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Fog precipitation in the Sierra de las Minas Biosphere Reserve, Guatemala

Curtis D. Holder*
Department of Geography and Environmental Studies, University of Colorado at Colorado Springs, Colorado Springs, CO 80933, USA

Abstract:

Fog precipitation occurs when fog droplets are filtered by the forest canopy and coalesce on the vegetative surfaces to form larger water droplets that drip to the forest floor. This study examines the quantity of throughfall compared with incident precipitation produced by the canopy of a lower montane rain forest (2100 m) and an upper montane cloud forest (2550 m) in the Sierra de las Minas Biosphere Reserve, Guatemala. Fog precipitation was measured with throughfall and precipitation gauges from 23 July 1995 to 7 June 1996. Fog precipitation occurred during sampling periods when throughfall exceeded incident precipitation. Fog precipitation contributed <1% of total water inputs in the cloud forest at 2100 m during the 44-week period, whereas fog precipitation contributed 7·4% at 2550 m during the same period. The depth equivalent of fog precipitation was greater at 2550 m (203·4 mm) than at 2100 m (23·4 mm). The calculation of fog precipitation in this study is underestimated. The degree of underestimation may be evident in the difference in apparent rainfall interception between 2100 m (35%) and 2550 m (4%). Because the apparent interception rate at 2550 m is significantly lower than 2100 m, the canopy probably is saturated for longer periods as a result of cloud water contributions. Data show a seasonal pattern of fog precipitation most evident at the 2550 m site. Fog precipitation represented a larger proportion of total water inputs during the dry season (November to May). Because cloud forests generate greater than 1 mm day^{-1} of fog precipitation in higher elevations of the Sierra de las Minas, the conservation of the cloud forest may be important to meet the water demands of a growing population in the surrounding arid lowlands. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS fog precipitation; montane cloud forest; throughfall; interception; Guatemala

INTRODUCTION

Although the term fog precipitation is not universally used, descriptions of fog precipitation from early writers in various locations suggest people have had knowledge of the process for many years (Cannon, 1901; Kerfoot, 1968). Fog precipitation is called horizontal precipitation, occult precipitation, fog drip and fog stripping by different authors (Stadtmüller, 1987). Fog precipitation occurs in any environment where wind and fog persists for a long enough period for cloud droplets to coalesce on vegetation surfaces. The environments that are especially likely to have fog precipitation are high elevation regions where cool temperatures result in the condensation of water vapour (Vogelmann *et al*., 1968; LaBastille and Pool, 1978) and coastal regions on the western side of continents where cool air off the oceans condenses and moves inland (Miller, 1957; Cereceda and Schemenauer, 1991).

During a rainfall event, vegetation intercepts precipitation and stores the water in the canopy (Kittredge, 1948; Helvey, 1967; Kimmins, 1987). Interception is a dynamic process in which the canopy approaches and sometimes reaches its storage capacity during a rainfall event, and the intercepted water evaporates during and shortly after the event (Rutter, 1967). As a result of the process of interception, a rain gauge in the open commonly receives more water during a rainfall event than throughfall gauges positioned under a canopy. If average throughfall exceeds incident precipitation, the additional water comes from fog intercepted

* Correspondence to: Curtis D. Holder, Department of Geography and Environmental Studies, University of Colorado at Colorado Springs, Colorado Springs, CO 80933, USA. E-mail: cholder@uccs.edu

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by the canopy. Fog precipitation is not, however, equal to the difference between incident precipitation and throughfall because evaporation of rain and cloud water and canopy storages during the process of interception are not accounted for in the equation.

