Changes in rainfall interception along a secondary forest succession gradient in lowland Panama

SUPPLEMENTARY MATERIAL

B. Zimmermann[1,*], A. Zimmermann[1], H. L. Scheckenbach[1], T. Schmid[2], J. S. Hall[3], and M. van Breugel[3]

[1]{Institute of Earth and Environmental Science, University of Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany}

[2]{Department of Geosciences, University of Tübingen, Hölderlinstraße 12, 72074 Tübingen, Germany}

[3]{Smithsonian Tropical Research Institute, Apartado 0843-03092, Balboa, Ancón, Panama}

[*]{now at: Research Institute for Post-Mining Landscapes (FIB e.V.), Brauhausweg 2, 03238 Finsterwalde, Germany }

Correspondence to: A. Zimmermann (alexander.zimmermann.ii@uni-potsdam.de)

1 Supplementary material S1

1.1 Short description of supplementary material

Supplementary material S1 contains a list of the five most abundant tree, shrub, and palm species in the throughfall monitoring plots and information on the status of deciduousness. Note that the deciduousness classification is solely based on our field observations and hence, is preliminary.

1.2 Botanical data

Table S1.1. List of abundant tree, shrub, and palm species in the throughfall monitoring plots. The species are ordered based on their share on the plot total basal area (BA, in %).

Plot	Genus	Species	% BA	Status[1]
1	Vernonanthura	patens	39.5	e
1	Conostegia	xalapensis	21.2	e
1	Vismia	baccifera	13.9	e
1	Byrsonima	crassifolia	6.9	e
1	Vismia	macrophylla	4.7	e
2	Conostegia	xalapensis	72.6	e
2	Byrsonima	crassifolia	12.8	e
2	Vismia	macrophylla	3.2	e
2	Vismia	baccifera	3	e
2	Terminalia	amazonia	1.9	e
3	Terminalia	amazonia	30.1	e
3	Conostegia	xalapensis	22.8	e
3	Citrus	x aurantium	8.4	e
3	Vismia	baccifera	7.1	e
3	Miconia	argentea	6.5	e
4	Conostegia	xalapensis	49.3	e
4	Vismia	macrophylla	14.8	e
4	Vismia	baccifera	12.4	e
4	Inga	thibaudiana	5.5	e
4	Byrsonima	crassifolia	4.3	e
5	Vismia	macrophylla	26.5	e
5	Conostegia	xalapensis	24.7	e
5	Vismia	baccifera	16.1	e
5	Gmelina	arborea	13.8	d
5	Cordia	bicolor	6.6	e

Table S1.1. continued.

Plot	Genus	Species	% BA	Status[1]
6	Alchornea	costaricensis	22.6	e
6	Conostegia	xalapensis	21.7	e
6	Vismia	macrophylla	10	e
6	Ceiba	pentandra	9.2	d
6	Vismia	baccifera	7.5	e
7	Xylopia	frutescens	28.7	e
7	Banara	guianensis	19.4	d
7	Terminalia	amazonia	5.9	e
7	Thevetia	ahouai	4.3	e
7	Piper	aduncum	3.4	e
8	Vismia	macrophylla	37.2	e
8	Inga	thibaudiana	11.7	e
8	Annona	spraguei	7.6	d
8	Terminalia	amazonia	6.9	e
8	Casearia	sylvestris	4.3	e
9	Terminalia	amazonia	40.1	e
9	Banara	guianensis	18	d
9	Byrsonima	crassifolia	9.7	e
9	Thevetia	ahouai	7.5	e
9	Vismia	baccifera	5.9	e
10	Xylopia	frutescens	20.3	e
10	Byrsonima	crassifolia	16	e
10	Vismia	baccifera	14.5	e
10	Vismia	macrophylla	6.2	e
10	Conostegia	xalapensis	5.1	e
11	Xylopia	frutescens	24.7	e
11	Terminalia	amazonia	6.6	e
11	Schefflera	morototoni	6.1	d
11	Conostegia	xalapensis	5.8	e
11	Vismia	macrophylla	5.5	e
12	Psychotria	grandis	20.4	e
12	Cecropia	peltata	9.5	e
12	Alchornea	costaricensis	7.6	e
12	Solanum	hayesii	6.8	e
12	Tetrathylacium	johansenii	4.9	e
13	Byrsonima	crassifolia	15.9	e
13	Schefflera	morototoni	13	d
13	Vismia	macrophylla	9.8	e
13	Byrsonima	spicata	7.9	e
13	Xylopia	frutescens	7.3	e

Table S1.1. continued.

