW-SW 760-940 SE-S	NE E SE S	SW W NW (S)(SE)	NE E SE	var.
S pH (20cm depth)	50-55	65-70	50-65	50-70	50-70	45-70	55-65
O colour of top horizon	DB-DRB	DB (DRB)	DB-DRB	DB-DRB	DRB-DYB RB-(DB)	DB-DRB DYB	YR-B (DRB)
I surf.stoniness (%)	3-8	5-10	0-40	0-20	0-5	0-18	0-5
L effective depth(cm)	50-99	30-99	10-99	10-99	20-99	15-99	80-99
* texture top horizon	LS-SL	SL	SL-LS-L	SL	SL-LS-S	SL-LS-L	LS
Soil subgroups	Eo (Iu)	1Eo (Eo) (Io)	1Eo-Io Iu-(Io)	1Eo-Eo Iu-(Io)	Ep-1Eo Eo (Iu-Io)	Eo-1Eo (Iu-Ia-Io-Ep)	Ep-Io (Eo) (Iu)
RELEVE NUMBER	36,37 38,39	33,34 35,40	5,9,11 18,26 27,28 29,50 51,60 61	3,6,8 10,12 23,24 25,49 55,56 57,58	7,16 19,20 22,30 31,32 46,47 48,52 53,62	1,2,4 13,14 15,21 43,45 54,59 63,66 67	17,41 42,44 64,65
Total number relevés	4	4	12	13	14	14	6
VEGETATION STRUCTURE TYPES	K (B)(L)	D (K)	A,K (C)(D) (E)(F) (H)(I)	H,F,G (A)(E)	I,A,H (D)(G) (L)	B,C,E (A)(D) (G)(I) (J)	I (A)(B) (E)(J)
SPECIES DIVERSITY (spp/plot) Mean	6,5	10,3	11,7	13,7	11,7	14,8	15,8
SPECIES DIVERSITY (spp/plot) Stand.Dev.	1,0	3,2	2,9	2,3	2,7	3,5	4,8
WOODY PLANTS DENSITY (plants/plot) Mean	45	38	32	31	35	33	41
WOODY PLANTS DENSITY (plants/plot) St.Dev.	10,4	2,9	9,0	11,1	8,3	11,1	4,8
% EVERGREENNESS	74	72	70	66	67	64	64

* references for soil colours, texture and subgroups symbols are given in Appendix L.

() = values found in one relevé

APPENDIX Q: Vegetation communities (= floristic types) relationship with altitude and slope orientation.



