Tropical Montane Cloud Forest-
Fire Disturbance and Water Input after Disturbance

Ylva Wård

Department of Forest Ecology and Management
Umeå

Licentiate Thesis
Swedish University of Agricultural Sciences
Umeå 2007

Department of Forest Ecology and Management
Report 3

ISSNXXXX
ISBN 978-91-576-7229-2

Printed by Arkitektkopia, Umeå, Sweden, 2007

ABSTRACT

Wård, Y. 2007 *Tropical montane cloud forest- fire disturbance and water input after disturbance.* Licentiate dissertation.

ISSN: 1654-245, ISBN: 978-91-576-7229-2

Tropical montane cloud forests (TMCFs) are covered in clouds and fog, by definition, and are abundant with mosses, lichens and epiphytes. The hydrology of these ecosystems is poorly understood due to the extreme wetness, complex topography, and remoteness, TMCF are also susceptible to several types of disturbance. The two main objectives of this thesis were to (i) study the fire history in a TMCF and (ii) investigate the changes in water input in a secondary TMCF. Field studies were conducted in southern Mexico and northern Costa Rica.

The Chimalapas region of Oaxaca, Mexico was subjected to fires during the El Niño events of 1997 to 1998. Previous fires were evident from charcoal, which was collected in soil pits. Radiocarbon dating indicated that at least nine fire episodes have occurred in this area during the past 10, 000 years and the findings suggest that there have been repeated fires in the investigated TMCFs.

The Costa Rican study aimed to estimate total soil water input from horizontal rain and fog (HP) in the edge and interior of a secondary TMCF. Net capture was defined as HP that reached the soil and was calculated as throughfall + stemflow - vertical precipitation. Over the 11-month measurement period, accumulated net capture decreased linearly from the forest edge (*ca.* 1200 mm) to the centre of the plot which was 20 m into the forest (*ca.*-1900 mm). Sixty-eight percent of the variability in weekly net capture could be explained by the plot position and the seasonal variation in HP input. In conclusion, the study demonstrated the potential to manage edges and emergent trees in landscapes with secondary TMCF for improved water input.

Key words: edge effect, fire history, hydrology, throughfall, tropical montane cloud forest (TMCF)

Author's address: Ylva Wård, Department of Forest Ecology and Management, SLU, S-901 83 Umeå, Sweden. E-mail: ylva.ward@sek.slu.se

To my grandmother Ilse for always supporting me and teaching me the joy of reading books.

Contents

List of papers

This licentiate thesis is based on the following two papers, which will be referred to by their respective roman numerals.

I. Wård, Y., Malmer, A. & H. Asbjorsen. Historical ^{14}C Evidence of Fire in Tropical Montane Cloud Forests in the Chimalapas Region of Oaxaca, Southern Mexico. (in press, Hawaii University press)

II. Wård, Y., Frumau, A., Ilstedt, U. & A. Malmer. Water input at the edge and emergent trees in a secondary tropical montane cloud forest in Costa Rica. Manuscript.

Introduction

In Central and South America 47% of the land surface is covered by natural forest, 95% of which is tropical forest (Moreira, 2000; FAO, 2001), however, the extent of tropical montane cloud forests (TMCFs) in Central and South America is unknown. TMCFs are some of the most threatened ecosystems in the world today (Bruijnzeel & Hamilton, 2000; Cayuela, Golicher & Rey-Benayas, 2006). They are vanishing at an alarming rate and restoration is extremely difficult since they typically occur in shallow soils on steep slopes. TMCFs account for *ca.* 2.5% of all tropical forests in the world today (Table 1) (Bubb *et al.*, 2004; Cayuela, Golicher & Rey-Benayas, 2006). Recent assessments by Mulligan and Burke (2005) show that 55% of TMCFs have been lost during the last 50 years, compared to 47% for all tropical forests. Fortunately however, large intact TMCFs can still be found in southern Venezuela, Borneo, Sulawesi (Celebes), Papua New Guinea and eastern parts of the Democratic Republic of Congo (Mulligan & Burke, 2005).

Table 1 Potential cloud forest area as a percentage of all tropical forests and tropical montane forests

Region	**All tropical forests (km^2)**	**Cloud forests as % of all tropical forest**	**Tropical Mountain Forests (km^2)**	**Cloud forest as % of all tropical mountain forests**
Americas	7, 762, 359	1.2	150, 588	8.4
Africa	4, 167, 546	1.4	544, 644	10.5
Asia	3, 443, 330	6.6	1, 562, 023	14.6
Global Tot	15, 373, 235	2.5	3, 257, 275	11.7

*Note: Data extracted from Bubb et al. (2004)

General description of TMCF

Tropical montane cloud forests (TMCFs) are covered in clouds and believed to capture water from clouds, fog and wind-driven precipitation (Grubb, 1977; Stadtmüller, 1987). Since there are frequent and/or persistent ground-level clouds (Grubb, 1977), the ground vegetation receives heavy, frequent deposits of moisture from fog. In addition, the low level clouds profoundly affect the temperature and light regime (Mulligan & Burke, 2005) making these ecosystems unique from both a biological and a hydrological perspective. TMCFs are influenced by various climatic and geographical factors and occur at various altitudes throughout the tropics. TMCFs are normally found at altitudes between 1500 m a.s.l. and 3300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1000 m at each site (Stadtmüller, 1987). On small tropical islands, such as Puerto Rico, TMCFs can be found at lower altitudes. On average, rainfall in tropical montane cloud forest ecosystems ranges from 500 to 10, 000 mm/yr (Hamilton, Juvik & Scatena, 1995).

According to Hamilton, Juvik & Scatena, (1995) the typical features and characteristics of TMCFs are:

1. capacity to capture or strip water from clouds, which may result in an increased catchment water yield compared to other vegetation types
2. high proportion of biomass in the form of epiphytes
3. fewer woody climbers than in lower altitude tropical forests
4. high local biodiversity in terms of shrubs, herbs and epiphytes, with a high proportion of endemic species
5. they typically occur in the following soil types: (i) wet, frequently water logged soils that typically have high organic matter contents (Histosols); (ii) shallow soils with weakly developed horizons (Leptosols); or (iii) drought sensitive soils with low water holding capacity (Regosols).

In the past, attempts to study TMCFs have been complicated by the lack of agreed definition of TMCFs, and a corresponding abundance of names for them. As many as 35 distinct definitions have been identified (Stadtmüller 1987). Finally, a rather simple system for classifying TMCFs, based purely on elevation and abundance of mosses, was proposed by Bruijnzeel and Hamilton (2000):

1. lower montane forest (rich in epiphytes, tall vegetation, little effect of low clouds)
2. lower montane cloud forest (affected by low clouds, 25-50% moss cover on stems)
3. upper montane cloud forest (affected by low clouds, 70-80% moss cover on stems)
4. subalpine cloud forest (elfin forest, affected by low clouds, >80% moss cover on stems)

The canopy height in TMCFs varies from 2 m, on the most exposed peaks in the elfin forests, to 35 m in sheltered areas. Excluding the lowest elfin forests, they are generally complex, two-layered canopy systems with abundant mosses, lichens and epiphytes (Frahm, 1990; Veneklaas & Van Ek, 1990), with epiphyte abundance increasing with elevation (Stadtmüller, 1987). One such example is Mount Kinabalu, Sabah, in Malaysia, where the canopy consists of two layers, one at *ca.* 30 m and one at *ca.*15m on lower altitudes, with increasing altitude the tree height decreases (Kitayama, 1995).

