Cloud Forests in the Humid Tropics

A Bibliographic Review

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Thomas Stadtmüller
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PREFACE

Cloud forests have always been a fascinating topic for scientists of various disciplines such as geographers, climatologists, meteorologists, forest ecologists, botanists, zoologists, hydrologists, and conservationists in general. One cannot help but be impressed upon entering these forests, a pastiche of the mysterious and the enigmatic, with their abundance of epiphytes, especially mosses, bromeliads and orchids, the presence of peculiar insects, reptiles, mammals, and birds such as the magnificent quetzal.

This scientific and multidisciplinary topic attracted the attention of the United Nations University (UNU), of Tokyo, which commissioned CATIE's bioclimatologist, Thomas Stadtmüller, to undertake a study on the subject. It would review the state of the art as a basis for generating new scientific effort, especially that which could be carried out as part of a worldwide network.

However, interest reaches beyond pure science. Cloud forests contribute additional water through what is known as "horizontal precipitation" which adds from 7% to as much as 158% of rainfall, as indicated in table 2 of this publication. In addition to the significant increase in precipitation, there are other regulatory effects, particularly regarding maintainance of the habitat of endangered species and possibilities of using this water for commercial ends.

Reading this document one is made aware that there are many kinds of cloud forests, occurring at elevations of less than 500 and up to 3,900 metres above sea level.

It is a tragedy that these cloud forests are disappearing as part of a worldwide conversion of tropical forests to other uses: it is estimated that only 500,000 square kilometres remain in the humid tropics.

After studying the location, ecology, composition, structure, and important climatic and hydrological aspects of tropical cloud forests, the author makes important conclusions and recommendations. Above all, he points out the gaps in our knowledge, such as the lack of quantification of horizontal precipitation over large areas, the role of epiphytes, effects on plant physiology, and local and regional hydrology. This last point is especially critical, since it influences water supplies vital to downstream areas.

It is eloquently argued that certain cloud forests should be totally protected while for others partial protection should suffice. This task falls less upon the scientist than the decision-maker, be he or she at the national or international level, with sufficient time, money, and multidisciplinary back-up to succeed.

Drawing from more than two hundred references, this present work summarizes the state of existing knowledge while at the same time highlighting what remains to be learned. It is hoped that this document will prove of great utility to those working or considering working on the subject of cloud forests, as well as to decision-makers. It should not only foster progress in different scientific fields of study, but above all be used to facilitate concrete actions and decisions which will ensure that this unique treasure remains to be benefitted from and enjoyed by future generations, preserving one of the many mechanisms that govern our biosphere.

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Natural Resources

Turrialba, March 5, 1986

"At these elevations between 2,500 and 3,500 metres above sea level, the traveller finds himself constantly surrounded by a dense fog. This precipitation (or this mysterious formation of water?) that could be the result of a strong electrical tension, gives the vegetation a verdent colour which is continously renewed."

Alexander von Humboldt in 1807 about high mountain vegetation in Colombia and Ecuador.

1. INTRODUCTION

The present study has the following principal objectives:

a) provide a detailed description of the state of knowledge of cloud forests in the humid tropics; considering and evaluating all related disciplines

b) provide a complete bibliography on the topic, including all relevant references

c) point out the limits and gaps in present knowledge

d) propose efforts to broaden and strengthen the current state of knowledge, as well as recommend new areas for research.

Cloud forests within and outside the humid tropics have generally been studied and described from various points of view and different disciplines:

- meteorology
- hydrology
- geography and biogeography
- floristic composition
- fauna
- ecology
- silviculture
- conservation

"Cloud forest" is neither a scientific term, nor does it serve as a definition within the above mentioned disciplines, and for this reason there may be confusion. (See terminology in chapter 3.) Nevertheless "cloud forest" is frequently used in scientific literature which recognizes the strong influence clouds and mist have on forest vegetation, its ecological properties and characteristics.

For the purposes of this study the following definition of "cloud forest in the humid tropics" is used:

Cloud forests include all forests in the humid tropics that are frequently covered in clouds or mist; thus receiving additional humidity, other than rainfall, through the capture and/or condensation of water droplets (horizontal precipitation), which influences the hydrological regime, radiation balance, and several other climatic, edaphic and ecological parameters.

Ellenberg (1964) provides a summarized definition, stating cloud forests as those that predominate in the zone of maximum cloud condensation.

The quantity, distribution and quality of horizontal precipitation relative to rain can vary considerably. Nevertheless, in many cases (not all), cloud forests occur in areas where clouds and mist appear in combination with heavy orographic rainfall. One feature characterizing all cloud forests in the humid tropics is the abundance of epiphytes, especially mosses and Hymenophylaceae (Walter, 1979), and in most cases the presence of Cyateacea (tree ferns) (Christ, 1910; Shreve, 1914; Kroener, 1968; Troll, 1970; Lamprecht, 1986). In the dwarf cloud forests, the mosses even cover the soil surface (Ellenberg, 1975; Ashton and Brünig, 1975; Grubb, 1977). The tropical cloud forests present optimum conditions for poikilohydric plants (Walter, 1973; Leigh, 1975).

Outside the humid tropics cloud forest research has a long history, and it is worth mentioning some of the outstanding research in this field. Although each study had distinct objectives based on priorities in each region, the main goal in many studies was the quantification of horizontal precipitation in relatively dry areas. In many cases the clouds or mist that passed through vegetation was looked upon as a possibile supplementary, and in some cases even a prime water source.

a) Due to the presence of the Humboldt current, high fog and advective stratus clouds occur frequently in the arid coastal zones of Chile and Peru (Eidt, 1968). This phenomenon, known as "garúa" in Peru and "camanchaca" in Chile, was the motive for various studies undertaken on the use of horizontal precipitation as the main source of water in a region which, due to its location and climate, is extremely arid (Knuchel, 1947; Follmann, 1963). The vegetation in this area, known as "vegetación de loma" has been studied in detail by Koepke (1961), who divided it into seventeen different categories.

   Trees in plantations or large artificial fog-catchers can be the means to remove water from clouds and mist through capture and/or condensation ("fog farming") (Kummerow, 1962, 1966; Gischler, 1981). Recent experiments with fog-catchers covered with polythene screening demonstrate that these can remove up to 15 litres of water per square metre of screen a day (Gischler and Fernandez, 1984).

b) A long series of experiments (from Marloth, 1903 and 1906 until Nagel, 1956 and 1962) were carried out near Capetown, South Africa, to quantify the horizontal precipitation of the orographic cloud known as the "table cloth" which frequently forms on the Table Mountain. This was considered as a possible contributor to Capetown's water supply. Using a system of fog-catchers, Nagel (1956) determined that the annual horizontal precipitation almost reached 170% of rainfall.

c) The effect of coastal fog and cloud on the distribution of vegetation, especially the redwoods (Cannon, 1901; Cooper, 1917; Byers, 1930, 1953; Prat, 1953), has been the focus of much research in California.

d) In Germany, Grunow (1952, 1955a and b, 1958, 1960a and b) carried out a long and complete sequence of studies on the quantity, distribution, intensity and structure of horizontal precipitation, including determination of droplet sizes. Several specialized instruments were designed and used in these studies, for example, the Grunow fog-catcher.
Horizontal precipitation, as well as the incidence of fog as an ecological and silvicultural factor in a Bavarian mountain forest, were studied and described by Baumgartner (1957, 1958a and b, 1959)

e) In Japan, various studies were carried out to determine the interception of sea fog by trees in windbreaks. Most of these studies have been evaluated by Hori (1953).

f) The islands of Tenerife and Hawaii are directly affected by clouds and fog and for this reason their climate and vegetation distribution has been widely studied. The occurrence of clouds and horizontal precipitation are considered to be important hydrological and ecological factors. Regarding Tenerife, it is important to mention the following publications: Ceballos and Ortuño (1952), Garcia-Prieto, Ludlam and Sounders (1960), Kämmer (1974), and Kunkel (1976).
Mordy and Hurdis (1955), Ekern (1964), Duffy (1965), Juvik and Perreira (1974), Juvik and Ekern (1978), and Ekern (1979) carried out relevant studies in Hawaii.

g) In recent years various studies have been undertaken in the United States on the effect of microclimate and the vegetation structure upon the direct capture of water. They also focussed on the chemical properties of droplets captured by vegetation (Schlesinger and Reiners, 1974; Lovett, Reiners and Olson, 1982; Lovett, 1984).
Merriam (1973) quantified the effects of artificial leaves on the capture of water under controlled conditions in a wind tunnel.

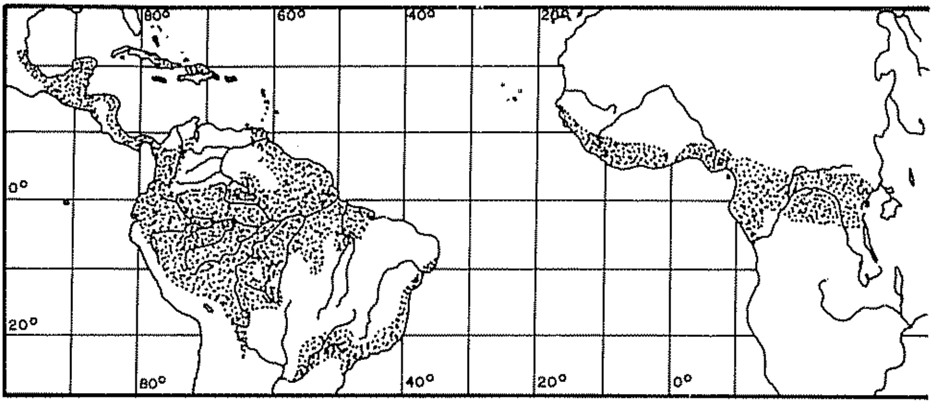


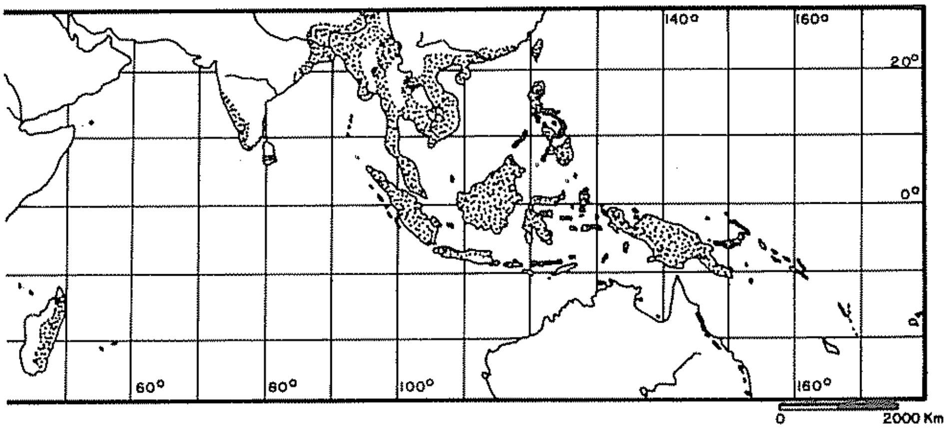
Figure I: Delimitation of the humid tropics

Shuttleworth (1977) in England, developed a theoretical estimate of the interchange of water between vegetation and mist driven by air currents.

The history of research on cloud forests **within the humid tropics** is rather short, since it has only been during the last fifteen to twenty years that the ecological and hydrological significance of these forests has been clearly recognized. It is for this reason that Kerfoot (1968), in an excellent review of literature titled "Mist precipitation on vegetation", was able to give only eight citations related to the humid tropics out of 156 total references. However, referring to Grubb and Whitmore (1966), he emphasized that, even though many authorities believe that mist is important only in restricted areas such as some mountain and coastal zones, it is probable that this phenomenon is of much greater importance in the tropics, where the atmosphere generally contains more water.

Kerfoot (1968) goes on to indicate, again referring to Grubb and Whitmore (1966), that in tropical mountain ranges, where water laden air masses move up against the mountains, the occurrence of clouds can be one of the most important ecological factors determining the distribution of forest types. This hypothesis has been confirmed by recent studies and research in various parts of the tropics. It is worth mentioning here the geographical areas in which principal cloud forest research in the humid tropics has been concentrated over the last twenty years.

For geographic and climatological reasons, the great majority of studies have been carried out in the American tropics. The two major areas of research have been Venezuela, where many studies have covered Andean cloud forests, and Puerto Rico, where scientists from the Institute of Tropical Forestry have done a series of studies on dwarf cloud forests (elfin woodlands). Cloud forests occur infrequently in the humid tropics of Africa. In contrast, they occur frequently in southeast Asia, except where the monsoon plays a dominant role in the hydrological and climatological regime, causing marked dry and wet seasons. Burgess (1969) reports that, in the



according to Küchler (Fosberg, Garnier and Küchler, 1961)

case of the mountains of Malaysia, cloud cover does not occur as regularly as in the Andes where it is probably significant in the distribution of different formations of vegetaion. Cloud forests do not exist in the western or central parts of the Himalayas, but are abundant in a well-defined orographic belt in the east (Schweinfurth, 1957).

For the purpose of this study, the "humid tropics" are specified in geographic terms according to Küchler's definition (Fosberg, Garnier and Küchler, 1961) which delimits the humid tropics using criteria based on vegetation. The shaded areas in figure 1 represent the "more or less permanently humid" areas according to Küchler. This area coincides to a great extent with the distribution of the "Tropical Rain Forest" according to Richards (1952). Following Vogel's recommendation (1966), the Hawaiian islands are also included within the humid tropics.

Nevertheless, several studies have been undertaken outside the humid tropics, for example, in parts of Venezuela as well as completely outside the tropics. As many of them are of particular interest to the topic or have validity within the humid tropics as well, they will also be discussed in this work.

