Hillslope Sediment Trapping by Natural or Cultivated Riparian Vegetation in Northern Laos

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Abstract

In recent years growing human pressure on agricultural land in the north of the Lao PDR has led to accelerated degradation processes along hillslopes, and higher sediment delivery rates to streams. Furthermore, high demand from urban centres is attracting farmers to cultivate vegetables in riparian areas. These land-use changes may have negative affects on stream water quality. The aims of this study were to assess i) the water and sediment trapping efficiency of riparian vegetation in northern Laos, and ii) the potential effect of cultivating riparian land on these efficiencies. In May-October 2006, flows of surface runoff and sediment were monitored across three riparian sites. Sites were arranged into pairs of adjacent riparian land plots; one plot was covered with riparian vegetation (native grass, banana or bamboo) and one plot cultivated with upland rice, which was used to test the effect of annual cropping and also acted as the control. Plots were equipped with three Gerlach troughs placed at the upper rim of the riparian zone and three troughs at the lower rim to measure event inflow and outflow (runoff volumes and sediment loads). Event trapping efficiency was calculated as the portion of inflowing water and sediment retained in the plot. Results showed that banana and native grass plots were active sinks, retaining sediment and water (median runoff trapping efficiency = 0.10, median sediment load trapping efficiency = 0.40). In contrast, the trapping efficiencies of runoff and sediment load by bamboo and upland rice were mostly negative, suggesting that these areas not only fail to retain inflows of water and sediment but also act as active sources, delivering more runoff and solids to the stream. We measured sediment concentrations in the runoff exported from upland rice plots and found that these were three-and-a-half times higher than the sediment concentrations in the runoff entering the plots, and nine to seven times the runoff sediment concentration exported from the banana and native grass plots. Thus, the cultivation of annual crops (i.e. upland rice) leads to the delivery of turbid runoff from the riparian areas directly into the stream, and therefore has a considerable effect on downstream water quality.

Keywords: trapping efficiency, riparian vegetation, riparian land management, water quality

1. Introduction

Riparian areas are ecotones at the interface between terrestrial and aquatic ecosystems, and act as natural biofilters that protect aquatic environments from excessive sedimentation, polluted surface runoff and erosion (Karssies and Prosser, 1999). Riparian land adjacent to a water course is the last potential sink for retaining hillslope sediments. In agricultural areas these zones can be managed to improve water quality by planting vegetation that prevents non-point pollutant sources from reaching water bodies (e.g. Karssies and Prosser, 1999). The ratio of incoming runoff or sediment that is trapped in the riparian area is referred to as trapping efficiency. Trapping efficiencies depend on many factors, such as i) incoming flow rates and sediment particle size; ii) vegetation cover and type; and iii) the hydrological and topographic settings of the riparian area (e.g. Dosskey, 2001). Research conducted in temperate climates showed that riparian areas can retain up to 70-99% of pollutant loads. However, there is still a lack of information about tropical riparian areas (Karssies and Prosser, 1999; McKergow, et al, 2004). In the wet tropics, McKergow et al. (2004) reported lower sediment trapping efficiencies (37-46%) and even negative values when exfiltration in the riparian area was observed.

Over the last two decades in northern Laos, growing human pressure on agricultural land has been accelerating degradation processes along hillslopes, leading to higher sediment loads delivered to streams (e.g. Lestrelin et al, 2005; Sengtaheuanghoung et al, 2006). Trapping sediments in riparian areas could be an effective way of reducing the downstream impacts of these higher sediment delivery rates. However, little is known about the water and sediment trapping efficiency of riparian vegetation types found in northern Laos. The issue is particularly important because high demand for fresh vegetables in urban centres is now attracting farmers to cultivate riparian land, where irrigation is easier. These changes in the use of riparian land may have important consequences for stream water quality.

The aim of this research was to assess i) the water and sediment trapping efficiencies of riparian vegetation in a northern Lao catchment, and ii) the potential effects of cultivating riparian land on these efficiencies. This study is the continuation of research on riparian land started in 2005 (Vigiak et al, 2006).

