WATER-RELATED ISSUES AND PROBLEMS
OF THE HUMID TROPICS
AND OTHER WARM HUMID REGIONS

IHP HUMID TROPICS PROGRAMME SERIES NO. 13

DECISION TIME FOR CLOUD FORESTS

WWF

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Hydrological Programme

NETHERLANDS COMMITTEE FOR
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THE WORLD CONSERVATION UNION

PREFACE

At a Tropical Montane Cloud Forest workshop held at Cambridge, U.K. in July 1998, 30 scientists, professional managers, and NGO conservation group members representing more than 14 countries and all global regions, concluded that there is insufficient public and political awareness of the status and values of Tropical Montane Cloud Forests (TMCF). The group suggested that a science-based "pop-doc" would be an effective initial action to remedy this. What follows is a response to that recommendation. It documents some of the scientific information that will be of interest to other scientists and managers of TMCF, but not overwhelming for a lay reader who is seeking to become more informed about these remarkable ecosystems. The purpose of this booklet, therefore, is to:

- Impart an understanding of what these TMCFs are and how they function, based on the best science currently available, incomplete though that information is;
- Engender an appreciation of the values of TMCFs and why they are important to humans and our biological consorts on this planet Earth;
- Develop an awareness of the forces that threaten these ecosystems and cause the losses that are resulting from our resource development activities;
- Arouse a concern that will influence the way and speed with which research, management, protection and policy are carried out.

Donor institutions and development agencies are especially invited to read this document. Conservation NGOs are urged to use this information to raise awareness among the stakeholders in TMCFs, and to work with decision-makers in halting the degradation and disappearance of these valuable and unusual forests. Information about the TMCF Initiative and the supportive organizations that made this booklet possible, is given on the final page.

We believe decision time for cloud forests is here. Let us see if we can convince you, and move you to action!

L.A. Bruijnzeel and L.S. Hamilton

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1. UP IN THE CLOUDS

With increasing elevation on wet tropical mountains, distinct changes in forest appearance and structure occur. At first, these changes are gradual. The tall and often buttressed trees of the multi-storied lowland rain forest, whose main canopy normally extends to heights of 25 - 45 m above the ground (with some large individuals reaching heights of 60 m or more), gradually give way to a new forest formation, *lower montane forest*. With a mean canopy height of up to 35 m in the lower part of the montane zone and individual emergent trees as high as 45 m, lower montane forest can still be quite impressive. Yet, with two rather than three main canopy layers, the structure of lower montane forest is simpler than that of lowland forest (Figure 1). Also, the large buttresses and climbers that are so abundant in the lowland forest have all but disappeared and on the branches and stems epiphytes (orchids, ferns, bromeliads) become more numerous with increasing elevation. The change from lowland to lower montane forest seems largely controlled by temperature as it is normally observed at the elevation where the average minimum temperature drops below 18 °C. At this threshold many tree species that are typical of lowland forest are displaced by a floristically different assemblage of montane species. On large equatorial inland mountains this transition usually occurs at an altitude of 1200 - 1500 m but it may occur at much lower elevations on small outlying island mountains and away from the equator.
(Figures 1 and 2).

As we continue our climb through the lower montane zone, it is clear to the observant eye that the trees not only become gradually smaller but also more ‘mossy’ (changing from ca. 10% to 25-50% moss cover of the bark). There is usually a very clear change from relatively tall (15-35 m) lower montane forest to distinctly shorter-statured (2-20 m) and much more mossy (70-80% bryophytic cover) *upper montane forest* (Figure 1).

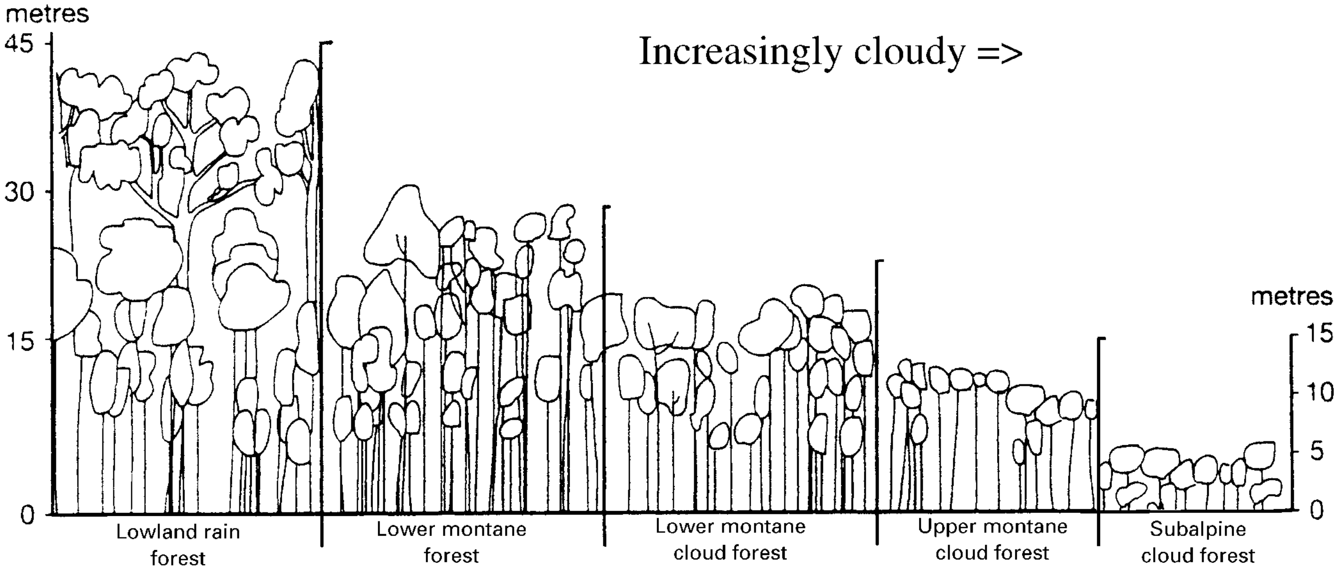

Figure 1. Generalized altitudinal forest formation series in the humid tropics.

Although the two forest types are not separated by a distinct thermal threshold this time, there can be little doubt that the transition from lower to upper montane forest coincides with the level where cloud condensation becomes most persistent. On large mountains in equatorial regions away from the coast this typically occurs at elevations of 2000 - 3000 m but incipient and intermittent cloud formation is often observed already from ca. 1200 m upwards, i.e. roughly at the bottom end of the lower montane zone. However, on small oceanic island mountains the change from lower to upper montane-looking forest may occur at much lower altitudes (down to less than 500 m above sea level; Figure 2).

Upon entering the zone of frequent cloud incidence, the floristic composition and overall appearance of the forest change dramatically. Leaves become smaller and harder, and no longer exhibit the elongated tips that characterize the leaves of forest formations at lower elevations. Twigs, branches and stems become festooned with liverworts, filmy ferns, lichens and mosses, in addition to the bromeliads, orchids and ferns that were already abundant in the lower montane belt. Mosses also start to cover rocks and fallen trunks on the soil surface. With increasing elevation and exposure to wind-driven fog, the tree stems become increasingly crooked and gnarled, and bamboos often replace palms as dominant undergrowth species. The eerie impression of this tangled mass wet with fog and glistening in the morning sun has given rise to names like ‘elfin’ forest or ‘fairy’ forest to the more dwarfed forms of these upper montane forests. Soils are wet and frequently waterlogged, peaty and acid. Indeed, in areas with high and year-round rainfall and persistent cloud, these upper montane forests are not hospitable places.

On drier mountains away from the oceans, where cloud incidence is less pronounced, the atmosphere is often more pleasant, however, and in many of these areas the forests have been cleared to make way for pasture or temperate vegetable cropping after harvesting of the useful timber species (see Section 4).

Aerial view of tall lower montane forest not subjected to frequent cloud at ca. 1500 m, Cordillera de los Andes, Colombia (photo by A.M. Cleef).

Interior of tall lower montane forest at ca. 1700 m in the Cordillera de los Andes, Colombia. Note the abundance of non-mossy epiphytes (photo by Th. van der Hammen).

A third major change in vegetation composition and structure typically occurs at the elevation where the average maximum temperature falls below 10 °C. Here the upper montane forest gives way to still smaller-statured (1.5 - 9 m) and more species-poor *subalpine forest* (or scrub). This forest type is characterized not only by its low stature and gnarled appearance but also by even tinier leaves, and a comparative absence of epiphytes. Mosses usually remain abundant, however, confirming that cloud incidence is still a paramount feature of the prevailing climate. On large inland equatorial mountains the transition to subalpine forest is generally observed at elevations between 2800 and 3200 m. As such, this type of forest is encountered only on the highest of mountains, mostly in Latin America and Papua New Guinea, where it may extend to ca. 3900 m.

It will be clear from the preceding descriptions that most lower montane, and all upper montane and subalpine, forests are subject to various degrees of cloud incidence.

So, welcome to the tropical montane cloud forest with its various gradations!

Definitions, names and classification of these remarkable vegetation complexes are myriad, as well as frustratingly overlapping and, at times, contradictory. Based on the preceding descriptions of montane forest types we distinguish the following forest types that become increasingly mossy with elevation: (i) lower montane forest (tall forest little affected by low cloud but often rich in epiphytes); (ii) lower montane cloud forest; (iii) upper montane cloud forest; and (iv) subalpine cloud forest. In doing so, we include the widely adopted broad definition of cloud forests as ‘forests that are frequently covered in cloud or mist’ while recognizing the important influence of temperature and humidity on overall montane forest zonation. However, as argued more fully below, to these should be added a more or less ‘a-zonal’ cloud forest type: (v) low-elevation dwarf (or ‘elfin’) cloud forest.

Interior of mossy upper montane cloud forest at ca. 2500 m elevation, Mount Kinabalu, Sabah.

Gnarled subalpine cloud forest at 2900 m, Mount Kinabalu, Sabah (photos by L.A. Bruijnzeel)

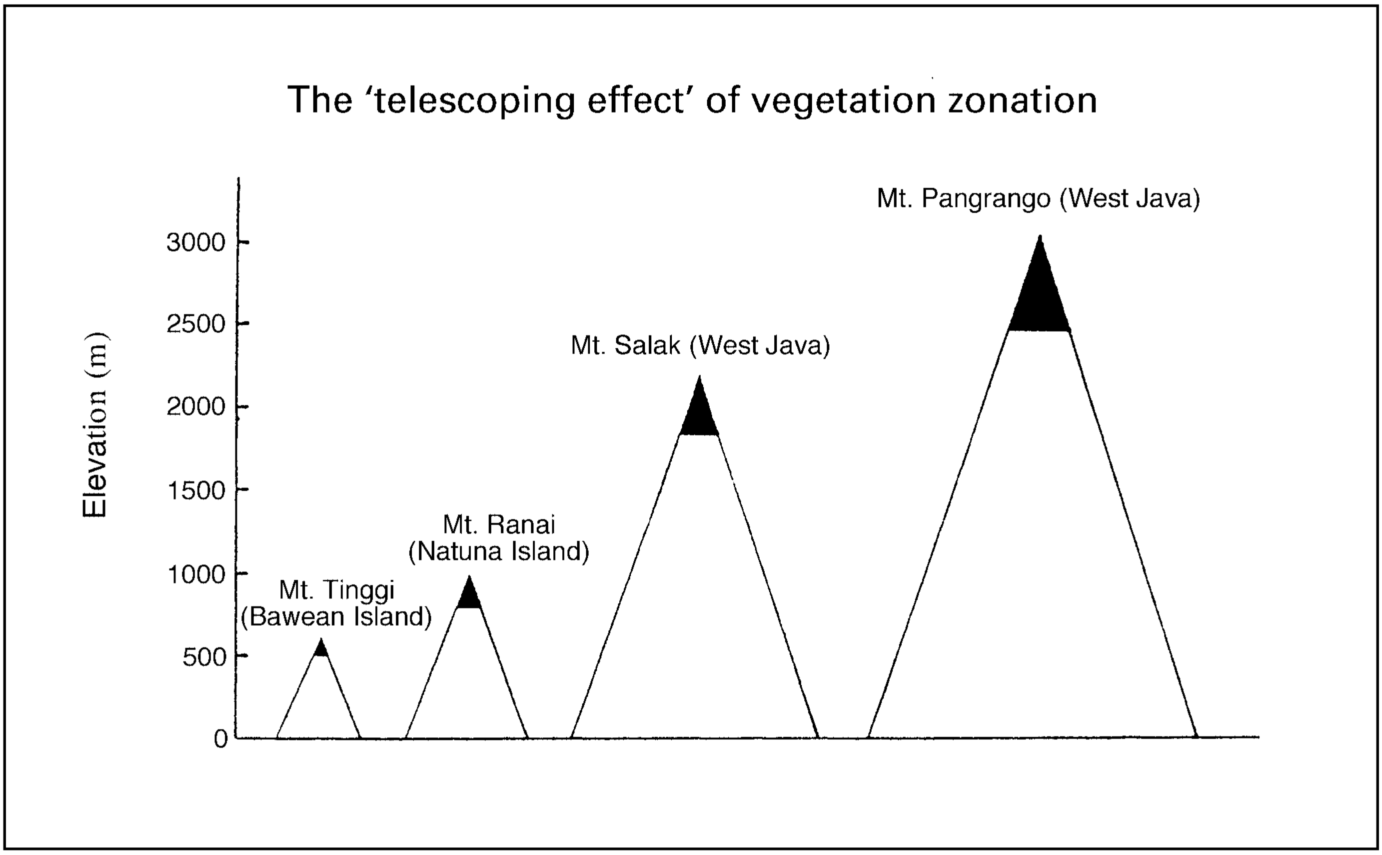

Figure 2. The 'telescoping effect' on the occurrence of mossy forest at contrasting altitudes on differently sized mountains in South-east Asia.