Disturbances to TMCFs

Fire

Tropical forests are at risk from prolonged droughts that cause moisture stress, resulting in highly flammable biomass, both living or dead (Cochrane, 2003). Radiocarbon dating of soil charcoal in the Amazon Basin has shown that fires occur in areas where there are no known human settlements, in several types of primary rain forests (Sanford *et al.,* 1985). Sanford *et al.,* (1985), state that " fire ecology of tropical rain forests should now be considered in both an ancient and a present day context".

Tropical montane cloud forest ecosystems are often very wet and moist, due to their climate, but as shown in some studies, they have been subject to drought and fire in both ancient and more recent times. When these systems dry up, a fire can cause substantial damage and fragment the landscape.

In 1997 and 1998 more than 20 million hectares of land burned in Central America and Southeast Asia during a severe El Niño Southern Oscillation (ENSO) event (Cochrane, 2003). There is evidence that historically fires have occurred (albeit infrequently) in most, if not all, humid tropical forests (Kauffman & Uhl, 1990), that they have severe effects on forest structure, biomass and species composition (Cochrane & Schulze, 1999), and that their frequency is increasing (Cochrane, 2003). TMCFs that are wet are more vulnerable to fires if they dry out, since most trees in wet forests have thin bark (Uhl & Kauffman, 1990) and tree mortality rates during fires can be assumed to be high (Cochrane, 2003).

Speer *et al.*, (2004) have shown that tropical dendrochronological records are useful for establishing fire history. They also found correlations between fires and ENSO events in Cordillera Central, in the Dominican Republic. Our understanding of the effects of fire on vegetation composition and structure in the tropics is, however, limited, especially in areas with trade wind inversions, *e.g.* TMCFs areas (Speer *et al.*, 2004).

It is often argued that the recent increase in tropical fire frequency is a consequence of global climate changes (Sanford *et al.*, 1985). The climate from 10, 000 to 7, 000 B.P. to the present has been relatively stable (Goldammer, 2000), but it has changed rapidly in the last few decades, increasing the frequency of drought in TMCFs. During severe drought events tropical moist forests become more flammable (Goldammer, 2000), and since the vegetation is poorly adapted to fire the consequences are generally severe. Furthermore, when forests are subjected to fires their sensitivity to repeated fires increases (Malmer, Van Noorwijk & Bruijnzeel, 2005). When forested areas are burnt their openness increases, which makes the fuel drier as well as increasing the amount of fuel. Henceforth, they tend to burn more easily and frequently, leading to degradation, fragmentation and, in worst-case scenarios, the loss of forest cover.

In undisturbed TMCFs the high moisture level in the vegetation often prevents fire from spreading into the forest (Asbjornsen *et al.*, 2005). There is, however, documented evidence of fire occurrence in various undisturbed TMCFs (Chimalapas, Mexico (Anta & Plancarte, 2001); Mt Kilimanjaro (Hemp & Beck, 2001); Chiapas Mexico (Ramirez-Marcial, Gonzalez-Espinosa & Williams-Linera, 2001); Andes, Ecuador (Sarmiento & Frolich, 2002), Cordillera de Talamanca, Costa Rica (Horn & Sanford, (1992)).

Other disturbances

The conversion of TMCFs to agricultural land and pastures is a major threat today (Bubb, Aldrich & Sayer, 2002; Hamilton, Juvik & Scatena, 1995). When TMCFs are changed to pasture or cropping land the vegetation´s water capture ability may be changed (Doumenge *et al.*, 1995), and thus the loss of an important environmental service provided by the former forest. Further disturbances include the use of lower parts of TMCFs for commercial cropping, fuel wood collection, exploitation of non-wood forest products and anthropogenic fires (Hemp & Beck, 2001).

Logging in a commercial sense is not a major problem in TMCFs, due to the low stature of the trees, but increasing amounts of non-timber forest products are being harvested from these forests. Orchids, bromeliads, medicinal plants and tree ferns are all valuable commodities, providing people with an extra income. Such harvests have even been commercialised, to varying degrees, in some TMCF areas (Hamilton, Juvik & Scatena, 1995).

Ecotourism/tourism may threaten these fragile ecosystems (Lush, 1995). As interest in TMCFs increases, more roads, tracks and trails are built to facilitate transport to and from inaccessible TMCF areas. These ecosystems are sensitive to human impact, and in the long-term the ecological footprint of litter, introduction of alien species and other unnatural disturbances may be devastating for these ecosystems.

Water issues in relation to TMCFs

Zadroga (1981) claimed that TMCFs have three direct hydrological benefits: (i) increases in net precipitation, (ii) regulation of flow regimes out into surrounding landscapes and (iii) low evapotranspiration rates. Whether the benefits are the same in all TMCFs has been one of the key issues that researchers have tried to address. Although TMCFs are covered in clouds and fog, there is a wide range of coverage among and within them. The water inputs in TMCFs differ somewhat from those in other tropical forests (Bruijnzeel, 2005). Distinguishing features in TMCFs are the persistent fog and near horizontal rain, here collectively called horizontal precipitation (HP) (Figure 1). In some TMCFs there is little to no vertical precipitation during some periods, making the impact of fog even more important (Bruijnzeel, 2005). If the vegetation composition changes, both the capture and the usage of water will change (Bruijnzeel, 2005; Fallas, 2002).

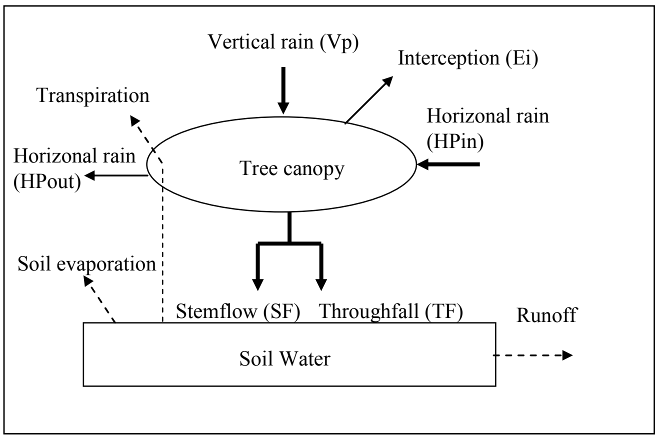

Figure 1. Illustration of the Tropical Mountain Cloud Forests (TMCFs) contribution to the soil water balance. Bold solid arrows indicate water flows that were measured in a secondary forest in Costa Rica. Thin solid arrows were studied indirectly, while dashed arrows indicate flows that were not studied.

Previous water cycling studies in TMCF

Bruijnzeel & Proctor (1995) and Bruijnzeel (2001) made comprehensive reviews of the hydrology in TMCFs (Table 2). Most studies have been done in Central and South America, only a few studies in South East Asia and one from Africa. The ten studies presented in Table 2 from Central and South America, Africa and South East Asia, represent a broad selection of forest types as well as altitudes (265 - 3700 m.a.s.l.). Mean annual precipitation ranged from 1453 to 6000 mm. Throughfall recorded in the same studies ranged between 50% and 125% and stemflow was between 0.1% and 10 % of the mean annual precipitation.