2. Materials and methods

2.1 Description of study site and vegetation

The study was conducted in the Houay Pano catchment (Luang Prabang Province), where average rainfall amounts to 1,259 mm per year, more than 90% of which falls during the monsoon season from mid-May to mid-October. The catchment is representative of the no-input slash-and-burn cropping system of Southeast Asia and the fallow period has been reduced from the traditional 10-15 years to 2-5 years at present (de Rouw et al, 2005). The main reach consists of a 1,200-m long, second-order perennial stream of irregular topography with an average slope gradient of 0.19 m/m (Ribolzi et al, 2005). The riparian areas in the catchment are mainly convex or convex-concave in shape, steep (10-130%), and narrow (4-23 m). More than 43% of the riparian areas along the Houay

Pano stream are covered with grass and shrubs, dominated by *Microstegium ciliatum* grass. Bamboo species, especially *Dendrocalamus* sp. and *Cephalostachium virgatum*, and banana stands cover 19% and 15% of these riparian areas respectively. The cultivation of banana in Houay Pano is a low-input farming activity. Farmers plant bananas, sometimes burn the undergrowth vegetation at the onset of the rainy season, and cut single stems carrying ready bunches to be sold at the market. They do not till the soil, and the vegetation cover remains quite high throughout the year. This low-labour, low-input management system should not be confused with intensive banana plantations found in other tropical areas. The remaining riparian zones are covered with forest vegetation (15%), cassava (5%) and Elephant grass (*Pennisetum purpureum*, 3%).

2.2 Determination of trapping efficiencies

During the 2006 monsoon season (May-October), the flow of surface runoff and sediment across three riparian sites was monitored using Gerlach troughs (Gerlach, 1967). The sites were chosen and equipped to include pairs of adjacent riparian land plots with similar upslope land use and topography. Each site consisted of one plot covered with riparian vegetation and one plot cultivated with upland rice, which is the most common annual crop in the area and was used as the control. The three vegetation types selected for this study were native grass dominated by *M. ciliatum*, bamboo, and banana. Table 1 summarises some of the site characteristics.

Plots were equipped with three Gerlach troughs placed at the upper rim of the riparian zone and three troughs at the lower rim to measure event inflow and outflow runoff volumes and sediment loads. The trapping efficiency (TE) of each riparian plot was measured as:

$$TE = (X_{in} - X_{out}) / X_{in} \qquad (1)$$

where X_{in} is the inflow measured in the three upper rim troughs, and X_{out} is the outflow measured in the three lower rim troughs. TE was calculated per event on runoff volumes (TER), sediment concentrations (TESC), and sediment loads (TESL).

Table 1: Characteristics of the riparian sites (A and B indicate the plot within the site)

Site	Vegetation	Slope (%)	Width[1] (m)	Upper/buffer ratio[2]	Upslope land use
1A	Banana (*Musa sapientum*)	57	3.3	5.8	banana
1B	Upland rice	65	5.5	7.2	banana
2A	Bamboo (*Dendrocalamus sp.*)	49	3.9	7.5	banana
2B	Upland rice	48	5.2	6.9	banana
3A	Natural grass (*Microstegium ciliatum*)	75	5.1	5.5	fallow
3B	Upland rice	65	7.0	6.0	fallow

[1]Width is the horizontal distance from the upper to the lower Gerlach trough rims.
[2]The upper/buffer ratio is the ratio of the watershed contributing surface divided by the riparian area surface (e.g. Dosskey et al, 2002).

2.3 Statistical analysis

Trapping efficiencies distributions were tested for normality with Kolmogorov-Smirnov tests. For non-Gaussian distributions, statistical analysis was conducted with non-parametric tests. Comparisons of adjacent plots in the same site (paired sample) were carried out using Wilcoxon two-sample tests. Comparisons of *n* paired sites were made with Friedman tests. All tests were run at the probability $\alpha = 0.01$ level. XLSTATS 5.2 (Addinsoft, 2002) was used for all statistical analysis.