Kittredge (1948) showed that in the fog environment of the coastal range of California and Oregon, throughfall totals exceeded precipitation totals. In these environments, fog precipitation contributed $>50\%$ of the total water input under selected trees during an 8-month period. This result may have underestimated the significance of fog precipitation in these coastal environments because the study did not account for the evaporation of intercepted fog and rain, which may have produced larger percentages of water inputs. During a rainless 39-day period on the San Francisco Peninsula, California fog precipitation was the only hydrological input recorded by throughfall gauges (Oberlander, 1956). Dawson (1998) reported that 34% of the annual water input from a coastal redwood forest in northern California was from fog precipitation. Additionally small quantities of fog precipitation were recorded in Australia (O'Connell and O'Shaughnessy, 1974) and Costa Rica (Fallas, 1995) by comparisons between throughfall and precipitation gauges. Vegetation directly exposed to wind receives the largest quantity of fog precipitation (Juvik and Ekern, 1978; Cavelier *et al*., 1996).

Fog precipitation often occurs during the dry season and on days without rainfall in tropical montane forests of Honduras and Guatemala (Stadtmueller and Agudelo, 1990; Brown *et al*., 1996). Brown *et al*. (1996) found an increase in net precipitation with elevation in the Sierra de las Minas, Guatemala after comparing throughfall, stemflow and incident precipitation at sites ranging in elevation from 2150 to 2750 m. Fog precipitation was most evident during the dry season. Additionally, Brown *et al*. (1996) found that stemflow contributed $<2\%$ of incident precipitation.

This study examines fog precipitation at two sites with different elevations in the Sierra de las Minas Biosphere Reserve, Guatemala. The objectives of this study were (i) to estimate the contribution of fog precipitation to the tropical montane cloud forest in Guatemala and (ii) to examine the difference in net precipitation between elevations.

STUDY SITE

An examination of net precipitation within a tropical montane cloud forest was conducted in the Sierra de las Minas Biosphere Reserve, Guatemala (15°05'N, 90°00'W) approximately 10 km east of the village of Chilascó (Figure 1). The Sierra de las Minas Biosphere Reserve was established in 1990, and consists of approximately 2400 km^2 of rugged mountainous terrain located between the Río Motagua and Río Polochic (Lehnhoff and Núñez, 1998). The reserve is a protected evergreen cloud forest with a high diversity of plant and animal life (Catling and Lefkovitch, 1989; Ack and Lehnhoff, 1992). Because of the steep slopes within the Sierra de las Minas, access to the cloud forest is difficult. Consequently, the cloud forest has not been seriously threatened by deforestation. Nevertheless, the region near the southern border of the Sierra de las Minas is more heavily deforested than the more remote northern border.

The Sierra de las Minas is an east–west orientated mountain range. Prevailing winds are from the north-east and produce a rain shadow on the south slope of the mountain range. Cloud forests dominate the windward slopes and summits of the Sierra de las Minas. The Sierra de las Minas creates a rain shadow for the southern side of the ridge. In the middle Río Motagua valley pine forest descends to about 800 m; below this level less than 500 mm of precipitation is received annually, and a distinct subhumid xerophytic vegetation extends to the valley floor.

Precipitation is highly variable in the Sierra de las Minas (Brown *et al*., 1996). A pronounced dry season occurs from the months of November to April. The rainy season at the two study sites begins in May and continues to October, during which time areas can receive over 80% of their annual precipitation. North-east tradewinds create extremely moist conditions along the northern slope of the Sierra de las Minas. From low elevation up to about 1300 m a tropical forest prevails and above this elevation precipitation can exceed 5000 mm in some areas (Campbell, 1982), where cold, damp cloud forest is the dominant vegetation. Because

Figure 1. Location of study area 10 km east of the village of Chilascó in the Sierra de las Minas

evaporation rates are lower in the cooler months of the dry season, the persistent fog may fill canopy storages to a greater degree in the dry season.

Temperature in the Sierra de las Minas is determined largely by elevation. Nightly low temperatures at a nearby cloud forest preserve (Biotopo Mario Dary located at 1520 m approximately 20 km northwest of Chilascó) range from 5 to 15 °C, regardless of season. Slightly lower temperatures occur during the winter months. Elevations as low as 1300–1500 m in the Sierra de las Minas may experience occasional frost.