Table 2 Review of tropical montane cloud forest studies of throughfall (TF), stemflow (SF) and mean annual precipitation (MAP). Forest types included in these studies, Elfin cloud forest (ECF) (short forest), montane cloud forest (MCF), lower montane cloud forest (LMCF) and upper montane cloud forest (UMCF)

Location	Altitude (m)	Forest type	MAP (mm)	TF (%)	SF (%)	Notes
[1]Puerto Rico	1000	ECF	5400	115	5	R^2 = 0.97 for all regressions. 60 fixed collectors in each plot; daily readings, undisturbed forest.
	1015	ECF	4800	125	10	
	930	ECF	6000	96	3	
[2]Honduras	1795	MCF	1449	94	X	3 sites (concave, convex and a ridge), TF measured in 4 troughs, no stemflow recordings, undisturbed forest
				129	X	
				179	X	
[3]Colombia	2250	UMCF	2115	87.6	X	TF measured in fixed position, precipitation in Lambrecht automatic recording pluviograph, primary forest with human intervention
	3700	UMCF	1435	81.6	0.1	
[4]Panama	1200	LMCF	3510*			*Bulk precipitation, TF in 50 fixed gauges, Primary forest
			62.8	62.4	0.4	
[5]Venezuela	2300	UMCF	2843	49	X	*cloud water accounts for 9% of VP in pasture, no information on method used, primary forest
		Pasture	3124*	X	X	
[6]Jamaica	1849	UMCF	3060	73	13	TF measured with gutter and 12 manual gauges for each site, VP in 3 gauges (1 automatic and 2 manual), primary forest
	1900	ECF	3060	60	18	
[7]Puerto Rico	265-456	LMCF	2249	74	4	TF used both roving (n=30) and fixed gauges (n=60), VP 2 different gauges n=28, SF for 4 different species n= 22, secondary forest
[8]Ecuador	1900-2150	LMCF	2504	59	0.1	fixed TF gauges in 5 transects in the 3 catchments (n= 28), VP 3 gauging stations with 5 fixed Hellman gauges, SF 5 trees in each transect. Standard deviations were given. Primary forest with indication o human disturbance in some parts.
[9]Tanzania	1500	LMCF	1230	78	<1	TF in 8 fixed gauges, daily readings for 30 months, primary forest
[10]Philippines	2200	LMCF	3900	76	12	TF varied with exposure measured in "improvised TF gauges, SF in "improvised G.I. gutter" 60 months of measurements.

([1]Weaver, 1972; [2]Stadtmüller and Agudelo, 1990, [3]Veneklaas and Van Ek, 1990; [4]Cavelier et al., 1997; [5]Ataroff and Rada, 2000; [6]Hafkenscheid, 2000; [7]Holwerda, 2005; [8]Fleischbein et al., 2006, [9]Lundgern and Lundgren, 1979, [10]Mamanteo and Veracion, 1985)

In these studies different approaches were used to measure vertical precipitation, throughfall and stemflow. When throughfall measurements using gauges in fixed positions or randomly relocated gauges (roving) were compared, no significant differences ($p > 0.05$) were found between the two techniques (Holwerda 2005). The variability analysis for total amounts of throughfall showed less variability in the roving approach (23%) compared to having the gauges in a fixed position (48 - 49%). Only Fleischbein *et al.* (2006) provided detailed statistics, further demonstrating the obvious difficulty of statistically synthesizing the results (meta-analysis), which would be a more objective way to analyse the overall hydrological contribution of forests.

The studies in Table 2 represent a range of forest types from the elfin forests (short stunted) that grow in wind exposed locations, to the tall productive forests such as upper and lower montane cloud forest (UMCF/LMCF) at lower altitudes. Apart from the Venezuelan study which compares a forest and a pasture, all other studies in Table 2 represent primary or secondary forests with little human disturbance.

One reason for the lack of studies in TMCFs is their inaccessibility and unfavourable environment for humans. Fortunately, their inaccessibility and harsh climate, with high rainfall and relatively cold temperatures, has also limited their exploitation. Since TMCFs are usually enveloped in clouds and fog, carrying out field work is not an easy task. Nevertheless, an increasing amount of research is being conducted in these ecosystems.

Problems with measuring water inputs

One of the greatest problems complicating research in TMCF ecosystems is that the results obtained using different types of fog and wind-driven collectors can vary substantially (Bruijnzeel, 2005). The lack of standardised methods for measuring HP, makes it difficult to compare results from different studies. Some fog gauges commonly used in these forests are *e.g.* wire harps, screens, tunnel gauges and Juvik gauges. Frumau et al., (in press) compared three commonly used gauges (wire harp, modified Juvik gauge and a tunnel gauge) for measuring HP, and found that the modified Juvik gauge (Figure 2) was the most effective, since it provides measurements that are independent of wind speed and direction. A problem is the lack of a standard height for measuring fog, which arise from the wide range of TMCFs with different tree height ranges.

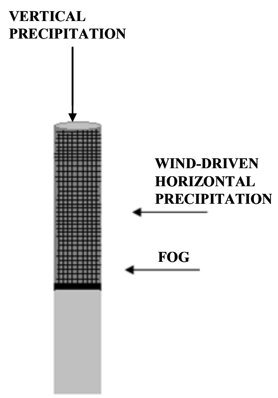

Figure 2. A modified Juvik gauge in which the vertical precipitation is recorded separately from the fog and horizontal precipitation.

A risk with using gauges in fixed positions and gutters is that the spatial variation in throughfall is lost if extensive sampling is not carried out. Lloyd and Marques (1988) suggested that a roving gauge approach is the preferable technique. Stemflow is believed to be of importance in TMCFs (Bruijnzeel & Proctor, 1995) and different approaches to measure this have also been proposed. Interception in TMCFs is calculated by subtracting throughfall and stemflow (were stemflow often is estimated) from the gross rainfall above the canopy (or a nearby clearing), introducing further uncertainty.

Water in disturbed TMCFs

There is little knowledge on how converting TMCFs into pastures or plantations affects dry season flows and total water yields (Ataroff, 2002; Bruijnzeel & Proctor, 1995; Cavelier & Goldstein, 1989). Depending on the type of TMCF (especially in terms of its seasonal fog variation) changes in dry season flows to the surrounding areas will differ. Establishing links between changes in hydrological pathways and land-use change, is a challenge for the future.

If the landscape is fragmented, it is important to determine whether TMCFs can still provide the environmental services that pristine TMCFs provide. This, however, is not easily determined since there are inadequacies in the techniques used to measure water inputs, the spatial variations in inputs, and the consequent difficulties in measuring water budgets in these areas (Bruijnzeel, 2005).

Objectives

There were two main objectives of the thesis:

- The first objective was to investigate the historic fires and fire intervals in TMCFs in Chimalapas, Mexico, and determine if and how these episodes were related to climate fluctuation in the region (Paper **I**). The

Hypothesis was that TMCFs have similar fire dynamics to other moist tropical forests.

- The second objective was to evaluate the water input at the edge of a secondary TMCF (Paper **II**). The hypothesis was that the difference in net capture of water between the forest edge and within the forest can be explained by the variation in horizontal precipitation and fog.

Materials and methods

Fire frequency in Chimalapas, Mexico

The field work for this study (Paper **I**) was conducted in Chimalapas, Mexico on the border between the states of Oaxaca and Chiapas (Figure 3). Chimalapas is one of the largest remaining tropical montane cloud forest areas in Mexico (Asbjornsen *et al.*, 2005) and is located in the southeast corner of the State of Oaxaca. The climate is warm sub-humid (Köppen classification: Aw2) to temperate sub-humid (Cw2). This mountainous region has highly varied geology and climate due to its strongly dissected topography (Figure 4), with peaks between 2000 - 3000 m a.s.l., and its proximity to two oceans. It is at the isthmus of Tehuantepec, a narrow part of the landmass between the Pacific and Atlantic Oceans, and hence is affected by weather systems from both oceans.

Figure 3. The location of the two field sites in Mexico and Costa Rica for this thesis.