We have already noted the large variation in elevation at which one forest formation may replace another. For example, the transition from lower to upper montane forest is mainly governed by the level of persistent cloud condensation. Cloud formation, in turn, is determined by the moisture content and temperature of the atmosphere. Clearly, the more humid the air, the sooner it will condense upon being cooled during uplift (for example, when the air is blown against a mountain side). Therefore, the further a mountain is removed from the ocean, the drier the air tends to be and thus the longer it will take to cool to its condensation point and the higher will be the associated cloud base. Likewise, for a given moisture content, the condensation point is reached more rapidly for cool air than for warm air. Thus, at greater distance from the equator, the average temperature, and thus the altitude at which condensation occurs, will be lower.

Superimposed on these global atmospheric moisture and temperature gradients are the more local effects of sea surface temperatures and currents, the size of a mountain and its orientation and exposure to the prevailing winds, as well as local topographic factors.

It goes almost without saying that sea surface temperatures influence the temperature of the air overhead and thus the 'starting point' for cooling. Also, where warm, humid ocean air is blown over a comparatively cold sea surface, a low-lying layer of persistent coastal fog tends to develop. Well-known examples of this situation are the fog-ridden west coast of California where tall coniferous forests thrive in an otherwise subhumid climate, and the coastal hills of Chile and Perú, where, under conditions approaching zero rainfall, forest groves are able to survive solely on water stripped from the fog by the trees themselves (see also Section 2).

The occurrence of low-statured mossy, upper montane-looking forest at low elevations on small, outlying mountains has puzzled scientists for a long time. This phenomenon is commonly referred to as the 'mass elevation' or 'telescoping' effect (Figure 2). The sheer mass of larger mountains exposed to intense radiation during cloudless periods has long been believed to raise the temperature of the overlying air, thus enabling plants to extend their altitudinal range. Whilst this may be true for the largest mountain ranges it is not a probable explanation for mountains of intermediate size on which the effect is also observed (Figure 2). Instead, the contraction of vegetation zones on many small coastal mountains must be ascribed to the high humidity of the oceanic air promoting cloud formation at (very) low elevations rather than to a steeper temperature lapse rate with elevation associated with small mountains. Further support for this contention comes from the observation that the effect is most pronounced in areas with high rainfall and thus high atmospheric humidity.

Whilst the cloud base on small tropical islands is often observed at an elevation of 600 – 800 m, dwarf cloud forests reach their lowermost occurrence on coastal slopes exposed to both high rainfall and persistent wind-driven cloud. Examples from the equatorial zone include Mount Payung near the western tip of Java, and Mount Finkol on Kosrae island (Micronesia) where dwarf forest is found as low as 400 - 500 m. An even more extreme case comes from the island of Gau in the Fiji archipelago where the combination of high precipitation and strong winds has led to the occurrence of a wind-pruned dwarf cloud forest at an altitude of only 300 – 600 m above sea level.

Due to the prevailing high atmospheric humidity, cloud formation on small tropical coastal mountains, such as here in North-east Borneo, is often observed at very low elevations (photo by M.J. Waterloo).

The previous examples already illustrate the importance of site exposure. Generally, the lower limits of mossy forest of any kind (upper montane, subalpine, or dwarf cloud forest at low elevation) on drier and more protected leeward slopes lie well above those on windward slopes. In extreme cases, such as in the Colombian Andes, the difference in elevation may reach 600 metres. Also, trees at protected leeward sites tend to be taller than their more exposed neighbours on the other side of the ridge. Again, such differences can be dramatic. In the Monteverde Cloud Forest Reserve in northern Costa Rica, the trees of ‘leeward cloud forest’ are 25 - 30 m tall whereas their counterparts of the nearby and floristically similar ‘windward cloud forest’ reach a heigh of 15 - 20 m. Moreover, towards the exposed crests of the windward slopes the height of the vegetation decreases further to 3 - 10 m along an altitudinal gradient of only 30 – 50 m.

Although the stunted appearance of low-elevation dwarf cloud forest resembles that of the transition from upper montane to subalpine cloud forests at first sight, the two differ in several important respects. At low elevations, the leaves are much larger and the floristic composition is usually very different. Also, the degree of moss cover on the ground (but not the vegetation) is generally much less pronounced at lower altitudes.

Low-elevation dwarf cloud forest near the summit of Mt Sebesi (845 m), an island situated between Java and Sumatra, Indonesia (photograph by R.J. Whittaker).

The soils of upper montane and dwarf cloud forests (regardless of elevation) are typically wet and, in extreme cases, persistently close to saturation. As a result, decomposition of organic matter is slow and topsoils become peaty and acid. Recent work in the Blue Mountains of Jamaica suggests that the most stunted upper montane cloud forests suffer from toxic levels of aluminium in their soils which, in turn, affect nutrient uptake by the trees and a host of other forest ecological processes. At the other end of the scale, the very tall (up to 50 m) montane oak forests found at high elevations (up to 3000 m) on the large inland mountain massifs of Latin America and Papua New Guinea more than likely reflect a fortunate combination of somewhat warmer and drier air (due to the ‘mass elevation’ effect, distance to the sea and topographic protection) as well as the presence of well-drained soils in which the toxic conditions described just now for the wettest localities do not easily develop.

Under especially favourable climatic and soil conditions, such as here on the Pacific side of the Talamanca Mountains in Costa Rica, unusually tall cloud forest may be found. The timber of these forests is so sought after that logging has become a threat (photo by M. Kappelle).

Thus far, we have focussed on the climatic gradients and other factors governing the elevation of the cloud *base*. Another climatological phenomenon, which influences the vertical temperature profile of the air and the *top level* of cloud formation, is the so-called 'trade wind inversion'. As part of a large-scale atmospheric circulation pattern (the Hadley cell), heated air rises to great elevation in the equatorial zone, flowing poleward and eastward at upper atmospheric levels and descending in a broad belt in the outer tropics and subtropics from where it returns to the equator (Figure 3). This subsidence reaches its maximum expression at the oceanic subtropical high pressure centres and along the eastern margins of the oceanic basins. As the air descends and warms up again, it forms a temperature inversion that separates the moist layer of surface air (that is being cooled while rising) from the drier descending air above. The inversion forms a tilted three-dimensional surface, generally rising towards the equator (Figure 3) and from East to West across the oceans. Over the Pacific ocean, the inversion is found at only a few hundred metres above sea level off the coast of southern California, rising to about 2000 m near Hawai'i and dissipating in the equatorial western Pacific. As such, the low elevations at which the inversion occurs on mountains situated well away from the equator (Figure 3) may constitute another reason as to why the vegetation zonation tends to become compressed on smaller mountains (Figure 2).

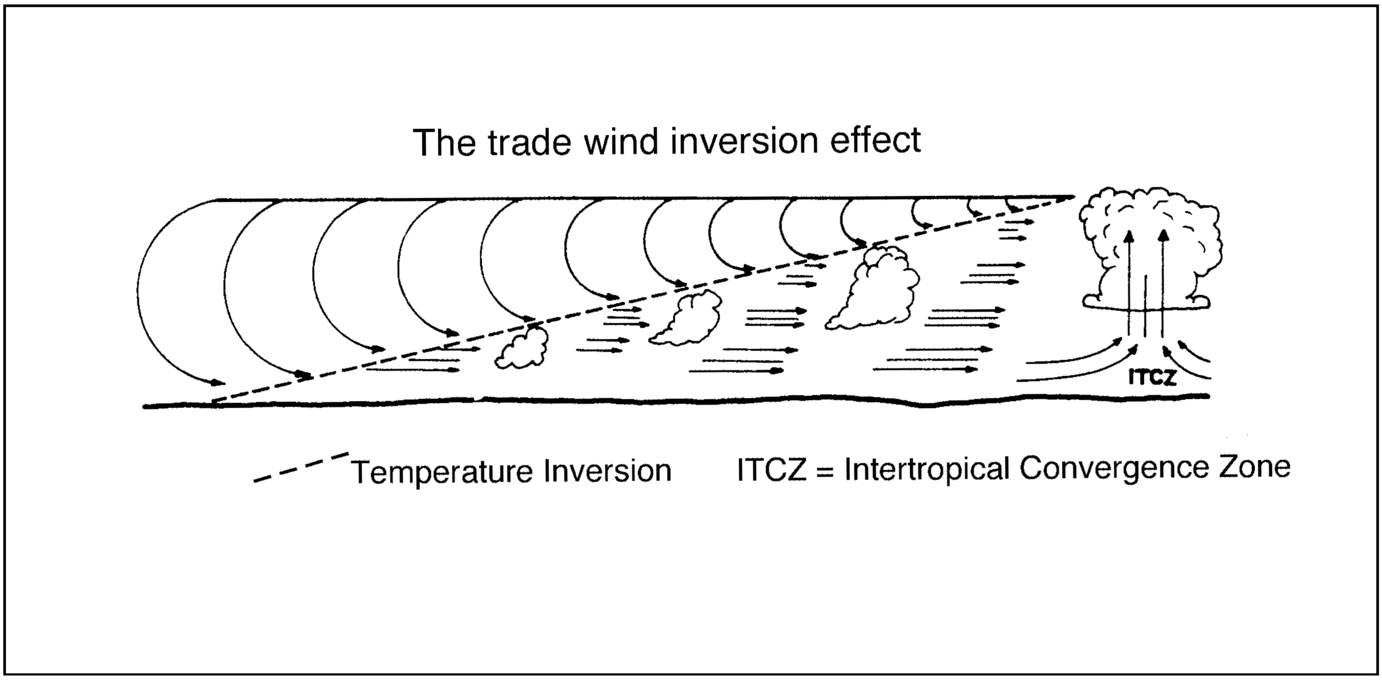

Figure 3. The Hadley circulation and the trade wind inversion effect.

The consequences of the trade wind inversion for the occurrence of the upper boundary of montane cloud forest are profound. For instance, at 1900 - 2000 m on the extremely wet windward slopes of the islands of the Hawai'ian archipelago, the montane cloud forest suddenly gives way to dry subalpine scrub because the clouds (which generally deliver more than 6 metres of rain per year below the inversion layer) are prevented from moving upward by the presence of the temperature inversion.

One of the best-known examples of the trade wind inversion and its effect on vegetation zonation comes from the Canary Islands. Situated between 27 and 29 degrees North off the west coast of Africa, a daily 'sea of cloud' develops between 750 m and 1500 m which sustains evergreen Canarian laurel forests (a relict from Tertiary times) in an otherwise rather arid environment.

The daily sea of cloud immersing the windward side of the Canary Islands below the inversion layer, seen from a vantage point on the island of Tenerife (photo by L.A. Bruijnzeel).