Plot	Genus	Species	% BA	Status[1]
14	Xylopia	frutescens	21.7	e
14	Vismia	macrophylla	10.8	e
14	Byrsonima	spicata	9.8	e
14	Coccoloba	manzinellensis	6.4	e
14	Schefflera	morototoni	6.3	d
15	Turpinia	occidentalis	7.5	e
15	Thevetia	ahouai	7.1	e
15	Inga	cocleensis	6.9	e
15	Apeiba	membranacea	6.8	e
15	Cordia	bicolor	5.4	e
16	Vochysia	ferruginea	25.3	e
16	Schefflera	morototoni	13.3	d
16	Xylopia	frutescens	11.6	e
16	Inga	sertulifera	4.1	e
16	Cupania	scrobiculata	4	e
17	Dipteryx	panamensis	27.4	d
17	Luehea	seemannii	17.2	e
17	Licania	platypus	14.5	e
17	Macrocnemum	roseum	5.2	e
17	Tetragastris	panamensis	4.7	e
18	Pachira	quinata	29.4	d
18	Alseis	blackiana	11.7	e
18	Anacardium	excelsum	11.6	e
18	Platypodium	elegans	9.2	e
18	Spondias	radlkoferi	6.1	d
19	Anacardium	excelsum	31.1	e
19	Spondias	mombin	9.4	d
19	Gustavia	superba	5.8	e
19	Astrocaryum	standleyanum	5.7	e
19	Sapium	glandulosum	5.5	e
20	Macrocnemum	roseum	26.5	e
20	Spondias	mombin	22.8	d
20	Attalea	butyracea	8.4	e
20	Hyeronima	alchorneoides	7.1	e
20	Oenocarpus	mapora	7.0	e

[1] Species were classified as “deciduous” (d) when leafless for extended periods (weeks to months), in all other cases (e.g. gradual leaf loss) plants were classified as “evergreen” (e).

2 Supplementary material S2

2.1 Short description of supplementary material

Supplementary material S2 contains stemflow data collected on Barro Colorado Island from the end of August to early October 2012.

2.2 Motivation to measure stemflow

The calculation of interception loss requires estimates of rainfall, throughfall and stemflow. In Panamanian young secondary, mature, and plantation forests stemflow estimates vary between 0.4 % and 2.6 % of gross precipitation (Cavelier et al., 1997; Macinnis-Ng et al., 2012; Park and Cameron, 2008). Another study conducted in a palm-dominated forest stand located in Panama calculated a stemflow contribution of 3.2 % of gross precipitation (Niedzialek and Ogden, 2012). None of our throughfall plots was dominated by palms (though plot # 20 contained some palms, see Supplementary material S1); hence, we may consider the range of 0.4 % – 2.6 % as a first rough estimate. Interestingly, these numbers are so low that they are within the range of ±1 standard error of our throughfall estimates (cf. Table 1). Moreover, three of the ten plots with forest regrowth younger than 10 years had interception values (based on rainfall and throughfall only) around 100 % (cf. Table 1), which virtually precludes the occurrence of stemflow.

Although there was no evidence that stemflow plays a significant role at our research sites we conducted a small ancillary study and measured stemflow in a 1 ha plot that overlaps with 2 of our throughfall study sites (plot # 17 and # 18, cf. Table 1). We conducted the stemflow measurements in the old-growth secondary forest on Barro Colorado Island (Fig. 1) because previous field observations indicated that some stemflow was produced by *Oenocarpus mapora* palms. We never observed stemflow in the young secondary forest plots in the Agua Salud area (plot #1 – #16, Table 1) and hence, did not consider measuring stemflow in these plots.

2.3 Methods

We measured stemflow in the middle of the rainy season 2012 in six 10 m by 10 m sized plots on Barro Colorado Island. The six plots represent the sampling units which were randomly located in a 1 ha area. We sampled each 10 m by 10 m plot applying a total sampling (cf. Hanchi and Rapp, 1997). That is, we measured stemflow of all stems > 5 cm diameter at

breast height in each of the 10 m by 10 m plots. The total sampling has the advantage that stemflow can be easily estimated for an area of interest:

$$\hat{\bar{S}} = \frac{1}{n}\sum_{i=1}^{n}\left(V_i * \frac{1}{A_i}\right) \quad \text{(S1)}$$

where $\hat{\bar{S}}$ is the estimated mean stemflow (in mm) of a given sampling area, n refers to the number of sampling units within the sampling area, and V_i is the total volume of stemflow (in L) collected in the area A (in m^2) of sampling unit i.

