

## Reply to comments of reviewer #2

**We thank this reviewer for her/his very constructive comments. Our responses to the comments are provided in bold (below each comment). In this reply we do not repeat the reviewer's summary of the content of our manuscript. However, we are pleased that this reviewer believes that our work represents an important contribution on the hydrologic impacts of tropical forest succession.**

### Specific comments of reviewer #2

In a future study, it would be interesting to compare data derived from hemispherical photos and a LiCOR Plant Canopy Analyzer as the latter might provide a more accurate measure of canopy structure (Moser et al. 2007), and hence improved throughfall predictions.

**We agree that using a LiCOR Plant Canopy Analyzer potentially provides more accurate data. Even more promising, however, might be the use of data from remote sensing (as discussed in section 4.3) because these data not only capture fine-scale three-dimensional forest structures (e.g. data obtained with airborne light detection and ranging; cf. Asner et al., 2011) but also they can be obtained for large areas (cf. Asner et al., 2011).**

The authors mention that this forest is semi-deciduous. It would be interesting to consider how changes in phenology over the course of a year influence estimated interception losses at both plot and landscape scales. Here, one might expect species composition to influence interception loss.

**We agree that the influence of phenological dynamics on interception is an interesting topic. Yet, we believe that these dynamics have only a limited impact on the overall water balance at our research sites because 1) only a fraction of the trees is deciduous and 2) the time during which trees have no leaves usually coincides with the driest months. Botanical surveys indicate that around 10 % of the canopy tree species in the old-growth forest on Barro Colorado Island are dry-season deciduous (Croat, 1978) and that around 17% of the total stand basal area of Agua Salud's secondary forests is deciduous (van Breugel, unpublished). However, deciduousness at our sites is a complex phenomenon; some trees are leafless for weeks, some for months, and others drop their leaves only in particularly dry years (Foster and Brokaw, 1996). Previous research on Barro Colorado Island (Zimmermann et al., 2009) showed that relative throughfall amounts at particular sampling locations changed little during times of leaf drop and leaf development. Probably more important than phenological dynamics are changes in rainfall characteristics as rain events during the dry season (mid-December – April) tend to be smaller and less intense. However, even changes of event characteristics will have a limited influence on the overall water balance because of comparatively low rainfall over the entire dry season (cf. January – April: 232 mm  $\pm$  146 mm vs. May – December: 2409  $\pm$  425 mm, mean  $\pm$  1 standard deviation, n = 82, data from 1929 to 2010 monitoring station on Barro Colorado Island, data courtesy of the Environmental Sciences Program, Smithsonian Tropical Research Institute, Republic of Panama).**

## Technical corrections of reviewer #2

Page 7999

Title: I suggest the authors consider changing the title. I think the manuscript does more than what the title suggests (i.e., quantifying the increase in rainfall interception). A few possible titles are “Forest structure influence on rainfall interception along a secondary succession gradient in lowland Panama” or “Changes in rainfall interception (or throughfall) along a secondary succession gradient in a tropical forest region of Panama.”

**We consider changing the title into: “Changes in rainfall interception along a secondary forest succession gradient in lowland Panama”.**

Page 8000

Line 1 – Include a hyphen in “Large-scale”.

**Changed as suggested.**

Line 2 – “land-cover dynamics”. Make sure to hyphenate two words that make a single descriptor (e.g., land-cover change or land-cover dynamics, or large-scale growth etcetera unless one of the words is an adverb (e.g., highly motivated).

**Changed as suggested.**

Line 3 – “the relationship between forest”

**Changed as suggested.**

Line 9 – “Regrowing” is redundant and “natural” is unnecessary. Edit and use past tense “The investigated gradient comprised 20 forest patches 3 to 130 years old”.