As a result of the various climatic and topographic gradients described in the previous paragraphs, concentrations of montane cloud forests in the tropical and subtropical parts of the world occur approximately as shown on the generalized map below.

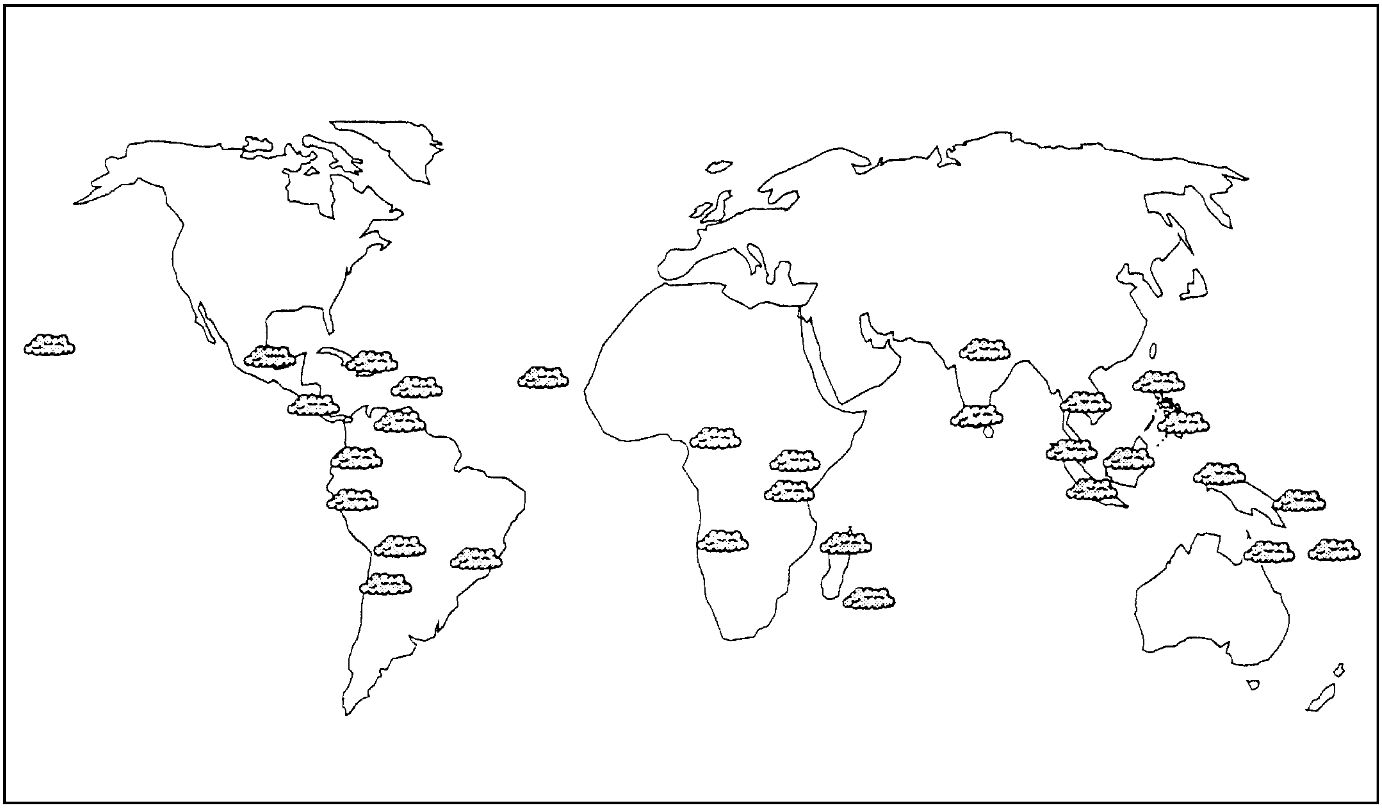

Figure 4. General concentrations of (sub)tropical montane cloud forest.

2. FOUNTAIN FORESTS: MYTH OR REALITY?

Mountain forests of all kinds have great value as protective cover on the steep slopes of headwater catchments. Mountains have been called the world's 'water towers', and forests the stabilizers that guard water quality and maintain the natural flow regime of streams and rivers emanating from these mountain headwaters. Soil surface erosion and occurrence of shallow landslips are minimized by natural healthy forest cover. Cloud forests on tropical mountains not only fulfill this protective role admirably, but they also provide additional hydrological benefits. Because of their frequent exposure to fog, cloud forests enjoy an additional source of water compared to forests situated below the average cloud base. During dry spells in otherwise humid areas, and in places with low rainfall but frequent low cloud, the 'stripping' of wind-blown fog by the vegetation becomes particularly important. Also, since water uptake from the soil by trees whose leaves are wetted by rain or fog comes to a halt, overall water use of cloud forests is typically much lower than that of forests lower down on the mountain. Because of this two-fold gain in water, volumes of streamflow emanating from cloud forest areas not only tend to be larger for the same amount of rainfall but also more dependable during dry periods. Let us look a little closer at the hydrology of these unique forests, therefore.

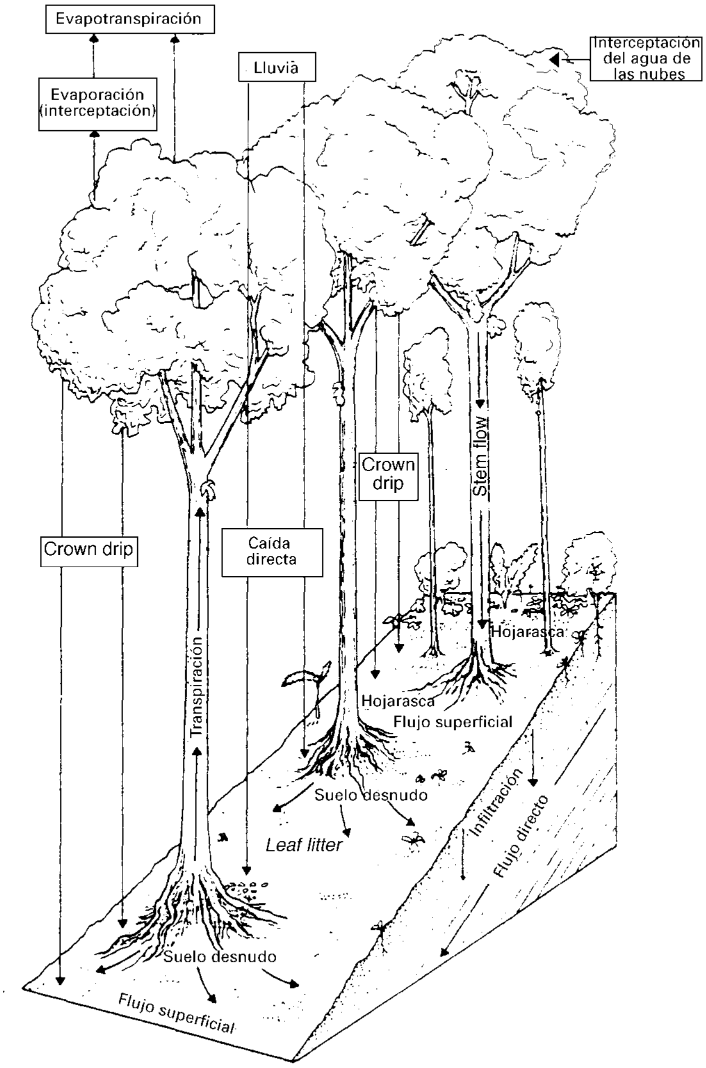

Figure 5. The hydrological cycle for a cloud forest.

Rain falling on a forest canopy reaches the ground through three routes (Figure 5). A small proportion arrives the forest floor as *direct throughfall*, falling through gaps in the canopy without touching leaves or stems, whereas a further, usually small, proportion flows down tree trunks as *stemflow*. The majority of the rain, however, first hits the canopy and then reaches the ground as *crown drip*. In cloud forests subject to wind-driven low cloud and fog, the situation becomes a little more complex. Amounts of fog touching and moving through the moss- and epiphyte-laden trees may be such that fog water begins to drip from the leaves and mosses as well, thereby adding a fourth component arriving at the forest floor, *fog drip*. The total amount of water that reaches the ground from all these sources is called *net precipitation*.

The difference between the amounts of net and gross precipitation that never reaches the ground is referred to as *rainfall interception*. This is rainfall intercepted by the canopy and evaporated back into the atmosphere during and shortly after the rain. The process is sometimes seen in action in the form of whiffs of freshly condensated moisture steaming from wetted tree canopies. Rainfall interception thus implies a *net loss* of water to the forest. This loss cannot be easily measured and is normally evaluated as the difference in catch of a series of rain gauges placed below the canopy and outside the forest, respectively. When fog or cloud only is present, a similar process of *cloud water interception* may be defined. However, because neither the actual amount of cloud impaction nor that evaporated from the wetted vegetation can be quantified reliably, a more practical approach is to simply measure net precipitation and equate the amount to *net* cloud impaction. In other words, the term 'cloud interception' implies a *net gain* of water to the ecosystem. In the even more complex case of rainfall plus cloud incidence it is best to follow the same approach and quantify the net overall effect of the respective processes by measuring net precipitation below the forest canopy.

Cloud forests enjoy an additional source of water compared to forests situated below the average cloud base. Under favourable conditions the 'stripping' of wind-blown fog by the forest may add hundreds of millimetres of water to the ecosystem per year (photo by L.S. Hamilton).

Under humid conditions, net precipitation typically ranges from 65 – 80% of incident rainfall in lower montane forest that does not experience much cloud. This figure may increase to 115 - 130% in more exposed mossy upper montane and summit dwarf cloud forests. A figure of 180% has even been reported for a single ridgetop forest in Honduras which must have been particularly well-exposed to the elements. More commonly, however, net rainfall totals in both lower and upper montane cloud forests are closer to 80 – 100% of incident rainfall. Although amounts of cloud water stripped by entire forest canopies are hard to measure directly in the presence of rainfall, 'ballpark' estimates of this extra input may be obtained by comparing the cited typical amounts of net precipitation in montane forests with and without frequent cloud. This would suggest a figure of 15 - 20% of ordinary rainfall under average humid conditions (or 300 – 600 mm per year for a rainfall of 2000 – 3000 mm), and up to 50 - 60% under more exposed circumstances. However, in areas of lower rainfall, or during extended dry periods, these figures may become much higher (100% or more, or up to 700 – 1000 mm per year).

In areas of low rainfall, but frequent cloud, even single trees can be important sources of water for wildlife, domestic stock or people. One of the most famous examples was found on El Hierro, one of the Canary Islands. Here, one of several 'fountain trees' (a laurel species) was used for centuries as the main source of water for man and beast alike until it was uprooted by a hurricane in 1610. This tree was so important that it is depicted on the island's municipal coat of arms. A similar tree planted in 1945 at the location of its illustrious predecessor now produces large amounts of fog water. In Hawai'i, watering troughs for game birds have been put beneath isolated trees to collect cloud water in an otherwise dry area. In the arid coastal hills of Chile and Perú, mesh barriers have been erected creating an artificial 'fog forest' that captures cloud water and nourishes communities in areas desperate for potable water.

This tree in the arid zone on Hawai'i survives primarily on water stripped from passing fog. The crown drip provides additional water to the vegetation under the tree and may even be sufficient for small-scale collections of water to feed game birds or cattle (photo by L.S. Hamilton).

Where soils are undisturbed, all of the water (both fog- and rain-derived) reaching the forest floor infiltrates the soil through the thick layer of dead organic matter that is so characteristic of tropical montane forests. Loss of water from the soil then occurs either upwards through uptake by roots and *transpiration* from the leaves, or via *drainage* to groundwater bodies feeding springs and maintaining the baseflow of streams (Figure 5).