Fog precipitation was measured within a closed-canopy cloud forest at two sites (2100 m and 2550 m) on the windward slope of Montaña de Miranda (2610 m). The elevation of the mountain base on the windward slope is 1900 m. At approximately 2000 m, a transition between lower elevation coniferous forest and higher elevation cloud forest occurs. Above 2000 m cloud forest species including a rich diversity of epiphytes and tree ferns are dominant. This vegetation type is classified as a lower montane cloud forest as the percentage cover of bryophytes is conspicuous from the lower elevations (Frahm and Gradstein, 1991; Bruijnzeel and Veneklaas, 1998). An abandoned logging road runs along the summit of Montaña de Miranda. Although the 2550 m site appears to be undisturbed, the proximity to the logging road suggests that some extraction could have been possible during the past 20 years. The vegetation type at the 2550 m site is classified as upper montane cloud forest based on the stunted trees and presence of mossy epiphytes, and may have formed at this elevation because of the *Massenerhebung* effect (Frahm and Gradstein, 1991; Bruijnzeel *et al*., 1993). Based on personal observations in the field, the duration of fog occurrence appears to be greater at the summit of Montaña de Miranda than at the 2100 m site.

MATERIALS AND METHODS

Placement of gauges

An abandoned agriculture site (2550 m) adjacent to the cloud forest on the leeward side of Montaña de Miranda and approximately 25 m from the summit provided sufficient open space to record rainfall. This site was abandoned for approximately 2 years prior to placing rain gauges. Five rain gauges were positioned in this open area on 24 July 1995. Data from the rain gauges at Montaña de Miranda were collected for 44 weeks until 7 June 1996.

Throughfall gauges were positioned within permanent plots at 2100 m and 2550 m on Montaña de Miranda. Fifty-eight throughfall gauges were positioned within the 2100 m plot, and 36 throughfall gauges were positioned at the 2550 m site. Throughfall gauges were monitored from 24 July 1995 to 7 June 1996. The rain and throughfall gauges were made of plastic funnels with a diameter of 200 mm and 20-L plastic containers. The funnels had a steep angle and a rim with a height of 35 mm. The throughfall gauges were positioned randomly and repositioned after each visit to ensure adequate sampling of drip points within the cloud forest (Lloyd and de O. Marques, 1988).

Although the open site near the summit is on the leeward of the mountain, cloud forests were present at the site prior to land clearing. Cloud forests can be found on the leeward slope as far as 100 m downslope from the summit. The zone of cloud forest is much narrower on the leeward slope because of the decrease in precipitation and cloud cover down the slope owing to adiabatic warming. In locations where humans have not removed the vegetation, the cloud forest is consistently present in the narrow strip near the summit of the leeward slope. Based on the preliminary data of Brown *et al*. (1996), fog precipitation was evident in forests >100 m in elevation down from the leeward summits in the Sierra de las Minas. Weaver (1972) found that wind orientation (leeward versus windward slopes) influenced values of precipitation and throughfall in a cloud forest of Puerto Rico. Given that stunted cloud forest vegetation is visible in the immediate vicinity of the clearing where the rain gauges were positioned and cloud cover persists during the same time intervals as the cloud forests on the summit, the effect on the calculated percentage of throughfall would be minimal.

Fog precipitation

Rainfall interception is the net loss of water to the forest during rain events. Cloud forests are hydrologically complex in that cloud water interception provides a net gain of water to the forest during time intervals of cloud cover. Because the actual rates of evaporation and cloud water impaction are not easily quantifiable during cloudy and cloud-free events in the field, apparent cloud water interception and apparent interception are often derived in studies that measure net precipitation by comparing rainfall, throughfall and stemflow. This study uses this approach to estimate apparent rainfall interception and apparent fog interception. Although stemflow was not measured in this study, the preliminary work of Brown *et al*. (1996) suggests that stemflow accounts for $<2\%$ of the hydrological inputs to the cloud forests in the Sierra de las Minas.