Table 1 shows the main regions of interest in the study of cloud forests in the humid tropics and adjacent areas, and includes authors of the principal research papers and publications.

Table 1. Geographic areas and principal authors from cloud forest studies in the humid tropics

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1. American Humid Tropics:

a) General: Beard (1944, 1949, 1955), Richards (1952), Lauer (1952, 1968), Troll (1959, 1968), Ellenberg (1959, 1975), Knapp (1965), Czajka (1968), Holdridge (1971, 1982), Grubb (1971, 1977), Walter (1973, 1979), La Bastille and Pool (1978), Vareschi (1980).

b) Venezuela: Beebe and Crane (1947), Lamprecht (1954, 1958, 1976) Roth and Mérida de Bifano (1971, 1979), Medina and Zelwer (1972), Veillon (1974), Steyermark (1974, 1975), Hetsch (1976), Hoheisel (1976), Huber (1976, 1978), Brun (1976), Steinhardt (1978), Bockor (1979), Vareschi (1980), Sobrevila, Ramirez and de Enrech (1983).

c) Puerto Rico: Baynton (1968, 1969), Howard (1968, 1970), Gates (1969), Odum and Pidgeon (1970), Weaver (1972a, 1972b, 1975), Weaver, Byer and Bruck (1973), Byer and Weaver (1976), Brown et al. (1983), Lugo (1983), Frangi (1983).

d) Jamaica: Grubb and Tanner (1976), Tanner (1977, 1980a, 1980b, 1981), Tanner and Kapos (1982).

e) Costa Rica: Holdridge (1971), Lumer (1980), Lawton and Dryer (1980), Cáceres (1981), Zadroga (1981), Lawton (1982).

f) Mexico: Martin (1955), Vogelmann (1973), Lonard and Ross (1979), Puig, Bracho and Sosa (1981).

g) Colombia: Sugden and Robins (1979), Sugden (1982a, 1982b, 1982c, 1983).

h) Ecuador: Grubb et al. (1963), Grubb and Whitmore (1966, 1967).

2. Asian Humid Tropics:

a) General: van Steenis (1935), Richards (1952), Grubb (1971, 1977), Whitmore (1975).

b) Malaysia: Burgess (1969), Whitmore and Burnham (1969), Flenley (1974).

c) New Guinea: Brass (1941, 1956, 1959, 1964), Paijchmans (1975).

d) Himalayas: Schweinfurth (1957).

3. African Humid Tropics:

General: Lebrun (1935, 1960), Hedberg (1951)

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2. CLOUD FOREST DISTRIBUTION IN THE HUMID TROPICS

Occurrence in Terms of Altitude (Altitudinal Belts)

The term "cloud forest" has always been used to describe and generally define forests that are influenced by the frequent presence of clouds or mist. All of the authors who apply the term recognize this influence within the microclimate, ecology, structure, and hydrologic behaviour.

For this reason, there are many classifications of tropical mountain vegetation that even assign altitudinal belts to cloud forest formations.

Here are a few examples:

- Troll (1956) developed a schematic profile of humid vegetation by altitudinal belts covering the globe from the north to the south pole. This profile shows an altitudinal belt for cloud forests in the humid tropics (figure 2)
- Mann (1968), in a study on South Ameriçan ecosystems attributes large areas, based on altitude, to the "silva nebula" (figures 3a and 3b)

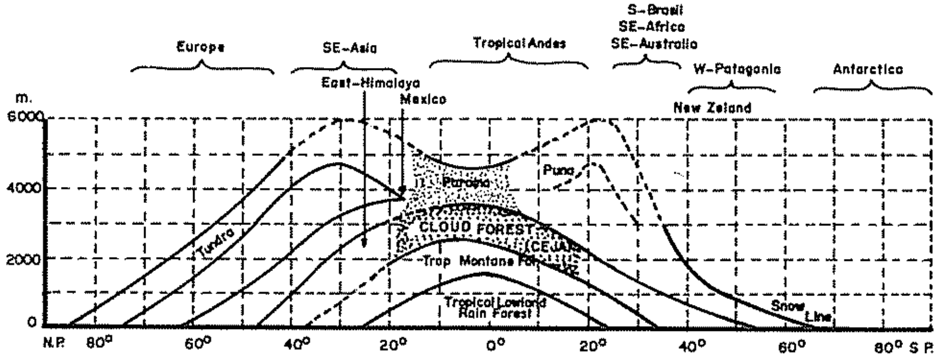


Figure 2: **A schematic profile of the world's humid vegetation from the north to the south pole with emphasis on the tropics, according to Troll (1956), modified**

- Lauer (1968) described the different altitudinal vegetation belts in Central America, including Panama, and in parts of Mexico and Colombia (figure 4). Using the geoclimatic classification first applied by Alexander von Humboldt in 1811, Lauer attributes cloud forests to a large portion of the "tierra fria" belt extending southwards from Nicaragua
- Troll (1959), considering topoclimatic phenomena, drafted the different altitudinal vegetation belts and landscape elements in the area of the "altiplano", La Paz and Las Yungas in Bolivia where cloud forests cover a large part of the mountain sides (figure 5).

The four examples mentioned indicate the influence of climate and orography on the distribution of cloud forests. Figure 2 shows, in a very general way, the boundaries of the cloud forest belt in the tropics. Depending on latitude, the **lower limit** varies between 1,500 and 2,500 masl, and the **upper limit** lies between 2,400 and 3,300 masl, indicating the existence of an altitudinal belt of approximately 800 to 1,000 metres at all latitudes. This, of course, is based on a very small scale graphic, giving only an approximate and generalized global overview.

Figures 3a and 3b show major variations in the distribution and extent of cloud forests in South America in relation to exposure.

Finally, figure 5 illustrates that climatic and geographic factors, on a local or regional level, may additionally influence formation and elevation of clouds, as well as their water content, thickness, and dynamics. For this reason, there are several authors who describe cloud forests even below 1,000 masl (Richards, 1952; Laserre, 1961; Weaver, Byer and Bruck, 1973; Walter, 1979; IUCN, 1982). Knapp (1965), referring to Beard (1949) mentions the presence of cloud forests at 300 masl in exposed areas of the Lesser Antilles.

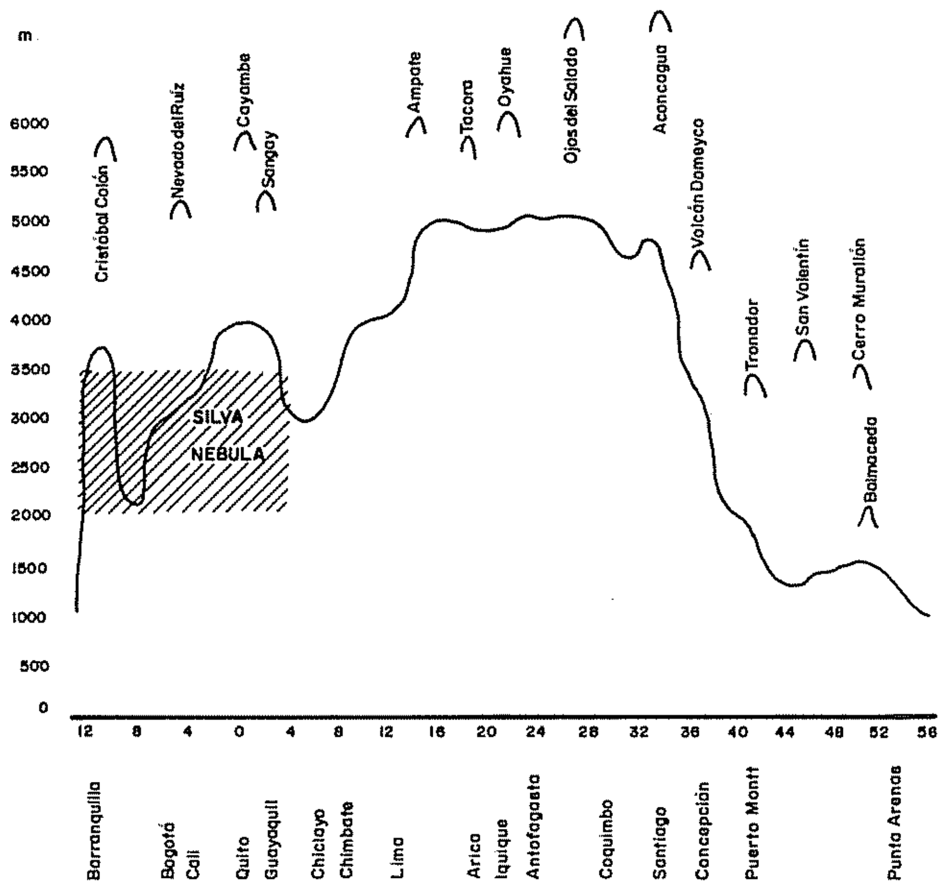


Figure 3a: The cloud forest zone ("silva nebula") on the western Andean slope, according to Mann (1968)

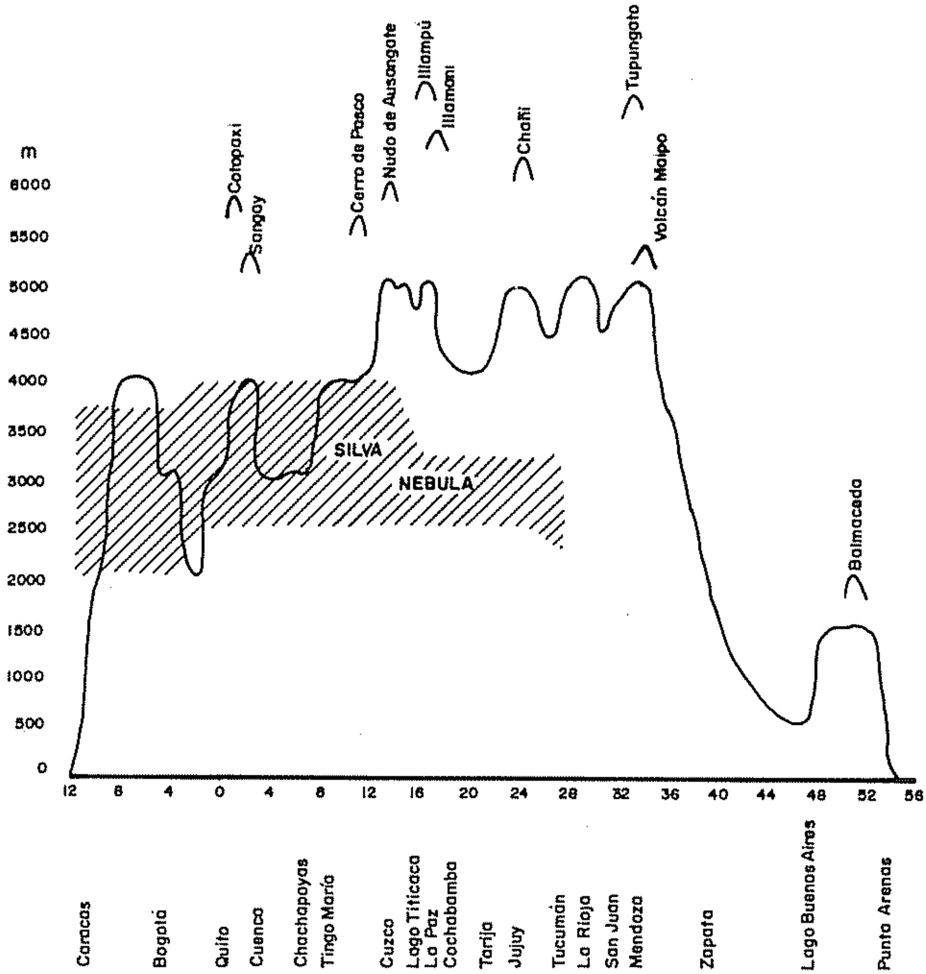
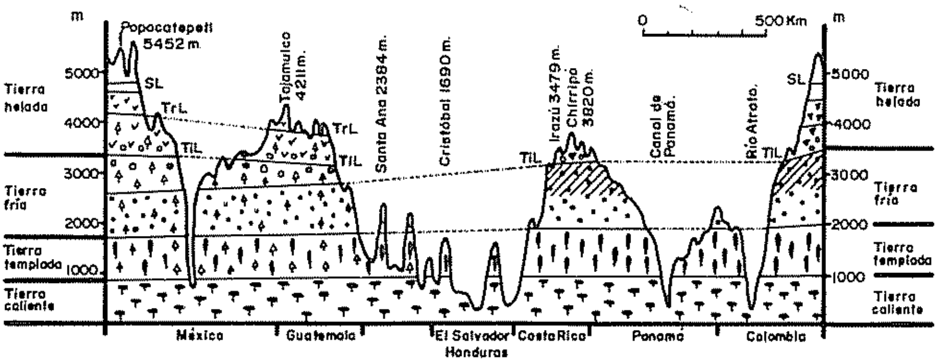


Figure 3b: The cloud forest zone ("silva nebula") on the eastern Andean slope, according to Mann (1968)



Lowland tropical evergreen and semi-evergreen forest
Tropical evergreen and semi-evergreen montane forest
Mixed montane pine/oak forest
TROPICAL CLOUD FOREST
Mixed tropical forest with boreal elements (pine, oak, fir)
Mixed upland boreal forest (pine, oak, fir, alder)
Grassland with pine and fir
Grassland
Tropical paramo
Ericaceaous belt
Bamboo belt
SL Snow line
TrL Tree line
TIL Timber line

Figure 4: The altitudinal vegetation belts from Mexico to Colombia, according to Lauer (1968)

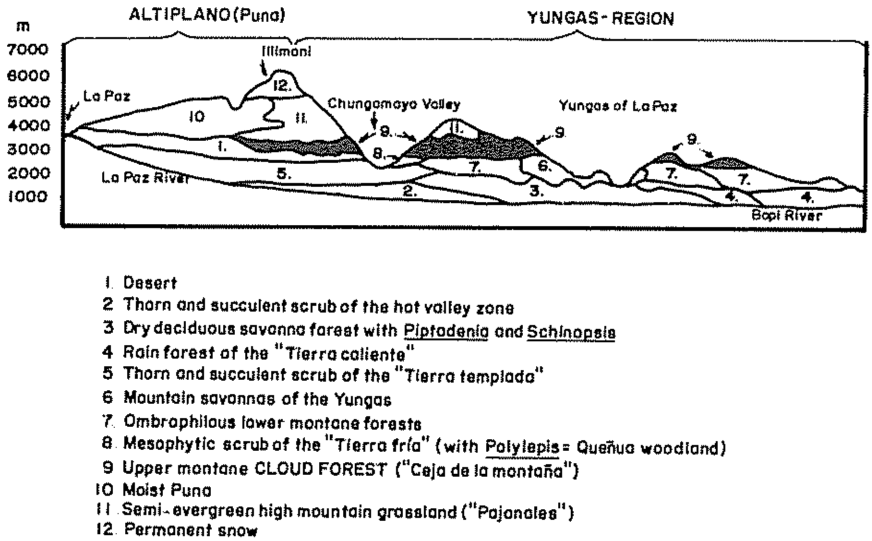


Figure 5: A schematic profile of vegetation on the eastern Andean slope, from La Paz to the "Yungas", according to Troll (1959), modified

On the other hand, according to Hedberg (1951), cloud forest reaches 3,500 masl on Mount Kenya. Also Troll (1959, 1968) found cloud forests ("bosques de ceja") in the eastern Andes at 3,500 masl. Hueck (1978) emphasizes that in some cases these forests can even reach 3,900 masl.