3. Results and discussion

3.1 Water and sediment flows across the riparian sites.

From the beginning of May to the 15th of October 2006, 19 rain events, with a total rainfall of 1,003 mm, caused flows of surface runoff and sediment load across the riparian sites. Figure 1 shows the total volume of water runoff and sediment load per metre of contour line measured at the upper rim (incoming flows) and at the lower rim (outgoing flows) of the riparian sites. Incoming flows were log-normally distributed. Incoming runoff into the study site ranged from 0-100 l/m, with a geometric mean of 6.5 l/m. Sediment load ranged from 0-0.54 kg/m, with a geometric mean of 0.011 kg/m. The volume of incoming flow did not vary significantly among paired plots with the exception of site 1, where plot 1A (banana) received more than three times the runoff and more than six times the sediment load than did the adjacent plot 1B (upland rice). Sediment concentration in the incoming flow ranged from 0.03 to 16.35 g/l, with a geometric mean of 1.64 g/l. and Friedman tests showed that it was not significantly different among plots. Outgoing flows were also log-normally distributed. Measurements of outgoing flows indicated that in general these riparian sites contributed water and sediment to the stream. Overall observations showed a three-fold increase in water (geom. mean = 20.2 l/m), a two-fold increase in sediment concentration (geom. mean = 3.03 g/l), and a six-fold increase in sediment load (geom. mean = 0.06 kg/m) in the outgoing compared to incoming flows. However, there were considerable differences among vegetation types.

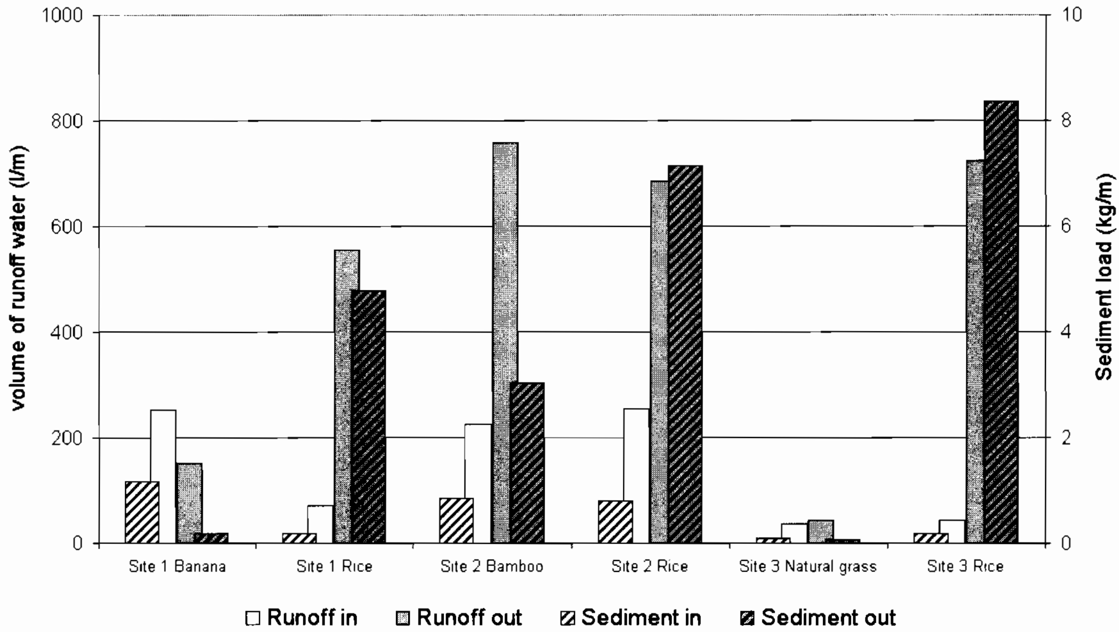

Figure 1: Total flows of water runoff and sediment loads across the three pairs of riparian sites for the season (May-October) 2006

Note that the flows are expressed as litres and kilogrammes per linear metre of contour line.