Two main areas were examined, each within a day's walking distance from Benito Juárez (BJ) (16°44'02-30''N, 94°11'30-46''W) and San Antonio (SA) (16°39'52-41''N, 94°13'57-49''W). The sites in the BJ-area were located 1585 to 1700 m a.s.l. in a crystalline bedrock region, while those in the SA-area were located 1640 to 1740 m a.s.l in a karst region. Soils at the BJ sites consisted of Humic Acrisols (Ultisols), while the SA site supports both Luvic Calcisols (Typic

Ustropepts) and Rendzic Leptosols (Lithic Troporthents) (Wård, 2003). At both sites forest structure was highly variable, with tree height reaching up to 30m in more sheltered and productive plots, while the most exposed plots supported low-stature elfin forests (4-6 m in height)

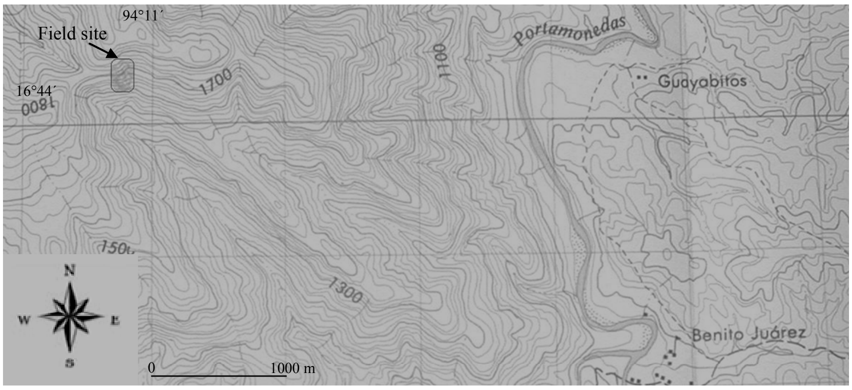

Figure 4. A topographical map of the Benito Juárez field site Chimalapas, Mexico.

To establish if natural forest fires had occurred historically in the TMCFs in these areas, charcoal from the soil was radiocarbon dated and were further compared to climate data. A total of eight pits (50*50*50cm) (BJ 2, SA 6) were excavated and all charcoal was collected (156 pieces > 2 mm). Charcoal was found down to a depth of 50 cm, in all soil horizons here. The charcoal samples were labelled according to site (SA/BJ) and soil horizon and 48 (BJ 20, SA 27) pieces were radiocarbon dated by Ångströms laboratoriet (Uppsala, Sweden). Since no suitable climate records for this area were available, and since nearby weather stations represent lowland areas near the coast, historical climate data from other areas in Central America were used.

TMCF water input in Monteverde, Costa Rica

The study described in Paper **II** was performed in Santa Elena (10°35'N,-84°80'W), Monteverde, in the northern part of Costa Rica (Figure 3). Monteverde has large remaining TMCF areas (Nadkarni & Wheelwright, 2000) and is often described as "a forest in the clouds". The weather in the area is affected by the movement of the Inter-Tropical Convergence Zone (ITCZ) (Clark, Lawton & Butler, 2000). Costa Rica is situated on the Caribbean continental plate, and the tectonic history in the area is very complex (Clark, Lawton & Butler, 2000). The Monteverde area consists of volcanic rocks, tuffs and breccias, which is very similar to the lower slopes of the Vulcan Arenal (Clark, Lawton & Butler, 2000).

The study area in a secondary forest lies 15 km to the northwest of Santa Elena in Los Olivos in the Rio Chiqito catchment (Figure 5). The 15 - 20 year old secondary forest (8 ha), is a result of selective logging and is surrounded by pastures. In this secondary forest the edge effects on hydrological parameters were studied (Paper **II**). The results are based on daily measurements from November

2003 to the end of September 2004. The effects of humans and livestock on the forest had been low and were further minimised during the measurement period. Grazing cows were excluded from the secondary forest by fencing and only pre-existing tracks were used for sampling, to avoid soil compaction and vegetation disturbance. Within the forest two main plots (20*50m) were established (Figure 5), one at the forest edge and one in the middle of the forest, in which both throughfall (TF) and stemflow (SF) were measured.

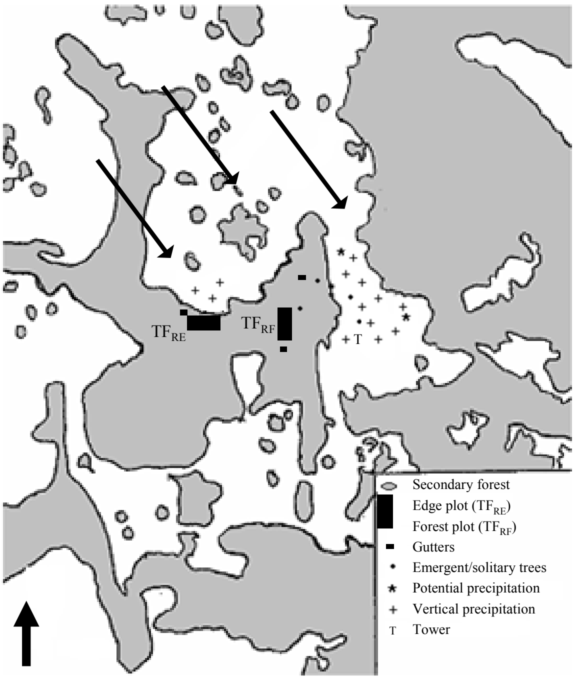

Figure 5. Map of a secondary forest in Los Olivos, Costa Rica with location of throughfall plots, throughfall gutters, throughfall emergent trees in forest, throughfall solitary trees in pasture, potential precipitation in Juvik gauges, the weather station and vertical precipitation. Arrows indicates the dominating wind direction measured during the sampling period.

Net capture model

An alternative approach to study the contribution of trees in delivering horizontal precipitation and fog (Figure 1) to the soil water by defining a combined variable, net capture (eq. 1), as the net horizontal precipitation (HP_{net}) minus interception (E_i). The variable net capture describes the water input by tree crowns that are specific for TMCFs, i.e. fog and horizontal precipitation, deducted with losses by interception which can be considerable in a windy environment (Figure 1).

$$\text{Net capture} = HP_{net} - E_i \qquad (1)$$

From the water balance of the forest (eq. 2) and the water balance of the soil (eq. 3) it can be seen that the soil water input part of ΔS, in accordance with Figure 1, is the positive factor precipitation (vertical precipitation Vp plus Hp_{net}) minus the canopy part of evapotranspiration (interception, Ei, eq. 4).

$$P = ET + R + \Delta S \qquad (2)$$

(P=precipitation, ET=evapotranspiration, R=runoff, ΔS=change in soil storage

$$\Delta S = P - ET - R \qquad (3)$$

$$\text{Soil Water Input} = Vp + HP_{net} - E_i = SF + TF \qquad (4)$$

Channelled trough the canopy (Figure 1) ΔS also equals throughfall plus stemflow (TF+SF, eq. 4). Inserting net capture from eq. 1 into eq. 4 gives an easier way to derive net capture (eq. 5), since it can be seen that subtracting vertical rainfall (Vp) from the sum of throughfall (TF) and stem flow (SF) is equal to HP_{net} - E_i. This is convenient since TF and SF are easier and more commonly measured than E_i. Since both TF and SF seldom are measured we also define water net capture via TF (TFcapture; eq. 6). Net capture is then TFcapture plus SF.

$$\text{Net capture} = SF + TF - Vp \qquad (5)$$

$$\text{TFcapture} = TF\text{-}Vp. \qquad (6)$$

Three approaches to measuring throughfall were selected. Firstly, in each plot, 20 manual throughfall gauges (TF_R) were used for daily measurements. They were randomly rearranged once a week to cover the spatial variation in the plots, as suggested by Lloyd & Marques (1988). Secondly, throughfall was measured by collecting and measuring water in three steel gutters ($TF_{G1\text{-}3}$) (Figure 5). Thirdly, throughfall measurements were made at fixed points under two emergent trees in the forest and two trees in the pasture outside the forest (Figure 5). Ten trees, representing the diversity in the forest with respect to tree size and species, were selected for daily stemflow measurements in each plot. A meteorological station was established just beyond the eastern side of the forest (Figure 5) to measure wind speed and direction (for more details see Paper **II**).