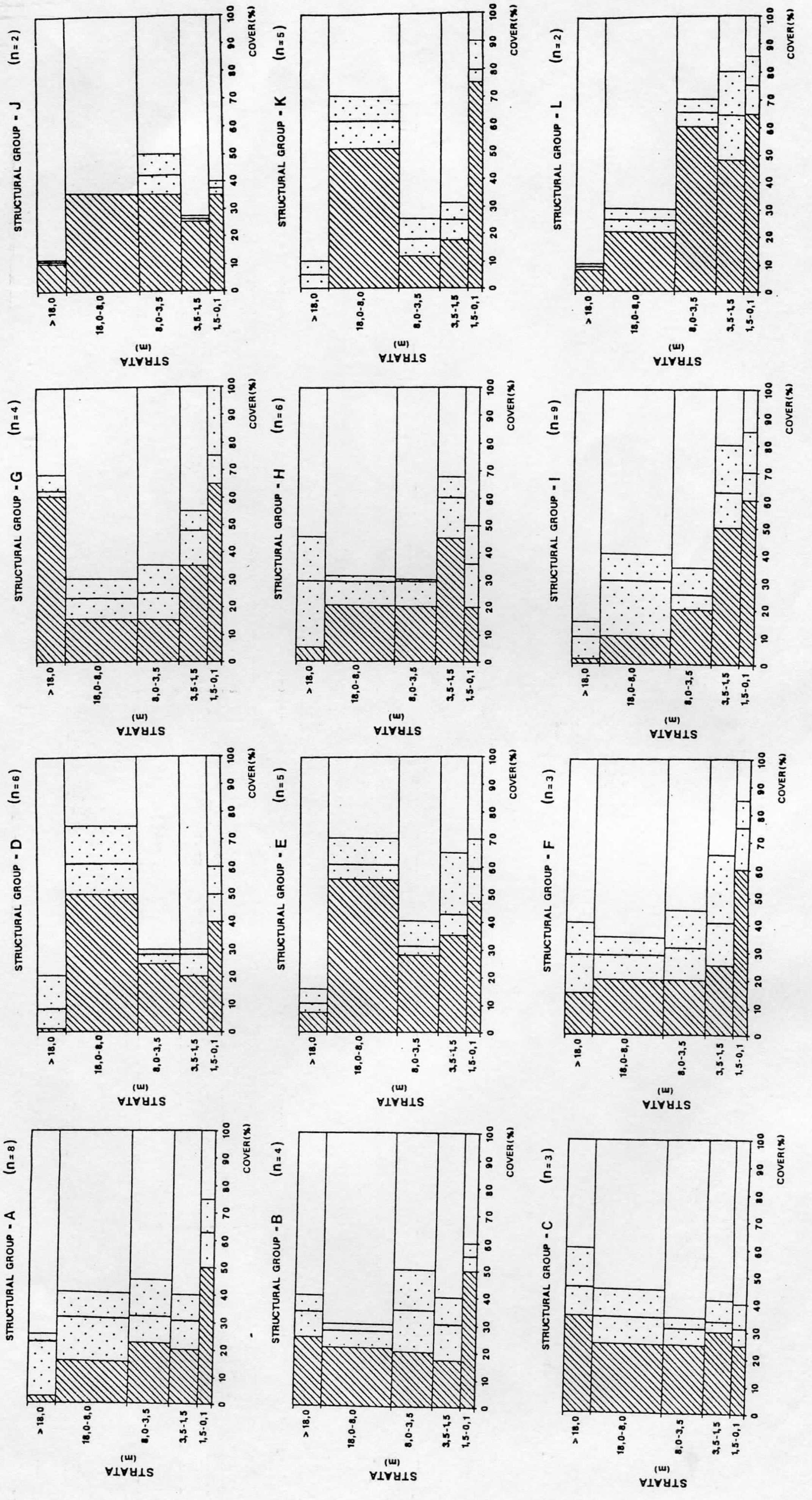
FLORISTIC TYPE	1	2	3	4	5	6	7
SYMBOL	∧	∆	▲	○	⦶	●	□