3.2 Trapping efficiencies of vegetation types

Table 2 shows the median trapping efficiencies for water runoff (TE_R), sediment concentration (TE_{SC}), and sediment load (TE_{SL}) for the six plots. Because trapping efficiencies were not normally distributed, and it was not possible to parameterise the distribution, pairwise comparisons between plots were made using non-parametric Wilcoxon two-sample tests. Table 2 shows the median trapping efficiencies per plot. The different letters besides the numbers in each column show results that were significantly different from each other, at the $\alpha = 0.01$ level, in the pairwise comparison (e.g. medians designated by 'a' are significantly different from medians designated by 'b', vice versa and so on, and also medians designated by the same letter were not significantly different from each other). The alphabetical order of the letters indicates the degree of efficiency in trapping from best to worst so that 'a' designates the relatively highest TEs and 'd' the lowest or most negative TEs. The TE_R

and TE_{SL} values for the banana and native grass plots were not significantly different and showed the best trapping efficiencies with an average TE_R of 0.10 and an average TE_{SL} of 0.40 (data from both plots taken together). Thus, our results suggest that these plots were active sinks for sediment and water runoff. On the other hand, both bamboo and upland rice showed mostly negative trapping efficiencies suggesting that these zones acted as sources of water and sediment. Although Wilcoxon tests did not indicate a significant difference in any trapping efficiency between bamboo and upland rice at site 2, the best rice trapping efficiencies were recorded for upland rice plot 2B. The median TE_{SL} of all upland rice plots was -20: this means that in half of the measured cases, the sediment load (kg/m) exported from the plot and being delivered to the stream was 20 times higher than the sediment load entering the plot from the upslope area.

Table 2: Median trapping efficiencies

Site	Plot	n	TE_R	TE_{SC}	TE_{SL}
Site 1	1A Banana	17	0.35a	0.52a	0.72a
	1B Upland rice		-8.79c	-2.90d	-25.83c
Site 2	2A Bamboo	19	-2.99b	-0.54c	-4.47b
	2B Upland rice		-1.73b	-0.66c,d	-7.23b
Site 3	3A Natural grass	17	-0.25a	-0.08b	-0.02a
	3B Upland rice		-22.02d	-6.63d	-204.22d

Efficiencies are shown for runoff volume (TE_R), sediment concentration (TE_{SC}), and sediment load (TE_{SL}) measured in the six plots during the rainy season (May-October) 2006, Houay Pano catchment, Lao PDR. Different letters indicate significantly different distributions (bilateral Wilcoxon two sample tests) at $\alpha = 0.01$.

Marked differences were observed in the capacity of different vegetation types to trap sediment suspended in the runoff water (TE_{SC}, figure 2, see also table 2). The banana stand plot showed the highest TE_{SC} scores, which were never negative. Native grass showed only a poor ability to reduce runoff water sediment concentrations, with a practically nil median TE_{SC} value. Wilcoxon tests indicated that TE_{SC} distributions for the three upland rice plots were not significantly different (table 2). The upland rice box plot in figure 2 includes all the upland rice data, and shows that these plots contributed the largest amount of sediment to the stream.

Measurements showed that the sediment concentration of the runoff exported from the site 1 upland rice plot was on average seven times higher than the runoff sediment concentration exported from its adjacent banana plot. Furthermore, the sediment concentration of the runoff exported from the site 3 upland rice plot was nine times that exported from its adjacent native grass plot. Thus, cultivation of annual crops (i.e. upland rice) leads to the delivery of runoff water with relatively high sediment concentrations from the riparian areas directly into the stream, thereby considerably increasing water turbidity.