Statistics

A linear regression model was used to analyse whether or not net capture was dependent on HP and plot position. Weekly averages of daily precipitation between the relocation of the manual throughfall gauges were used for the regression analysis. In the regression model the residuals were found to be normally distributed and had homogenous variances. For the analysis of seasonal effects of net capture the residuals deviated from normality assumptions. Henceforth, a non-parametric Wilcoxon signed rank test was used to assess if the net capture at the edge and within the forest (during both seasons) were significantly different. For the same reason, the data from the gutters and the emergent /solitary trees were also assessed using the non-parametric Wilcoxon signed rank test. The Minitab 14 software (Minitab Inc, Pennsylvania, US) was used for all statistical analysis.

Results and discussion

TMCFs and Fire

Fires have occurred in TMCFs both recently and historically (Paper **I**). The results from the radiocarbon dating indicate that 39 of the charcoal pieces originated from fire episodes occurring between 2350 and 470 B.P., and only one of the 48 pieces sent for analysis contained too little organic material to analyse. At least nine distinct fire episodes occurred in the studied TMCF during the past ~10, 000 years (Figure 6).

In addition, the two study sites had different fire histories, the interval between fires being longer at the BJ site than at the SA site. There were at least five separate fires during the 1300 yrs between 1800 and 500 B.P. at the BJ site. The second half of this period (1800-1050 B.P.) coincides with recorded drought data from the Cariaco Basin in the southern Caribbean (Haug et al., 2001). The driest conditions on the Yucatan peninsula occurred 1300 to 1100 B.P. (Hodell, Curtis & Brenner, 1995). A few charcoal samples from the BJ site originated from this period. The remaining eight sample datings are well spaced in time, ranging from 11, 550 B.P. to 2735 B.P. (Figure 6).

In SA the fire episodes covered a limited time span, ~ 450 years, and there was a major episode, represented by ten pieces of charcoal (2350 - 1900 B.P.), coinciding with records of dry periods (2200 to 1200 B.P.) on the Yucatan peninsula (Hodell, Curtis & Brenner, 1995) and at Lake Miragoane (2500 to 1500 B.P.), Haiti (Curtis & Hodell, 1993; Hodell *et al.*, 1991). A second fire episode, represented by 17 pieces, lasted ~ 495 yrs from 970 to 475 B.P. (Figure 6). Interestingly, more recent episodes at the two sites appear to have overlapping confidence intervals (Figure 6), indicating that there have been more frequent fires. The overlapped confidence intervals make it difficult to establish whether there were one or several repeated fires. In any case, this could indicate that successional vegetation dries more quickly than primary vegetation, as stated by Goldammer (2000). This finding is consistent with the idea that the fuel supply in burnt forests increases and exacerbates the risk of fire following previous fires (Malmer, Van Noorwijk & Bruijnzeel, 2005; Scatena, Planos-Gutierrez & Schellekens, 2005). An increase in fire frequency retards the rehabilitation of mature forests and decreases soil fertility (Malmer, 2004). The three clusters of charcoal pieces 1300 to 470 B.P. (Figure 6) are an indication of repeated fires.

The fire episodes in Chimalapas are linked to climatic data from other regions in Central America indicating that fire episodes in TMCFs coincide to periods when the climate becomes drier (Curtis & Hodell, 1993; Haug *et al.*, 2001; Hodell, Curtis & Brenner, 1995; Hodell, *et al.*, 1991).

From 7100 to 3000 B.P. the evaporation/precipitation ratio was low, suggesting a wetter climate on the Yucatan peninsula (Hodell, Curtis & Brenner, 1995). Accordingly, no charcoal from this period was found at our sites at the nearby Chimalapas.

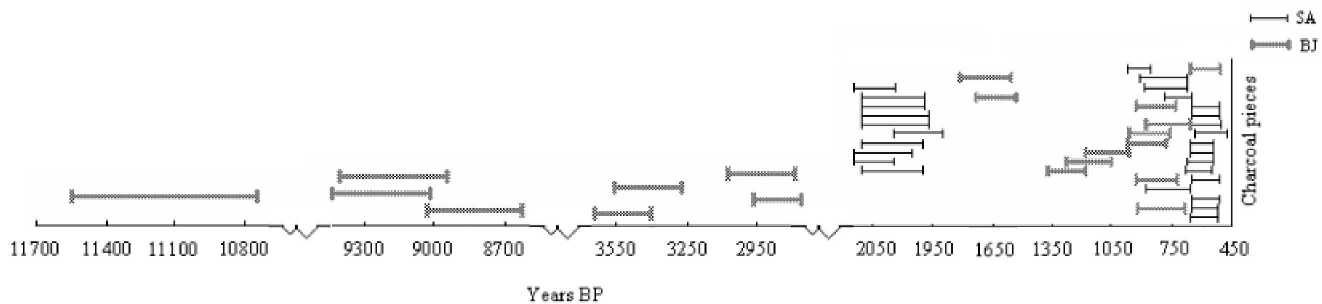

Figure 6. Radiocarbon dates of the charcoal found in the mineral soils in Chimalapas, Mexico. Each bar represents the dates within a 95% confidence interval for one of the pieces of charcoal with calibrated B.P. age interval, B.P.=1950.

Water inputs in secondary TMCF

The results in Paper **II** clearly demonstrates that variations in net capture can be explained both by variations in horizontal precipitation and position of the plot(s). My results (Table 3) agree with those of Weaver (1972) and Stadtmüller and Agudelo (1990) (Table 2). Their studies (Table 2) show a positive water net capture via throughfall, especially if the measurements are performed in areas with higher wind exposure. Plots with a windward position, with ridges and convex locations show positive net captures while plots having leeward and concave positions had net captures close to zero, or slightly negative. My results are similar in that the 'forest edge' was like the windward and ridge sites and my 'forest plot' was comparable to their leeward or concave sites (*cf.* Table 2). The exposure to wind is apparently of great importance in TMCFs.

Table3 Water inputs in the secondary forest during 11 months (1 November 2003 to 30 September 2004). Values within parenthesis represents a shorter time period of 5 months started 9 April 2004. *, **, *** denote TFcapture different from zero on the 0.05, 0.01, 0.001 significant level respectively with a Wilcoxon signed rank test

Variable (mm)	Acc. TF or P (mm/day)	Daily TF mean (mm/ day)	SD daily TF mean (mm/day)	Daily TFCapture (mm/ day)
Forest roving TF				
TFRE	4160	12	18	0.98
TFRF	3400	10	15	-1.38***
Forest TF gutters				
TFG1	5560	17	25	5.5*
TFG2	3380	10	13	-1
TFG3	2680	8	11	-3.1**
Emergent tree TF				
TFE1	5770 (2680)	18 (15)	26 (22)	6.61** (0.41)
TFE2	4820 (2500)	15 (14)	22 (22)	3.79 (-0.62***)
Pasture solitary tree TF				
TFS1	(3700)	(21)	(25)	(5.9)
TFS2	(3650)	(21)	(29)	(6.19*)
Stem flow				
SFE	170	0.5	0.7	
SFF	340	1	1	
Precipitation				
Vertical	4530(2613)			
Potential	8306(2908)			

There was a clear seasonality in water input from horizontal precipitation (Figure 7). Overall, if our plots together are taken as representative of secondary TMCF then trees do deliver more water to the soil than vertical precipitation alone. The general perception about TMCFs has been that they have a higher capture of HP relative to lower vegetation (Stadtmüller, 1987). Since HP also can vary between years, long term records are imperative in determining if a particular forest contributes positively to the soil water input or not. Since there is an apparent positive relationship between HP and water capture, one could rely on long-term HP measurements to establish long term records at several sites. HP measurements are less expensive to obtain and readily available, this could be used as a proxy for net capture as long as the relationship is developed fore the specific gauge type used and the TMCF type of interest.

