

Point-to-point rebuttal and reply

General Comments by W. Wollheim

This study quantified the inorganic N and P fluxes from Taiwan watersheds subject to annual typhoons and that are also undergoing agricultural intensification. The authors report that the response of DIN to agricultural activity is greater than for DIP, and that a large proportion of the annual fluxes come during the typhoon period. A greater proportion of DIP flux occurs during the typhoon period than for DIN, because DIP was highly correlated with sediment concentrations, which were also highly correlated with flow conditions. They point out that even the background fluxes of N are high, likely because of high atmospheric deposition and geologic sources. Because N responds more than P to cultivation, the N:P ratios also increase with cultivation. Background N:P levels were much higher than world average, suggesting the possibility that these areas are already or are more prone to rapid N saturation.

This is a useful study that paints a picture of dynamics in Oceania watersheds. I think the methodology is fairly standard and robust, with the results being solid. I think the discussion could focus a bit more on the big ideas. We know that Oceania watersheds are more closely tied to their coasts because watersheds are small. It is known for example that Oceania has a disproportionate share of global land to ocean sediment fluxes because they are mountainous and have small watersheds (see publications by Syvitski and others). The study reported here identifies that geology also contributes to the high N and P fluxes in Oceania watersheds. More discussion regarding these similarities should be developed.

Further, the idea that these watersheds are, even when pristine, relatively high emitters of N in part due to the geology and N deposition (from China?) is also worth elaborating on. Does the response to agricultural intensification differ as a result, compared to other world regions or is it similar? In general, the discussion should tie more to the literature, focusing on some bigger ideas, and placing the results from this study in a broader context. Much of the discussion currently reads like a results section.

To reach the standard of BG's publication, we thoroughly revised our manuscript following reviewers' comments. The ms is now entirely different in text giving much more information and innovative findings to readers. The Oceania's significance was highlighted and we compared with two global models revealing causes why the two reported models underestimated the nutrient loading from small rivers in Oceania. We rewrote Introduction, restructured Discussion, re-examined our hypothesis going much deeper into the data itself, thus, eliminated old Figure 6 and add a new figure with 2 tables and refined the conceptual model diagram. We believe, this version

may satisfy reviewers and gain more readerships. As for geology, we do not have enough information of N content in different rock types from other Oceania islands, thus, we give up the discussion on this particular issue. As for atmospheric deposition, it is well known that in Taiwan abundant atmospheric deposition could be measured and long-range transport from China is one of the major causes. However, this is not the focus in this study. Hopefully, we have chance in future to explore more about geology and N-deposition influence on N yield for other islands.

Major changes in the new version are listed below. Old Figure 6 is not informative enough, thus we created a new figure (Figure 8) to provide more information. Besides, we broke the old Table 2 into two new tables (i.e. Table 3 and 4) which contain more detailed information in the tables. (Please see the updated manuscript in the supplement)

The new Figure 8 is for the rating curves using typhoon samples taken at three stations (see new Figure 8 and new Table 3). This version, we apply them to precisely estimate nutrient export for every individual typhoon (4 typhoon periods in 2007 and 4 in 2008) and properly estimate the fractional contribution from typhoon events. In previous version, only monitored typhoon was estimated. However, for the non-typhoon periods, we still used flow-weighted method (See 3.2 and 4.4). Therefore, more precise numbers in the new version are given.

We clearly separate all descriptions into Results and Discussion as suggested. In this version, the Discussion section starts with **5.1 Importance of human activity on nutrient export**, then **5.2 Hydrological control on nutrient exports**, **5.3 Differential transport for DIN and DIP**, and **5.4 Significance of Oceania streams**.

We add more in-depth discussions in Results, Sections 5.1 and 5.2, thus readers can easily understand and directly link the transport mechanisms to the changes of nutrient status in the stream that illustrated in our conceptual model (Figure 9).