Throughfall and gross precipitation were measured approximately every week for each gauge at each study site (2100 m and 2550 m), and a water-depth equivalent was calculated. Apparent fog precipitation was determined from the equation for apparent rainfall interception (I)

$$I = P_g - T \tag{1}$$

where P_g is gross precipitation and T is throughfall. If apparent rainfall interception was a negative number, fog precipitation was present. In this study, the sum of all negative quantities of interception during the study period at each elevation investigated was assumed equal to the quantity of fog precipitation occurring in the cloud forest watershed. Because only the negative values of apparent interception were assumed to indicate the presence of fog precipitation and the actual rates of evaporation and cloud water impaction were not measured, the values for fog precipitation were underestimated in this study. Fog precipitation was measured approximately every week as a proportion of the total precipitation inputs. The seasonal variation in fog precipitation was expressed as a percentage of the total precipitation inputs.

RESULTS

Precipitation totals

Precipitation at Montaña de Miranda for the 44-week period was 2559 mm. Two weeks had precipitation exceeding 250 mm. The standard deviation of average precipitation varied from 0·1 to 24 mm for each collection period. The standard deviation was greatest on 20 August 1995 when only four precipitation gauges were recorded. Based on the precipitation data, the dry season is estimated to be approximately 6 months from 29 October to 27 April. The rainy season occurred for approximately 6 months from 28 April to 28 October. Seventy-nine per cent of precipitation at the summit of Montaña de Miranda occurred during the rainy season. The designation of the rainy season from May to October is consistent with climate classifications in which precipitation is $<$60 mm per month.

Variation among plots

Apparent rainfall interception varied from $-$15·3 mm on 13 August 1995 to 139·3 mm the following week on 20 August 1995 at 2100 m. Fog precipitation occurred when net precipitation was a negative value. Apparent interception at the 2100 m site over the 44-week period was 35% of incident rainfall. Apparent interception at the 2550 m site ranged from $-$32·6 mm on 26 November 1995 to 102·7 mm on 20 August 1995. Only 4·3% of incident precipitation was intercepted at the 2550 m site over the 44-week period. Apparent interception totals were lower at the 2550 m site than the 2100 m site in all but two sample intervals. Apparent interception was lower at 2550 m because of the persistence of fog near the summit of Montaña de Miranda, and greater quantities of fog precipitation found in throughfall measurements.

During two sampling periods fog precipitation was recorded at 2100 m (Figure 2). Total fog precipitation at 2100 m from 23 July 1995 to 7 June 1996 was 23 mm or $<$1% of total water input to the forests. Although the average sampling period recorded no fog precipitation, individual gauges recorded fog precipitation at 2100 m (Figure 3). Fifty-nine per cent of all individual gauges at 2100 m recorded fog precipitation during a sampling interval within the 44-week period. Forty-one per cent of all the gauges at 2100 m never recorded fog precipitation during a sampling interval during the 44-week sampling period. Two gauges recorded fog precipitation $>$150 mm during the 44-week period, and may be an indication that these gauges were positioned underneath drip points during the sampling interval. During two sampling periods at the 2100 m site, $>$50% of the throughfall gauges detected fog precipitation. During 17 sampling periods at 2100 m no individual throughfall gauges recorded fog precipitation. No gauges recorded fog precipitation $>$1 mm day^{-1} at 2100 m during the 44-week period. The average fog precipitation over the entire period totalled 0·01 mm day^{-1}.