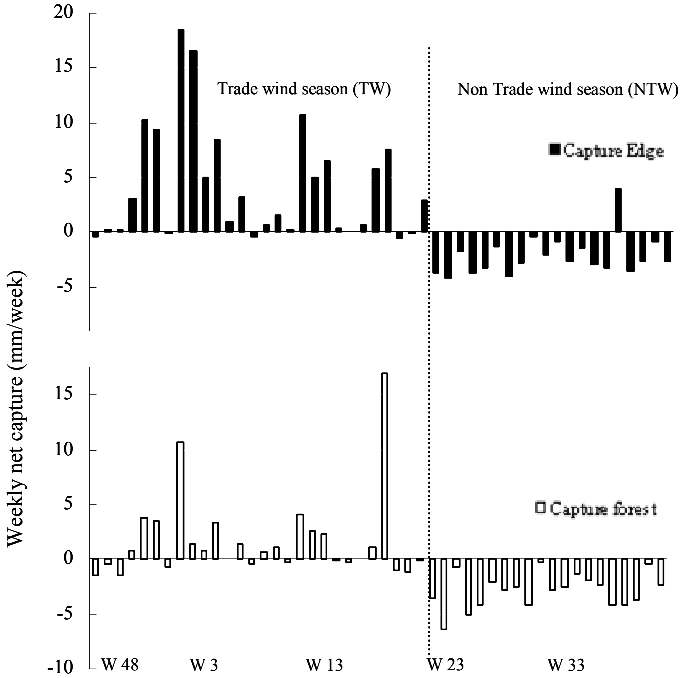

Figure 7. Mean weekly net capture values in at the forest edge and within the forest plot in the secondary TMCF in Los Olivos, Costa Rica.

To my knowledge this is the first study considering hydrological effects of forest edges in tropical montane cloud forests (Paper **II)**. To investigate the spatial variability from the forest edge into the closed forest, all throughfall measurements (gutters, and manual methods) were used. Although we have only studied one site, the use of gutters together with roving TF measurements gives an indication of the degree of spatial variability in TF. In spite of this variability the edge effect reaches at least 20m into the forest (Figure 8). The linear regression (R^2=83%) indicated a sharp linear decrease in net capture from the edge into the forest from about 1200 mm to -1900 mm over the full measurement period (Figure 8). Common disturbances such as fire or clearing for pasture or cultivation, often create fragmented forests with long edges and many solitary trees or groups of trees (*cf.* Figure 5). With increasing fragmentation of TMCFs, there will be more edges created in the landscape. How these edges and solitary trees are located in relation to the ratio of edge versus closed forest, as well as cloud bearing winds, will be important for down stream water resources. For example, having edges facing the most common wind direction, such as in the study in paper **II**, might contribute more than other forests to downstream water resources (Figure 5). Solitary trees in the pasture had a somewhat higher water net capture than the forest edge and even single emergent trees seemed to capture significant amounts of water. This confirms the importance of keeping old trees in the forest structure for maintaining downstream runoff.

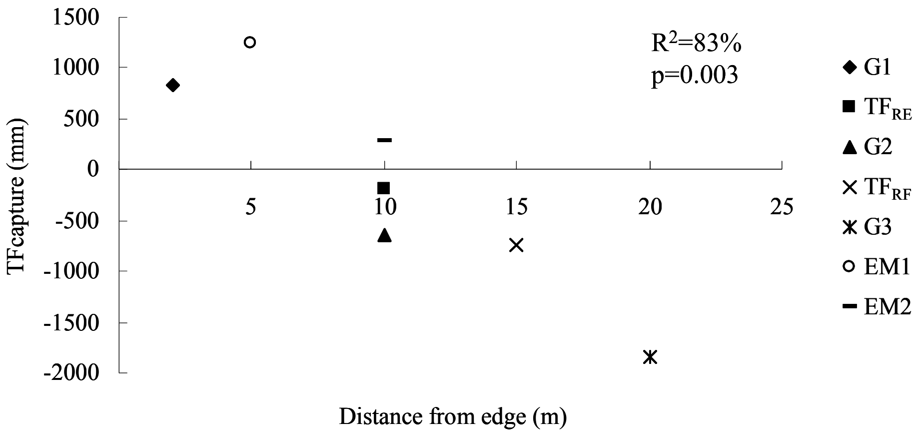

Figure 8. Decrease in water net capture in a secondary forest in Los Olivos, Costa Rica from the forest edge inward.

Conclusions and further questions to address

The main question addressed in Paper **I** was whether or not TMCFs have similar fire dynamics to other moist tropical forests. The key finding in Paper **I** was that pieces of present charcoal appear to have originated from fires with long intervals between them. This supports the general perception that very wet TMCFs have a very low incidence of fire, but after exposure to fire and with repeated fires, the risk of fire episodes increases. With climatic changes, otherwise extremely wet ecosystems such as TMCFs have a higher potential to burn due to extensive droughts. Evidence of fire episodes, linked to periods of droughts (ENSO events), in the Chimalapas in Central America is indicating that even these wet ecosystems can be compromised by fires. With the present escalating climatic changes and a possible shift of the ITZC. We will likely face a situation where even more fires occur in TMCFs and possibly an increase in forest fragmentation, which will ultimately result in more forest edges being formed.

There are possible differences in water capture in pastures, pastures with trees, secondary TMCFs and primary TMCFs. So if the aim is to optimize water to the surroundings it is important to establish which type of vegetation is the most efficient in capturing water. Paper **II** showed that positive net capture by secondary forests is possible when the input of horizontal rain and fog is large enough. The net capture by forest edges and even single emergent or solitary trees lends itself to the possibility of managing fragmented forests and pastures for improved water delivery down stream. The positive relationship between horizontal precipitation and water net capture indicates that records of horizontal precipitation can be used to generalise water net capture. This can be done for longer time periods and regions as more detailed studies in a range of TMCFs become available.

This knowledge can then be used in areas were TMCFs have already been converted into agricultural land to plant “forest edges” to capture water on ridges facing the prevailing wind direction, which could be a next step to secure water. The natural next step would be to conduct a study of how solitary trees capture water in fragmented TMCF landscapes and to determine whether or not tree position on the slopes makes a difference.

References

Anta, S.F. & Plancarte, A.B. 2001. The Forest Fires. Chimalapas: The last oppertunity. In *The Castor Workshop:249*. Mexico City: World Wildlife Fund and the Mexican Secretariat of the Environment.

Asbjornsen, H., Velazquez-Rosas, N., Garcia-Soriano, R. & Gallardo-Hernandez, C. 2005. Deep ground fires cause massive above- and below-ground biomass losses in tropical montane cloud forests in Oaxaca, Mexico. *Journal of Tropical Ecology 21*, 427-434.