Because we made significant changes, particularly the Results and Discussion section, all mentioned inappropriate sentences or paragraphs no longer exist.

There should also be some discussion about the lack of particulate phosphorus measurement in this study. The study focuses on DIP, but most P is thought to be associated with sediments. The result that DIP is correlated with sediments is suggestive of this. Some discussion of sediment P is needed, especially given the mountainous nature of Oceania watersheds. TP fluxes may be even more responsive. Sediments exported from Oceania watersheds should be high, in part because of typhoons, and so TP fluxes might also be high, and perhaps elevated in disturbed catchments. This ought to be discussed with reference to the literature.

Except for the dissolved phase, particle-associated nitrogen (PN) and phosphate (PP) might be an important input in mountainous rivers, especially in rivers influenced by agricultural activity. However, the narrow isotopic signature range and ~4 orders of magnitude in sediment export fluctuation during high flow conditions (Kao and Milliman, 2008); we can hardly separate agriculture-associated PN and PP from the extraordinarily high sediment export sourced from typhoon-triggered landslides (Kao and Liu, 2000; Huang et al., 2012). Therefore, this entire study focuses on DIN and DIP export which are more directly accessible by biota and influence the aquatic ecosystem.

We added some description in the text as “It is well known that the Oceania characterizes the world highest sediment yields (Milliman and Syvitski) and Taiwan Rivers features more extraordinary values (Mulder and Syvitski, 1995; Milliman and Kao, 2005), implying the significance of particulate nitrogen and phosphorus export. However, this entire study focuses on DIN and DIP export which are more directly accessible by biota and influence the aquatic ecosystem.”(Lines 521-525)

The study is designed to look at an agricultural gradient, with one of the catchment being intensively managed. However, even this watershed is mostly forested (Table 2), so some justification is needed for why this should be considered intensively managed. It is not as intensive as many other agricultural watersheds worldwide. Also, it would be useful to have some ballpark estimate of *how big fertilizer inputs may be relative to atmospheric and geologic inputs*. Even if numbers are not available, this should be discussed as information that is needed to better understand the responses that were measured.

We added more description in the text as “Although Yusheng Creek Watershed has only 8.9% agriculture land which is not intensive at all when comparing with the cultivated extent in the Continents, it not only resulted in a low water quality index but also a degradation in benthic algae biodiversity (Yu et al., 2005). Moreover, the mountainous watersheds are more sensitive to farming activity (Huang et al., 2012) even a few percent cultivation is influential particularly the water quality demand of upstream biome is very high.” (Lines 116-122)

The condition of fertilization of farmers is also shown in the new version. “In Taiwan, the frequent summer typhoon rain forces the farmers to apply much higher amount of ammonium sulfate and urea (~3,750 kg-N/ha/yr) to speed up cabbage growth (N demand ~600-900 kg-N/ha/yr) and harvest earlier before typhoon invasion. The over-fertilization is also due to farmers’ anticipation of a substantial flush away in wet season. Basing on watershed monitoring network in our study area and a sophisticated deconvolution method, Huang et al. (2012) obtained a very high nitrate

yield number for the active farms, ~3,000 kg-N/ha/yr, which apparently the major contributor to enhance nitrate in stream water. 1% increment of active farm will increase DIN_y from background value (i.e. ~8.3 kg-N/ha/yr) to ~38 kg-N/ha/yr. Even if the yield for the inactive farm, ~770 kg-N/ha/yr, was obtained revealing the lingering effect of agricultural activities.” (Lines 347-355)

Make sure NO₃ units are as NO₃-N. I’m not sure whether they are or not - I don’t think so based on figure 2 pristine, but I may be mistaken.

We now use the unit of μM to avoid confusion.

The conceptual model (Figure 9) needs some work so that it can stand alone.

The model had been re-drawn and now we believed it can stand alone to explain the dynamics of DIN and DIP export.