The sum of intercepted rainfall (evaporation from a wet canopy) and transpiration (evaporation from a dry canopy) is called *evapotranspiration* (*ET*). A third component, evaporation from the forest floor or the soil, is usually negligibly small below a dense forest canopy. It is important to know the total *ET* associated with a particular forest type because its magnitude determines the amount of streamflow that can be expected for a given precipitation total. Generally speaking, it is difficult to measure forest *ET* directly, and this holds even more true under the extreme climatic and topographic conditions that are so typical of many cloud forest locations. This, plus the often limited areal extent of cloud forests (e.g. around ridges and mountain tops), usually precludes the use of sophisticated micro-meteorological equipment which has given good results in flat lowland rain forest terrain. Also, the very low transpiration rates of some cloud forest types (see below) are a major challenge to the application of modern 'bottom-up' (tree-based) approaches, such as sapflow gauging. For these and other logistic reasons, such as remoteness of sites, there are very few data on cloud forest *ET*, and virtually all of these are based on the classic catchment water budget technique in which overall forest *ET* is simply evaluated from the difference between measured inputs (read: rainfall) and outputs (streamflow). Whilst the approach is potentially liable to large errors due to the possibility of ungauged subterranean water transfers into or out of the catchment, it is capable of giving good estimates of annual *ET* for areas that are demonstrably watertight. A major drawback in the current context is the fact that any unmeasured cloud water inputs lead to proportionately smaller estimates for *ET*. As such, the low *ET* figures derived in this way for lower and upper montane cloud forests (see below) are partly an artefact and any extrapolations must be made with caution (i.e. only to areas where cloud incidence may be expected to be similar).

Typical annual *ET* values for lower montane forest that are little or not affected by fog amount to ca. 1150 – 1350 mm. Its mossier variant, lower montane cloud forest, evaporates between 700 and 1000 mm of water, depending on site elevation and degree of cloud incidence. By contrast, the persistently cloud-ridden upper montane and dwarf cloud forests exhibit still lower apparent evaporation totals (typically 300 – 450 mm), mainly due to the inclusion of unmeasured contributions by fog in the water budget calculations.

It should be borne in mind that the estimates of water use by cloud forests are based on only a small number of studies (less than 10). Most of these lasted only a year or less and therefore they do not include any effects of climatic variability between different years. More information on cloud forest *ET* and net precipitation as a function of site elevation and exposure is needed. Nevertheless, despite the paucity of data, there is a clear trend of gradually decreasing apparent water use from tall lower montane forest experiencing little cloud incidence to upper montane and dwarf cloud forests at more exposed locations. *Thus, fountain forests are no myth!*

Like other forests, cloud forests guard the quality and natural flow regime of the streams and rivers emanating from them. But due to their unique hydrological features, the volumes of streamflow produced by cloud forested mountain headwater areas are larger than those associated with non-cloud forests (photo by L.S. Hamilton).

In humid climates, tropical montane cloud forests may be wet and inhospitable places for human activity, but, as we have seen in the preceding paragraphs, they are providing valuable hydrological functions at no charge. In seasonal or semi-arid climates trees, groves and woodlands in the cloud or fog belt are much more pleasant for humans and animals alike, and as a result, the cloud water capture functions of these vegetations have often been eliminated (or at least severely impaired), by their clearance for other, non-forest uses, particularly cattle ranching and temperate vegetable cropping. The various threats to montane cloud forests and the hydrological consequences of their massive clearing will be explored further in Sections 4 and 5, respectively. But first, let us examine the remarkable biodiversity of these forests.

The impressive flowers of Aethantus mutissi (a laurel) are pollinated by the sword-billed hummingbird, Cordillera Oriental, Colombia (photo by W. Ferwerda).

The magnificent hummingbird is one of the many beautiful birds that inhabit the cloud forests of Central America (photo by L. Becht).

The harlequin frog from the cloud oak forests near the Cerro de la Muerte, Costa Rica, has become rare in the last ten years (photo by W. Ferwerda).

3. BIODIVERSITY BANK ACCOUNT

The Biodiversity Heritage of montane cloud forests is of great global importance, as well as of national and local value. This is true not only in terms of species diversity, but especially because of high endemism (the occurrence of species confined only to the area of concern and found nowhere else). In humid environments it is generally assumed that montane cloud forests are not as species-rich as their tropical lowland and lower montane counterparts. This is because of the generally observed decline in the number of tree species, lianas, large vertebrates, birds, bats and butterflies with elevation that reflects the lower temperatures, steeper slopes and diminished food supplies associated with increasing altitudes. However, there is new and substantial evidence from the humid tropics that the number of species of lichens, orchids, bryophytes (mosses and liverworts), shrubs, herbs and ferns increases with elevation. In the past, epiphytes (plants deriving support, but not nutrients directly from their host trees) such as bromeliads, orchids, mosses, lichens and ferns, were often discounted or ignored in forest surveys, as their biomass was considered relatively insignificant. But we now know that epiphytes make up a conspicuous and substantial part of rain forest canopies, reaching their greatest abundance and diversity in montane cloud forests. This suggests that total floral diversity in cloud forests may not compare unfavourably with the much-valued tropical lowland rain forest. For example, Mount Kinabalu in Sabah, East Malaysia, the highest mountain between the Himalayas and the snow-capped peaks of New Guinea, boasts more than 1,000 species of orchid (mostly in the upper montane zone). This represents half of the number of orchid species found on the entire island of Borneo which itself counts about one-tenth of the world total. The mountain also harbours over 600 species of ferns, including many spectacular tree ferns, a figure that is equivalent to about one-fifth of the world's total (and 200 above the number of fern species known for the whole of North America). And while the numbers of large vertebrate species may decline with elevation, there is an amazing wealth of invertebrates and frog species. About half of the 90,000 known higher plant species in the Neotropics - the world's richest flora – are found in the montane zone.

Where tropical montane cloud forests really shine, however, is in endemism, which is one of the most important components of biological diversity wealth and heritages. Due at least in part to the heterogeneity in environmental conditions caused by variations in altitude and compass orientation, mountains in general provide the habitats for species found nowhere else. In some cases, this tendency is reinforced by what has been called the free-standing 'mountain island' effect. A spectacular example is presented by the Cerro de la Neblina, an isolated cloud-bathed mountain in southern Venezuela close to the border with Brazil where many of the shrubs, orchids, and insectivorous plants found near the summit (3,014 m) are restricted to this mountain only. Almost half of all birds endemic to Borneo (with an area of 746,305 km^2 the world's third largest island) and 65% of the island's endemic mammals occur on Mount Kinabalu. On a more regional scale, BirdLife International has conducted studies, particularly in the Andes, showing the importance of cloud forest to restricted-range and threatened bird species. One research project reported that of over 270 endemic birds, mammals and frogs in all of Perú, one-third had cloud forest habitats.

A significant proportion of the plant biodiversity in cloud forests is found in the canopy where branches are usually laden with mosses, orchids and other epiphytes (photo by L.A. Bruijnzeel)

As a result of the comparative remoteness of most remaining cloud forests, many of the new species discoveries made in the last five years have been in montane cloud forests. One of the most recent birds that has been discovered (in November 1997) was the jocotoco antpitta, in an Ecuadorian cloud forest. In 1996 it was a new barbet in Perú in an eastern slope Andean cloud forest. Similarly, some mammals new to science or rarely seen have been recently located in the Annamite Mountain cloud forests on both the Lao and Vietnam sides of the border: the saola (a bovid; placed in a new Genus), two new barking deer species, the Vietnamese warty hog, a short-eared rabbit and a palm civet. Nor are new biodiversity discoveries or rare species limited to animals. In cloud forests of Oaxaca, Mexico (1400 - 2800 m above sea level) a new species of *Vaccinium* growing as an epiphyte, an endangered fuchsia, and a new tree genus (*Ticodendron*) representing a family new to Mexico, have recently been found.

The discovery of the jocotoco antpitta was an economic bonanza to the people of Quebrada Hondo, for within months of discovery, eager naturalists from around the world converged on the area, and brought hard cash for food, accommodation and guiding. The ornithological richness of this cloud forest includes golden-crowned tanagers, gray-breasted mountain toucans, blue-and-black tanagers, streaked tufted-cheeks and hosts of others such as the rare bearded guans and golden-plumed parakeets. Add in the possibility of seeing mountain tapir, spectacled bear or cougar and this area with no mining potential and meagre agricultural value has a tourism and nature study potential that strongly argues for the maintenance of its biological wealth.

Is this cloud forest biodiversity treasure house important? The value of biological diversity at the genetic, species and ecosystem levels, and the need for conserving it has now been well established. These range from ethical to utilitarian and economic. Even common sense tells us in an analogy with taking a watch apart, not to lose or throw away any of the pieces, for they all contribute to making the whole system function smoothly. This is also true for cloud forest biodiversity. Compared to lowland rain forests, cloud forests have been only sparsely researched, so that we know relatively little about what is there in our biodiversity bank account. Indeed, each new piece of botanical or zoological inventory seems to find new species, unexpected occurrences, or new values and uses. For instance, recent inventories in three Ecuadorian montane protected areas found numerous wild relatives of temperate horticultural crops such as strawberry, raspberry, blueberry and gooseberry. Such relatives are often used in plant breeding to improve existing commercial varieties. Much knowledge of the usefulness of plants and animals of the cloud forest resides in the indigenous cultures who have been the traditional users and stewards of these areas. In Perú, which has 25,000 species of known plants, no less than 3,140 species are used for 33 different purposes and about 1,000 species of these are cultivated. It may well be the country with the highest number of its native species being gathered, cultivated or domesticated. The Biodiversity Programme within the Global Environmental Facility (GEF) of the United Nations Development Programme, which is studying human use of this flora, states that a very important part of this genetic economic richness is in the Andean montane forests of Perú, and it warns of serious loss of this treasure house.

Tropical montane cloud forests are, moreover, a vital benchmark and monitoring resource par excellence for assessing global changes in air quality and climate. Generally speaking, organisms which are living in an already stressful environment are particularly sensitive to changes in habitat factors. Thus, diversity and frequency of occurrence of lichens and liverworts have been used in several temperate areas as sensitive indicators of air quality change from pollutants. Likewise, there are strong indications that the serious recent declines in the populations of anoline lizards and a variety of frogs and toads in cloud forest in Costa Rica mirror changes in dry-season mist frequency caused, in turn, by a more general warming of the atmosphere (see also Box in Section 4). As such, the highly adapted species assemblages that are so characteristic of montane cloud forests may be used as sensitive indicators of global climate change, rather like the canaries that miners used to take down the mines as an early warning of life-threatening air pollution. Finally, the research value of these ecosystems is another valuable item in the bank account of cloud forests. A network of cloud forest monitoring and research sites along the gradients of global airsheds is a high priority, therefore (see also Section 7).

The value of biodiversity and its increasing erosion has been officially recognized by the Convention on Biological Diversity held in in 1992 in Rio de Janeiro and ratified by 174 nations of the world. Concrete conservation measures are being worked out by the signatories of the convention at a series of ‘Conferences of the Parties’ (COPs). The need for accelerated conservation programmes in mountain areas will be considered at the COP in 2004. Hopefully by then the world’s governments will have a better realization of the importance of tropical mountains, and of tropical montane cloud forests as the storehouse for these riches. It is encouraging to note in this context that these isues are becoming recognized increasingly by international bodies such as the United Nations Intergovernmental Forum on Forests, which stated recently that ‘mountain cloud forests are of particular concern’ regarding soil and watershed protection and the conservation of biological diversity in environmentally critical areas.

The Andean spectacled bear, largely restricted to cloud forests, is being used as a ‘flagship’ species in efforts to conserve a corridor of protected habitats in the National Parks of Venezuela, and extending south into Colombia, Perú and Bolivia (photo by WWF/Canon Photolibrary – K. Schaefer).

4. CLOUD FORESTS UNDER SIEGE

The original extent of cloud forests worldwide was thought to be around 50 million hectares in the early 1970s. There are no accurate data as to how much might now remain, but it is known full well that cloud forests are disappearing rapidly. The 1990 global forest survey published by the United Nations Food and Agricultural Organization (1993) indicated that annual forest loss in tropical highlands and mountains was 1.1% which is higher than for any of the other tropical forest biomes. For example, it has been estimated that as much as 90% of the cloud forest in the northern Andes of Colombia has been lost, mostly to pastures and agricultural fields. What remains then is of great global, national and local importance, both from the hydrological, the biological and human-use perspectives. The causes of cloud forest disappearance and degradation are myriad. The main threats are discussed below.