Ataroff, M. 2002. Warer fluxes in a Cloud Forest of the Venezuelan Andes. In *Proceedings of the Second International Colloquium on Hydrology and Water Management*, Edited by J.S. Gladwell. Pamamá City, Panamá: UNESCO. 384-388. pp.

Bruijnzeel, L.A. 2001. Hydrology of tropical montane cloud forests: A reassessment. *Land Use and Water Resources Research 1*

Bruijnzeel, L.A. 2005. Tropical montane cloud forests: a uniqe hydrological case. In *Forests, Water and people in the Humid Tropics*. Edited by M. Bonell & L.A. Bruijnzeel. Cambridge University Press. Cambridge. p. 462-483. pp.

Bruijnzeel, L.A. & Hamilton, L.S. (2000). Decision time for cloud forests. IHP Humid Tropics Programme Series no 13. UNESCO Division of Water Sciences.

Bruijnzeel, L.A. & Proctor, J. 1995. Hydrology and Biogeochemistry of Tropical Montane Cloud Forests: What Do We Really Know? In *Tropical Montane Cloud Forests.* Edited by L.S. Hamilton, J.O. Juvik & F.N. Scatena. Springer-Verlag. New York. 38-78. pp.

Bubb, P., Aldrich, M. & Sayer, J. 2002. Tropical montane cloud forests- time for action. *Unasylva International year of mountains 208*, 36-37.

Bubb, P., May, I., Miles, L. & Sayer, J. (2004). Cloud forest agenda. UNEP-WCMC.

Cavelier, J. & Goldstein, G. 1989. Mist and Fog Interception in Elfin Cloud Forests in Colombia and Venezuela. *Journal of Tropical Ecology 5*, 309-322.

Cayuela, L., Golicher, D.J. & Rey-Benayas, J.M. 2006. The extent, distribution, and fragmentation of vanishing Montane cloud forest in the Highlands of Chiapas, Mexico. *Biotropica 38*, 544-554.

Clark, K.L., Lawton, R.O. & Butler, P.R. 2000. The Physical Environment. In *Monteverde: Ecology and Conservation of a tropical cloud forest*. Edited by N.M. Nadkarni & W. Nathaniel.TOxford Univ. Press, New York. 15-38. pp.

Cochrane, M.A. 2003. Fire science for rainforests. *Nature 421*, 913-919.

Cochrane, M.A. & Schulze, M.D. 1999. Fire as a recurrent event in tropical forests of the eastern Amazon: Effects on forest structure, biomass, and species composition. *Biotropica 31*, 2-16.

Curtis, J.H. & Hodell, D.A. 1993. An Isotopic and Trace Element Study of Ostracods from Lake Miragoane, Haiti:A 10,500 year Record of Paleosalinity and Paleotemperature Changes in the Caribbean. In *Climate Change in Continental Isotopic Records*. Edited by P.K. Swart. American Geophysical Union. Washington. 135-152. pp.

Doumenge, C., Gilmour, D., Pèrez, M.R. & Blockhus, J. 1995. Tropical Montane Cloud Forests: Conservation Status and Management Issues. In *Tropical Montane Cloud Forests.* Edited by L.S. Hamilton, J.O. Juvik & F.N. Scatena. Springer-Verlag. New York. 24-37. pp.

Fallas, J. 2002. Net Precipitation in Undisturded and Fragmented Costa Rican Cloud Forest. In *Proceedings of the Second International Colloquium on Hydrology and Water Management*, Edited by J.S. Gladwell. Pamamá City, Panamá: UNESCO. 389-398. pp.

FAO (2001). Global forest resources assessment 2000: Main report. 140. FAO Forestry Paper.

Fleischbein, K., Wilcke, W., Valarezo, C., Zech, W. & Knoblich, K. 2006. Water budgets of three small catchments under montane forest in Ecuador: experimental and modelling approach. *Hydrological Processes 20*, 2491-2507.

Frahm, J.P. 1990. The Ecology of Epiphytic Bryophytes on Mt Kinabalu, Sabah (Malaysia). *Nova Hedwigia 51*, 121-132.

Frumau, A., Bruijnzeel, L.A. & Todón, C. 2006. Measurement of precipitation in montane tropicl catchments: comperative performance of conventional, spherical and 'potential'rain gauges. In *Forest and water in a changing environment*, Edited by S. Liu, G. Sun & P. Sun. Beijing China

Frumau, A., Burkard, R., Schmid, S., Bruijnzeel, L.A., Tobon-Marin, C. & Julio, C. in press. Fog gauge performance under fog and wind-driven rain conditions. In *Mountains in the Mist: Science for Conserving and Managing Tropical Montane Cloud Forests*. Edited by L.A. Bruijnzeel & J.O. Juvik. Hawaii University press.

Goldammer, J.G. 2000. The Fire and Smoke Episodes of 1983 to 1998 in South East Asia: Ecological Background, Socio-Economic and Environmental Implications, and Challenges for Regional and Global Fire Research Programmes. Proceedings, XXI IUFRO World Congress 2000 Sub-Plenary Sessions Vol.I, p15-24.

Grubb, P.J. 1977. Control of forest growth and distribution on wet tropical mountains: with special reference to mineral nutrition. *Annual Review of Ecology and Systimatics 8*, 83-107.

Hamilton, L.S., Juvik, J.O. & Scatena, F.N. 1995. The Puerto Rico Tropical Cloud Forest Symposium: Introduction and Workshop Synthesis. In *Tropical*

Montane Cloud Forests. Edited by L.S. Hamilton, J.O. Juvik & F.N. Scatena. Springer-Verlag. New York. 1-23. pp.
Haug, G.H., Hughen, K.A., Sigman, D.M., Peterson, L.C. & Rohl, U. 2001. Southward migration of the intertropical convergence zone through the Holocene. *Science 293*, 1304-1308.
Hemp, A. & Beck, E. 2001. Erica excelsa as a fire-tolerating component of Mt. Kilimanjaro's forests. *Phytocoenologia 31*, 449-475.
Hodell, D.A., Curtis, J.H. & Brenner, M. 1995. Possible Role of Climate in the Collapse of Classic Maya Civilization. *Nature 375*, 391-394.
Hodell, D.A., Curtis, J.H., Jones, G.A., Higueragundy, A., Brenner, M., Binford, M.W. & Dorsey, K.T. 1991. Reconstruction of Caribbean Climate Change over the Past 10,500 Years. *Nature 352*, 790-793.
Holwerda, F. (2005). *Water and energy budgets of rain forests along an elevation gradient under maritime tropical conditions,* Vrije Universiteit.
Horn, S.P. & Sanford, R.L. 1992. Holocene Fires in Costa-Rica. *Biotropica 24*, 354-361.
Kauffman, J.B. & Uhl, C. 1990. Interactions of anthropogenic activities, fire, and rain forests in the Amazon Basin. In *Fire in the tropical biota. Ecosystem processes and global challenges*. Edited by J.G. Goldammer. Springer-Verlag. Berlin-Heidelberg-New York. 497. pp.
Kitayama, K. 1995. Biophysical Conditions of the Montane Cloud Forest of Mount Kinabalu, Sabah, Malaysia. In *Tropical Montane Cloud Forests*. Edited by L.S. Hamilton, F.N. Scatena & J.O. Juvik. Springer-Verlag. New York. 183-197. pp.
Lloyd, C.R. & Marques, A.D. 1988. Spatial Variability of Throughfall and Stemflow Measurements in Amazonian Rainforest. *Agricultural and Forest Meteorology 42*, 63-73.
Lundgren, L. & Lundgren, B. 1979. Rainfall, inerception and evaporation in the Mazumbai forest reserve, West Usambara Mts., Tanzania and their importance in the assessment of land potential. *Geografiska Annaler 61A*, 157-177.
Lush, C. 1995. Cloud Forests of the Rwenzori Mountains, Uganda:Research and Management Possibilities. In *Tropical Montane Cloud Forests*. Edited by L.S. Hamilton, J.O. Juvik & F.N. Scatena. Springer-Verlag. New York. 212-222. pp.
Malmer, A. 2004. Streamwater quality as affected by wild fires in natural and manmade vegetation in Malaysian Borneo. *Hydrological Processes 18*, 853-864.
Malmer, A., Van Noorwijk, M. & Bruijnzeel, L.A. 2005. Effects of shifting cultivation and forest fires. In *Forests- Water- People in the humid tropics: Past, present and future hydrological research for integrated land and water managment.* Edited by M. Bonell & L.A. Bruijnzeel. Cambridge University Press, 2004. Cambridge. 533-560. pp.
Mamanteo, B.P. & Veracion, V.P. 1985. Measurements of fogdrip, throughfall and stemflow in the mossy and Benguet pine (*Pinus kesiya* Royle *ex* Gordon) forests in the Upper Agno River Basin. *Sylvatrop, the Philippines Forest Research Journal 10*, 271-282.

