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Throughfall in a Puerto Rican lower montane rain forest: A comparison of sampling strategies

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Summary During a one-year period, the variability of throughfall and the standard errors of the means associated with different gauge arrangements were studied in a lower montane rain forest in Puerto Rico. The following gauge arrangements were used: (1) 60 fixed gauges, (2) 30 fixed gauges, and (3) 30 roving gauges. Stemflow was measured on 22 trees of four different species. An ANOVA indicated that mean relative throughfall measured by arrangements 1 (77%), 2 (74%), and 3 (73%) were not significantly different at the 0.05 level. However, the variability of the total throughfall estimate was about half as high for roving gauges (23%) as for fixed gauges (48–49%). The variability of stemflow ranged from 36% to 67% within tree species and was 144% for all sampled trees. Total stemflow was estimated at 4.1% of rainfall, of which palms contributed about 66%. Comparative analysis indicated that while fixed and roving gauge arrangements can give similar mean values, least 100 fixed gauges are required to have an error at the 95% confidence level comparable to that obtained by 30 roving gauges.

Introduction

On the basis of limited evidence, Shuttleworth (1989) hypothesized that because of relatively high levels of rainfall interception, tropical deforestation at continental edge and island locations is likely to have a greater effect on stream flow than deforestation in mid-continental sites. Since then an increasing number of interception studies conducted in tropical forests located at continental edges and islands suggest that interception may indeed be higher under 'maritime' climatic conditions (Scatena, 1990; Cavelier et al., 1997; Dykes, 1997; Clark et al., 1998; Schellekens et al., 2000). These high interception losses have been attributed variously to an orographic rainfall regime (i.e. frequent low intensity rains) (Scatena, 1990; Schellekens et al., 1999); advection of sensible heat from the nearby ocean (Dykes, 1997; Schellekens et al., 2000); high epiphyte loading (Cavelier et al., 1997; Ataroff, 1998), or a combination of these factors (Clark et al., 1998; Hölscher et al.,

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2004). Nevertheless, it cannot be ruled out that some of the high interception estimates and variability between studies were caused by an underestimation of amounts of throughfall because of the use of a limited number of fixed gauges (Schellekens et al., 2000).

Lloyd and Marques (1988) demonstrated that the distribution of relative throughfall values was much broader for an Amazonian lowland rain forest (typically about 0–200% of rainfall) than for a temperate pine plantation forest (typically about 0–100% of rainfall). This broader distribution in lowland rain forest indicates that throughfall is increasingly concentrated at certain spots, or 'drip points', and consequently, more strongly depleted elsewhere (Shuttleworth, 1989). Because of this large spatial variation, measurements of throughfall in tropical rain forests are particularly prone to large sampling errors, especially if only a limited number of fixed gauges are used (Lloyd and Marques, 1988). Therefore, Lloyd and Marques (1988) recommended the frequent random relocation of gauges (i.e. roving gauge method) to increase the area sampled and so reduce the error.

In most studies of interception loss in maritime tropical locations, throughfall was measured using a fixed gauge arrangement (Scatena, 1990; Cavelier et al., 1997; Clark et al., 1998; Schellekens et al., 2000). A roving gauge approach has only been used occasionally (e.g. Dykes, 1997). In addition, only a few studies have reported the spatial variability of throughfall; for lower montane rain forests in Puerto Rico and Panama, individual gauge catch was found to range between 0–107% (Scatena, 1990) and 0–1000% (Cavelier et al., 1997) of incident rainfall, respectively. Similarly, the actual sampling error associated with throughfall measurements has been reported only sporadically (e.g. Clark et al., 1998), whereas in several studies (Cavelier et al., 1997; Dykes, 1997; Schellekens et al., 2000) the error was estimated using the equations derived by Lloyd and Marques (1988) for central Amazonian rain forest.

Therefore, comparatively little is known about the variability of throughfall in tropical forest under maritime tropical conditions, and requirements for adequate sampling of throughfall in these forests are poorly defined. This study measured throughfall using different gauge arrangements from November 2000 through November 2001 in the same Puerto Rican lower montane rain forest studied earlier by Scatena (1990) and Schellekens et al. (1999). Stemflow was also measured on trees of various species. The main objectives of this study were to assess the variability of throughfall and the errors associated with different gauge arrangements.

Study area

The study was conducted in the 6.4 ha Bisley 2 catchment, which is located at 18°19′N, 65°50′W at an elevation between 265 and 456 m in the Luquillo Mountains, northeastern Puerto Rico. The catchment is covered with Tabonuco-type rain forest consisting of 20–25 m high irregularly shaped trees with an understory dominated by palms, and ground level herbs and shrubs (Scatena and Lugo, 1995). There are 107 tree species in the catchment, and the three dominant species, *Dacryodes excelsa* (Tabonuco), *Prestoa montana* (a frequently occurring palm), and *Sloanea berteriana*, comprise 51% of the basal area, 49% of the stem density, and 57% of the importance value (Chinea et al., 1993). The average leaf area index of the forest was estimated at 6.4 (Odum et al., 1970).

The Bisley 2 catchment receives about 3000–4000 mm of rainfall per year (Scatena, 1989). Rainfall is distributed fairly evenly within the year. In general, May and November are the wettest months with about 385 mm each. The period January–March is relatively dry with 200 mm per month on average (Schellekens et al., 1999). Mean monthly temperatures in the area vary little throughout the year (24 °C in December–February vs. 27–28 °C in July–August), and seasonal variation in average daily relative humidity is small (84–90%) (Brown et al., 1983). Whilst hurricanes are common, mean daily wind speeds are generally low (1–2 m s^{-1}) and have little seasonal variation (Brown et al., 1983; Van der Molen, 2002). The forest was hit by hurricane Hugo in September 1989, which caused considerable damage to the forest (Scatena and Lugo, 1995). However, approximately one year after the hurricane throughfall approached pre-storm levels, and after five years aboveground biomass was 86% of the pre-hurricane value (Scatena et al., 1996).

Methods

Rainfall

Rainfall (*P*, mm) was measured with a Casella CEL tipping bucket rain gauge (400 cm^2 orifice, 0.10 mm per tip) and a totalizer rain gauge (100 cm^2 orifice) placed on a 24.2 m scaffolding tower situated at 335 m on the northern water divide of the Bisley 2 catchment. The recording rain gauge (25.7 m above the ground) was connected to a Campbell Scientific 21× data logger and 60 min totals were stored in an external storage module. The totalizer gauge (25.5 m above the ground) was read at the same time as the throughfall measurements, approximately every 2–3 days. Rainfall totals as measured with the recording gauge (P_{rec}) and the totalizer (P_{tot}) correlated very well ($P_{tot} = 1.01P_{rec} - 0.16$, $r^2 = 1.00$, $N = 28$). Rainfall data from the totalizing gauge were used in the present analysis.

Throughfall

Throughfall (TF, mm) was measured between November 2000 and November 2001 on the northern slope of the Bisley 2 catchment (directly to the south of the tower) using three different gauge arrangements (Table 1). For the first arrangement, a 139 m transect was outlined with numbered flags placed at 1 m intervals, representing 140 possible sampling positions. Next, 60 fixed gauges were placed by randomly selecting 60 from the 140 possible sampling positions. For the second and third arrangements, a separate 159 m transect was outlined. The 30 fixed gauges were distributed by randomly selecting 30 from the 160 possible sampling positions. For the roving gauge arrangement, the 160 sampling positions were divided into 30 groups of 5–6 neighbouring positions. Within each group, a gauge was placed by randomly selecting one from the 5–6 possible sampling positions. This procedure was repeated each time