**Changed as suggested.**

Line 11 – “two-month period in 2011 that had ... ”

**As described in section 2.2.3, we did not collect all data in 2011. For our analysis we included data from two old-growth forest sites which had been obtained in 2007 and 2008. Therefore, we cannot state that we obtained the data in 2011.**

Line 11 – “We acquired forest inventory data collected in 2011? and derived forest structural attributes for the sampled locations”. I am not sure what “the same time” refers to. Were the data collected during the two-month sample period or during the year in which data were collected?

**We acquired the forest inventory data during the throughfall sampling period. To make this sentence clearer, we changed the text to: “During the same period, we ... ”.**

Line 14 – “the vegetation parameters that had the strongest influence on the variation in canopy interception”

**Changed as suggested.**

Line 15 – “Our analyses yielded three main findings”

**Changed as suggested.**

Line 23 – “Our results suggest that where entire catchments are undergoing forest regrowth, initial stages of succession ...”. Can you be a bit more specific here. What does undesirable effects mean? Do you mean that the initial stages of succession may result in substantial decreases in streamflow generation due to associated interception losses?

**As suggested, we clarified the sentence.**

Line 25 – “We further highlight the need to study changes in hydrology? Interception? throughfall? during all stages of forest succession.”

**As suggested, we clarified the sentence.**

Page 8001

Line 1 – Delete “proportions”

**We changed “proportions” to “parts”; simply deleting the word would not be correct.**

Line 3 – “rural-to-urban”

**We used the term “rural-urban migration” because it seems to be a frequently used term in the literature (cf. Aide and Grau, 2004).**

Line 6 – Change “spreading” to “expanding”

**Done as suggested.**

Line 7 – “In addition, there is evidence that”

**Changed as suggested.**

Line 10 - “Most often, regrowing forests are found alongside ::: and thus they are part of”

**We adopted the suggestion. Thanks for improving the sentence.**

Line 16 – Do not use “original” as this would be hard to ascertain. Instead use “mature”

**Done as suggested.**

Line 17 – “secondary forest hydrology” and “former agricultural areas”

**We changed the first phrase but did not change the second one because we wanted to contrast the hydrological characteristics of mature forest and agricultural areas (citing the work of Bruijnzeel (2004) and Giambelluca (2002)). Rephrasing the sentence to “former agricultural areas” would imply that there is already enough information on the hydrological characteristics of secondary forests, which is not the case.**

Line 20 – “rate of mature forests” and “the high rainfall interception storage

**We clarified the sentence as suggested.**

Line 25 – “rainfall interception in forest hydrology, reliable”

**As suggested, we added “in forest hydrology”.**

Page 8002

Line 1 – A definition of recovery time would be good here as you use this term throughout the paper. In fact, I wonder if forest age wouldn't be clearer?

**We adopted the recommendation and replaced all occurrences of “recovery time” with “forest age”, except at page 8002 line 1 where we replaced recovery time” with “regrowth stage” (as suggested by this reviewer).**

Line 1 – Delete successional trajectories” “that influence forest structure and composition”

**Done as suggested.**

Line 1 – “For instance, regrowth stage”, “the composition of the regrowing forest” (e.g., invasive versus native plants)

**Done as suggested.**

Line 3 – “e.g., pasture versus “shifting cultivation”. Slash-and-burn has a negative connotation in the social sciences whereas shifting cultivation does not.

**Thanks for this suggestion – we changed the sentence accordingly.**

Line 7 – Cut “it should be evident” and “forests of different ages and ... age class are needed to describe”

**We cut “it should be evident” but left the rest of the sentence unchanged. The further suggested cutting would result in a fragmented sentence.**

Line 9 – From here forward, edit “change in interception” rather than “change of interception

**Done as suggested.**

Line 10. Cut “it would thus be desirable if we could” and begin “Ideally, forest inventory data could be used to predict the change IN interception

**Done as suggested.**

Line 15 – “relate canopy interception to secondary forest succession?”

or rather to “forest structure along a secondary succession gradient”

**We left the sentence unchanged because the main objective should be more general than the following specific objectives.**

Line 17 “forest structural”

**The phrase “forest structural” sounds quite odd to us – we left the sentence unchanged.**

Line 23 – Cut “At the end of the article”

**Done as suggested.**

Page 8003

Line 1 – “loss along”

**As suggested we replaced “in” with “along”.**

Line 5 – Delete “a”, “have steep”.