Moreira, A.G. 2000. Forest Fires in Tropical America: Challanges for Research. Proceedings, XXI IUFRO World Congress 2000, Sub-Plenary Sessions Vol.I, p. 25-33.
Mulligan, M. & Burke, S. (2005). DFID FRP Project ZF0216 Global cloud forests and environmental change in a hydrological context.
Nadkarni, N.M. & Wheelwright, N.T. 2000. Introduction. In *Monteverde: Ecology and Conservation of a tropical cloud forest*. Edited by N.M. Nadkarni & N.T. Wheelwright. Oxford University Press. New York. 3-13. pp.
Ramirez-Marcial, N., Gonzalez-Espinosa, M. & Williams-Linera, G. 2001. Anthropogenic disturbance and tree diversity in Montane Rain Forests in Chiapas, Mexico. *Forest Ecology and Management 154*, 311-326.
Sanford, R.L.J., Saldarriaga, J., Clark, K.E., Uhl, C. & Herrera, R. 1985. Amazon rain-forest fires. *Science. 227*, 53-55.
Sarmiento, F.O. & Frolich, L.M. 2002. Andean cloud forest tree lines - Naturalness, agriculture and the human dimension. *Mountain Research and Development 22*, 278-287.
Scatena, F.N., Planos-Gutierrez, E.O. & Schellekens, J. 2005. Natural disturbances and the hydrology of humid tropical forest. In *Forests- Water- People in the humid tropics: Past, present and future hydrological research for integrated land and water managment.* Edited by M. Bonell & L.A. Bruijnzeel. Cambridge University Press, 2004. Cambridge. 489-512. pp.
Speer, J.H., Orvis, K.H., Grissino-Mayer, H.D., Kennedy, L.M. & Horn, S.P. 2004. Assessing the dendrochronological potential of Pinus occidentalis swartz in the Cordillera central of the Dominican Republic. *Holocene 14*, 563-569.
Stadtmüller, T. 1987. *Cloud Forests in the Humid Tropics*. The United Nations University. Costa Rica. 81 pp.
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.
Uhl, C. & Kauffman, J.B. 1990. Deforestation, Fire Susceptibility, and Potential Tree Responses to Fire in the Eastern Amazon. *Ecology 71*, 437-449.
Weaver, P.L. 1972. Cloud Moisture interception in the Luquillo Mountains of Puerto Rico. *Caribbean Journal of Science 12*, 129-144.
Veneklaas, E.J. & Van Ek, R. 1990. Rainfall Interception in 2 Tropical Montane Rain-Forests, Colombia. *Hydrological Processes 4*, 311-326.
Wård, Y. (2003). *Soil descriptions in burned and unburned cloud forest and indications of fire history in the Chimalapas, Oaxaca State, Mexico.,* M.S. Thesis, Swedish University of Agricultural Sciences.
Zadroga, F. 1981. The hydrological importance of a montane cloud forest area of Costa Rica. In *Tropical agricultural hydrology: watershed management and land use*. Edited by R. Lal & E.W. Russell. John Wiley & Sons Ltd. Chichester, UK. 59-73. pp.

Acknowledgements

First of all I would like thank SIDA, SAREC, project no. SWE-2002-233 for the financial support. Thank you for making a dream possible.

There are several people that need to be thanked for their involvement in the field work in Chimalapas and Monteverde. Thank you for all the good times in rainy, misty, foggy mountains and for trying to teach me Spanish!

Jag skulle även vilja tacka Anders Malmer för all hjälp och att han fångade mitt intresse för tropikerna, det var för 8 år sedan på min första föreläsning på Skogis.

"Confusions and further breakdowns"

Ibland har det verkligen känts så (oftare på slutet), jag måste säga att utan allt stöd så hade det inte gått. Ett stort tack till Ulrik Ilstedt för alla uppmuntrande ord, bra idéer, ”peppning" och att du har kunnat ”klura" ut vad jag har försökt att säga i både skrift och tal. Det kan inte ha varit enkelt, har inte alltid förstått själv vad jag menat…..

Min kappa skulle inte ha sett ut som den gör idag om jag inte hade haft en helt underbar grupp av villiga ”redaktörer", tack snälla ni för allt! Tack Lena S, Ingeborg C, Ishi B, Charlotta E, Sofia F och sist men inte minst Michelle S. Ni är underbara vänner.

Jag skulle vilja tacka medarbetarna på institutionen för Skogens Ekologi och Skötsel. Kaffe automaten nere i ”skötsels" fikarum förtjänar också ett tack, den bästa chokladen i byggnaden, det hade varit omöjligt att överleva. Tack till Elisabeth och Margareta för att ni har funnits och fixat intyg, gigantiska reseräkningar och andra praktiska detaljer. Inga-Lis, utan din hjälp skulle framsida fortfarande ha saknats, tack! Tack Ulf S för att du lagt märke till mina skor, det är ”crocs" tider igen! Mikaell O.L, tack för alla tomat plantor! Ett sista tack till ni som läst igenom manus och kappan i olika stadier!

Ett stort tack för all stöd och hjälp under den här tiden till alla nuvarande och gamla doktorand kollegor!

Hans Arrendal, din hjälp är guld värd. Tack för alla telefonsamtal.

”to whom I may concern", Håkansson utan våra rådslag hade det inte gått!

Till mina vänner utanför jobbet som har försökt att förstå och stöttat i alla år. Ni har fått mig att tänka på annat, att dansa bugg, fjällvandra, paddla kajak och långa ridturer. Kickan, för att du finns, att du är helt orädd på Ràn och att du är en vän genom allt. Eva, dina mail, brev, telefonsamtal till Costa Rica höll mig uppe och att din familj är som min egen!

Min familj, ni är underbara! Pappa, jag ska vara mindre ”vrång” nu när detta är över. Jag uppskattar verkligen att du försöker att förstå! Mamma, för att du skämmer bort mig med allt. Att du alltid har tid och du är du. Syrran, för att du finns och kommer med goda råd. Brorsan, alla små och stora projekt som du fixar och hjälper mig med, att du lyssnar när jag får ”fri spel” och att du alltid ställer upp!!

”uppträd alltid som en anka - paddla som en jävel under vattnet” okänd källa

Umeå, April 2007