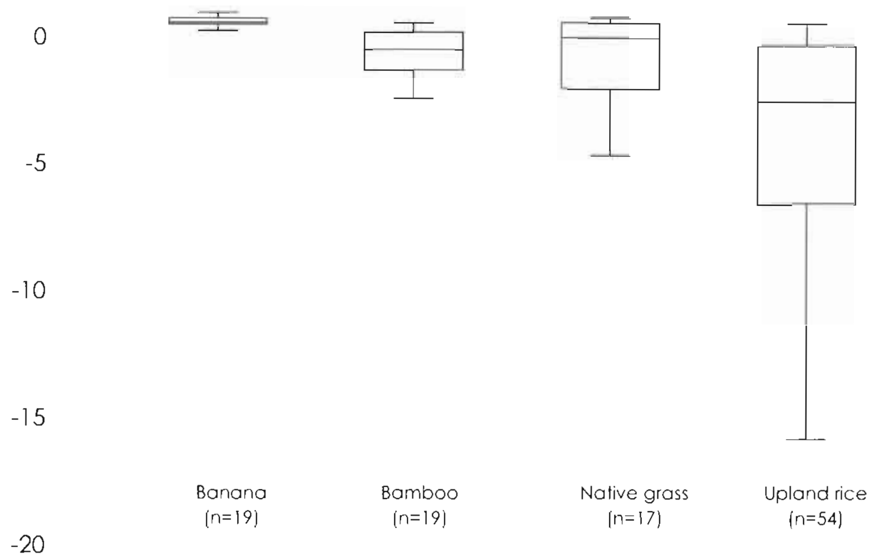

Figure 2: Box plots of sediment concentration trapping efficiency (TE_{SC}) by the four vegetation types

Measurements from Houay Pano, Laos, May-October 2006: n indicates the number of observations for each vegetation type. The rectangle limits represent first and third quartile, the black line represents the median, and the tails represent 1.5 times the interval between first and third quartile of the series.

Table 3: Ranges and Spearman's correlation coefficients of trapping efficiencies

	unit	min	max	TE_R	TE_{SC}	TE_{SL}
Inflow						
Runoff volume	l/m	0	101	0.659*	0.068	0.436*
Sediment concentration	g/l	0.03	16.35	0.477*	0.649*	0.647*
Sediment load	kg/m	0	0.54	0.760*	0.389*	0.706*
Rainfall						
Rainfall amount	mm	4	106	0.175	-0.203	-0.085
30-min max intensity	mm/h	8	74	0.278	-0.231	0.040
Average intensity	mm/h	1.5	46	0.333	-0.183	0.339
72-hour antecedent rainfall	mm	0	52.5	0.139	-0.116	-0.127

Coefficients show surface runoff (TE_R), sediment concentration (TE_{SC}) and sediment load (TE_{SL}) correlations with inflow properties and rainfall characteristics as measured in the three plots cultivated with upland rice. * indicates significant correlation at $\alpha = 0.01$ (n = 54).

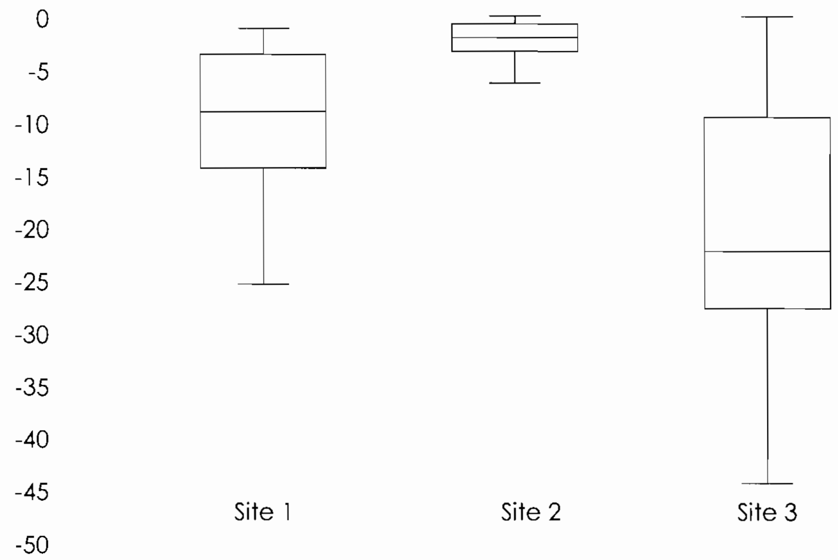

Figure 3: Box plots of water runoff trapping efficiency in the three upland rice plots

TER from Houay Pano, Laos, May-October 2006. The rectangle limits represent first and third quartile, the black line represents the median, and the tails represent 1.5 times the interval between first and third quartile of the series.