Tropical montane cloud forests are disappearing even more rapidly than lowland rain forest. It has been estimated that over 90% of the cloud forests of northern Colombia have disappeared in the last few decades, mostly for the creation of pasture (photo by A.M. Cleef).

Conversion to grazing land

Worldwide, the greatest loss of montane cloud forest comes from its deliberate conversion to grazing land for cattle, sheep and goats. This is particularly the case in seasonally dry climates because such areas are deemed most suitable for ranching. Usually, the conversion pressure occurs on the lower altitudinal boundaries of cloud forests as graziers from the valleys extend onto steeper slopes and into higher elevations. However, in some instances where population centres and agriculture are traditionally found at higher elevations (e.g. in the Andes), the nibbling away of the cloud forest is from above, as animals are moved down into the forest. The extension of the grazing frontier into these cloudy, wet environments is driven by a combination of population growth, uncertainty about land ownership, land hunger and poverty.

The soils and climate of most cloud forest sites (except those in seasonally dry areas) are not very conducive to sound and profitable animal husbandry, however, and erosion due to overgrazing, or landsliding on steep unstable slopes are a common feature in cleared cloud forest terrain (see photographs on previous and this page). Where the cloud deck is in contact with the ground during the dry season, any trees that have been left standing can go on performing their cloud-stripping function. The resulting crown drip and stemflow may provide additional water to the vegetation under the tree, or even be sufficient for small-scale collections of water to feed game birds or cattle (see Section 2).

Conversion to cultivated crops

Where the soils are not waterlogged there are cloud forest situations where agricultural or horticultural crops can be grown, and substantial clearing for these crops is occurring. Traditional ethnic minority mountain swiddeners are being pushed into cloud forest environments by colonists from the lowland ethnic majority, in places such as the Philippines and Thailand. Commercial temperate vegetable production has opened up the cool lower edges of cloud forests in Malaysia (including Sabah's Mount Kinabalu, as well as various mountains in the Philippines and Guatemala, to name but a few examples. Tree crops such as coffee or cardamom (Cameroon and Sri Lanka), flowers (Venezuela, Ecuador), or berries (Dominican Republic) are other examples of this upward shift of cool commercial crops. Finally, there is clearing for legal or illegal drug production, including coca in Bolivia, opium poppy in Colombia and Thailand, and kava or sakau (*Piper spp.*) in various Pacific Islands. Depending on the level of sophistication of the operation, the use of pesticides as well as the degree of surface erosion may be very high. Both impair water quality for downstream use.

Fuelwood cutting

Many tropical cloud forests are threatened by the need for fuelwood and charcoal for heating and cooking at the higher elevations. The slow growth rates in these environments produce a denser wood, with a high combustion value. While a small amount of this could be sustainable, and not greatly impair either the forest's hydrological or ecological functioning, most of the harvesting is destructive because normally there are no effective controls. Even if the forest is under some kind of protected area status, the usual remote location makes regulation or prohibition a difficult task.

Agriculture and road building on steep slopes encroaching into cloud forest territory, northern Venezuela (photo by M. Ataroff).

Fortunately, the methods used for wood harvesting and charcoal production in montane cloud forests, such as here in Colombia, are normally rather low-tech which limits their impact on forest hydrological and ecological functioning (photo by J.H.D. Wolf).

The pretty bromeliad Tillandsia etzii is being depleted by unsustainable harvesting for ceremonial use by an increasingly large number of indigenous people in Chiapas, Mexico (photo by F. Ontiberos).

Non-wood product harvesting and hunting

Many cloud forests are being degraded by the over-harvesting of their interesting, useful or commercially marketable non-wood products. While traditional uses of medicinal or ceremonial plant and animal products from the cloud forest has been ongoing for centuries, the development of large-scale commercial trade in orchids, bromeliads, medicinal plants, reptiles, amphibians, birds and mammals is impoverishing many of these ecosystems. The pretty bromeliad *Tillandsia etzii*, for example, is being depleted by unsustainable harvesting for ceremonial use by an increasingly large number of indigenous people in Chiapas, Mexico (see photograph). The Orchid Specialist Group of IUCN estimates that of the 5 million orchids traded annually, about 1 million are collected from the wild, possibly mostly from cloud forests. This wild collection, which does not include orchids collected and sold within country, is seriously affecting the existence of many of the 20,000 known species.

In general, the mountain forest flora and particularly fauna of South-east Asia are being heavily impacted by a massive international wild products trade that includes even endangered species. The rich and unusual biodiversity of the cloud forests, and their remoteness make it difficult to control and develop sustainable harvesting or give adequate protection where species are rare or endangered. Cloud forest preserves have been set up for some rare species such as the mountain gorilla in the Trans-Border Parks of Rwanda, Uganda and the Democratic Republic of Congo, or the spectacled bear in the Central and Northern Andes. The Convention on International Trade on Endangered Species of Fauna and Flora (CITES) is also putting on the brakes, but hunting (poaching), trapping and collecting outside of the law remain serious threats to cloud forest species biodiversity in many areas.

Alien species

The introduction of alien species is a threat to any native ecosystem, and is one of the most serious threats to biodiversity from a global perspective. For cloud forest ecosystems, where species are living under conditions of unusual stress, alien plants and animals can be catastrophic. This is especially true where the cloud forest patches are small, as they often are on small islands or on isolated mountains. The presence of alien feral pigs in Hawai‘i has not only contributed to plant and bird extinctions, but causes serious erosion in the cloud forests of these islands as well. Goats in Venezuela and the Galapagos and introduced grasses in Puerto Rico are other examples of the threat posed by alien species.

Tourism

While nature-based tourism can not only raise awareness of the values of cloud forests, and generate economic returns to nearby communities, it must be carefully orchestrated. These are slow-to-recover environments, and severe deterioration can occur due to their sensitivity to disturbance. Track or trail erosion and miring, litter, removal of plants and animals and introduction of alien species have occurred in such popular places as Mount Stanley (Uganda), Mounts Makiling and Pulog (Philippines) and El Yunque (Puerto Rico). Touristic development in the form of golf courses or resort hotels in these cooler environments of hot, tropical countries is increasingly occurring, e.g. on Sabah’s Mount Kinabalu and Peninsular Malaysia’s Genting and Cameron Highlands.

Eco-tourism in montane cloud forests needs to be carefully orchestrated to avoid adverse impacts on the environment (photo by K. Beenhakker).

Air quality and climate change

The adverse impacts of air pollution on cloud forests have been best documented for the cool-temperate zone. Gaseous and particulate pollutants carried in clouds have caused serious changes in soil chemistry and tree mortality when deposited in excessive amounts. Such damage is undoubtedly occurring in the tropics as well, although the effects of pollution on soils and vegetation have rarely been studied. They have been reported, however, for a cloud forest in the vicinity of Caracas that is exposed to heavy air pollution. Also, the increase in acidity of the cloud bank in northern Costa Rica has been attributed to large-scale burning activity in the Atlantic lowlands.

The photo on the right below shows the cloud base in the Luquillo Mountains, Puerto Rico, well above its normal mountain-enshrouding position. This elevating of the cloud base (by about 300 m) occurred after Hurricane Hugo had defoliated the forests of the windward slopes in September 1989. The associated drop in forest evapotranspiration caused a significant rise in air temperatures and thus in the level of cloud condensation. The effect disappeared in a few months after the leaves had grown back again.

Indeed, scientists are encountering increasing evidence of the reality of a lifting-cloud-base hypothesis associated with global or regional warming. Amongst other things, the recent disappearance of 20 out of 50 species of frogs and toads from the cloud forests of Monteverde, northern Costa Rica, has been attributed to increased warming due to increases in sea surface temperatures which, in turn, is believed to have resulted in declines in mist frequency (see also Section 5). Box I elaborates on this disturbing evidence which has serious implications if global warming will proceed as expected.

The cloud base was lifted by several hundred metres after Hurricane Hugo defoliated the forests of the windward slopes of the Luquillo Mountains, Puerto Rico. The effect disappeared in a few months when the leaves had grown back again (photos by A.J. Wickel (L) and M. Larsen (R)).

Are Amphibian Declines in Cloud Forest a Warning Like Miner's Canaries?

A decrease in cloud (mist) frequency has occurred at Monteverde Cloud Forest Preserve (Costa Rica), with most extreme decreases in 1983, 1987, 1994 and 1998, but with an overall downward trend, associated with warmer sea surface temperatures. Anoline lizard populations have declined in association with this pattern, with major population crashes in 1987, 1994 and 1998. Two species had disappeared by 1996. Similarly, populations of red-eyed stream frogs and terrestrial-breeding tree frogs crashed over large areas in 1987 and 1998. Currently, 20 out of 50 species of frogs and toads, including the spectacular and locally endemic golden toad, have disappeared. At the same time, species from drier, lower elevations are invading and becoming residents. This has been particularly noted for bird species. El Niño/Southern Oscillation events, if they result in extended dry periods, have always been hard on cloud forests and the species in them that are, after all, adapted to cope with more or less persistently wet conditions. Although recovery is the rule, long-term global warming with a more frequently elevated or less abundant cloud deck would spell serious trouble for these valuable ecosystems with their often high endemism. Similarly, the decreasing trend in minimum streamflow values observed for the Río Cañas in the Monteverde area may be seen as a further warning sign on the wall. This and other hydrological evidence will be discussed in Section 5.

On single mountains, a lifting of the average cloud condensation level will result in the gradual shrinking of the cloud-affected zone. On multiple-peaked mountains, however, the effect may be not only that, but one of increased habitat fragmentation as well, adding a further difficulty to the chances of survival of the remaining species (Figure 6).

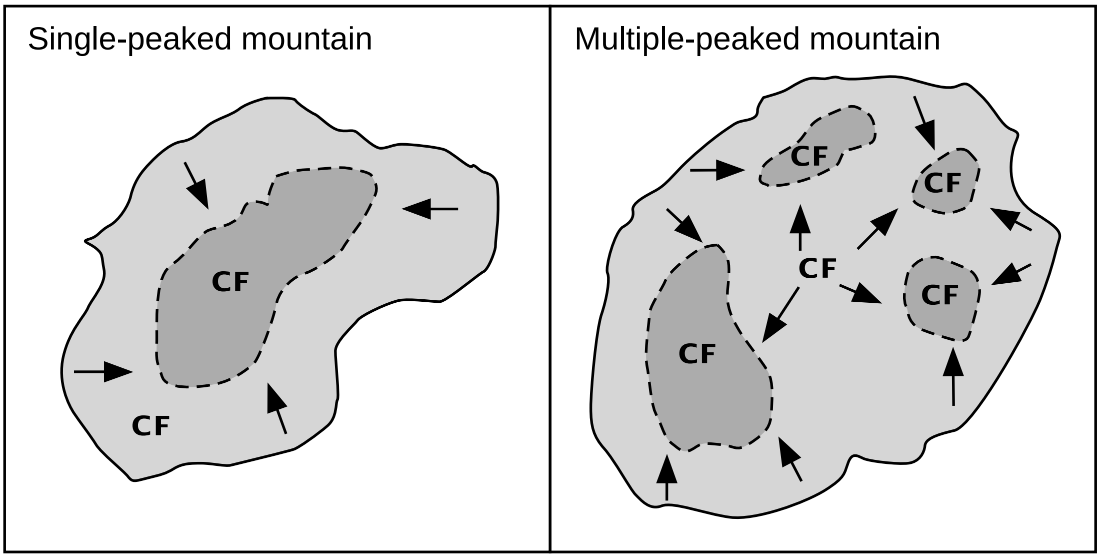

Figure 6. Possible changes in spatial cloud forest distribution in response to a rise in the cloud condensation level on (A) a single peak and (B) a mountain with several peaks (diagram courtesy of F. Sperling Esq.).

Fire

Anthropogenic fire is not a problem in the perennially wet types of cloud forests, but in those which are seasonally dry, burning in adjacent areas can extend into these important ecosystems. In these cases, burning is often used in conjunction with extension of grazing into cloud forest areas, for instance in parts of the Nepal Himalaya and on some Pacific and Atlantic islands. Fire in the lowlands from burning grasslands or sugar cane may be extensive and alter the chemistry of cloud water as shown by the example from Costa Rica cited earlier.