Ellenberg (1964), in a description of mountain vegetation and its productivity in Peru, points out that there generally exist three different levels of cloud condensation, each having its respective type of vegetation influenced by clouds or fog:

- cloud forests between 2,000 and 3,000 masl in the eastern Andes (the humid region)
- semi-evergreen scrub vegetation between 3,000 and 3,500 masl on the western slope of the Andes
- "loma" vegetation caused by the "garúa" phenomenon, existing from sea level to approximately 1,000 masl along the arid Pacific coast.

All the previously mentioned examples indicate that there are various climatic and geographical factors which intervene and influence the elevation limits of the cloud forest belt in the humid tropics:

- mean moisture content of the atmosphere (Kerfoot, 1968)
- cloud formation by convective or advective processes

- effect of the trade wind inversion and its variation on cloud formations (Riehl, 1954, 1979; Dohrenwend, 1972)
- direction and velocity of the prevailing winds (Kämmer, 1974)
- the mass elevation effect ("Massenerhebungseffekt") (Richards, 1952; Grubb, 1971, 1977)*
- size and orientation of the principal mountain ranges (macro-relief)
- micro-relief within mountains which can have important topoclimatic effects (Troll, 1968)
- mean distance to the nearest sea as a function of prevailing winds
- surface temperature and prevailing water currents of the nearest sea.

For these reasons, it is not possible to define universally valid elevation limits for the occurrence of cloud forests in the humid tropics. Furthermore, the width of the altitude belt of the cloud forest as a function of latitude cannot readily be determined. But, the following general conclusions may be made:

The band of dense cloud cover in the humid tropics is generally found between 1,200 and 2,500 masl but in many cases it can reach more than 3,000 masl or begin below 1,000 masl. These limits depend on the structure of the troposphere, temperature and humidity conditions, the behaviour of the trade wind inversion, and on landmass elevation. Independent of the structure of the troposphere, but in accordance with the air temperature and relative humidity, orographic clouds occur frequently in mountain areas as a result of congestion and ascent of air masses. In coastal areas, gradual transitions between coastal fogs and orographic clouds may result (Flemming, 1971).

The adiabatic ascent of moist air causes condensation at certain elevations and thus produces clouds. Together with strong winds, the vegetation in contact with the clouds can capture a considerable amount of water in addition to the orographic rainfall that is often produced in these zones. The presence of cloud forests apparently requires that the clouds occur with a certain frequency, regularity, or periodicity and in combination with winds that permit a more intensive exchange between vegetation and the atmosphere.

According to Holdridge's (1967, 1982) life zone system, cloud forests as "wet atmospheric association" predominate in the life zones from moist forest to rain forest in the premontane and lower montane belts, although Myers (1969) points out that cloud forests can also occur in other life zones or orographic belts.

Grubb (1971, 1977) emphasizes that dense and frequent clouds can decrease the

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* This effect causes the occurrence of a determined species or vegetation formation on isolated and exposed mountains at much lower elevations than in extensive areas of high mountains, e.g. the mountain moss forest formation is found at 500 masl in the Seychelles, at 1,000 masl in the Philippines, at 2,400 masl on Mt. Kaindi, and at 3,100 masl on Mt. Wilhelm in New Guinea, according to Jeffrey, Brown, and McVean (In: Flenley, 1974).

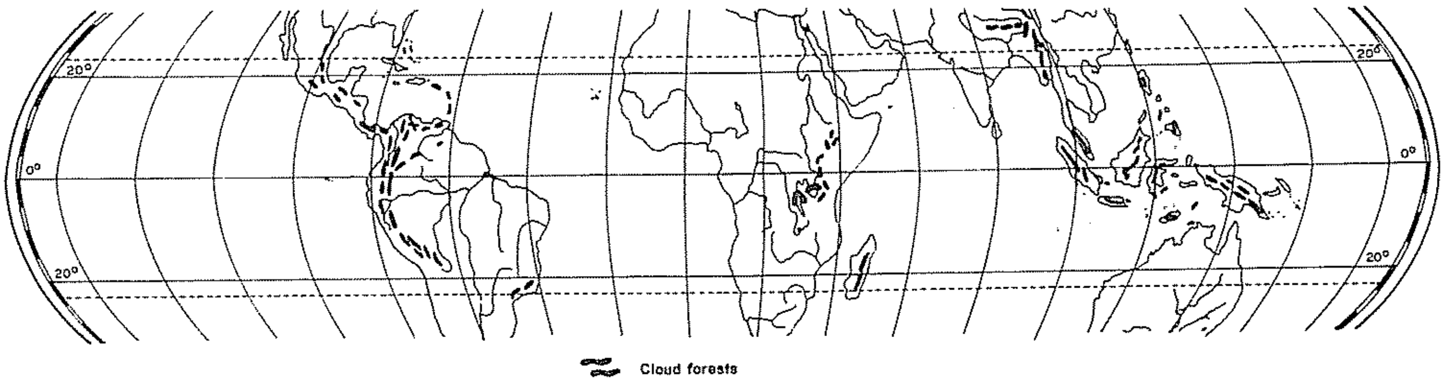

Figure 6: Cloud forest distribution in the humid tropics and adjacent areas

lower elevation limits of different tropical forest formations such as the "Upper montane rain forest" and the "Lower montane rain forest".

Area of Distribution (Horizontal Extension)

The following is an attempt to determine the extent of the principal areas of cloud forests in the humid tropics within the zone defined in the introduction (see figure 1). Bockor (1979) estimates the total surface of cloud forests in the humid tropics at 500,000 km^2 which would be equivalent to approximately 10% of the existing "tropical rain forest" according to Persson (1974) and would correspond, for example, to the total area of Kenya or Thailand.

Given that the occurrence of cloud forests is strongly linked to geographic and climatic factors, different sources are used to define the distribution of the cloud forests and indicate their limits in a general fashion in figure 6. The principal references used are: Martin (1955), Schweinfurth (1957), Lauer (1968), Wiebecke (1971), Paijchmans (1975) and IUCN (1982).

It is important to mention here that figure 6 is only an attempt to give a general idea of the geographic distribution of cloud forests in the humid tropics, due to considerations of scale and to lack of sufficient secondary information for the African and Asian tropics. For this reason figure 7, which shows the contiguous distribution of the Cyatheaceae according to Kroener (1968), is added for comparative purposes and as an additional indicator. As already mentioned in chapter 1, various authors indicated that the presence of Cyatheaceae was typical of tropical cloud forests. Comparing the two maps (figures 6 and 7), one can observe that in the humid tropics the distribution of cloud forests coincides, to a very great degree, with the contiguous distribution of the Cyatheaceae.

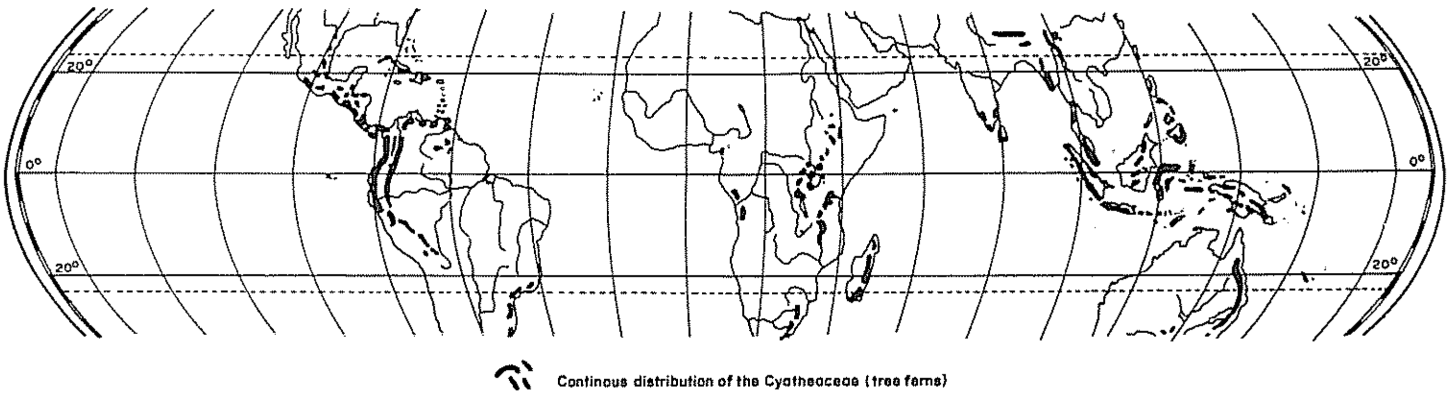

Figure 7: Continous distribution of the Cyatheaceae (tree ferns) in the tropics and adjacent areas, according to Kroener (1968)

3. CLOUD FOREST TERMINOLOGY

The term "rain forest", which attempts to classify a certain type of tropical vegetation, has frequently been the object of discussion due to varying interpretations or having been substituted by other equivalent, partly equivalent or more specific terms (Richards, 1952; Odum and Pidgeon, 1970; Letouzey, 1978). Furthermore, according to different authors, terminologies, and classification systems, there are various types of forests which may or may not belong to the category "rain forest".

Equally, the term "cloud forest", as frequently used in publications, lacks precision, has been interpreted, defined and used in different ways for distinct types of vegetation. In spite of this, many forests merit the appellation because the frequent presence of clouds plays a predominant ecological role (Huber 1976). According to the type, frequency and periodicity of the clouds, together with the other climatic and geographic factors, one can observe the occurrence of different types of cloud forests.

On the other hand, there exist types of vegetation sometimes called "cloud forests" which would better be called otherwise, due to other predominating factors. Ashton et al. (1978) proposed the term "wind forest" for forests in very exposed sites even though in these places wind frequently occurs together with dense, rapidly moving clouds thus depositing a great quantity of horizontal precipitation. These forests which, due to their form and structure, are also known as dwarf forests, elfin woodlands, mountain thickets, mossy forest and frequently even cloud forests

(Howard, 1970), are treated separately at the end of this chapter.

Spanish Terminology

The term "bosque nublado" is the most frequent and general denomination in Spanish to descibe forests under the strong influence of clouds (Lamprecht, 1954). Veillon (1974) uses the term "selva nublada" which he considers equivalent to the "bosque muy humedo montano bajo" according to Holdridge's (1967, 1982) classification. Other authors, e.g. Cáceres (1981) mention cloud forests in the "bosque muy humedo premontano" life zone.

Beard (1944) in his system of classification equates the term Montane Rain Forest with the Spanish "selva nublada". This latter term was first applied by Pittier (1937) as a sub-category of the "selvas ombrófilas". In Central America, especially in El Salvador, the term "bosque nebuloso" is frequently used (Serrano, 1977). Czajka (1968), in a study of vegetation profiles of the mountains between Alaska and Tierra del Fuego, utilizes the term "bosque montano nebuloso" to describe the cloud forests in the American humid tropics. The term "bosque montano nebuloso" is a literal translation of the German "Gebirgs-Nebelwald" used by Lamprecht (1954).

Other terms used to describe forests and vegetation of frequently clouded areas of the eastern Andes of Peru and Bolivia are "bosques de ceja" or "ceja de montaña" (Weberbauer, 1911; Troll, 1968; Hueck, 1978). These terms, particularly "ceja de montaña" as used by Weberbauer, frequently describe dwarf forests ["mist forests" or "elfin woodlands" (Richards, 1952)] that occupy the altitudinal belt below the "páramo" or "puna". However, high, dense forests are sometimes also included in the "bosques de ceja" types.

Acosta-Solis (1968) on the other hand distinguishes within the eastern range of the Ecuadorian Andes, between "selva mesotérmica higrofítica nublada" (800 masl) and "ceja andina" (2,800 - 3,200 masl), the latter falling within the category "selvas sub-mesotérmicas".