Gauges recorded fog precipitation at 2550 m during 12 sampling periods (Figure 2). Total fog precipitation at 2550 m was 203·4 mm, which accounts for 7·4% of the total water input to the forest. All but one individual throughfall gauge recorded fog precipitation. Fog precipitation was $>$1000 mm during the 44-week period in two gauges. During 10 sampling periods, $>$50% of the throughfall gauges recorded fog precipitation (Figure 3). Thirty-nine per cent of the gauges recorded the rate of fog precipitation as $>$1 mm day^{-1}. The average rate of fog precipitation recorded by the throughfall gauges at 2550 m was 1 mm day^{-1}.

Variation between sites

Fog precipitation between the two sites was significantly different ($p < 0{\cdot}001$) for the 44-week sampling period. Fog precipitation at 2550 m was over eight times greater than at 2100 m. Fog precipitation was 23·4 mm at 2100 m and 203·4 mm at 2550 m. Maximum adiabatic temperature differences between the two sites was 4·5 °C. This temperature difference can produce fog conditions only at the summit of Montaña de Miranda, whereas the mid-elevation ranges are not submerged in fog. Fog precipitation increased with elevation, and is consistent with the preliminary data of Brown *et al.* (1996). The upper slopes of the Sierra de las Minas receive more water input from fog precipitation than the mid-elevation slopes and the windward base of the mountain range.

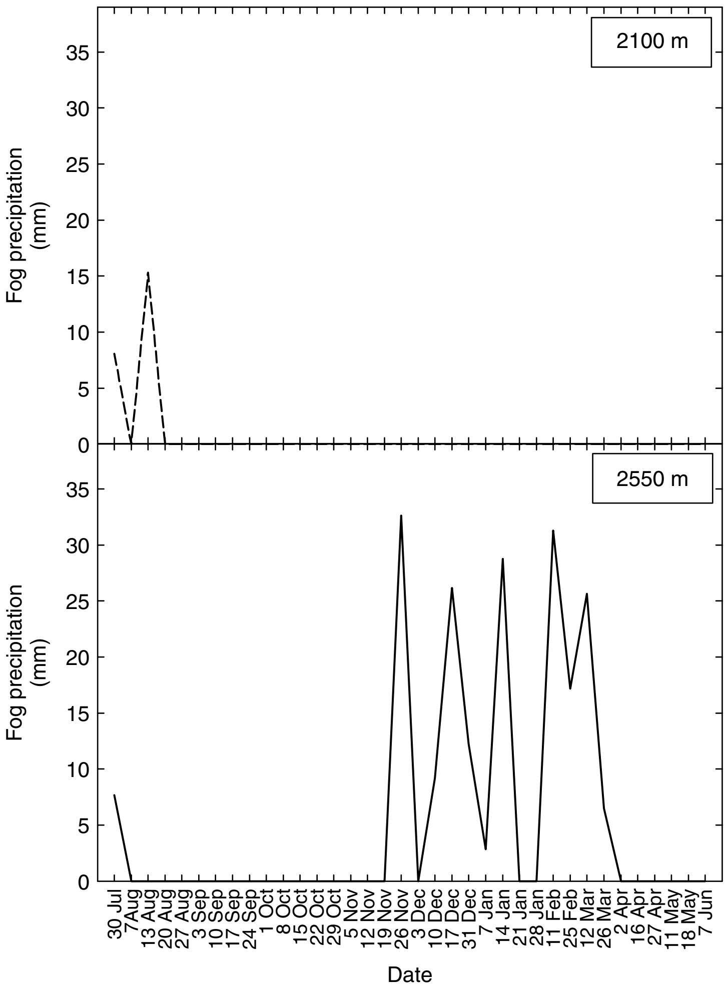

Figure 2. Fog precipitation at 2100 m and 2550 m from 30 July to 7 June 1996

Seasonal variation

Fog precipitation data show a seasonal pattern most evident at the 2550 m site (Figure 2). At the 2100 m site, 48% of all gauges recorded fog precipitation during at least one sampling interval during the rainy season. In the dry season only 31% of all gauges recorded fog precipitation during at least one sampling interval. No fog precipitation during the wet season was measured at six gauges at the 2100 m site. This contrasts with the data at 2550 m. At this location during the rainy season, 58% of the gauges collected fog precipitation during at least one sampling interval. Only one gauge did not collect fog precipitation during the dry season.