APPENDIX R: Vegetation structural types characteristics

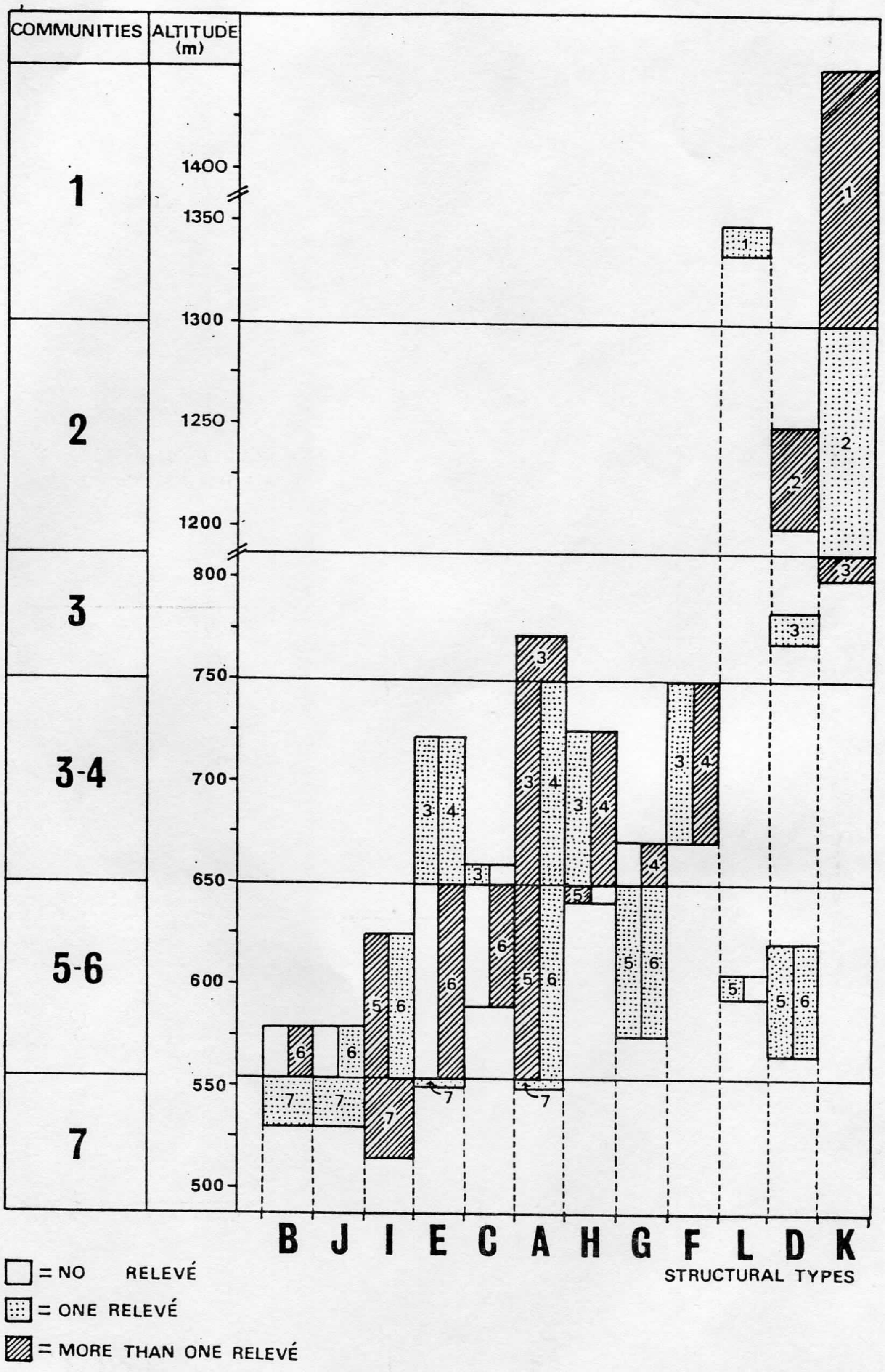
TYPE	A	B	C	D	E	F	G	H	I	J	K	L
L (1)	3-25	25-40	35-60	2-20	7-15	15-40	60-67	5-45	3-15	10-12	0-10	8-10
A (2)	15-40	22-30	25-45	50-75	55-70	20-35	15-30	20-32	10-40	35-35	52-70	22-30
Y (3)	22-45	20-50	25-35	25-30	27-40	20-45	15-35	20-30	20-35	35-50	12-25	60-70
E (4)	20-40	17-40	30-42	20-30	35-65	25-65	35-55	45-67	50-80	25-27	17-32	47-80
R (5)	50-75	50-60	25-40	40-60	47-70	60-85	65-99	20-50	60-85	35-40	75-90	65-85
Layer(1): +18,0m Layer(2): 8,0-18,0m Layer(3): 3,5-8,0m Layer(4): 1,5-3,5m Layer(5): 0,1-1,5m (values are given in % of aerial cover per layer)												
TERR-AIN UNITS	M1 H3 (H21) (H22) (F2)	H22 (M1) (F2)	H22 (F12)	M1 (H21) (H3) (F11)	M1 (H1) (H21) (F2)	(H3) (F2) (M1)	F2 (A2) (H1)	H3 F11 (H22) (F12)	F2 A2 (M1)	H22	M1	(M1) (H1)
SLOPE (%)	4-4 35-99	60-80	10-99	4-11 50-90	4-8 65-99	14-75	2-14	25-70	0-6	70-99	8-99	80-95
ALTIT mx10	55-75	53-58	59-66	56-77 120-125	55-72	65-75	57-67	64-72	51-62	53-58	80- 145	60- 134
EXPOS	var.	var.	var.	SE-SW	SE	var.	SE-E	var.	var.	var.	var.	var.
SOIL (1)	50-60	50-55	55-65	50-70	45-65	55-70	70-70	50-60	45-70	50-60	50-60	45-55
(2)	DRB (DB) (RB)	(DRB) (DYB) (RB)	(DYB) (DB) (B)	DRB DB (DYB)	DRB (DGB) (YR)	DRB	DRB	DRB (DYB) (DB)	DYB DRB var.	(DYB) (B)	DB (DRB)	DRB