Specific Comments

90-91 At 8.9% ag (Table 1) I would not say that Yusheng is intensively cultivated.

As replied above.

114 How were three hour samples collected? By hand or with an autosampler?

No autosampler is feasible for this kind of small river with highly fluctuating water level (7m) and extreme flow speed (5m/s) during flood. We added more descriptions in Material and Methods regarding the water sampling.

“Depth integrated water samples were obtained using a vertically mounted 1 L bottle attached to a weighted metal frame that was gradually lowered from the bridge. The U.S. Geological Survey DH-48 sampler was not used because of its difficulty in sinking in turbulent flows >2.5 m/s (Milliman et al., 2008).” (Lines 151-155)

170 - Doesn’t seem to be highest with first storm in 2007. Be clear about which stream you are giving results for - not clear in the text.

We removed the old statement. We now marked typhoon events in Figure 2 and 3. Wet and dry seasons were also clarified by using horizontal bar on x-axis. The old description of “rainstorm” is incorrect. These events we monitored are typhoons announced by Central Weather Bureau rather than rainstorm.

180 use of term "carrying capacity" - how do you know what carrying capacity is?

This term is specific to maximum amount. The point about N supply and transport compromise is for the discussion section, not results. In discussion, need to provide

more theoretical context for these ideas.

We abandoned the term “carrying capacity”, which we cannot estimate as indicated by reviewer. We also revised the manuscript thoroughly including the structure and figures. Results and discussion are clearly separated and the ideas in Discussion about the final conceptual model had been enhanced.

180-183 - incomplete sentence

Corrected and now the sentence is in Discussion.

192 - first mention of forbidden cultivation. Please elaborate

It is now “To rehabilitate the land locked salmon, the cultivated farms along Yusheng Creek were expropriated by the government since 2005. The expropriated vegetable farms were categorized as inactive farms in this study. On the other hand, the currently growing farms are designated as active farms (Huang et al., 2012).”.

199 - what are you comparing to the large rivers?

As pointed out by reviewer, we found this sentence is meaningless. This sentence had been eliminated.

202 - typo

Corrected.

202-203. Doesn't make sense - please clarify.

The old sentence is misleading. After re-structuring and rephrasing, this sentence no longer exists.

203-204. wording unclear.

We followed the suggestion by Dr. Ziegler, the sentence is now in Discussion “Increasing phosphate concentration accompanies the increase in discharge, congruent with the hydrologic controls on the enhancement of phosphate concentration in other watersheds”. (Lines 415-418)

206-207. how are sediments released. Do you mean desorption in the river? Phosphate you measured was dissolved, right?

In old version, the sentence is wrong and misplaced in Results. This desorption process was discussed now in Discussion. Although the PO_4 we measured is dissolved, however, high PO_4 always accompanied by high TSM and high discharge indicating

that surface erosional process and subsequent PO_4 desorption from soil must be involved. Since PO_4 is particle-reactive to enhance the PO_4 export cannot be achieved by solely leaching from soil.

Relevant discussion about the mechanism for phosphate transport is now in Lines 413-423.

243-244. Unclear. Please elaborate.

We drew more references regarding the atmospheric deposition and N storage in forest soil for discussion. The N storage (6909 kg-N/ha) in forest soil is $\sim 200\times$ the atmospheric N deposition and $\sim 1000\times$ the N export. Such huge storage is supportive to our old statement that though the NO_3 concentration was diluted during high flow yet the N flux was still increasing as discharge increases.

However, recovery is not a good term thus we modified the old sentence. We speculate the unceasing nitrogen export from the watershed may partially be attributed to the fast supplement of nitrogen to the watershed system. The old sentence now changed to "This may imply either the nitrogen storage in the watershed is sufficient to afford frequent flooding or the supplement of nitrogen to the watershed system is fast." (Lines 409-410). Please refer to Lines 361-368 for more discussions.

254 - First sentence does not make sense - what does "Except for the concentration", refer to?