Veillon (1955) in a study of Andean forests of Venezuela, mentioned "bosques nublados andinos" which possess characteristics of high, dense, evergreen, species rich forests which are not equivalent to "bosques de ceja".

English Terminology

"Cloud forest" is the most common term used worldwide to describe forest types under the influence of clouds. (Beebe and Crane, 1947; Beard, 1955; Drewes and Drewes, 1957; Ellenberg, 1964; Troll, 1968; Roth and Mérida de Bifano, 1971, 1979; Lawton and Dryer, 1980; Sugden, 1983). However, considerable numbers of authors have created other terms to describe such forests. The majority of these terms are those included in tropical vegetation classifications systems, e.g. Montane rain forest (Beard, 1944, 1949, 1955).

Richards (1952) cited various authors of local studies that created different terms for the denomination of cloud forests: Exel (1944) named the vegetation of Sao Tomé above 1,400 masl "mist forest". Lane-Poole (1925) described two types of cloud forests in the mountains of New Guinea: "mid-mountain forest" which coincides with the presence of cloud cover, and "mossy forests" that are dwarf forests with a large amount of epiphytes found in the persistant mist zone. The terms "submontane rain forest" and "montane rain forest" used by van Steenis (1935) in Malaysia correspond with the terms "mid-mountain forest" and "mossy forest" of Lane-Pool (1925) in New Guinea.

Holdridge (1967) in his life zone system, developed the term "climatic association" within azonal climates. One of these associations is "wet atmospheric association of lower montane wet or rain forest" to which Holdridge assigned the cloud forests. However, Myers (1969) indicated that cloud forests also occur in other life zones. Zadroga (1981), in a study of the hydrological importance of a cloud forest, applied the term "montane cloud forest" emphasizing orographic factors and the role of cloud forests in high altitude watersheds within the tropics.

One of the best known and most widely used classifications of tropical vegetation is that of Beard (1944, 1949, 1955). His term, which corresponds with cloud forest or "selva nublada" is the term "montane rain forest" (Beard, 1944). In his presentation of improved classification, Beard (1955) compared "montane rain forest" with "cloud forest". Lamprecht (1977) confirmed the synonomy of the two terms.

However, above the "montane rain forest" two further types exist which are also subjected to the influence of the mist belt (Beard, 1955), but have not been classified by Beard as cloud forest: "montane thicket" and "elfin woodland" or "mossy forest". Probably, for these two types, Beard attributed other ecological or climatological factors as predominant ones (e.g. exposure to strong winds). Myers (1969) considered "montane thicket" and "elfin woodland" as particular types of cloud forest in his studies in Panama.

Generally speaking, the terms "cloud forest" and "montane rain forest" are synonymous, although Ellenberg (1964) used "montane rain forest" to describe forests occurring below the cloud forest belt. Ellenberg's "montane rain forest" is probably a literal translation of the German term "Montaner Regenwald".

Although Beard (1944, 1955) has dwarf forests (elfin woodlands, mossy forests) as special types outside the montane rain forest, some authors include dwarf (cloud) forests within the montane rain forest (Richards, 1952; Leigh, 1975; Lawton, 1982).

German Terminology

The most frequently used term in German literature to describe cloud forest is the term "Nebelwald" (Lauer, 1952; Schweinfurth, 1957; Troll, 1959; Ellenberg, 1959, 1964; Knapp, 1965; Walter, 1973, 1979; Brun, 1976). The term "Nebelwald" signifies fog forest. In recent years the majority of authors use the term "Wolkenwald" (Lamprecht, 1972, 1976, 1978; Hoheisel, 1976; Steinhardt, 1978;

Bockor, 1979) in order to represent the translation of the most widely used term at the international level, "cloud forest", more accurately.

Ellenberg (1975) created the term "Orealer Wolkenwald" emphasizing the orographic influence on the occurrence of cloud forest.

Huber (1976) indicated that from the meteorological point of view, there is no difference between clouds and fog other than that fog is in direct contact with the earth's surface. In the case of mountains swathed in clouds, this difference has already been eliminated. Therefore, "Nebelwald" and "Wolkenwald" can be considered synonymous. Nonetheless, many authors now prefer the term "Wolkenwald" which more accurately reflects the climatic conditions than "Nebelwald" (Bockor, 1979).

Vareschi (1980), on the other hand, makes a strict difference between "Nebelwald" and "Wolkenwald" attributing to each distinct climatological and ecological properties. According to Vareschi the type "Nebelwald" or "Bergnebelwald" is very common in all mountainous zones within the tropics and corresponds with the general cloud condensation level. But the "Wolkenwald" type, according to Vareschi, is conditioned and caused by a rare and particular combination of climatic factors which permit cloud condensation in very warm areas at low altitude. In conformity with Vareschi's studies, the "Wolkenwald" type represents the global optimum for the vegetation and at the same time receives the highest diversity parameter according to Vareschi's classification. The "Wolkenwald" type (sensu Vareschi) is extremely rare and not synonymous with cloud forests or dwarf forests that occur at relatively low altitudes in the Antilles and which were described by Beard (1949).

Knapp (1965) using the term "Nebelwald" distinguishes between "montaner Nebelwald" (mountain cloud forest) and "Krummholz-Nebelwald" (dwarf cloud forest), a most useful differentiation of the two categories which probably corresponds to the montane rain forest and elfin woodland (mossy forest) types of Beard (1955).

Another German term synonymous with cloud forest, created by Lamprecht (1954) and also used by Huber (1976), is "Gebirgs-Nebelwald" which means mountain cloud forest.

Other Language Terms

In French the most frequently used terms to define cloud forests are "forêt de nuage" and "forêt néphéliphile" (Letouzey, 1978). Lebrun (1975) described cloud forests in the Congo creating the term "forêt mésophile de montagne". Another term mentioned by Letouzey (1978) is "sylve à lichens" which was used to describe mossy forests in Madagascar. Aubreville (1949) described cloud forests with the term "forêt tropical humide de hautes altitudes".

Beard (1944) presents the Portuguese equivalents for montane rain forest (mata nublada) and elfin woodland (bosque anão).

Mann (1968) used a Latin term "silva nebula" to describe large altitudinal levels of vegetation under the influence of clouds (see figures 3a and 3b).

Terminology - Elfin Woodlands

Woody vegetation, which frequently forms the upper limit of tropical mountain forests (Letouzey, 1978) or covers the summits and ridges of isolated and exposed mountains, has been the object of many studies. This type of vegetation is generally characterized by its stunted stature, twisted trunks with many branches and by a large number of epiphytes (especially mosses) that can completely cover the trunks, branches and ground (Howard, 1968; Weaver, Byer and Bruck, 1973). Beard (1944) in his classification system, referred to this type of vegetation by its physionomy, as elfin woodlands, which has been translated into Spanish as "bosques enanos".

One can generalize in saying that elfin woodlands occur at altidudes above those of cloud forests. Nevertheless, many authors include elfin woodlands within cloud forests (Richards, 1952; Troll, 1968) while others have a tendency to exclude them (Beard, 1944 and 1955; Holdridge, 1982).

Given that elfin woodlands frequently form the upper limit of cloud forests, their occurrence in tropical mountain zones varies likewise: in the Lesser Antilles, Beard (1949) describes elfin woodlands below 1,000 masl, and in special cases even as low as 500 masl. On the other hand, in the Peruvian eastern Andes, Hueck (1978) mentions that elfin woodlands ("bosques de ceja") in some cases reach 3,900 masl. This disparity is due to various factors, among which the most significant is the so-called mass elevation effect ("Massenerhebungseffekt") (Richards, 1952). Grubb (1971) tied this effect and its variations to the frequency of clouds or fog.

A large number of different terms exist to describe elfin woodlands, particularly in English works. The oldest and most widely used term is elfin woodlands. Beard (1955), although continuing to use the term, recommends more correct terms such as "montane woodland" or "elfin thicket". Another term frequently used is "mossy forest" (Richards, 1952).

Whitmore (1975) indicates that mossy forests can be found as an element within types of upper montane rain forest.

Other terms describing elfin woodlands due to the high incidence of mosses are "mountain moss forest" (Flenley, 1974) and "mossy montane forest" (Richards, 1952). Weaver (1972a, 1975) and Byer and Weaver (1976) preferred to use the terms "dwarf forest" and "dwarf cloud forest". Troll (1959), Baynton (1968, 1969) and Gates (1969) applied the term "elfin forest". Beard (1955) in his classification of tropical American vegetation excludes "montane thicket" from "elfin woodlands", while other authors include it [e.g. Howard, (1970)].

Other terms also refer to the characteristics of elfin woodlands subjected to strong winds that supposedly occur in sites in which elfin woodlands predominate. Ashton et al. (1978) use the term "wind forest", while Holdridge (1982) classifies elfin woodlands as "climatic association of strong winds."

Lugo (1983) and Frangi (1983) propose the inclusion of certain elfin woodlands within wetlands and calls them mountain wetlands or "tierras pantanosas de la montaña", supposing that the hydrological environment is the principal factor in these ecosystems, which would indeed correspond with many elfin woodlands according to the two authors.

Knapp (1965) used the term "Krummholz-Nebelwald" for a vegetational map of the Antilles, which also included wetlands without trees. Beard (1944) translates elfin woodland into Portuguese as "bosque anão" and Letouzey (1978) mentions that elfin woodlands in Madagascar were referred to by the French term "sylve à lichens".

Each one of the above mentioned terms attempts to describe elfin woodlands, placing emphasis on certain characteristics: be they altitude and form of vegetation ("bosque enano", dwarf forest, elfin woodland, "Krummholz-Nebelwald"), density (montane thicket), environmental factors such as clouds (dwarf cloud forest), winds (wind forest, climatic association of strong winds), humidity (wetlands, "tierras pantanosas de la montaña") or the abundance of epiphytes, particularly mosses (mossy forest, mountain moss forest).

Each one of these descriptions can represent an element of reality, but the great variety of terms indicates that knowledge and research is still lacking. However, many authors have speculated over the reasons for the small size and structure of elfin woodlands. Weaver, Byer and Bruck (1973) summarize with the following list of possible causes:

- saturated soils and reduced root respiration
- insufficient drainage of the soil and physiological desiccation
- strong winds
- nutrient leaching combined with low temperatures and frequent cloud cover
- reduced transpiration
- shallow soils
- reduced solar radiation

Some of these hypotheses were investigated and discussed in more recent publications by Leigh (1975), Grubb (1977), Jaffe (1980) and Lawton (1982).

Leigh (1975), in order to explain the stunted growth of dwarf forests, supports the theory of reduced transpiration due to high air humidity, and accepts a certain influence of wind in exposed sites. He attributed the stunted growth of the trees and their branches to thin, nutrient-poor soils.

Grubb (1977) on the other hand, rejects the theory of reduced transpiration which, in his view, does not effect the absorption of nutrients. He attributes the stunted growth of the trees to low temperatures in combination with reduction of photosynthetically active radiation. He accepts the effect of strong winds, particularly in regions dominated by trade winds.

Jaffe (1980) showed that the wind's bending effect can cause reduced growth. He incorporates this effect within the thigmomorphogenesis phenomenon.

Lawton (1982), describing elfin forests at an altitude of 1,750 masl in the continental divide of Costa Rica, also considers strong winds as a principal cause of the low and twisted stature of these forests. He additionally mentions lightning as another destructive factor on mountain ridges, which does not permit normal tree development.

In this present study elfin woodlands are included within cloud forests, since it is proved that the majority is subjected to the presence and influence of dense and frequent clouds, which, apart from other factors, play an important ecological role.

4. CLOUD FOREST ECOLOGY

The present chapter attempts to deal with those ecological factors which condition and affect cloud forests. Within these factors, climatic elements per definitionem take priority and will be discussed in more detail; then edaphic and hydrologic parameters will be dealt with; and finally mention will be made of other ecological factors, particularly those of a biotic nature.

Climatic Elements and Factors

Horizontal precipitation and its measurement. It has already been necessary on various occasions to point out the influence of climate and its parameters on the presence, distribution and structure of cloud forests. Holdridge (1971) summarizes the climatic conditions necessary for cloud forests, naming them "special atmospheric conditions":

> Wherever fogs and mists occur with great frequency, as they do on windward mountain slopes in the condensation or "cloud belt" ... they may constitute a significant source of additional moisture. Fog-borne moisture, dew, and heavy mists may condense upon exposed vegetational surfaces, and drip, or run down stems, to the ground. Such moisture, however, is not recorded in properly installed standard rain gauges, and its quantity is known to be highly dependent upon both the

successional stage and foliage characteristics of the dominant vegetation. Hence, it does not enter into the computation of mean and annual precipitation for the determination of the Life Zone itself. Rather, it is considered to be a wet-atmospheric factor entering the classification at the secondary or association level.

Many authors consider that the additional supply of water, in combination with lower temperatures in mountainous zones, is an important ecological factor affecting the different types of cloud forests. This input of precipitation, in addition to rain, has been variously named by different authors (Kittredge, 1948; Geiger, 1961; Lamb, 1965; Kerfoot, 1968; Holdridge, 1971; Whitmore, 1975; Cáceres, 1981):

- horizontal interception
- negative interception
- cloud moisture interception
- fog precipitation ("Nebelniederschlag")
- fog drip/cloud drip
- condensation drip
- mist precipitation
- fog stripping
- occult precipitation
- horizontal precipitation

In the present study, the entry of water into the ecosystem conditioned by the condensation process of the humidity of clouds or fog on vegetational surfaces, or by means of direct contact of cloud droplets with the vegetation, will be called **horizontal precipitation** and signifies an input of additional water to rainfall. The term "horizontal interception" used in different publications could be misleading in that "interception" as a micrometeorological and hydrological parameter, is generally understood to mean water intercepted by vegetation and then evaporated from the plant surfaces; in other words, water leaving the ecosystem.