Fog precipitation was greatest during the dry season at the 2550 m site. Additionally, the seasonal difference in fog precipitation totals was only significantly different at 2550 m ($p < 0{\cdot}001$). The average fog precipitation recorded in gauges at the 2100 m site was 23 mm, all of which occurred during the rainy season. However, the average fog precipitation recorded in gauges at the 2550 m site was 195·7 mm in the dry season and 7·7 mm in the rainy season. The dry season has the coolest months of the year. Evaporative water loss from the canopy is less during the dry season. The canopy is more likely to maintain water storage capacity in the dry season when temperatures are cool than during the wet season when temperatures are warmer. In summary, fog precipitation occurs most often when cool temperatures prevail and the canopy is saturated.

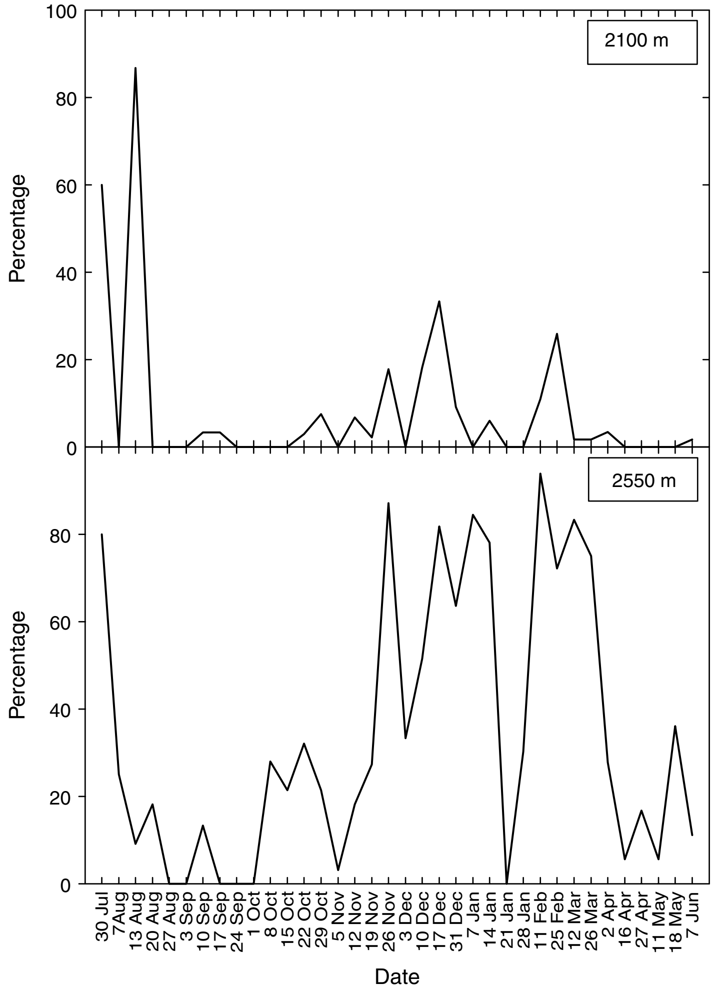

Figure 3. Percentage of gauges that detected fog precipitation at 2100 m and 2550 m during each sampling period

DISCUSSION

Precipitation totals in this study of the Sierra de las Minas (2527 mm in 44 weeks) are similar to those reported at the cloud forest Monteverde in Costa Rica with a mean annual precipitation of 2519 mm from 1959 to 1995 (Clark *et al.*, 1998).