(3)	1-10	1-15	0-3	0-8	0-20	0-5	1-5	5-20	0-1	0-5	0-10	5-8
(4)	20-99	15-80	35-80	30-99	80-99	15-99	60-99	20-60	70-99	70-80	30-99	90-99
(5)	LS-L (SL)	LS(S) (SL)	(SL,L LS)	SL-L	LS-SL	SL (LS)	SL (L)	SL (L,S)	SL-LS S	LS	LS-SL	(SL) (LS)
(6)	lEo Eo(Iu Io)	Io (lEo) (Eo)	Eo (lEo)	lEo (Iu, IaEo)	Eo (lEo, IuEp)	Eo (lEo)	Eo (Iu) (Ep)	lEo (Eo)	Ep-Eo (lEo)	(Eo) (Io)	Io-Eo (Iu)	(Iu) (Eo)
(1) = pH at 20 cm depth (2) = color of top horizon (3) = surface stoniness(%) (4) = effective depth (cm) (5) = texture of top horizon (6) = soil subgroups. Symbols references for (1), (2), (5) and (6) are given in Appendix L												
RELE-VE NUMB-ER	20,21 26,30 44,50 58,62	39,41 59,63	29,45 66	11,14 19,34 35,40	15,54 57,61 65	18,23 58	12,25 43,46	24,28 31,32 49,56	13,17 22,47 48,51 52,53 64	42,67	27,33 36,37 60	16,38
Total	8	4	3	6	5	3	4	6	9	2	5	2
COMM-UNI-TIES	5,3 (4) (7) (6)	6 (1) (7)	6 (3)	2 (3) (5) (6)	6 (3) (4) (7)	4 (3)	4 (5) (6)	4,5 (3)	5,7 (6) (3)	(6) (7)	1,3 (2)	(1) (5)
Spp X	13,1	13,3	15,0	12,7	13,6	11,0	16,3	13,5	10,4	19,0	9,6	13,0
DivSD	1,0	6,2	4,4	5,0	1,9	2,0	2,9	3,8	3,0	4,2	3,9	7,1
Spp Div = species diversity (number of spp/plot) X=media SD=standard deviation												
Ind X	41	45	38	36	41	31	32	32	35	39	41	32
NumSD	6,0	7,3	9,3	6,2	10,4	8,1	6,8	6,7	5,9	11,3	10,7	0,7
Ind Num = number of woody plants per plot X=media SD=standard deviation												