**Done as suggested.**

Line 6 – Delete “a”, “with high drainage densities”.

**Done as suggested.**

Line 7 – “mainland” one word.

**Done as suggested.**

Line 7 “after the Chagres River was dammed to form Lake Gatun”

**Done as suggested.**

Line 10 – Delete “the”. “to Soberanía National Park”

**Done as suggested.**

Line 16 – “Data courtesy of”

**Done as suggested.**

Line 17 – “... Republic of Panama). Mean daily temperature ... ”

**Done as suggested.**

Line 20 – Break into 2 sentences. This vegetation type covers all of BCI.

**Changed as suggested. In addition we changed the text to avoid having three consecutive sentences starting in a very similar fashion. So the text now reads as follows: “The natural vegetation of the central Panama Canal Watershed is classified as semideciduous lowland forest (Foster and Brokaw, 1996). This vegetation type covers all of BCI. The Agua Salud Project area consists of pastures, subsistence agriculture and timber plantations as well as secondary forests in varying stages of recovery”**

Line 22 - forests in varying stages of recovery

**Changed as suggested.**

Line 25 – “For our study, we”

**Changed as suggested.**

Page 8004

“Sampling design? Rather than scheme?”

**According to de Gruijter et al. (2006) the terms “sampling design” and “sampling schemes” are defined as follows: a “sampling design” assigns a probability of selection to a set or sequence of sampling units in the sampling universe. That is, a “sampling design” determines the sampling locations using a selection rule. A “sampling scheme”, in contrast, refers to the entire sampling plan which includes decisions on sampling design, sampling frequency, and sample support (i.e. size and orientation of sampling units). Because section 2.2 describes all decisions regarding the throughfall monitoring and acquisition of forest structure data we use the term “sampling scheme”.**

Line 3 – “to forest structure using a regression-type”

**We shortened the sentence as suggested.**

Line 5 – “we optimized site selection by spreading the range of succession stages as far as possible and by sampling the distribution of potentially important predictor variables as evenly as possible”. This sentence is unclear. Perhaps you can cut this sentence and combine with the following sentence, which is very clear. My suggestion is to rewrite as follows: “we optimized site selection by including very young forests (i.e., 3 yrs old) as well as sites in the mature secondary forest of BCI. We chose ...”

**We rewrote the section as suggested.**

Line 15 – Why did plot sizes differ?

**Plot sizes differed because the larger plots were also part of another study. In the revised version of the manuscript we state the reason why we used different plots sizes.**

Line 20 – “of our forest plots through interviews”

**The revised sentence reads as follows: “In the ASP area, we determined the forest age of our plots through interviews with the former land owners”. Because we use “forest age” instead of the ambiguous term “recovery time” throughout the revised manuscript we solely wrote “of our plots” (and not “of our forest plots”).**

Line 22 – “in the stage of forest succession”

**Done as suggested.**

Line 23 – “(e.g., by cattle treading)”

**Done as suggested.**

Line 24 – “downslope”

**Done as suggested.**

Line 25 – Delete “of course”. How does streamside influence secondary succession? Does it speed it up, slow it down? By encouraging dispersal, for example?

**We clarified the sentence.**

Line 25 – “For this reason, recovery time is considered ... and is not used”

**Done as suggested.**

Page 8005

Line 5 – Delete “of all stems” “species with a dbh ...”

**Done as suggested.**

Line 7 – “Delete “the same was done”. “In every other quadrant, individuals with dbh ... were identified and measured”.