In total, we collected stemflow of 60 stems (Table S2.1). The dataset comprises 25 species including several individuals of the palm species *Oenocarpus mapora* H. Karst. (Table S2.1). In addition to the stemflow measurements, we collected rainfall in a nearby opening with 10 manual read-out collectors (the receiving area of each rainfall collector was 113 cm^2; cf. section 2.2.3 for more details on the collector type).

2.4 Results and interpretation of data

During the sampling period we collected 26 rain events (minimum rainfall: 0.2 mm, maximum rainfall: 52.6 mm, mean rainfall: 6.5 mm). Our measurements indicate that rains < 5 mm produced negligible stemflow volumes (Fig. S2.1). However, even larger rainfalls produced only comparatively small amounts of stemflow (Fig. S2.1). Based on accumulated rainfall data of event 1–26 (167.8 mm) and corresponding volumetric stemflow data presented in Table S2.1, we estimated that total stemflow amounts to 0.98 % of rainfall. Of course, this number varies depending on the frequency of large events during the observation period. Our stemflow estimates for events > 10 mm, however, indicate that even during periods dominated by larger rainfall events, the percentage of stemflow is likely to be small. Based on our measurements, our field observations, and the available data from the literature (Cavelier et al., 1997; Macinnis-Ng et al., 2012; Park and Cameron, 2008), we consider stemflow as negligible in our research areas.

Table S2.1. Species list, selected botanical data, and total stemflow volume data from Barro Colorado Island.

Stemflow Plot	Stem	Genus	Species	dbh[1] (cm)	CD[2] (m)	Total Stemflow (L)
1	1	Heisteria	concinna	27.2	10.0	43.37
1	2	Licania	platypus	113.5	21.7	37.71
1	3	Oenocarpus	mapora	8.3	5.5	12.45
1	4	Oenocarpus	mapora	7.6	6.2	19.36
1	5	Oenocarpus	mapora	5.7	7.6	16.19
1	6	Oenocarpus	mapora	8.0	4.4	15.98
1	7	Oenocarpus	mapora	7.3	6.0	39.59
1	8	Trichilia	tuberculata	8.1	5.5	5.95
1	9	Garcinia	intermedia	5.2	3.7	2.07
1	10	Hirtella	triandra	7.0	3.9	8.11
1	11	Guapira	standleyanum	42.0	10.5	20.78
1	12	Protium	panamense	15.1	3.2	10.93
2	13	Protium	tenuifolium	14.5	4.0	5.50
2	14	Quassia	amara	5.8	0.0	0.91
2	15	Swartzia	simplex	7.8	4.7	4.26
2	16	Oenocarpus	mapora	8.6	7.9	82.22
2	17	Oenocarpus	mapora	10.1	3.8	4.04
2	18	Tabernaemontana	arborea	31.0	13.8	11.60
2	19	Protium	tenuifolium	11.0	5.2	14.09
2	20	Hirtella	triandra	7.2	3.9	30.80
2	21	Protium	panamense	5.1	2.3	8.14
2	22	Protium	tenuifolium	5.6	3.8	14.40
2	23	Cupania	sylvatica	7.5	4.5	38.85
2	24	Cupania	sylvatica	6.0	4.4	16.02
2	25	Maquira	costaricana	7.7	0.0	2.67
3	26	Coussarea	curvigemmia	6.4	3.5	5.35
3	27	Cupania	sylvatica	5.0	3.8	6.74
3	28	Inga	quarternata	6.6	4.9	19.54
3	29	Calophyllum	longifolium	34.0	11.0	15.77
4	30	Faramea	occidentalis	6.0	4.2	20.24
4	31	Faramea	occidentalis	9.0	2.8	33.25
4	32	Swartzia	simplex	5.9	2.5	2.62
4	33	Swartzia	simplex	13.1	3.8	29.60
4	34	Quassia	amara	7.6	2.6	12.53
4	35	Faramea	occidentalis	6.4	4.4	5.63
4	36	Heisteria	concinna	8.4	4.1	20.23
4	37	Garcinia	intermedia	10.9	4.4	6.10
4	38	Heisteria	concinna	13.9	4.0	7.91
4	39	Faramea	occidentalis	7.2	3.6	32.65
4	40	Alseis	blackiana	18.0	5.5	20.95

Table S2.1. continued.