Miscellaneous

Commercial logging is not globally an important threat to cloud forests directly. The inaccessibility, poor form of trees, and short stature of, especially, upper montane cloud forests makes them an unattractive economic option. However, the usually taller-statured trees of the lower montane cloud forest may become subjected to commercial logging, particularly if logging is already occurring in the adjacent non-mossy forests where there may be valuable high elevation oaks or Podocarps. (See photographs on pages 8 and 32). The roads associated with such logging can provide access for other interventions as well as cause landslides.

Mining also, is not a major threat to cloud forests globally, due to the very site specific nature of mines. However there are instances of serious damage to specific cloud forests, including gem mining in Sri Lanka, geo-thermal development in the Philippines and Java, and gold mining in New Guinea and Ecuador. In Ecuador, the famous Podocarpus National Park with its fine cloud forests, is under assault. This biodiversity treasurehouse, where a new bird species, an antpitta (see Section 3) was recently discovered, has for many years been seriously impacted by illegal mining. Though mining is specifically prohibited under the Forest Law in National Parks, both spontaneous artisanal mining and multinational corporation gold mining has been going on for several years. Unfortunately the economic situation in Ecuador currently is so critical that in 1999 there has been serious governmental discussion of opening up all protected areas to mining, in the national interest.

Among the numerous other less common threats to cloud forests, one deserves special mention. An increasing number of telecommunication and media transmitting stations is being sited on the summits of hills and mountains throughout the tropics and may coincide with cloud forest sites. Though the area that is affected directly may be relatively small, these installations are a scenic blight, and the servicing and access required extends the overall impact tremendously. The effect of service roads especially can be destructive where steep, wet slopes become more prone to landsliding and alien biological baggage is brought in by service personnel. Fortunately, new technologies should be able to keep these facilities small, and their servicing can be done by helicopter and less frequently due to greater automation, eliminating the need for destructive roads.

The servicing and access required by the increasing number of telecommunication and other installations on the summits of tropical mountains constitute a relatively recent threat to cloud forests, especially where steep, wet slopes become more prone to landsliding and alien biological baggage is brought in by service personnel (photo by L.A. Bruijnzeel).

5. DIMINISHING STREAMFLOWS: SIGNS ON THE WALL?

Where forests of any kind are replaced by annual cropping or heavy grazing there are bound to be profound changes in the area's hydrology. To start with, the beneficial effect on soil aggregate stability and water intake capacity afforded by the high organic matter content and abundant faunal activity of forest soils may linger for a year or two after clearing. However, exposure of the soil surface to the elements generally leads to a rapid decline thereafter, particularly if fire was used during the clearing operation. In wet areas farmers often even encourage surface drainage to prevent waterlogging and rotting of sensitive root crops. An additional aspect in densely populated smallholder agricultural steeplands is that considerable areas may become permanently occupied by compacted surfaces, such as houses, yards, trails and roads. In areas with heavy grazing pressure, soil infiltration capacities suffer further from compaction by trampling cattle. As a result, conversion of forest to annual cropping or grazing is almost inevitably followed by increases in amounts of surface runoff (Figure 7).

Rainfed agricultural activities encroaching into cloud forest in Vietnam (photo by W. Ferwerda).

A second consequence of forest clearing relates to the associated changes in net rainfall: no longer are there trees to intercept rainfall or fog. Neither, of course, are levels of forest water use (transpiration) maintained. Whilst annual crops and grass also intercept rainfall and cloud water, and take up water from the soil, the associated amounts are (much) smaller than for forest due to the generally larger total leaf surface area and deeper root systems of forests compared to crops or grass. Thus, the clearing of montane forest that does not experience appreciable inputs of cloud water results in an increase in the total volume of streamflow (‘water yield’) emanating from such areas (typically by 100 – 400 mm per year, depending on rainfall). In theory, the extra amount of moisture available in the soil due to the reduction in rainfall interception and transpiration after (non-cloud) forest conversion should permit a healthy increase in baseflow levels – *given good soil management*. In practice, however, the degeneration of the soil’s infiltration capacity after forest removal is often such that this potential gain in soil water is more than offset by the increase in overland flow and peak runoff during the wet season (Figure 7), with diminished streamflow during the dry season as the sad result.

It cannot be stressed enough, however, that the risk of reduced dry season flows following forest clearance becomes even more serious in the case of cloud forest. As we have seen, extra inputs of water to the forest ecosystem afforded by cloud interception may be substantial (up to hundreds of millimetres of water per year), particularly in cloud forests at exposed locations. Needless to say, such extra additions assume particular importance during periods of low rainfall (Figure 8). Whilst the cloud stripping ability of the trees remains more or less intact and could even be enhanced due to greater exposure to passing fog as long as only *small* patches are cut, it would surely disappear altogether in the case of a wholesale conversion to vegetable cropping or grazing.

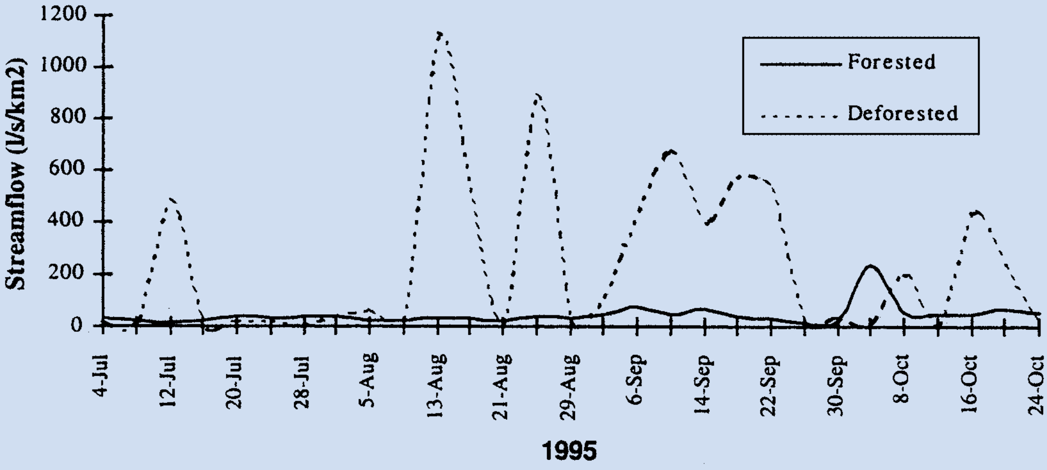

Figure 7. After forest clearance, a catchment’s runoff response to rainfall tends to become more ‘spiked’ as shown by this example from Honduras.

Similarly, a general lifting of the cloud base or a reduction in the frequency of mist incidence due to global or regional warming of the air associated with a rise in sea surface temperatures or large-scale deforestation (see photographs on page 24) could be equally disastrous, both in terms of diminished dry season flows (Figure 9) or species declines and habitat fragmentation (Figure 6; Box I in Section 4).

In recent years, strongly diminished dry season flows after removal of montane forest have been reported for various parts of the tropics, including Costa Rica, Honduras, Guatemala and eastern Indonesia. Whilst the evidence presented in Figure 9 does indeed suggest a worrying relationship between global warming and drying of the air on the one hand, and reduced streamflows on the other in the case of northern Costa Rica, it should not be forgotten that these data pertain to an area that is rather protected from the moisture-bearing trade winds from the Caribbean. As such, one should be careful to generalize such findings to 'all' cloud forest situations. For example, simulation studies of the effects of global warming on rainfall patterns predict a distinct rise in some cloud forest areas, such as the Pacific slopes of the Andes in South-west Colombia.

Also, it is not clear to what extent the reported reductions in dry season flows are primarily the result of the loss of the fog stripping capacity of the former forest, or of diminished rainfall, reduced infiltration and water retention capacities of the soil due to erosion, or even increased take offs for irrigation at upstream locations. Identifying the precise cause(s) of the observed decreases in dry season flows and finding ways of restoring them, should be given very high research priority. *Despite these caveats, one would do well to heed these signs on the wall.*

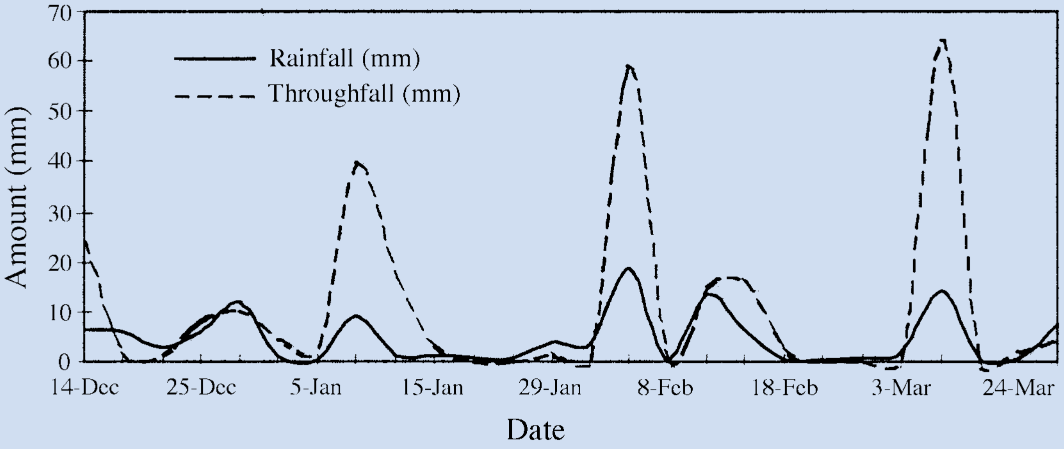

Figure 8 Amounts of rainfall and crown drip in an upper montane cloud forest in Guatemala illustrating the importance of cloud water interception by the forest vegetation during the dry season.

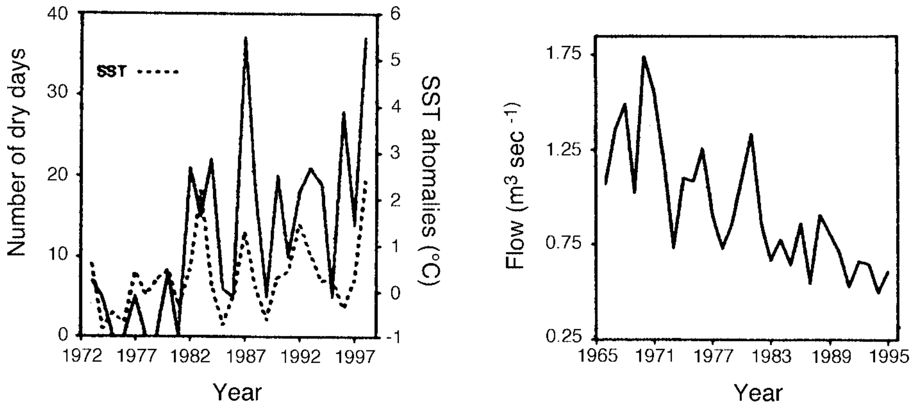

Figure 9. The similarity in trends for deviations in sea surface temperatures, the number of rainless days, and minimum streamflows in northern Costa Rica is striking.

Whatever the cause(s) of the diminished flows, there can be no doubt that they spell serious trouble for upland farmers and lowland city dwellers alike. The loss of precious water during periods when it is needed most not only causes reductions in irrigated agriculture and industrial production potential (and thus in the incomes of countless farmers and labourers) but also more frequent cut-offs in domestic water supply and electric power. Clearly, a more direct link should be established between downstream water use (of all kinds) and upstream maintenance of the resource.

The strikingly coloured golden toad, an endemic species from the Monteverde area in northern Costa Rica, has disappeared in recent years, probably as a result of global warming (photo by WWF/BIOS photolibrary – P. Arnold).

6. IRREVERSIBILITY OF LOSS

The century beginning in 2000 should surely be characterized by words such as restoration, repair and rehabilitation. This should be the case for both our natural systems and our social and cultural systems. In the biosphere, for some ecosystems, the consequences of many land use decisions are somewhat reversible, if they were wrong ones, given sufficient time and inputs of energy and other resources. While much more research is needed to increase our knowledge about montane cloud forests, *the current consensus is that consequences of activities which remove cloud forest cover are usually irreversible*. This is because of the high biological diversity, unique gene pools, small size of the areas ('eyebrows' of the higher mountains or 'caps' on the lower mountain summits), and slow recovery after disturbance of these already stressed systems. It is true that one of the important values, namely the cloud water capture function, can be restored without great difficulty. Reforestation, or even erecting large screen structures (as is done for water supply in the arid fog belt of Perú and Chile) can provide the necessary surfaces for cloud stripping. But restoration of the intricate mix of life forms (including the amazing variety of epiphytes and the unusual fauna), of the authenticity and of the complexity of the ecological interactions that maintain a healthy ecosystem is simply beyond our capability.