The quantity of fog precipitation was larger at the 2550 m site (1 mm day^{-1}) than the 2100 m site (0·1 mm day^{-1}). Given that cloud forests in the study area are distributed in elevations that range between the two study sites, fog precipitation contributes approximately 0·5 mm day^{-1} to the hydrological budget of the Sierra de las Minas. The rate of fog precipitation reported in this study is lower than the rates reported in other Neotropical cloud forest studies (Veneklaas and van Ek, 1990; Cavelier *et al.*, 1997). However, the quantity of fog precipitation in this study was underestimated because evaporation and cloud water interception rates were not measured. Fog precipitation was determined when negative values of apparent rainfall interception were recorded. The low value for apparent rainfall interception at the 2550 m site (4% of incident rainfall) included cloud water interception that was not separated from net precipitation. Given the height and development of the canopy at 2550 m, it is probable that fog contributions are in the order of 25–30% of incident precipitation.

Fog precipitation represented a larger proportion of total water inputs at 2550 m (7·4%) than at 2100 m (<1%). This trend along elevation gradients is similar to proportions calculated from data presented in studies of other cloud forests in Mexico (Vogelmann, 1973), Colombia (Cavelier and Goldstein, 1989), Venezuela (Gordon *et al*., 1994a), Panama (Cavelier *et al*., 1996) and Costa Rica (Fallas, 1995; Clark *et al*., 1998). It is important to understand that the measurements of fog precipitation in Mexico, Colombia and Venezuela were estimated using Grunow-type fog gauges, and the studies from Panama and Costa Rica calculated fog precipitation based on net precipitation. Measurement of fog precipitation derived from fog gauges and throughfall gauges are not directly comparable given differences in instrumentation error. The data from the Sierra de las Minas show a trend of an increase in fog precipitation with an increase in elevation. Fog precipitation increased 0·7 mm day^{-1} for every 1 m in elevation in the Sierra de las Minas. Cavelier *et al.* (1996) and Cavelier and Goldstein (1989) reported similar findings in Panama and Colombia, respectively, although the study by Cavelier *et al.* (1996) may have incorrectly reported fog precipitation because of exposure to high wind and wind-driven rain. Fog precipitation increased 0·2 mm m^{-1} in Colombia (Cavelier and Goldstein, 1989).

Fog precipitation represented a greater proportion of hydrological input in the cloud forest in the dry season (19%) than the rainy season (<1%). Although fog precipitation probably occurs in the rainy season as suggested from other studies (Fallas, 1995; Brown *et al*., 1996), fog precipitation in the rainy season could not be estimated accurately based on the method chosen in this study. Fog precipitation is underestimated in this study because fog precipitation was measured only when throughfall exceeded precipitation.

Fog precipitation in this study did not account for as large a percentage of total water input as some previous studies (Table I). Ellis (1971) estimated that fog precipitation accounted for 8·1 to 30·5% of the hydrological input in an Australian forest. Fog precipitation in tropical cloud forests has been reported as >50% of total water input in Mexico (Vogelmann, 1973), Hawaii (Juvik and Ekern, 1978) and Panama (Cavelier *et al*., 1996). However, it should be noted that these studies applied a different method when reporting fog precipitation, using fog gauges rather than net precipitation based observations. Studies that report fog precipitation >50% of total water input commonly pertain to the dry season or an arid location.