The quantity of horizontal precipitation depends as much on inherent vegetational factors as climatic factors and elements. These will be discussed later, when the different climatological scales (macro, meso and micro) will be analysed.

The inherent vegetational characteristics, are roughly the following:

- height of the vegetation
- canopy structure (influencing the roughness thus causing micro turbulence)
- size, quantity, location and arrangement of leaves
- quantity, forms and types of epiphytes

According to Juvik and Ekern (1978) two basic methods exist for the measurement of horizontal precipitation:

a) collect total precipitation beneath the canopy by means of troughs or a large number of rain gauges, subtracting from this the rainfall above the forest or in a nearby unforested area;

b) collect cloud droplets by means of artificial apparatuses known as "fog catchers".

The first method gives real values for net precipitation, being ecologically and hydrologically relevant for the ecosystem under study. Considering the interception (water intercepted by vegetation and then evaporated) the behaviour of gross rainfall (measured outside or above the forest) together with other climatic elements, this method allows the calculation of the actual contribution of horizontal precipitation to net precipitation. Measurement techniques require a large quantity of equipment, and are thus costly and present a difficulty in that the location of the collection troughs or rain gauges does not give readings that are representative of the ecosystem as a whole.

The second method that has been used by many scientists outside the tropics (see chapter 1) and by Ekern (1964), Baynton (1969), Vogelmann (1973), Juvik and Ekern (1978) and Cáceres (1981) in humid tropical zones, determines the quantity of water that can theoretically be extracted from clouds by condensation processes and through capture by artificial obstacles. The main difficulty in using fog catchers is finding a design which gives accurate and representative readings of the horizontal precipitation within the ecosystem under study (Baynton, 1969). Another problem relating to the installation of the fog catcher is the selection of the level above the ground at which it is located (Ekern, 1964).

Table 2 shows, in a summarized form, the results of horizontal precipitation calculations with fog catchers in different cloud forests within the tropics. The values indicated within the table show a great variability at the absolute level, as well as the relative level compared to rainfall.

Absolute values vary between 325 mm/y and 941 mm/y; and the relative values between 7.2% and 158.5% of rainfall. Relative values for extremely rainy climates or seasons remain quite low (between 7.2% and 18% of rainfall equivalent).

On the other hand, it is important to note that during the dry seasons (Vogelmann, 1973) the relative values of horizontal precipitation are extremely high and can even exceed those of rain. Juvik and Ekern (1978) mention a reading of 181.9 mm of horizontal precipitation in 3 dry months with only 14.5 mm of rainfall in a site located near a peak, which is the equivalent of 1,254% of rainfall. It is very probable that the relatively high quantity of water received through horizontal precipitation during the "dry" periods plays an important role in cloud forest ecology.

Juvik and Ekern's (1978) results additionally show that windward sites generally receive a great deal more horizontal precipitation than leeward ones, in absolute as well as relative values. However, in many cloud forests, where not only the slopes but also the peaks are swathed in clouds carried by winds, it is possible to observe what is known as the "spill-over effect" immediately on the leeward side of the crest where horizontal precipitation can reach very high levels. See data from Honulalai of Juvik and Ekern (1978) in table 2.

Table 2 Contribution of horizontal precipitation according to different studies undertaken in specific areas of the humid tropics

Author (Year)	Country; location	Surrounding vegetation	Specific conditions	Horizontal precipitation (mm/year)	Horizontal precipitation (% of rainfall)
Baynton (1969)	Puerto Rico; Luquillo Mountain (Pico del Oeste)	elfin cloud forest	1050 masl; very rainy	325 390	7,2 8,6
Vogelmann (1973)	Mexico; Sierra Madre	oak cloud forest	1330 masl;		
			rainy season (14 weeks)		18,0
			dry season (39 weeks)		85,5
			TOTAL	941	31,3
			1361 masl;		
			rainy season (13 weeks)		17,5
			dry season (40 weeks)		60,5
			TOTAL	512	30,9
			1898 masl;		
			rainy season (21 weeks)		14,0
			dry season (32 weeks)		102,9
			TOTAL	462	22,3
Juvik and Ekern (1978)	Hawaii;		windward:		
	Kulani Camp	Closed forest	1580 masl	770	30,0
	Kulani Mauka	Alpine shrubs	2530 masl	706	68,0
	Mauna Loa	(lava)	3415 masl	186	43,4
			leeward:		
	Honuaula	Pastureland	1905 masl	226	25,9
	Honulalai	Subalpine shrubs	2496 masl	569	158,5
Cáceres (1981)	Costa Rica; Atlantic slope	Premontane rain forest	1300 masl	approx 550	15,3

Cáceres (1981) also reports, in addition to the readings of fog catchers, interesting values for net precipitation (throughfall and stem flow). Net precipitation varies between 82% and 99%, with an average of 92%, of the rain measured outside the forest. In a broad study carried out on the hydrological cycle of an Andean cloud forest, Steinhardt (1978) measured gross precipitation (outside the forest) and the net precipitation. The latter represents 90% of the gross precipitation. In both studies stem flow did not amount to even 1% of precipitation.

In comparison with other studies carried out on tropical forest interception, mentioned by Baumgartner and Brünig (1978), the readings cited by Steinhardt (1978) and Cáceres (1981) for net precipitation are extremely high, which indicates a significant and effective contribution of horizontal precipitation to net precipitation.

Another study, not included in table 2, is that of Dohrenwend (n.d.) that determined, through the use of fog catchers, the contribution of horizontal precipitation to sub-alpine tropical vegetation resulting in approximately 20% of additional rainfall equivalent.

It is worthwhile mentioning here that solitary trees collect a great deal more horizontal precipitation per surface area than forests of the same species (Ekern, 1964; Vogelmann, 1973). According to Kämmer (1974) this is due to the efficiency of the vegetation to collect and condense cloud moisture through exposure to wind. Merriam (1973), who studied horizontal interception with artificial leaves in controlled conditions, in a wind tunnel, concluded that:

- the quantity of water that enters and crosses the canopy is determined by the quantity of water held in the clouds, the height and arrangement of the forest canopy and the velocity and turbulence of the wind. The latter, according to Lamb (1965), is increased by the forest and its physical characteristics (roughness parameter);

- the horizontal precipitation (fog drip) in turn depends on the total leaf surface, the spacial distribution of the leaves, and the physical properties of their surfacies.

Little is known of the effect of form and size of the leaves on horizontal interception, however, Went (1955) and Vogelmann (1973) consider that conifers are more efficient than broadleaved species.

Macroclimatic aspects. The relation between macroclimate and cloud forests and their occurrence has been discussed in chapter 2. In general, macroclimatic paramaters affecting cloud forests are:

- Grubb and Whitmore (1966) suggest that the most important factor is the frequency of clouds. Lower montane rain forest and upper montane rain forest are associated with frequent and persistent clouds respectively;

- the structure of the troposphere, including the temperature profile, affect the level of cloud condensation (Flemming, 1971);

- the mass elevation effect influences the distribution and vertical temperature profile and thus cloud formation (Richards, 1952; Hastenrath, 1968). Grubb (1971, 1977) thinks that the occurrence of clouds plays an important role within the mass elevation effect ("Massenerhebungseffekt");

- the direction and velocity of predominant winds (Kämmer, 1974) together with the average atmospheric humidity (Kerfoot, 1968), are important factors in orographic cloud formation;

- the temporal distribution of rains and the presence of clouds (horizontal precipitation). Vogelmann's (1973) and Juvik and Ekern's (1978) measurements (see table 2) indicate that the effects of a dry season can be mitigated or compensated for by horizontal precipitation. This phenomenon could be an important ecological factor, in that Lauer (1952) showed that 1,000 mm of precipitation spread over twelve months has the same biological effect as 2,200 mm in nine months;

- the frequent cloud cover not only effects precipitation, but also other climatic elements as well as physiological processes. Budowski (1966) indicates that cloud cover represent an effective protection against radiation and large differences in temperature and relative humidity. Grubb and Whitmore (1966) and Baynton (1969) mentioned that the quantity of light can be reduced to a level at which assimilation is limited. Drewes and Drewes (1957) think that the "wet cloud forests" of the Eastern Andes are not primarily the result of an excessive precipitation but rather the lack of sunshine, resulting in a low evaporation rate and cool temperatures, and to the condensation of cloud moisture on plant surfaces;

- the diameter of water droplets contained in clouds strongly influences the condensation process and the deposition of water on vegetation surfaces and therefore the quantity of horizontal precipitation. Grunow (1960b) found that the most effective diameter of water droplets in the horizontal precipitation process is 8-14 μ;

- another most important climatological phenomenon in tropical areas is the trade wind inversion which modifies the vertical temperature profile, thus influencing cloud formation (Riehl, 1954, 1979). The trade wind inversion is instable in that it is subjected to daily and annual variations. In addition, according to Dohrenwend (1972), the trade wind inversion that forms part of a Hadley cell, is situated at lower elevations in regions that are located far from the intertropical convergence zone (ITCZ), and higher in areas nearer the ITCZ (see figure 8). This could intensify the mass elevation effect in certain areas, for example, the Caribbean as opposed to Central America. The areas in which trade wind inversion occurs are shown in figure 9;

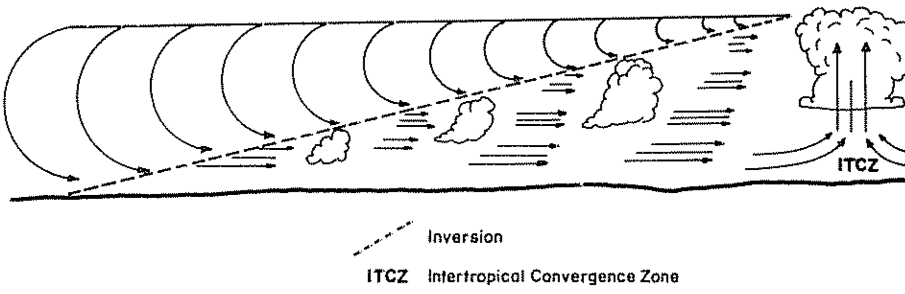

Figure 8: Meconisms forming the trade wind inversion, according to Dohrenwend (1972)

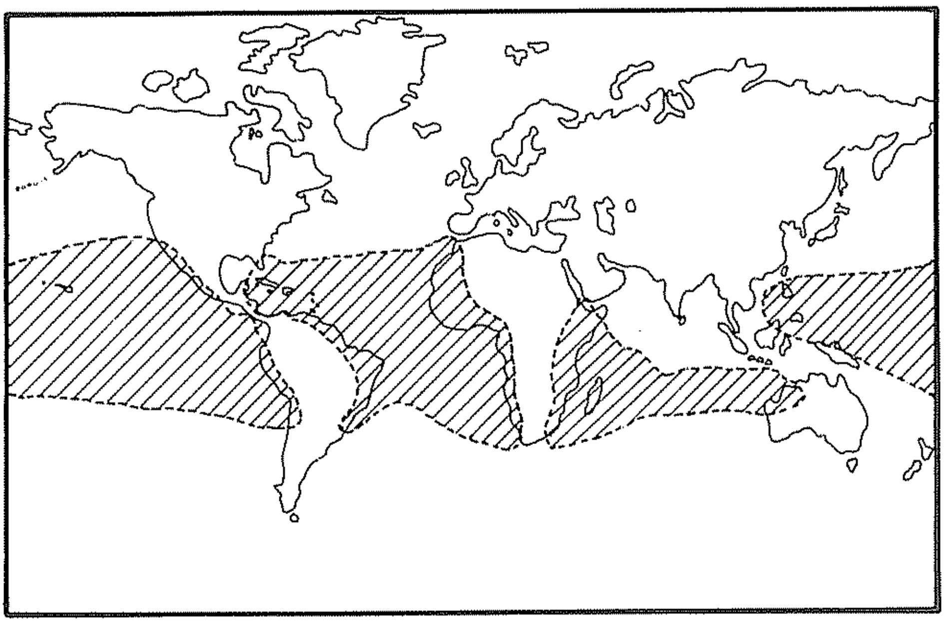

Figure 9: Areas of trade wind inversion occurrence, according to Dohrenwend (1972)

the type of cloud formations that predominate in different cloud forest sites could also be an influencing climatological factor. Grubb and Whitmore (1966) indicate that stratus clouds predominate in the Ecuadorian Andes, while cumulus clouds are most frequent in the Western Antilles.

Mesoclimatic aspects. With reference to the meso and topoclimatic scales, little information exists relating to tropical cloud forests. Huber (1976), in his research on the ecology of the cloud forest in Rancho Grande (Venezuela), divides it into three types according to structural differences:

- transition cloud forest with three storeys and trees that frequently extend beyond the canopy (approximately between 800 and 1,100 masl);

- true cloud forest with two storeys, with some trees extending beyond the canopy, palms abound and maximum of epiphyte syunsiae in quantity and diversity (approximately between 1,100 and 1,600 masl);

- upper level cloud forest, with a storey of dominating trees, a storey of dominated palms, and much fewer epiphytes than in the two other types (above 1,600 masl).

Huber (1976) came across these three types over a horizontal distance of two kilometres. It is likely that, apart from altitudinal differences, other climatic effects at the mesoclimatic level, especially the density and frequency of clouds and wind velocity modified by the topography, would contribute to these vegetational differences.