() = found in one relevé only   var. = variable
ALTIT = altitude (m x 10) EXPOS = slope exposure SLOPE = slope steepness

APPENDIX S: Vegetation structural types (= structural groups) range of aerial cover per layer (·.·.·.·.·), and mean value (|). n = number of releves per type



APPENDIX T: Vegetation structural types and communities relationships with altitude.



APPENDIX U: Area occupied by each terrain unit, floristic community and land unit within the Pescado river study area. Values are given in square km and percentages are included between brachets.

TERRAIN UNITS		VEGETATION 1	2	3	FLORISTIC 4	5	6	COMMUNITIES 7	8
M1	27,0 (23,2)	M1/1 7,1 (26,4)	M1/2 10,0 (36,9)	M1/3 7,8 (28,8)	M1/4* 1,3 (4,9)	M1/5* 0,3 (1,0)	M1/6* 0,4 (1,6)	- - -	M1/8* 0,1 (0,4)
H1	5,0 (4,3)	- - -	- - -	H1/3 1,5 (29,1)	H1/4 0,5 (10,5)	H1/5 1,3 (27,2)	H1/6 1,0 (19,8)	H1/7 0,7 (13,4)	- - -
H21	2,3 (2,0)	- - -	- - -	- - -	H21/4* 0,0 (0,4)	H21/5 0,7 (28,4)	H21/6 0,3 (14,6)	H21/7 1,3 (56,6)	- - -
H22	14,7 (12,6)	- - -	- - -	H22/3 0,9 (6,0)	H22/4 1,1 (7,5)	H22/5 4,9 (33,7)	H22/6 5,3 (35,8)	H22/7 2,5 (17,0)	- - -
H3	22,6 (19,4)	- - -	- - -	H3/3 15,2 (67,5)	H3/4 5,5 (24,2)	H3/5* 1,1 (4,7)	H3/6* 0,8 (3,5)	H3/7* 0,0 (0,1)	- - -
F11	2,1 (1,8)	- - -	- - -	F11/3 1,8 (84,8)	F11/4 0,3 (15,2)	- - -	- - -	- - -	- - -
F12	17,1 (14,7)	- - -	F12/2* 0,2 (1,1)	F12/3 12,2 (71,6)	F12/4 3,9 (22,7)	F12/5* 0,3 (1,8)	F12/6* 0,5 (2,8)	- - -	- - -
F2	21,4 (18,4)	- - -	- - -	F2/3 3,3 (15,6)	F2/4 4,1 (19,0)	F2/5 6,8 (31,8)	F2/6 3,3 (15,5)	F2/7 3,9 (18,1)	- - -
A1	2,2 (1,8)	- - -	- - -	- - -	- - -	- - -	- - -	- - -	A1/8 2,2 (100)
A2	2,1 (1,8)	- - -	- - -	- - -	- - -	A2/5 1,7 (81,4)	- - -	A2/7 0,4 (18,6)	- - -
(T)	116,5 (100)	7,1 (6,1)	10,2 (8,7)	42,7 (36,7)	16,7 (14,3)	17,1 (14,7)	11,6 (10,0)	8,8 (7,5)	2,3 (2,0)

(T) = total area (km 2)
* = land unit occupying less than 5% of a terrain unit

APPENDIX V: Photographs of the study area

References:

Photo 1: Cutting of Anadenanthera collubrina ('cebil colorado'), a tree timber species, in land unit F12/3

Photo 2: Anticlinal structure developed in devonian quartzitic sandstones in the 'angosto' of the Pescado river, in land unit M1/8.

Photo 3: Relevé in land unit M1/3.

Photo 4: Forest in land unit F2/3. A big stem of Ficus maroma ('maroma'), developed by accumulation of secondary stems, is found on the right. Epiphytes can be seen on the branches to the left.

Photo 5: Forest in land unit M1/1. The main tree species is Blepharocalyx gigantea ('horco molle'). The density of epiphytes is in this land unit higher than in all others (compare with photos 3 and 4).

Photo 6: Cyathea o'donelliana, a tree-fern of 4 meters height, exclusive of floristic community 1

Photo 7: An emergent specimen of Tipuana tipu ('tipa blanca') in land unit F12/3.

Photo 8: View taken from the 'Sierra de las Pavas' showing on the right a part of this mountaineous ridge (land unit M1/3). In the left and in the center a part of the alluvial plain of the Pescado river (land unit A1/8) and a terrace (land unit A2/5) are visible. On the horizon line is the 'Serranía del Divisadero' (land units H1/3, H1/4,H1/5 and H1/6) and part of the hills of land units H3/3 and H3/4.

Photographs by the author except photo 1 by Dr. Hein van Gils

APPENDIX V: Photographs of the study area (see references)

1.

2.

APPENDIX V: Photographs of the study area (see references)

3.

4.

APPENDIX V: Photographs of the study area (see references)

5.

6.

APPENDIX V: Photographs of the study area (see references)

7.

8.