Table I. Measurement of fog precipitation in cloud forest environments

Location	Elevation (m)	Rainfall (mm)	Fog precipitation (mm)	Fog precipitation (as percentage of total water input)	Method	Source
Colombia/ Venezuela	815–3100	450–1125	72–796	3·5–48·3	Fog gauges	Cavelier and Goldstein (1989)
Costa Rica		72–435	0–42	0–37	Net precipitation	Fallas (1995)
Costa Rica	1500	3191	886	21·7	Fog gauges	Clark *et al.* (1998)
Guatemala	2100	2559	23	<1	Net precipitation	This study
Guatemala	2550	2559	203	7·4%	Net precipitation	This study
Hawaii	981–3397	300–2449	134–832	2·6–61·2	Fog gauges	Juvik and Ekern (1978)
Mexico	1330–2425	215–1082	0–339	0–50·7	Fog gauges	Vogelmann (1973)
Panama	500–1270	1495–6763	138–2299	2·3–60·6	Fog gauges	Cavelier *et al.* (1996)
Puerto Rico	1050		3·8–325	0·9–6·7	Fog gauges	Baynton (1969)
Puerto Rico	930–1015	3204–4001	0–436	0–26·2	Net precipitation	Weaver (1972)
Venezuela	1750–2150	828–1009	354–592	26–41·7	Fog gauges	Gordon *et al.* (1994a,b)

Mature cloud forest canopies may produce fog precipitation even though throughfall is less than precipitation. Because fog precipitation was conservatively measured by reporting fog precipitation when throughfall exceeded precipitation, the contribution of fog precipitation to the annual water budget of the Sierra de las Minas at 2550 m would be greater than 7·4% as determined in this study.

During several days of the dry season, fog precipitation is the only hydrological input to the cloud forest. Fog precipitation would not occur without the vegetative surfaces in the canopy. Given the importance of the Sierra de las Minas mountain range in generating potable water used by communities in the arid lowlands, the conservation and management of the remaining cloud forests should be prioritized. Cloud forests in the core zone of the biosphere reserve above 2100 m generate large quantities of fog precipitation. Areas in the Sierra de las Minas with an elevation greater than 2100 m total greater than 350 km^2. Although most of this 350 km^2 region above 2100 m elevation has been depleted of cloud forest cover, large tracts of remnant cloud forests exist within the core zone of the Sierra de las Minas Biosphere Reserve. Because major water-demanding industries are located in the arid Río Motagua valley and the growing population of the valley receives their water from springs in the Sierra de las Minas, fog precipitation in regions >2100 m may become more important to the arid lowlands in the near future.

CONCLUSIONS

Depending on site elevation, fog precipitation contributes from <1 to 7·4% of the total water input to the experimental watershed. Because these are conservative estimates of fog precipitation in this study, fog precipitation in the Sierra de las Minas contributes to a larger proportion of the annual water budget. The contribution of fog precipitation to the water budget of the Sierra de las Minas is less than the 30–50% contribution in Mexico (Vogelmann, 1973) and the 48% contribution in Colombia (Cavelier and Goldstein, 1989), but the small proportion of fog precipitation calculated in this study based on conservative estimates equals a large hydrological input within the core zone of the Sierra de las Minas Biosphere Reserve.

This study found that fog precipitation increases with elevation in the Sierra de las Minas. Fog precipitation at the 2100 m site totalled 23·4 mm from 30 July 1995 to 7 June 1996. At the 2550 m site fog precipitation totalled 203·4 mm during the same time interval. Because more than three-quarters of the land area of the Sierra de las Minas Biosphere Reserve lies above 2100 m, fog precipitation may occur in most areas of the reserve. Seasonal differences in fog precipitation occurred, and these differences were most evident at the 2550 m site. Because the dry season has a significant quantity of fog precipitation, management of the cloud forest is particularly important in maintaining water resources for arid lowland communities that ration water during the dry season (Brown *et al.*, 1996).

Based on the quantity of fog precipitation generated in the Sierra de las Minas Biosphere Reserve, the conservation of the cloud forest may be very important to meet the water demands of a growing population in the arid lowlands (Zadroga, 1981). Cloud forests in the Sierra de las Minas are hydrologically different from the lowland vegetation in the surrounding valleys because cloud forest vegetation passively collects water from passing fog (LaBastille and Pool, 1978; Bruijnzeel and Proctor, 1995). Deforestation of the cloud forest will have an impact on this hydrological input and may reduce water resources of the surrounding arid valleys of Sierra de las Minas.

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