Troll (1968) mentioned two topoclimatic effects which could influence cloud forests:

- one refers to cloud formation due to circulation of air masses generated by the topography on the valleys of the Eastern Andes (see figure 10). These cloud banks condition cloud forests of "ceja de montaña" and allow the "Yungas" forests to extend as a wide zone towards the interior of the mountains;

- another topoclimatic phenomenon described by Troll (1968) refers to the general vegetional limit which can be of particular importance to cloud forests. Comparing tropical and boreal zones, forest vegetation in the latter reaches its highest limits in mountain ridges; on the other hand, in the tropics trees find their most favourable conditions in valleys (see figure 11). Among the explanations given by Troll (1968) of this phenomenon, there are some which could hold true for cloud forests that frequently extend to extremely high elevations in mountain valleys (Hueck, 1978; Mann, 1968): daily temperature variations are generally less and air humidity is greater in the valleys than on the ridges. These two phenomena correspond with typical climatic characteristics of cloud forests and can therefore modify their distribution at the topoclimatic level.

In addition, topography can significantly modify wind action in certain mountain locations, increasing wind velocity and thus speeding up the exchange between atmosphere and vegetation. This can augment the quantity of water entering the ecosystem by means of horizontal precipitation, or strongly alter the structure of the forests conditioning elfin woodlands at the topoclimatic level (wind forests, according to Ashton et al., 1978).

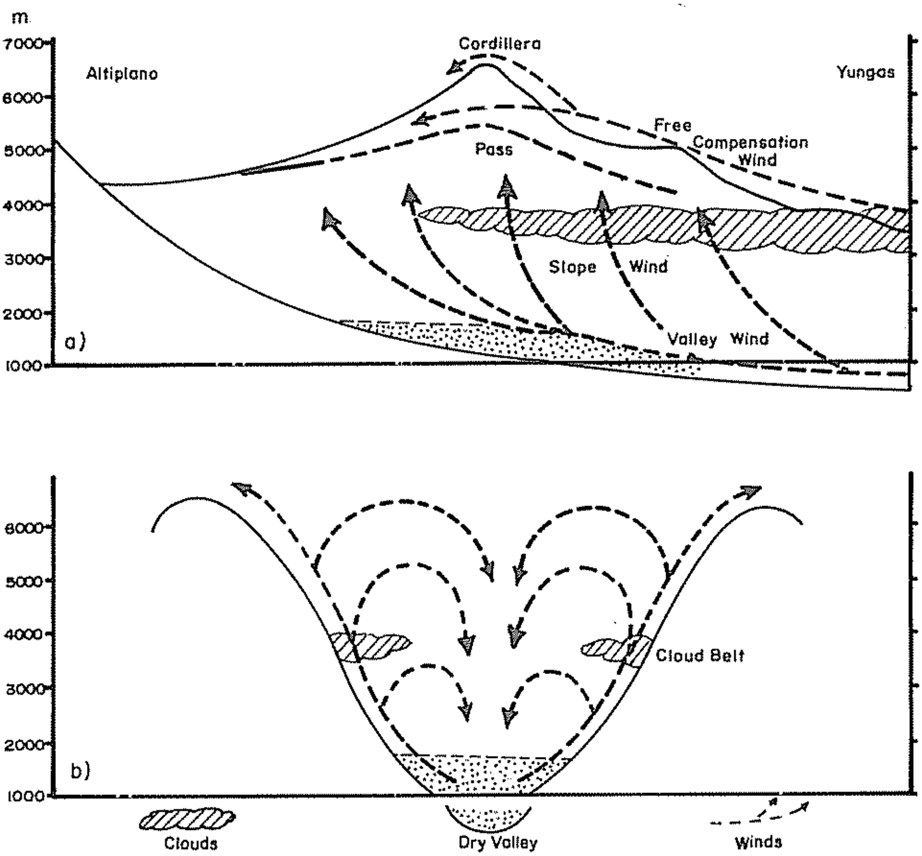

Figure 10: Daytime local wind system in an eastern Andean valley, according to Troll (1968)

a) longitudinal section

b) cross section

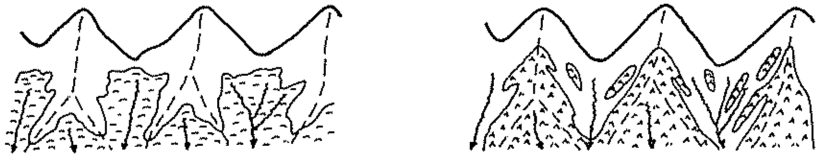

Figure 11: The effect of topoclimatic conditions on the altitude of the timber line in mountains of the tropical and boreal belt, according to Troll (1968)

Microclimatic aspects. Richards (1952) gives an extensive summary of tropical rain forest microclimate in general. However only a few limited studies exist of microclimates within cloud forests.

Beebe and Crane (1947), as well as Huber (1976), included some simple microclimatic measurements (mainly temperature, humidity and light) in their ecological studies of the cloud forest at Rancho Grande (Venezuela). In addition Huber (1976, 1978) determined the light compensation point of 54 species resulting in a very large variability. Baynton (1968, 1969) investigated the microclimate of a dwarf cloud forest in Puerto Rico, including the establishment of wind profiles. Lötschert (1959) included evaporation measurements within his microclimatic studies of a cloud forest in El Salvador.

Apart from the general characteristics of microclimate within humid tropical forests (Richards, 1952) it is possible to summarize the microclimatic properties of cloud forests as follows:

The principal microclimatic parameter affecting cloud forests is the high relative humidity of the air in combination with horizontal precipitation. These two elements, very often associated with rather low temperatures, keep cloud forests permanently humid. This in turn facilitates the presence of epiphytes (mosses and lichens) which are able to keep the microclimate humid even when, at the macroclimatic level, the relative humidity has dropped (Leigh, 1975; Grubb, 1977; Tanner, 1980b). In elfin woodlands the reduction in transpiration below the canopy, due to the abundance of mosses, can result in a complete obstruction of development of undergrowth or any other vegetation on the soil away from the mosses (Leigh, 1975).

Wind generally favours transpiration by reducing the external resistance to transpiration. However, extremely humid air, particularly that charged with water droplets, can block transpiration with a permanent layer of water on the leaves. This effect and its ecological importance within cloud forests has been discussed in chapter 3 (Other Language Terms). The hydrological aspects of reduced transpiration in cloud forests at watershed level is discussed below. Grubb (1977) indicated that the high humidity favourized the "invasion of lichens and bryophytes" and, referring to Berrie and Eze (1975), mentions the damage which can be caused by such invasions; not only by covering and obscuring the leaves, but also through the destructive effects on the cuticula. Grubb (1977) considers that "infections" of these epiphyllic organisms, conditioned by the extremely humid microclimatic environment, cause the most serious damage to the vegetation. It therefore appears strange that drip tips* are lacking in cloud forests. Grubb (1977) supposes that these are only effective in climatic conditions when heavy rain (or storms) are interspersed with periods of sunshine, but are ineffective in permanently cloudy conditions. Ellenberg (1975), who also mentions the lack of drip tips in cloud forests, on the other hand, actually questions the teleological interpretation of this phenomenon.

Another relevant microclimatic phenomenon that has attracted the attention of various authors is the presence of xeromorphism within cloud forests in the humid tropics. Walter (1979) considered that the leaves on the trees, even in the most humid tropical zones, were exposed to solar radiation for several hours thus resulting in a heating up of the leaves by 10 K above air temperature. Ellenberg (1959) mentions xeromorphism of epiphytes, giving the same explanation as Walter. Leigh (1975), on the other hand, considers that there is still no satisfactory explanation of the phenomenon that, according to him, assumes a considerable importance in the formation of a thick layer of undecomposed organic matter frequently found in cloud forests. Grubb (1977) rejects the climatic explanation of xeromorphism in cloud forests; for him physiological factors and nutritional effects determine the xeromorphism of leaves in cloud forests.

The formation of xeromorphic structures in cloud forests can also be interpreted as a protective mechanism for plant surfaces against the chemical impacts of horizontal precipitation which, according to Lovett, Reiners and Olson (1982) have different chemical properties from the rainfall, tending to be much more acid (Falconer and Falconer, 1980; Schrimpff et al., 1984). According to Falconer and Falconer (1980), the acidity of cloud moisture droplets is more pronounced in humid tropical air masses with dew point > 15°C.

It is worth mentioning here that a great deal of microclimatic research remains to be carried out in different types of cloud forests to increase knowledge of its ecological and hydrological importance. To date only dwarf cloud forests have been the object of more detailed microclimatic studies and considerations in that their unusual appearance has attracted the attention of various scientists (see chapter 3, Terminology - Elfin Woodlands).

Edaphic Characteristics

According to Whitmore (1975) cloud forests, and particularly those of the upper mountane rain forest type, show a thick and widespread layer of undecomposed

* Thin extension at the apex of the leaves which supposedly facilitates the trickling of water.

organic matter ("peat"). Brass (1941), Reynders (1964), Grubb and Whitmore (1966) and various other authors, indicate that peaty mountain areas correspond with dense and persistent cloud zones. Soil formation is particularly affected by the large amount of water entering the ecosystem. Following Whitmore (1975), the different consequences of this phenomenon are:

- leaching
- podsolization
- waterlogging

Frangi (1983) emphasized that the low deficit of atmospheric saturation in cloud forests results in a reduction of the pumping of water from the soil to the atmosphere, thus favouring wetland conditions even in areas of high permeability and inclination.

In addition the predominating low temperatures due to high altitude reduce the biological activity in the soil and the chemical meteorization in many cloud forests. The soils are usually highly acidic (pH 3.0-3.5) even in those originating from calcareous bedrock (Reynders, 1964) since there is permanent leaching.

Grubb and Tanner (1976) and Tanner (1977) studied soils in four different cloud forests (mountane rain forests) in Jamaica and established four different categories:

- mor ridge forest soils
- mull ridge and very wet ridge forest soils
- wet slope forest soils
- gap forest soils

In the case of mor ridge forest soils the organic layer is substantial (20-50 cm) and less in the other types.

Lötschert (1959) mentions a layer of organic material more than a metre deep in a cloud forest in El Salvador. Brewer-Carias (1973) reported that the soil of the Cerro de la Neblina cloud forest in Venezuela was covered with a thick layer of raw humus that in certain localities reached more than four metres in depth.

Leigh (1975) quoting Burgess (1969) emphasized that hardpans were frequently found between the peat and the mineral horizon. This phenomenon could lead to blocking plant access to the nutrients within the mineral layer. According to Schuylenborg (1958) podsolization within the tropics is generally more common in more humid and cold environments, although podsols are also frequently found in the humid tropic lowlands.

Peat formation can also be conditioned by the type of foliage that in certain cloud forests exhibits a high degree of xeromorphism, making its decomposition difficult (Whitmore and Burnham, 1969).

Hetsch (1976), who investigated relationships between precipitation and soil formation in the Venezuelan Andes, found that in cloud forest zones, in spite of the stability and structure of the soils, the high permeability and great capacity for infiltration and a permanent percolation, the soils were practically always saturated with water.

According to Hetsch (1976) the humus content of the soil and the C/N relationship increased with precipitation, reaching its highest level in cloud forest areas and diminishing above the cloud forest belt. However, it appears that various other factors interfere with this phenomenon in addition to the quantity of water entering the ecosystem (complex interplay of factors).

Fölster and Fassbender (1978), in a soil study of Colombian and Venezuelan Andean forests, mentioned an abrupt change in soils at the level dominated by cloud forests: the colour of the soils changes from reddish to yellow with a lowering of the pH due to high precipitation and the associated change in humus dynamics. Although Hetsch (1976) supposes that the H^+ ions of the organic soil matter, which suffers from decomposition difficulties, is the principal source of acidity, it is important to stress here that horizontal precipitation tends to have a lower pH than rain (Falconer and Falconer, 1980; Schrimpff et al., 1984). This could considerably affect the ecosystem, not only at soil level, but also at the plant surface level and particularly the leaves.

Another factor which could influence soil acidity of cloud forest soils is the high level of leaching as a result of abundant rainfall (Tuckey, 1970). Given that horizontal precipitation is extremely high in many cloud forests, and more acid than rainfall, two possible consequences are:

- increased leaching
- a reaction of the vegetal surfaces (e.g. xeromorphism)

Both cases promote acidification of the soil and create favourable conditions for the formation of a peat layer.

Generally, the presence of peat is most pronounced in those parts of cloud forests of the upper montane rain forest type where Grubb (1971) believes that there is a reduced level of phosphorous, nitrogen and oxygen. Nonetheless, in all cloud forests of restricted growth a fairly thick layer of practically un-decomposed organic matter is noted. On the other hand, the soils in cloud forests with vigorous growth and high trees do not show this phenomenon (Huber, 1976).

With respect to the distribution and nutrient cycling within cloud forests, an extremely extensive and complex subject, it is worth mentioning that the principal research and publications are to be attributed to Grubb and Whitmore (1966), Grubb (1977) and Steinhardt (1978).

Hydrological Characteristics at Watershed Level

Studies of the hydrological behaviour of watersheds in temperate zones indicate that the elimination of tree cover results in an increase in runoff, due to the reduction of water loss through the high level of evapotranspiration, characteristic of forests. However, in the case of cloud forests, particularly in tropical zones, deforestation can result in substantial water loss (Zadroga, 1981). This is due to various factors, of which the most important is the additional input of water into the forest through horizontal precipitation, which can represent a considerable increase in the water balance.

Wicht (1961) emphasized that the lack of consideration for the input of water through horizontal precipitation in watersheds with cloud forest components, demonstrates a serious error in the volumetric determination of precipitation, which in turn introduces false values in the calculation of the water balance of the waterhsed.