**Changed as suggested.**

Line 13 – “2-L”

**Corrected as suggested.**

Line 17 – “between each throughfall and the closest rainfall site”

**Done as suggested.**

Line 18 “760 m maximum”.

**Done as suggested.**

Line 23 – “decline in canopy openness”

**Done as suggested.**

Line 26 – “size of 36 collectors”

**Done as suggested.**

Line 26 – “collector surface area of 113 ...”

**Done as suggested.**

Line 28 – “limits of estimated mean”

**Done as suggested.**

Page 8006

Line 10 – “Data from the other ...”

**Done as suggested.**

Line 12 – “Stemflow measured at”

**Changed as suggested.**

Line 14 – “report similarly low”

**Corrected as suggested.**

Line 18 – Delete “of”; “Calculation of relative throughfall and interception loss”

**Corrected as suggested.**

Line 19 – Delete “First”. “At each site, we added measured throughfall and rainfall values over the entire measurement period. I suggest you delete “to obtain long-term data (i.e. throughfall and rainfall during several months)”.

**Done as suggested.**

Line 21 – “we calculate relative..”

**We are not sure why we should switch here to present tense. Therefore, we did not change this sentence.**

Page 8007

Lines 3-5 –You compared throughfall to the nearest rainfall site both at BCI and ASP, and this makes sense, hence I wonder if this text is necessary.

**We believe that it is important to mention which rainfall sites have been used to calculate relative throughfall.**

Line 7 – “forest inventory data”

**Changed as suggested.**

Line 9-10 –“abbreviated with BA1 etcetera. This is awkward and perhaps not necessary here but rather in the table?”

**We think that the use of these abbreviations throughout the text saves space and makes the text overall easier to read by avoiding repeating terms such as ‘basal area of class 1’. To be consistent, we define the abbreviations at first use in the text and from then on, use the abbreviations instead of the complete term.**

Line 10 – “For dbh-class 2, we had ... for all plots. Therefore, we calculated ... ”

**Changed as suggested.**

Line 11 – “hereafter diversity”

**Changed as suggested.**

Line 12 – no hyphen with dbh-classes

**Corrected as suggested.**

Line 13 – “we defined as the ratio”

**Changed as suggested.**

Line 15 – I think it is important here to include a sentence here, which explains how basal area of the smaller trees is related to that of canopy trees given its importance in the study.

**We clarified the sentence and deleted the reference to Montgomery and Chazdon (2001) which did not fit anymore.**

Line 19 – Cut “The” before openness.

**Done as suggested.**

Line 21 – “most strongly” instead of “strongest”

**Done as suggested.**

Line 25 – “rough terrain” and “We derived these”

**Done as suggested.**

Page 8008

Line 14 - “was designed to examine whether the inclusion”

**Done as suggested.**

Line 15 – “would improve predictive”

**Done as suggested.**

Line 16 – “parameters was best suited to”

**Done as suggested.**

Line 20 – “on a weighted average of all of them”

**Done as suggested.**

Page 8009

Line 23 – “summarize, for example, with the posterior mean and standard deviation”

**Done as suggested.**

Page 8010

Line 2 – “age-class dependent”

**Corrected as suggested.**

Line 3 – cut “finally”

**Done as suggested.**

Line 5 – “throughfall across different age”

**Changed as suggested.**

Line 6 – “data for the years”

**Changed as suggested.**

Line 8 – “year, which we”

**Partly changed as suggested, we did not include “we” because it would not fit in the sentence.**

Line 9 – “landscape-scale estimates”

**Changed as suggested.**

Line 9 – “relative throughfall input to the secondary forests”

**Changed as suggested.**

Line 17 – “to a maximum”

**Changed as suggested.**

Line 21 – Cut “natural”

**Done as suggested.**

Line 23 – “had a low skeweness”

**Changed as suggested.**

Line 24 – “showed a skewness ... due to the influence of single ... ”

**Changed as suggested.**

Page 8011

Line 8 – Cut “at all”