Stemflow Plot	Stem	Genus	Species	dbh[1] (cm)	CD[2] (m)	Total Stemflow (L)
4	41	Quararibea	asterolepis	14.0	3.3	8.72
4	42	Faramea	occidentalis	7.2	2.7	24.63
4	43	Luehea	seemannii	39.5	15.3	26.55
4	44	Faramea	occidentalis	7.0	0.7	3.70
4	45	Faramea	occidentalis	8.0	2.1	23.95
5	46	Alseis	blackiana	26.6	9.5	38.42
5	47	Brosimum	alicastrum	9.0	2.2	11.29
5	48	Quararibea	asterolepis	7.5	3.8	4.06
5	49	Gustavia	superba	14.0	1.5	4.08
5	50	Gustavia	superba	12.7	2.9	5.50
5	51	Gustavia	superba	18.2	6.4	57.34
5	52	Gustavia	superba	13.5	2.8	25.08
5	53	Gustavia	superba	5.7	1.2	7.04
5	54	Cupania	sylvatica	5.2	2.3	4.76
5	55	Alseis	blackiana	9.7	5.4	2.66
5	56	Swartzia	simplex	5.7	2.1	10.45
5	57	Faramea	occidentalis	6.9	3.3	10.19
6	58	Heisteria	concinna	19.5	7.9	2.04
6	59	Sorocea	affinis	5.5	2.1	4.39
6	60	Macrocnemum	roseum	8.6	3.6	5.11

[1] diameter at breast height; [2] crown diameter; [3] dead tree (i.e. no tree crown).

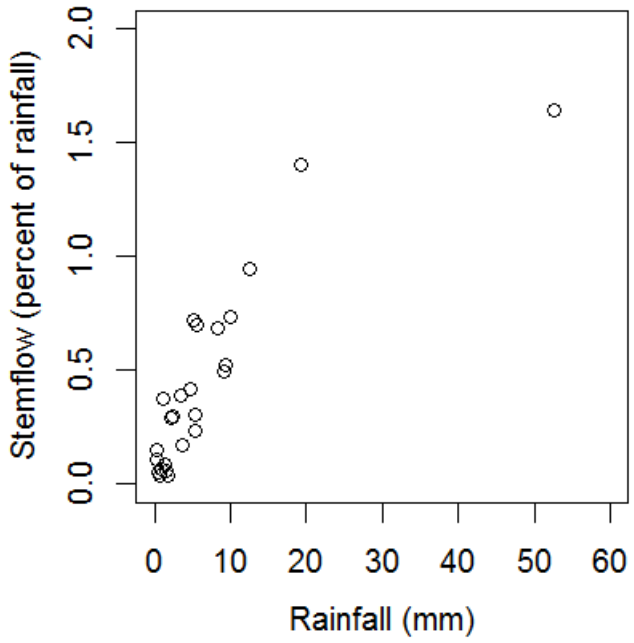

Figure S2.1. Stemflow data (n = 26 events) from Barro Colorado Island.

References

Cavelier, J., Jaramillo, M., Solis, D., and de León, D.: Water balance and nutrient inputs in bulk precipitation in tropical montane cloud forest in Panama, J. Hydrol. 193, 83–96, 1997.

Hanchi, A., and Rapp, M.: Stemflow determination in forest stands, Forest Ecol. Manag., 97, 231–235, 1997.

Macinnis-Ng, C. M. O., Flores, E. E., Müller, H., and Schwendenmann, L.: Rainfall partitioning into throughfall and stemflow and associated nutrient fluxes: land use impacts in a lower montane tropical region of Panama, Biogeochemistry, 111, 661–676, 2012.

Niedzialek, J. M., and Ogden, F. L.: First-order catchment mass balance during the wet season in the Panama Canal Watershed, J. Hydrol., 462–463, 77–86, 2012.

Park, A., and Cameron, J. L.: The influence of canopy traits on throughfall and stemflow in five tropical trees growing in a Panamanian plantation, Forest Ecol. Manag., 255, 1915–1925, 2008.