This sentence does not exist anymore.

261 - Wouldn't high yields be due to fertilizer applications or human waste inputs? More discussion needed

We used "partially" from atmospheric deposition this sentence. Although atmospheric deposition may not be as substantial as the fertilization is, $\sim 30\text{kg-N/ha/yr}$ is not a small amount particularly for the pristine catchment where no agricultural activities but atmospheric deposition from long-range transport.

281 - can you put together a course budget of inputs and outputs to confirm that they are N saturated.

We used "likely N saturated" in previous version. In this revised version, as replied above we added estimation of input-output budget and more discussions.

"In the pristine watershed (Sta. G), net increase of DIN inventory is likely occurring in the system. Besides, the DIN leaks out of the forest in growing season (DIN concentration follows air temperature) showing a syndrome of nitrogen

saturation.”(Line 361-363)

“The estimation of the soil total N pool in the neighboring watershed (Owen et al., 2010) was 6,909 kg-N/ha, which is 1000x the export from pristine watersheds, being supportive to our speculation of sufficient nitrogen storage.”(Lines 410-412)

293 - I don't understand how the immediate recovery implies the intrinsic storage is large. This requires more elaboration

This statement was inferred from the temporal recovery of DIN:DIP ratio. We agree the rebound of DIN:DIP “ratio” does not necessarily imply a large storage, thus the expression has been removed.

297 – results

Done as advised.

313 incomplete sentence

It is now “In this condition, most of the additional stream discharge comes from the subsurface that contains more nitrate yet less phosphate, therefore, $DIN_c:DIP_c$ elevates significantly (Fig. 8).” (Lines 457-459)

315 add: most nitrates WERE depleted IN the surface runoff. Sentence seems incomplete.

We modified the original sentence to “During the typhoon or rainstorm flood (Fig. 9c), stream discharge, dominated by surface runoff in which nitrate is depleted, decreases nitrate concentration in the river.” (Lines 461-462)

317 I don't think a ratio can be thought of as being diluted.

Reviewer is right. The description is inappropriate. We changed our entire statement in Section 5.3.

Conclusion - don't include results you presented earlier (e.g. line 331 - 333).

We rewrote Conclusion and included more scientific implications instead of merely description of the results.

Eqn 1 - use subscripts with load to indicate month

We added subscript, m, into the Eqn. 1.

Figure 1. Can't tell how the three sites are situated in relation to one another. What is

inactive vegetation? Do you mean farming? Define the abbreviations for the three catchments in the caption.

The three sites are actually very close. We re-drew Figure 1 to make it visually separable on purpose.

We also re-named the abbreviations for the catchment and defined them in the caption.

Inactive vegetation is now changed to inactive farm in Figure 1.

Figure 6 - Hard to interpret. 4 axes per plot? Only two things plotted. I would simplify to only what you need to make the point. No legend is given that define bars vs. lines. kg unit is meaningless, is this supposed to be concentration or flux? Give each subplot its own letter in figure and in caption. Hard to compare the different types of rivers because scales vary for each - keep constant.

Unit of kg is wrong. Since Figure 6 is less informative we decided to remove.

Figure 8. Create legend that indicates open symbols vs. solid symbols are from different flow levels.

It is now Figure 7. Legends had been created.

Figure 9. This conceptual model needs work. It is difficult to understand. In caption state that arrow size refers to water runoff amounts (as opposed to nutrient runoff amounts). Conceptual model in a) shows NO₃ highest in surface soils, but surface runoff says NO₃ is low. Why is that? Doesn't match the description in the text, which says that surface nitrate is high. Unclear that the arrows in the stream refer to the change in concentration during the event. In general, this figure is very hard to interpret by itself. I suggest trying to redo it so that it does.

The conceptual model has been re-drawn and now we believed it can stand alone to explain the dynamic DIN and DIP export. The relevant descriptions are now in Section 5.3.