Tosi (1974) mentions that deforestation of tropical cloud forests results in a marked reduction in runoff, which at the same time signifies a diminution in the feeding of ground-water. Budowski (1976, 1980) indicates that cloud forests through their sponge effect are of considerable hydrological importance, and their disturbance could result in catastrophic consequences for valleys located downstream.

An energetic factor also enters cloud forest hydrology: a certain quantity of water deposited through horizontal precipitation on leaves corresponds with the quantity of water evaporated from the leaves during cloudless periods. This quantity of water would have been used in transpiration of soil water (McCulloch and Dagg, 1965).

Zadroga (1981) therefore summarizes three components of major importance in the evaluation of the effect of cloud forests on the hydrology of a watershed:

- increase in net precipitation
- reduction in the evapotranspiration rate
- regulation of the hydrological regime, particularly during "dry" periods (in terms of rainfall)

The increase in runoff in tropical watersheds with cloud forest components was recognized as far back as the 1960s, particularly in Hawaii. For this reason Duffy (1965) published an article with the title: "Water becomes the most important forest crop".

Zadroga (1981), in a study of the hydrological importance of cloud forests, analyzed data on precipitation and runoff in watersheds on the Atlantic and Pacific slopes of Costa Rica. Considerable differences were noted as far as the runoff/precipitation relationship was concerned. The value for the Atlantic slope, affected by the high incidence of clouds, was 102%. The Pacific slopes however, demonstrated a value of 34%. In the waterhseds on the Atlantic side, runoff exceeded the amount of rainfall over a seven month period. These seven months corresponded to the period of trade wind domination, pushing moisture-laden air masses towards the Atlantic slopes. Zadroga (1981) thus considers that an under-estimation of horizontal precipitation would be the principal explanation of this phenomenon.

Horizontal precipitation can maintain the base flow of a river even during periods of scarce rainfall. But Zadroga (1981) stresses that studies and quantitative analyses were still lacking to explain the hydrological behaviour of the cloud forests.

Pereira (1981) indicates in a work on "Future trends in watershed management and land development research" referring to the tropics:

> There are plenty of problems remaining
> such as the interesting examples of
> unusual situations in cloud forests.

In spite of this, there is an increasing consciousness of the hydrological value of certain cloud forests within the tropics. It is worth mentioning here the case of the La Tigra National Park (formerly San Juancito Forest Reserve) in Honduras. This park, located barely 20 km from the capital of Honduras, Tegucigalpa, has a surface area of 7,500 ha, the majority covered in cloud forest at altitudes between 1,500 and 2,200 masl. The area provides between 30% and 50% of drinking water for Tegucigalpa (Campanella et al., 1982). During the dry months (March, April and May) the percentage of drinking water provided by the La Tigra area rises dramatically while other sources of water for Tegucigalpa drop their supply to a marked degree*. It is for this reason that many efforts to improve protection of this area have been justified with the argument of the hydrological importance of this forest. For the Honduran institutions involved, it is obvious that the supply of water to the capital could be endangered if the La Tigra area is inadequately protected.

Biotic Factors

The abundance of epiphytes is one of the outstanding biotic factors within cloud forests. Many authors (Ellenberg, 1959; Grubb et al., 1963; Myers, 1969; Letouzey, 1978; Walter, 1979) mention that the cloud forest zone represents the optimal environment for epiphytes, particularly mosses, lichens, orchids and bromeliads. According to Tuckey (1970) the latter can take advantage of leaching of the upper parts of the vegetation, and Küchler (1967) points out that epiphytes include a great variety of life forms thus introducing a new physionomic element in their host trees.

Given that epiphytes are capable of taking direct advantage of horizontal precipitation they are frequently found in the upper levels of tree canopies (Carr, 1949; Walter, 1973; Nadkarni, 1984). This indicates that the crowns of the dominant trees are markedly exposed to atmospheric exchange, thus receiving high quantities of horizontal precipitation. However, in dwarf cloud forests, Ashton and Brünig (1975) and Grubb (1977) mention that epiphytes, especially mosses, can even cover the surface of the soil, which in dwarf forests almost invariably consists of a layer of peat.

Grubb and Whitmore (1966) indicate that the abundance of epiphytes in cloud forests should first be linked to horizontal precipitation, and not to the high relative humidity that predominates at the microclimatic level within cloud forests. Walter (1973, 1979) and Leigh (1975) mention that the cloud forest zone represents optimal climatic conditions for poikilohydric epiphytes on vascular homoiohydric plants.

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* Personal communication from Jim Barborak; Head, Wildlands Program, CATIE.

However, in the upper layers of the forest canopy vascular epiphytes with xeromorphism also exist (Brass, 1956; Grubb and Whitmore, 1966), resisting dessication during cloudless periods.

The formation of xeromorphic structures and their different climatological and ecological interpretations in cloud forests were discussed in previous sections of this chapter.

Another phenomenon frequently encountered in cloud forests is endemism, whether floral or faunal. A typical case is that of the Cerro de la Neblina at the frontier between Venezuela and Brazil, where in recent years studies have been initiated on existing species. According to Begley (1984), scientists currently working in this area think that the greater majority of plant species found at the Cerro de la Neblina exist nowhere else in the world. The reason for this phenomenon is probably the biogeographical effect of isolation. Begley (1984) cited R. MacDiarmid, one of the researchers currently working at the Cerro de la Neblina, who calls the area "an island in the clouds", offering excellent conditions for biological studies, especially those relating to the evolution of species.

Many authors have mentioned endemism in cloud forests, among them Martin (1955), Myers (1969), Howard (1974), Lewis (1971) and Tanner (1977). The biogeographical "island" effect in the case of Colombian cloud forest has been dealt with in various publications by Sugden (1982a, b and c; 1983). Myers (1969) stressed that, from the biogeographical and ecological points of view, the concept of "cloud forest" as a habitat is extremely useful in the definition of problems and in data organization. Endemism can be observed in a more marked form in cloud forests directly bordering relatively dry zones.

In many cases of protected cloud forests endemic fauna, found and studied by biologists, has been an important factor in justifying and ensuring their protection for the future.

Other cases, as for example the cloud forest of Montecristo in El Salvador, represent the only remaining habitat for various mammals, which have been exterminated in the rest of the region (Daugherty, 1973).

5. STRUCTURE, COMPOSITION AND SILVICULTURAL ASPECTS

Various different studies of the structure and floral composition of cloud forests exist. Given the great variety and heterogenous nature of different ones described in literature, it is difficult to generalize. However, this present chapter will limit itself by briefly describing studies of structure, followed by mentioning those of the composition and floristics of cloud forests, and ultimately there will be a discussion of the possibilities of forest management.

Leigh (1975) emphasized that in mountain forests affected by the presence of clouds, the "storey structure" is much more obvious than in lowland forests.

In the case of dwarf cloud forests, where a single tree-stratum exists above epiphyte-covered peat, a microclimatic explanation of this phenomenon is given by Leigh (1975) (see chapter 4, Climatic Elements and Factors).

The majority of studies of the structure of specific cloud forests have been undertaken in Andean cloud forests in Venezuela (Lamprecht, 1954, 1958, 1976, 1977; Roth and Mérida de Bifano, 1971, 1979; Hoheisel, 1976; Huber, 1976; Bockor, 1979; Vareschi, 1980). Practically all these, which contain a large number of vegetation profiles, confirm the fact that structure displays distinct strata. However, Vareschi (1980) emphasizes that in different locations of the same cloud forest, the number and distribution of the strata can vary considerably (see figure 12).

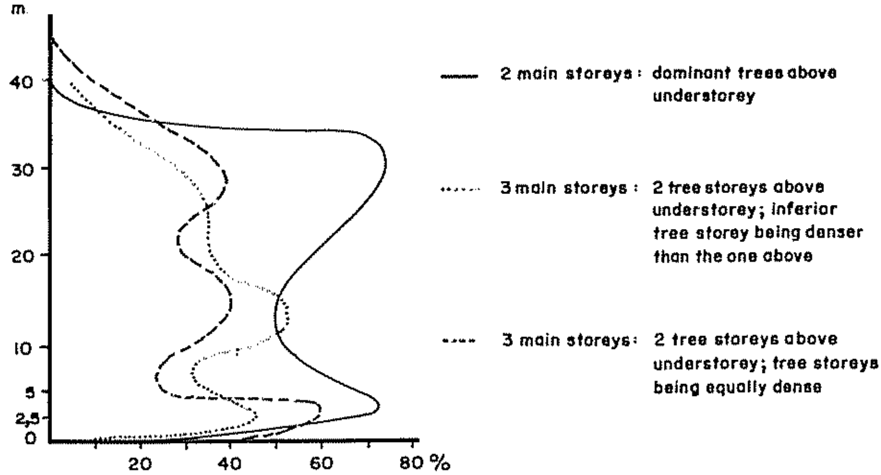

Figure 12 : Tree storey diagrams in different cloud forest sites of Rancho Grande, Venezuela, according to Vareschi (1980)

According to Beard (1955), the structure of a typical cloud forest (montane rain forest) has two tree strata that reach 10 m and 20 m, respectively. The upper stratum can be higher under favourable conditions. The four principal cloud forest formations, according to Beard (1944, 1955), are shown in figure 13.

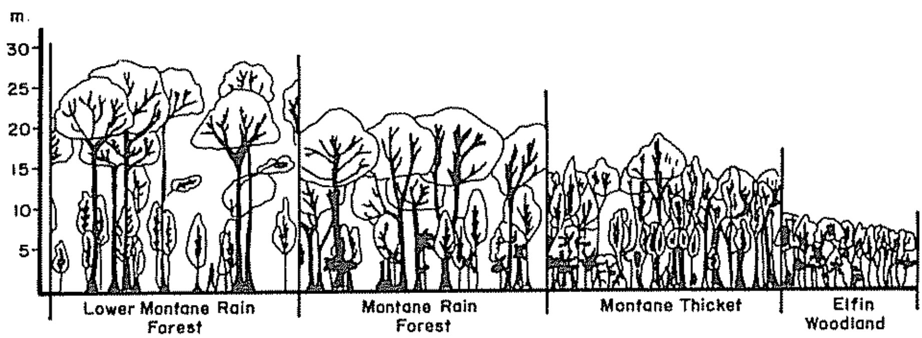

Figure 13 : Profiles of the four principal cloud forest types according to Beard (1944, 1955)

Concerning the floristic composition of cloud forests, this present work has to limit itself to mentioning the principle studies undertaken in specific areas. The ecological, phytogeographical and climatic conditions of the different cloud forests studied are quite distinct, resulting in equally differentiated floristic compositions. Table 3 lists the authors of key studies and their study locations.

Table 3. List of authors of key studies of floristic composition in specific cloud forests

Beard (1949)	Lesser Antilles
Beebe and Crane (1947)	Rancho Grande, Venezuela
Bockor (1979)	La Carbonera, Venezuela
Brass (1956, 1959, 1964)	New Guinea
Burgess (1969)	Malaysia
Grubb et al. (1963)	Cordillera de Guarca Urcu, Ecuador
Hoheisel (1976)	San Eusebio, Venezuela
Howard (1968)	Pico del Oeste, Puerto Rico
Huber (1976)	Rancho Grande, Venezuela
Lamprecht (1954, 1958)	Valley de Mucuy, Venezuela
Lawton and Dryer (1980)	Monteverde, Costa Rica
Lonard and Ross (1979)	Tamaulipas, Mexico
Puig, Bracho and Sosa (1983)	Tamaulipas, Mexico
Roth and Mérida de Bifano (1971, 1979)	Rancho Grande, Venezuela
Schweinfurth (1957)	Eastern Himalayas
Sobrevila, Ramírez and de Enrech (1983)	Sierra de San Luis, Venezuela
Steyermark (1974, 1975)	Sierra de San Luis, Venezuela
Sudgen (1982a, b, c, 1983)	Serranía de Macuira, Colombia
Tanner (1977)	Blue Mountains, Jamaica
Vareschi (1980)	Rancho Grande, Venezuela
Veillon (1955, 1974)	Andean cloud forests, Venezuela
Whitmore and Burnham (1969)	Malaysia

More general publications on important floral aspects in tropical mountain areas, including incidence of clouds, are those of Knapp (1965) for the Central American region; Troll (1959) and Hueck (1978) for the South American subcontinent; Whitmore (1975) for Southeast Asia; and Richards (1952) and Letouzey (1978) for the tropics worldwide.

Some data concerning biomass above ground have been published by Brun (1976), Grubb (1977) and Tanner (1977, 1980a). Table 4 summarizes the different data obtained.

Table 4. Soil biomass (t/ha) in different types of cloud forests

Forest type	Altitude (masl)	Geographical location	Source	Biomass above ground (t/ha)
"Bosque nublado andino"	2300	Venezuelan Andes	Brun (1976)	420
Lower montane rain forest	2500	New Guinea	Grubb (1977)	310
Lower montane rain forest	500	Puerto Rico	Grubb (1977)	148-194
Upper montane rain forest:				
Mor ridge forest	1615	Blue Mountains, Jamaica	Tanner (1977, 1980a)	218
Mull ridge forest	1615	"	"	312
Wet slope forest	1570	"	"	230
Gap forest	1590	"	"	238

Considering the relatively high biomass values in cloud forests of the Venezuelan Andes studied by Brun (1976) it is not surprising that these forests are the only ones to have been subjected to silvicultural studies (Lamprecht, 1954, 1958; Bockor, 1979).

Lamprecht (1954) recommended the selection system ("Plenterbetrieb") for management and exploitation of high production cloud forests, although admitting that this method, which has been successfully applied in many temperate regions, should be modified according to local conditions taking into consideration future new findings. The principal considerations of Lamprecht's recommendations were to improve sustainable production (both in quantity and quality), ensure and promote natural regeneration, and enrich the forest with valuable species.