It is essential that these remarkable but fast-disappearing ecosystems be protected and maintained for the many services and values that they provide. The Protected Areas System of each country should include the remaining montane cloud forests. Some might well be designated as National Parks, some as Strict Nature Preserves, and others as Protected Landscapes or Watershed Reserves. Their fragile nature and difficulty of restoration makes such as protection policy a sound allocation of land and water resources. Some of these designations may permit harvesting of useful products, but they should foster the instituting of controls over the kind and amount of harvesting, so that irrepairable damage is avoided. *Participatory planning and management involving local people is essential for these controls to be effective and sustainable.*

Pristine upper montane cloud forest on Mt Bartle Frere, Queensland (photo by A. Dennis).

In many areas, cloud forests are under siege, especially where they contain valuable timber or where the climate favours the cultivation of temperate vegetables or fruit trees, such as here on the Pacific slopes of the Talamanca area, Costa Rica (photo M. Kappelle).

7. DECISION TIME FOR CLOUD FORESTS

In the Talamanca Mountains which cross the border of Panamá and Costa Rica, a large trans-border Biosphere Reserve, called La Amistad (friendship) has been created. This 1.1 million hectare area includes the largest tract of cloud forest in Central America. La Amistad contains roughly 10,000 higher plant species, 400 bird species, 250 reptile and amphibian species and many species of mammals, including six species of tropical cats. More than one-third of the plant species are found nowhere else on earth. What a treasure house of biological diversity! Yet it is under assault even though it has Protected Area status. The rugged terrain, high rainfall and miserable soils once discouraged forest clearing for conversion to other land uses, when better lands were still available. But with population increases and the loss of fertility of previously farmed land on lower slopes, colonists are rapidly moving up the mountain slopes into the montane rain forest, largely for grazing but also for fruit and vegetable production (see adjacent photograph). Illegal drug production is extremely lucrative, is best carried out in remote areas, and cloud forests in Colombia and other Andean countries are under assault from this also. Similar processes are at work in mountain areas around the world as discussed more fully in Section 4. *Yes, cloud forests are under siege and it is indeed 'decision time for cloud forests'.* The rate of loss must be slowed and hopefully halted. With few exceptions, the land uses that replace or impair cloud forests are not sustainable and are economically marginal at best, or illegal.

Knowledge of how tropical montane cloud forests function remains limited, but critical to their long-term conservation. Provisions for monitoring the state of cloud forests need to be incorporated, for as we have seen repeatedly, these are often stressed, slow-to-recover ecosystems. Measures of change should be made not only for local impactors but also for more subtle global changes in weather, air and precipitation quality, and possibly in ozone and UV-B radiation levels as well. After all, many plant and animal species in cloud forests are finely adapted to the prevailing extreme climatic and soil conditions and by nature sensitive to even slight changes therein. The dramatic crashes in cloud forest amphibian populations in Costa Rica since the 1970s following changes in the regional climate (see Box I, Section 4) suggest that they might well be good target species to serve as bio-indicators. Similarly, the epiphyte communities living on the exposed branches of the upper canopies of cloud forests may be equally suited to detecting changes in climatic conditions, rainfall and cloud water chemistry, as well as ozone and UV-B levels.

Compared with almost all other major forest ecosystems tropical montane cloud forests have been subjected to little research and even less long-term monitoring. Perhaps this is due to their relative inaccessibility and their generally inhospitable environment for research. There are hardly any integrated research programmes in cloud forests that involve scientists from many different disciplines working on the principal ecosystem processes and elements, as is the case in several lowland tropical rain forests (for instance La Selva, Costa Rica; Barro Colorado Island, Panamá). Probably the Monteverde Cloud Forest Preserve in Costa Rica and the elfin cloud forest research in

Installing probes to measure temperature and humidity in dwarf cloud forest on Krakatau, Indonesia (photo by L.A. Bruijnzeel).

the Luquillo National Forest in Puerto Rico come closest to being this kind of integrated project. There is an urgent need to initiate integrated studies of climate, vegetation, soils, fauna and hydrology, and of the socio-economic factors driving these forests out of existence, in other cloud forest situations as well, notably in Africa and South-east Asia.

Sites where benchmark data are being collected on many elements offer exceptional opportunities for a global monitoring network with respect to near-surface atmospheric changes (where clouds or fog come in contact with the vegetation). Because the values of tropical montane cloud forests have been so little understood or appreciated by those who fund research, it has lagged sadly. *Thus, it is also decision time for a greater research effort into these unusual, interesting and valuable ecosystems.*

As a basis for action, there is an immediate need to raise awareness of the values of cloud forests. This needs to be carried out not only at all levels from local to international, but also with the many actors who directly impact, or derive benefit from, cloud forest. Of particular importance here are water-dependent communities (including downstream city dwellers) as well as the local grazers, fuelwood cutters and plant and animal collectors. Development aid donors have rarely heard of cloud forests and currently have their sights focused on biodiversity conservation in the lowland rain forests. National or local politicians are an even more pressing target for education. Local, national or international non-governmental organizations (NGOs) may be effective at all levels, if given reliable information by the scientific community. *Cloud forests will not be conserved until people know what values are being lost, and this requires education.*

Educational programmes with local communities, such as the one shown here on the ecology of bromeliads in the cloud forests of Chiapas, Mexico, are an essential element of any forest conservation and management plan (photo by J.H.D. Wolf).

There are also some macro-level issues for which a decision time has come. Global climate change, possibly due to human activity in producing greenhouse gases, is affecting montane ecosystems more than others. Long-distance transport and deposition of pollutants also impact mountains most adversely. Cloud and rain-borne pollutants (including ‘acid rain’) in the lower levels of the atmosphere encounter these high elevation land forms more than the lowlands, and cold-condensation occurring at upper levels brings suspended materials such as pesticides out of the atmosphere. These issues must be addressed at an international level and the awareness of the importance of tropical montane cloud forests must be reinforced amongst decision-makers. Some progress has been made on greenhouse gas emissions from fossil fuels in the Kyoto Protocol, but it is painfully slow.

The underlying causes of the adverse impacts on cloud forests relate to such basic, pervasive pressures as rapid population increase, inequity in access to the earth's resources, demand for increasing per capita levels of consumption, uncertainty of land tenure, greed, political expediency, and, in some cases, trans-boundary air pollution or global warming. These pressures are very complex and difficult to reduce by a land manager or administering agency wishing to protect or better manage a cloud forest area. In some areas, positive steps are being taken, because it was 'decision time'. For instance, in La Amistad Biosphere Reserve a project called AMISCONDE (combining Amistad, Conservation and Development) is being implemented by a coalition of groups from the United States working under the Foundation for Sustainable Development (based in Panamá) and the Tropical Science Center (based in Costa Rica). The project is aimed at stabilizing the shifting agriculture in the Buffer Zone in order to keep the Core Zone (which includes most of the cloud forest) intact and unintervened. This stability is being promoted through a mix of actions that include agricultural credits, productivity enhancement, soil and water conservation, marketing assistance, reforestation of degraded areas, development of cottage industries and training programmes for men, women and children. In Perú, in the National Cloud Forests of Jaén - San Ignacio, a communal forest enterprise called 'La Bermeja Limited' has been set up under the assistance of the International Tropical Timber Organization as a local cooperative. It uses low technology methods (for example, no roads or heavy logging equipment) to manually harvest timber on a sustained-yield basis to produce simple products in a small sawmill and woodworking shop (tables, beds, chairs). The main species being harvested is a *Podocarpus* (Andean pine), and the project is attempting to demonstrate that natural cloud forest management is consistent with helping people by conserving the forest.

Elsewhere the answer is to preserve cloud forests through the creation of a strictly protected watershed and biodiversity preserve, or as a national park. In the case of the cloud forests of the Virunga Volcanoes (Central Africa), these forests are the sole habitat of the mountain gorilla, a species at risk, and one with great attraction to tourists. Rwanda, Uganda and the Democratic Republic of Congo have each established national parks which produced significant revenues through gorilla tourism before the outbreak of war, terrorism and civil unrest. The demand for visitation permits was such that visits had to be booked well in advance. Similarly, in the Monteverde Cloud Forest Reserve in northern Costa Rica (only 10,000 hectares in extent) visits and local expenditures by ecotourists form the second largest source of local income.

The mountain gorilla is limited in occurrence to the cloud forests of the Democratic Republic of Congo, Uganda and Rwanda, and with a population estimated at 620, is a 'listed' endangered to critically endangered species. It has great ecotourism as well as scientific and heritage value (photo by WWF/Canon photolibrary – M. Harvey).

The high hydrological and biological values of these remarkable ecosystems warrant that most, if not all, of those remaining be given some type of protected area status. An example has been already given in this section. Several options are available under the system recognized by the World Conservation Union (IUCN) such as national park, strict nature reserve, habitat management area, or managed resource protected area. While formal designation of a protected area does not guarantee protection, it is the first step. There is considerable urgency in this action for all countries having cloud forests. The World Conservation Monitoring Centre (WCMC) in Cambridge, U.K., has prepared a Directory of Tropical Montane Cloud Forests, giving their protection status. While the information is still incomplete at present, it can assist in indicating where are the gaps in a protection system for a country.

Therefore, where public unprotected lands exist (public domain), it behooves governments to establish formal protected areas legislatively or by other effective means, adding important cloud forest areas to the official Protected Areas System of the country or lower jurisdiction. In many cases, and especially in Latin America where the juridical context of private ownership is well defined, the last remnants of cloud forests may only be saved by buying them. Successful examples of privately owned cloud forests are Monteverde and Rara Avis in Costa Rica, La Reserva Huitepec in Chiapas, Mexico, El Chicaque near Santa Fé de Bogotá in Colombia, and Bilsa and Maquipucuna in Ecuador. NGOs, local community-based organizations or private foundations which have shown that they have the capacity and the will to manage such forests should be stimulated to buy these cloud forest remnants.

There is also a role for ‘conservation easements’ where NGOs or other environmental bodies such as a public land trust, acquire by gift or purchase the rights of private land owners to cut down or otherwise degrade a cloud forest area. Such a purchase has recently been acquired in the Talamanca area of Costa Rica in cloud forest by The Nature Conservancy, and given to CEDARENA, the Environmental and Natural Resources Law Centre, - as Latin America’s first land trust to hold such easements. CEDARENA will hold and monitor these lands in perpetuity. Financial institutions as well as the private sector should consider contributing to an international trust fund for the purchase of tropical montane cloud forests, assisting governments, NGOs and other responsible conservation bodies to acquire title or easements to these forests.

Whatever the land ownership (state, communal or private), the most important part of a protected area designation is the control over use so that there is no serious nor irreversible degradation. This, after all, is what protection or sustainable use means. Controls over timber extraction, conversion to other land uses, intensity of use (as in tourism), roads and trails and introduction of new species, are all necessary elements. Management plans that are made and then effectively implemented *with local community input and support* are important elements of control in meeting the threats. Indeed, educational programmes with local communities must precede the planning and adoption of management policies. Much valuable knowledge may be obtained from traditional resource users in this process. Surveys and inventories need to extend beyond the boundaries of the cloud forest and include not only biophysical information about land use, but tenurial and demographic data as well.

It is clear that significantly more needs to be done if we are to successfully conserve tropical montane cloud forests. There must be greater understanding of how these forests function. Research is essential, for without this knowledge, it will not be possible to raise awareness amongst communities that live with these unique assemblages of life. It will not be possible to influence the decion-makers in national capitals and international fora whose decisions have a direct impact on the future of cloud forests. And, it will not be possible to design and develop effective conservation programmes that establish protected areas and help to sustainably manage tropical montane cloud forests. Efforts are underway to bring together researchers, communities, decision-makers and conservation and development practioners to better integrate understanding, awareness, policy change, and on-the-ground experience to ensure that tropical montane cloud forests continue to provide the ecosystem services necessary for nature and mankind into the future (see Box II below) Yes, *decision time for cloud forests is now*.