**Done as suggested.**

Line 17 – “models using the variables most strongly related to relative throughfall as predictors”

**Done as suggested.**

Line 21 - “Using the BAratio as an explanatory ... ”

**Done as suggested.**

Page 8012

Line 2 - “also in multivariate space: it has”

**Changed as suggested.**

Line 5 - “In addition, in almost all models, the BA ratio is positively ... ”

**Corrected as suggested.**

Line 8 - “over the course of forest”

**Changed as suggested.**

Line 23 - “to predict relative throughfall at the landscape scale. In a first step, ... ”

**Changed as suggested.**

Page 8013

Line 3 - “a next step, ... throughfall input to all secondary ... ”

**Partly done as suggested. We did not insert a comma between “step” and “of our analysis” but changed the rest of the sentence.**

Line 9 - Please fix “changes of canopy interception” to “Changes in canopy interception” throughout.

**Done as suggested.**

Line 13 - “after land abandonment”

**Changed as suggested.**

Line 15 - “early succession as is reflected ... ”

**Changed as suggested.**

Line 16 - “increase in basal area” “decrease in the ratio of ... ” and so forth.

**Changed as suggested.**

Line 19 - For clarity, I suggest rewriting the sentence as follows. “The large scatter in relative throughfall amounts within a given period (Table 1, Fig. 4a) reflects the tremendous spatial variation in forest structure, and the underlying factors that influence secondary forest regrowth, including the intensity of past land use, landscape features, and nutrient availability (Guariguata and Ostertag, 2001; Hölscher et al., 2005).

**Changed as suggested.**

Line 23 – “two important implications?” rather than consequences?

**Changed as suggested.**

Line 25 – “interception at landscape scales”

**Changed as suggested.**

Line 26 – “forests ... early successional stages”

**Changed as suggested.**

Page 8014

Line 14 – “are likely difficult to detect.”

**Changed as suggested.**

Line 19 – “succession was less efficient”

**Changed as suggested.**

Line 21 – “to relate more strongly to the development of canopy structure during forest succession”

**Changed as suggested.**

Line 27 – “its potential to explain ... amounts and longer-term data”.

**Partly changed as suggested. We replaced “value” with “potential” but we prefer “long-term” over “longer-term”.**

Page 8015

Line 10 – Are you suggesting that empirical relationships should not be used? If so, I am not sure I agree that interception modeling alone is the way forward.

**Following the argument of reviewer # 3 that the relationship between forest structure and canopy interception cannot be “improved”, we changed the second part of the sentence. From the revised sentence it is clear that we see the application of empirical relationships as an option to predict canopy interception.**

Line 18 – “for predicting interception”. You may consider citing Weathers et al. 2006 who have similarly suggested the potential application of LiDAR for capturing fine-scale variability in throughfall deposition.

**Indeed, Weathers et al. 2006 suggested using LiDAR for improving estimates of atmospheric deposition of pollutants and nutrients. Although we acknowledge the similarity of the call for using LiDAR, we believe that the work of Weathers et al. (2006) is too little related to justify a citation in this particular sentence.**

Line 19 – “exhaustive?” Do you mean it has good spatial coverage? Also, hyphenate here “landscape-scale”.

**We changed the sentence.**

Page 8016

Line 3 – “during tropical? Forest succession”

**We changed the sentence.**

Line 5 – “mature tropical forests”

**Changed as suggested.**

Line 9 – “are often correlated with ... ”

**We did not adopt this suggestion because the word “often” would imply that sometimes forest structure parameters are not correlated, but this is not the case.**

Line 12 – “collinearity, and, hence, ... ”

**We did not follow this suggestion. From our point of view, these commas are not needed.**

Line 13 – “to model canopy interception than multiple regression”

**Changed as suggested.**

Line 14 – “small and large stem basal area, ... predictions in this study”

**Changed as suggested.**

## **References**

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