In another publication Lamprecht (1958) concentrates his forest management recommendations on two types of cloud forests within which the valuable Podocarpus spp. dominate.

The most recent research into the possibility of managing Andean cloud forests is the work of Bockor (1979). According to his studies, almost 70% of the trees with dbh >10 cm are likely to eventually find a place in the upper forest canopy. In addition there is considerable potential for the natural regeneration of wood-producing trees that in their natural environment do not have a great deal of competition from shrubs, ferns or bamboo.

Bockor (1979) emphasizes the importance of the genus Podocarpus and indicates the possibility of enriching the forest with species of this genus. In addition, he mentions the possibility of taking advantage of the high rate of natural regeneration, to transform certain parts of the forest, through careful management procedures, into more uniform and economically valuable stands without reducing its secondary functions.

The silvicultural studies undertaken by Lamprecht (1954, 1958) and Bockor (1979) represent a theoretical base for possible future management of certain Andean Venezuelan cloud forests, but practical experience is lacking. Such forests, due to composition and climate (relatively low rainfall), are not comparable in silvicultural terms, with the majority of other cloud forests.

Generally, most of the tropical cloud forests do not offer reasonable or favourable conditions for forest management and exploitation due to one or a variety of the following reasons:

1. unfavourable climatic conditions (particularly high rainfall)
2. unfavourable topographical conditions (cloud forests are usually found on steeply-sloping or highly irregular terrain)
3. unfavourable edaphic conditions
4. high erosion risk (combination of 1, 2 and 3)
5. hydrological function (many cloud forests are found in upper watersheds, being the principal regulators of the water regime, protecting: a) the downstream areas of the watershed and ensuring continuity in the water flow; b) the hydroelectric potential; and c) the useful lifespan of reservoirs)
6. protection of communities of endemic flora and fauna; conservation of genetic resources
7. protection of unique landscapes

Any future attempt to manage cloud forests should take into account the above mentioned points. Only those cloud forests that do not present one or a variety of the above mentioned characteristics can be considered for future management and sustained exploitation, on the condition that there is a certain quantity and uniformity of valuable species (e.g. Podocarpus spp. or Quercus spp.) as for example in certain Costa Rican cloud forests, where Blaser (1987) found a relative abundance of Quercus spp. of 76% within the trees with dbh > 25 cm and of 93% within the trees with dbh > 45 cm.

6. CONVERSION AND CONSERVATION OF CLOUD FORESTS

In the humid tropics the main causes of deforestation and forest conversion are generally the following:

a) forest exploitation without planning or silvicultural management, causing degradation and erosion;

b) the advancement of the "agricultural frontier" which converts natural forests into farm areas - a more and more frequent occurrence in areas unsuitable for cultivation or grazing;

c) new roads that cross forested and frequently mountainous areas provoking spontaneous and uncontrolled human colonization the length of their trajectories.

In many tropical mountain areas it is possible to observe the agricultural frontier moving rapidly towards increasingly steeper areas with high rainfall, including large areas of cloud forest. The deforestation of cloud forests in mountainous areas endangers their protective role in hydrological terms and soil conservation. The consequences of erosion provoked by the destruction of cloud forests can be indeed disastrous, as shown by Daugherty (1973).

Cloud forests are frequently destroyed with the aim of establishing grazing land for extensive cattle farming, resulting in soil compaction thus reducing its infiltration capacity and provoking a considerable increase in surface runoff. This change in the hydrological regime, combined with the erosion processes in the upper watersheds, presents a great flood danger for lower watersheds where there are frequently large concentrations of people on river banks.

Although it is not possible to give figures on the loss of cloud forests through the different deforestation and degradation processes, Zadroga (1981) thinks that cloud forests are currently being converted into one of the most rapidly disappearing forest ecosystems under pressure from man.

It is therefore important to support and promote all attempts and activities to protect cloud forests against a change in land use, not only because they are fragile ecosystems (La Bastille and Pool, 1978), but also because of their important hydrological properties (Budowski, 1976; Hamilton and King, 1983). Other arguments in favour of the total protection of cloud forests include the danger of erosion, and the protection of endemic species, unique landscapes and genetic resources, mentioned in the previous chapter

For the Central American and Caribbean region, La Bastille and Pool (1978) described the currently protected cloud forests (generally in the form of national parks) and proposed various additional areas for future protection. They also emphasized the necessity of creating a system or network of cloud forests in the region, with the aim of improving and strengthening their protection and the exchange of scientific information between the different institutions charged with managing and administering the parks.

La Bastille and Pool's (1978) proposal concentrated primarily on cloud forests that, from the biogeographical point of view, exhibit outstanding ecological characteristics, such as special biotopes or endemic species, and are generally restricted to limited areas. Beyond this extremely valid approach, the necessity of ensuring the protection of relatively extensive areas of cloud forest should also be emphasized here, where particular ecological characteristics are of secondary importance to their hydrological role. In the case of Central America, for example, it can be seen that a wide belt in the mountains, particularly on the Atlantic slope, serves this function. According to Holdridge (1982) tropical cloud forests predominate as a wet atmospheric association in the life zones from Moist Forest to Rain Forest of the Premontane and Lower Montane belts. The exposure to prevailing winds must be considered a factor of great importance; in the case of Central America, for example, this implies that the majority of cloud forest zones are situated in the Premontane and Lower Montane belts of the Atlantic slope.

The neotropical region currently has 67 protected areas which include cloud forests (IUCN, 1982). The principal categories of these areas are: National Parks, Biological Reserves, National Reserves, Ecological Reserves, Biosphere Reserves and National Monuments (see table 5).

Table 5. Protected areas, including cloud forests in the humid tropics of the Neotropical Realm according to IUCN (1982)

Bolivia:	Bellavista NP, Isiboro Sécure NP, Pilón-Lajas NP, Ulla Ulla BR, German Busch. NR
Brasil:	Pico da Neblina NP, Serra da Bocaina NP, Caparo NP, Itatiaia NP, Serra dos Orgaos NP.
Colombia:	Natural La Macarena NP, Natural Paramillo NP, Natural Sierra Nevada de Santa Marta NP, El Cocuy NP, Natural Cordillera de los Picachos NP, Natural Nevado del Huila NP, Natural Sumapaz NP, Natural Los Farallones de Cali NP, Natural Puracé NP, Natural Tama NP, Natural Munchique NP, Natural Las Orquídeas NP, Natural Cueva de los Guácharos NP.
Costa Rica:	La Amistad NP, Chirripó NP, Braulio Carrillo NP, Rincón de la Vieja NP, Volcán Poás NP, de Monteverde BR.
Dominican Rep.:	Morne Trois Pitous NP
Ecuador:	Sangay NP, Cayambe-Coca ER
El Salvador:	Montecristo NP
Guatemala:	Río Dulce NP, Biotopo Universitario para la Conservación del Quetzal
Honduras:	La Tigra NP, Cusuco NP (proposal)
Nicaragua:	Saslaya NP
Panama:	Darién NP, Volcán Barú NP
Peru:	Manú Biosphere Reserve and NP, Tingo María NP, Cutervo NP, Machu Pichu National Monument, Huascarán Biosphere Reserve
Puerto Rico:	Luquillo Experimental Forest Biosphere Reserve
Santa Lucia:	Quilesse Forest Reserve
Trinidad and Tobago:	Northern Range Wildlife Sanctuary
Venezuela:	Canaima NP, La Neblina NP, Sierra de Perija NP, Sierra Nevada NP, El Tama NP, Henry Pittier NP, Guatopo NP, El Avila NP, Yurubí NP, Terepaima NP, El Guácharo NP, Macareo NP, Yacambú NP, María Lionza Natural Monument, Chorrera de los González Natural Monument, Alejandro Humboldt Natural Monument.

NP = National Park; BR = Biological Reserve;
NR = National Reserve; ER = Ecological Reserve.

7. CONCLUSIONS AND RECOMMENDATIONS

The history of cloud forest research in the humid tropics is extremely short considering that it has only been over the last fifteen to twenty years that the value and importance of these forests has been recognized, from the ecological as well as the hydrological viewpoints.

The first individuals to draw attention to the particular value of certain cloud forests were forest ecologists and biologists that discovered special formations and vegetational structures in addition to endemic species of flora and fauna.

It has only been within recent years that interest has been raised in (micro-) climatic processes and the hydrological importance of cloud forests. In spite of the fact that the term "cloud forest" has been used to describe a large number of different vegetation types, it is a term placing emphasis on climatological and hydrometeorological phenomena, which have been thoroughly dealt with in previous chapters of this study.

Cloud forests can occur at extremely different altitudes above sea level. Depending on the influence of a number of climatic and geographical factors, as for example the mass elevation effect, cloud forests have been described at elevations between 500 and 3,900 masl in the tropics (Beard, 1949; Hueck, 1978). The majority of cloud forests, the extent of which has been estimated by Bockor (1979) at 500,000 km^2 in the humid tropics, are found between 1,200 and 2,500 masl. This indicates that cloud forests are situated in upper and middle-level watersheds and thus play an essential hydrological role.

As shown in figure 6, cloud forests extend the length of large parts of mountain ranges and mountains within the tropics, many slopes of which are subjected to rapidly accelerating deforestation and spontaneous colonization. Figure 6, referring to the tropics throughout the world, can only give a broad idea of the geographic distribution of cloud forests. For the preparation of more detailed maps at regional and country level, it is recommended that consideration be given to likely locations of cloud forests, those life zones extending from Moist Forest to Rain Forest in the Premontane and Lower Montane belts where, according to Holdridge (1982), the wet atmospheric association dominates, this being equivalent to cloud forest

The vegetation classification systems and climate zoning in tropical mountainous areas should consider the cloud belt as a special unit (Baumgartner and Brünig, 1978), since the continual cloud cover, its direct contact with vegetation and the process of horizontal precipitation, directly and indirectly influence the water and energy balance, physiological processes, soil properties and the vegetation ecology.

Although studies exist that attempt the quantification of horizontal precipitation through fog catchers in a specific location within the forest, there is no clear idea of the contribution of horizontal precipitation in more extensive areas. Further research is necessary in a series of selected cloud forest sites, related to the different types of precipitation: gross precipiation, throughfall and stem flow, with emphasis on the interception process. The data supplied by such research, together with standard meteorological observations at each site, would allow an accurate calculation of the role played by cloud forests in the quantity and distribution of net precipitation in which horizontal precipitation can be of great significance.

Microclimatic and hydrometeorological research undertaken to date in cloud forests has been concentrated on elfin woodlands (dwarf forests) in the analysis and interpretation of physiological processes (e.g. reduction of transpiration) and the explanation of its structure and ecology.

The majority of detailed studies being undertaken in certain specific cloud forests are generally of the ecology, composition and endemic species. Without depreciating the great value of these studies, which have frequently played a key role in the protection of cloud forests, it is proposed here that future research should also place emphasis on the analysis and quantification of the hydrological importance of cloud forest as components of watersheds in the humid tropics.

These research efforts should not only focus on the process and quantity of horizontal precipitation, but also study the total hydrological impact of the cloud forest, as well as considering the hydrological importance of the large quantity of epiphytes that predominate in cloud forests, together with the thick peat layer which frequently covers the soil.

Bearing these considerations in mind, two distinct types of cloud forest, affected by different climatic conditions (of particular hydrological importance), could be selected:

a) an area of cloud forest where the frequency of cloud cover occurs in combination with heavy and sometimes persistent orographic rainfall, with high annual precipitation;

b) an area of cloud forest with a regime or seasons that are "dryer" and where horizontal precipitation could represent a relatively high component of total precipitation.

According to the current state of knowledge of the process and quantity of horizontal precipitation in different tropical cloud forests (see chapter 4, Climatic Elements and Factors) and their hydrological characteristics at watershed level (see chapter 4, Hydrological Characteristics at Watershed Level), the following hypothesis provides working guidelines for research into the two above mentioned cases:

Case a) those cloud forests in areas of heavy orographic rainfall, with their distinctive canopy strata, richness of epiphytes, and thick peat layer functioning as a sponge mechanism with a high capacity for water retention and runoff control, being able to mitigate the impact of torrential rains;

Case b) in areas or during very "dry" seasons, horizontal precipitation captured by cloud forests, represents a considerable increase in precipitation and runoff (as indicated, for example, in the case of La Tigra National Park in Honduras).

In both cases cloud forest destruction would have serious consequences for the lower watersheds. In the first case disastrous results could be expected in the form of floods combined with accelerated erosion. The second case would result in a marked reduction of river flow during the "dry" seasons and with the possibility of high-water problems during the rainy periods.

The greater majority of tropical cloud forests are considered as extremely fragile ecosystems playing an important hydrological and ecological role. These are rapidly being converted into one of the ecosystems most threatened by human colonization (Zadroga, 1981). Many institutions and decision makers remain unaware of the serious consequences of cloud forest destruction.

Daugherty (1973) demonstrated that deforestation of cloud forests can trigger off quite catastrophic erosion processes. Apart from the danger of erosion and the hydrological function of cloud forests, there are various further arguments in favour of total protection (see chapter 5). Nonetheless, some special cases exist which allow the consideration of and research into sustainable and cautious forest management for the future. Such management practices must also be based on previous detailed research into the ecology, structure and dynamics of the forest and ensure all its secondary functions. In such cases, sound and sustainable forest management at the technical level can prove to be the best tool for forest protection.

The initiation, support and promotion of activities for the protection of tropical cloud forests is an important task for the future. Not only should their ecological value and significance as a special ecosystem be recognized, but also their important hydrological role as water regulators in watersheds, in combination with their soil conservation capacities on mountain slopes.

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