THE CHOICE IS OURS:

Do we want this?...

Vast expanses of undisturbed cloud forest in the Sierra de las Minas, Guatamala (photo by R. Klein)

or this?...

Former cloud forest terrain cleared for pasture in Colombia (photo by W. Ferwerda)

SELECTED REFERENCES

In keeping with the style and format of this Series, no specific references to literature have been included within the main body of the text. The following books and articles comprise our principal sources of information, and may form a basis for further reading.

Aldrich, M. et al. 1997. Tropical montane cloud forests: An urgent priority for conservation. *WCMC Biodiversity Bulletin* no. 2, World Conservation Monitoring Centre, Cambridge, U.K.

Asbury, C.E. et al. 1994. Solute deposition from cloud water to the canopy of a Puerto Rican montane forest. *Atmospheric Environment* 28: 1773-1780.

Benzing, D.H. 1990. *Vascular Epiphytes*. Cambridge University Press, Cambridge, U.K.

Benzing, D.H. 1998. Vulnerabilities of tropical forests to climate change: the significance of resident epiphytes. *Climatic Change* 39: 519-540.

Brown, M.B. et al. 1996. *A Valuation analysis of the Role of Cloud Forests in Watershed Protection. Sierra de las Minas Biosphere Reserve, Guatemala and Cusuco N.P., Honduras*. RARE Center for Tropical Conservation, Philadelphia, U.S.A.

Bruijnzeel, L.A. 1990*. Hydrology of Tropical Moist Forests and Effects of Conversion: A State of Knowledge Review*. UNESCO, Paris, and Vrije Universiteit, Amsterdam.

Bruijnzeel, L.A. 2000. Hydrology of tropical montane cloud forests: a reassessment. In: J.S. Gladwell (Editor). *Proceedings of the Second International Colloquium on Hydrology of the Humid Tropics*. CATHALAC, Panama City, Panama (in press).

Bruijnzeel, L.A. & Proctor, J. 1995. Hydrology and biogeochemistry of tropical montane cloud forests: what do we really know? In: L.S. Hamilton et al. 1995, pp. 38-78.

Bruijnzeel, L.A. et al. 1993. Hydrological observations in montane rain forests on Gunung Silam, Sabah, Malaysia, with special reference to the '*Massenerhebung*' effect. *Journal of Ecology* 81:145-167.

Calamini, G. et al. 1998. Fog interception and water budget of *Caesalpina spinosa* trees in the Lomas ecosystems of Mejia (Arequipa, Perú). In: R.S. Schemenauer & H.A. Bridgman (Eds.), *First International Conference on Fog and Fog Collection*, IDRC, Ottawa, pp. 473-476.

Cavelier, J. & Mejia, C. 1990. Climatic factors and tree stature in the elfin cloud forest of Serrania de Macuira, Colombia. *Agricultural and Forest Meteorology* 53: 105-123.

Clark, K.L. et al. 1998. Atmospheric deposition and net retention of ions by the canopy in a tropical montane forest, Monteverde, Costa Rica. *Journal of Tropical Ecology* 14: 27-45.

Dawson, T.E. 1998. Fog in the California redwood forest: ecosystem inputs and use by plants. *Oecologia* 117: 476-485.

Doumenge, C. et al. 1995. Tropical montane cloud forests:conservation status and management issues. In: L.S. Hamilton et al. 1995, pp. 24-37.

Frahm, J.P. & Gradstein, S.R. 1991. An altitudinal zonation of tropical rain forests using bryophytes. *Journal of Biogeography* 18: 669-676.

Gordon, C.A., Herrera, R. & Hutchinson T.C. 1994. Studies of fog events at two cloud forests near Caracas, Venezuela - II. Chemistry of fog. *Atmospheric Environment* 28: 323-337.

Hafkenscheid, R.L.L.J. 2000. *Hydrology and biogeochemistry of montane rain forests of contrasting stature in the Blue Mountains of Jamaica*. PhD thesis, Vrije Universiteit, Amsterdam.

Hamilton, L.S. 1995a. *A Campaign for Cloud Forests*. International Union for the Conservation of Nature, Gland, Switzerland.

Hamilton, L.S. 1995b. Montane cloud forest conservation and research: a synopsis. *Mountain Research and Development* 15: 259-266.

Hamilton, L.S., Juvik, J.O. & Scatena, F.N. (Eds.) 1995. *Tropical Montane Cloud Forests. Ecological Studies* 110, Springer Verlag, New York.

Harr, R.D. 1982. Fog drip in the Bull Run municipal watershed, Oregon. *Water Resources Bulletin* 18: 785-789.

Ingwersen, J.B. 1985. Fog drip, water yield, and timber harvesting in the Bull Run municipal watershed, Oregon. *Water Resources Bulletin* 21: 469-473.

IUCN 1994. *Guidelines for Protected Area Management Categories*. IUCN Commision on National Parks and Protected Areas, Gland, and World Conservation Monitoring Centre, Cambridge.

Kappelle, M. 1995. *Ecology of mature and recovering Talamancan montane Quercus forests, Costa Rica*. PhD thesis, University of Amsterdam, Amsterdam.

Kerfoot, O. 1968. Mist precipitation on vegetation. *Forestry Abstracts* 29: 8-20.

Kitayama, K. 1992. An altitudinal transect study of the vegetation on Mount Kinabalu, Borneo. *Vegetatio* 102: 149-171.

Kitayama, K. & Müller-Dombois, D. 1992. Vegetation of the wet windward slope of Haleakala, Maui, Hawai'i. *Pacific Science* 46: 197-220.

La Bastille, A. & Pool, D.J. 1978. On the need for a sytem of cloud-forest parks in Middle America and the Caribbean. *Environmental Conservation* 5:183-190.

Leo, M. 1995. The importance of tropical montane cloud forest for preserving vertebrate endemism in Peru: the Río Abiseo National Park as a case study. In: L.S. Hamilton et al. 1995, pp. 198-211.

Long, A.J. 1995. The importance of tropical montane cloud forests for endemic and threatened birds. In: L.S. Hamilton et al. 1995, pp. 79-106.

MacKinnon, K. et al. 1996. *The Ecology of Kalimantan. The Ecology of Indonesia Series, Volume III*. Periplus Editions, Hong Kong.

Martin, G.J. & de Avila, B. 1990. Exploring the cloud forests of Oaxaca, Mexico. WWF/US Reports, October-December 1990: 8-11.

Nadkarni, N.M. & Wheelwright, N.T. 2000. *Monteverde: Ecology and Conservation of aTropical Montane Forest*. Oxford University Press, Oxford.

Nullet, D. & Juvik, J.O. 1994. Generalised mountain evaporation profiles for tropical and subtropical latitudes. *Singapore Journal of Tropical Geography* 15: 17-24.

Ohsawa, M., Wildpret, W. & del Arco, M.1999. *Anaga Cloud Forest: A Comparative Study on Evergreen Broad-leaved Forests and Trees of the Canary Islands and Japan*. Laboratory of Ecology, Chiba University, Chiba, Japan.

Pounds, J.A., Fogden, M.P.A. & Campbell, J.H. 1999. Biological response to climate change on a tropical mountain. *Nature* 398: 611-615.

Richardson, B.A. et al. 2000. Effects of nutrient availability and other elevational changes on bromeliad populations and their invertebrate communities in a humid tropical forest in Puerto Rico. *Journal of Tropical Ecology* 16: 167-188.

Schemenauer, R.S. & Cereceda, P. 1994. Fog collection's role in water planning for developing countries. *Natural Resources Forum* 18: 91-100.

Stadtmüller, T. 1987. *Cloud Forests in the Humid Tropics: A Bibliographic Review*. United Nations University, Tokyo, and CATIE, Turrialba, Costa Rica.

Stadtmüller, T. & Agudelo, N. 1990. Amount and variability of cloud moisture input in a tropical cloud forest. *International Association of Hydrological Sciences Publication* 193: 25-32.

Still, C.J., Foster, P.N. & Schneider, S.H. 1999. Simulating the effects of climate change on tropical montane cloud forests. *Nature* 398: 608-610.

Veneklaas, E.J. et al. 1990. Hydrological properties of the epiphyte mass of a montane tropical rain forest. *Vegetatio* 89: 183-192.

Vogelmann, H.W. 1973. Fog precipitation in the cloud forests of Eastern Mexico. *BioScience* 23: 96-100.

Weathers, K.C. et al. 1995. Cloud deposition to a spruce forest edge. *Atmospheric Environment* 29: 665-672.

Weaver, P.L. 1995. The Colorado and dwarf forests of Puerto Rico's Luquillo Mountains. In: A.E. Lugo & C. Lowe (Eds.) 1995. *Tropical Forests: Management and Ecology*. *Ecological Studies* 112, Springer Verlag, New York, pp. 109-141.

Wolf, J.H.D. 1993. *Ecology of epiphytes and epiphyte communities in montane rain forests, Colombia*. PhD thesis, University of Amsterdam, Amsterdam.

World Conservation Monitoring Centre, 1997. *A Global Directory of Tropical Montane Cloud Forests (draft)*. M. Aldrich et al. (Eds.), WCMC, Cambridge, U.K.

Zadroga, F. 1981. The hydrological importance of a montane cloud forest area of Costa Rica. In: R. Lal & E.W. Russell (Eds.), *Tropical Agricultural Hydrology*. J. Wiley, New York, pp. 59-73.

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Sources of remaining illustrations:

Figure 1: Adapted from T.C. Whitmore (1984). *Tropical Rain Forests of the Far East* (2nd edition). Clarendon Press, Oxford.
Figure 2: Adapted from C.G.G.J. van Steenis (1972). *The Mountain Flora of Java*. Brill, Leiden, The Netherlands.
Figure 3: Adapted from R.E. Dohrenwend (1972). *The energetic role of the trade wind inversion in a tropical subalpine ecosystem*. PhD Dissertation, SUNY College of Forestry, Syracuse, New York.
Figure 4: Adapted from L.S. Hamilton et al. (1995), (see reference list).
Figure 5: Adapted from L.A. Bruijnzeel (1990), (see reference list).
Figure 6: F. Sperling (2000). *Tropical montane cloud forests – Ecosystems under the threat of climate change*. Unpublished report prepared for the World Conservation Monitoring Centre, Cambridge, U.K.
Figure 7: Adapted from M. Brown et al. (1996), (see reference list).
Figure 8: Adapted from M. Brown et al. (1996), (see reference list).
Figure 9: Adapted from J.A. Pounds et al. (1999), (see reference list).

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THE TROPICAL MONTANE CLOUD FOREST INITIATIVE

Because of the threats to cloud forests, the relatively low scientific state-of-knowledge of these ecosystems, and lack of information about their location and status, the World Conservation Union (IUCN) in 1995 called for a 'Campaign for Cloud Forests'. The World Conservation Monitoring Centre (WCMC) rose to this challenge and began to acquire data for a tropical montane cloud forest directory and eventually an atlas. An initial draft directory of 268 pages was issued in August 1997. With funding from the Netherlands Committee of IUCN Forest Programme, IUCN's Forest Conservation Programme, WWF's Forests For Life Programme and the Department for International Development (DFID) of the U.K., a planning and advisory workshop was held at WCMC at Cambridge in 1998, bringing together key players from the scientific, professional management and NGO communities. This meeting laid the groundwork, subsequently refined at a smaller meeting, for what is now the Tropical Montane Cloud Forest Initiative. Concurrently DFID largely funded a part-time Coordinator position at WCMC. The Initiative's Steering Group consists of representatives from WCMC, IUCN's Forest Conservation and Wetlands and Water Resources Programmes, the IUCN/World Commission on Protected Areas Mountain Theme, WWF's Forests For Life and Fresh-water Programmes, UNESCO's International Hydrological Programme, Vrije Universiteit Amsterdam, The Netherlands Committee for IUCN and an NGO representative from Africa, Latin America and Asia.

The Cambridge Workshop called for the production of an UNESCO science-based publication, written in terms that would also inform and stimulate concern among a non-scientific audience. This document is that awareness-raising early product of the TMCF Initiative. A Spanish version is expected to become available later in the year.

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