4. Conclusions and recommendations

The trapping efficiencies measured in open field conditions for the entire 2006 rainy season in Houay Pano were rather low. The median trapping efficiency for water runoff (TE_R) measured in banana stands and native grass plots (i.e. the riparian vegetation types that acted as sediment sinks) was 0.10, and the median trapping efficiency of sediment load (TE_{SL}) was 0.40. Nevertheless, our results are comparable to those reported by McKergow et al. (2004) from data collected in the wet tropics. The presence of seepage and exfiltration of return flow leading to soil saturation may affect the capacity of riparian zones to infiltrate incoming runoff, trap water and sediment. These low trapping efficiencies imply that management of riparian zones alone may not compensate for the negative impacts that increased erosion of hillslopes has on surface water quality. Rather, this management should be accompanied by the implementation of conservation measures in the fields.

Banana stands, however, may show a promising ability to reduce sediment delivery rates: over the whole season, 84% of incoming sediment load was retained in the banana riparian plot. Banana stands and native grass were the most effective riparian vegetation types in retaining *in situ* water and sediments. The bamboo plot was most often a source of water and sediment, probably because of the poor undergrowth vegetation.

This comparison of riparian vegetation with upland rice plots shows the danger of annual crop cultivation in riparian zones. The observed sediment concentrations (geom. mean = 6.6 g/l) were 3.5 times higher in runoff coming out of the rice plots than that going in, and seven to nine times higher than that exported from native grass and banana plots. Similarly, water runoff volumes and sediment loads delivered to the stream from upland rice plots were many times higher those from naturally vegetated plots. While cultivation of low-input, extensively-managed banana stands may reduce pollutant delivery to streams, the conversion of riparian vegetation into annual crops could transform riparian land from a sink to a source of sediment. This would greatly deteriorate the quality of surface water bodies.

References

Addinsoft. 2002. XLAST version 5.2. Paris.

de Rouw, A., Soulilad, B., Phanthavong, K. and Dupin, B. 2005. "The adaptation of upland rice cropping to ever-shorter fallow periods and its limit". In Bouahom, B., Glendinning, A., Nilsson, S. and Victor, M. (eds.). *Poverty reduction and shifting cultivation stabilisation in the uplands of Lao PDR*. Vientiane: NAFRI. pp.139-148.

Dosskey, M.G. 2001. "Toward quantifying water pollution abatement in response to installing buffers on crop land". *Environmental Management*. 28: 577-598.

Dosskey, M.G., Helmers, M.J., Eisenhauer, D.E., Franti, T.G. and Hoagland, K.D. 2002. "Assessment of concentrated flow through riparian buffers". *Journal of Soil and Water Conservation*. 57: 336-343.

Gerlach, T. 1967. "Hillslope troughs for measuring sediment movement". *Revue de Géomorphologie Dynamique*. 17: 173.

Karssies, L.E. and Prosser, I.P. 1999. *Guidelines for riparian filter trips for Queensland irrigators*. Canberra: CSIRO Land and Water Technical report 32/99.

Lestrelin, G., Giordano, M., and Keohavong, B. 2005. *When "Conservation" leads to land degradation. Lessons from Ban Lak Sip, Laos*. Colombo: IWMI Research report 91.

McKergow, L.A., Prosser, I.P., Grayson, R.B. and Heiner, D. 2004. "Performance of grass and rainforest riparian buffers in the wet tropics, Far North Queensland. 2. Water quality". *Australian Journal of Soil research*. 42: 485-498.

Ribolzi, O., Silvera, N., Xayyakummanh, K., Latchachak, K., Tasaketh, S. and Vanethongkham, K. 2005. "The use of Ph to spot groundwater inflows along the stream of a cultivated catchment in the northern Lao PDR". *The Lao Journal of Agriculture and Forestry*. 10: 74-84.

Sengtaheuanghoung, O., Valentin, C., Ribolzi, O., de Rouw, A. and Thiébaux, J.-P. 2006. "Enhancing Water Quality through the Better Land Management of Degraded Highland Regions in Northern Lao PDR". Proceedings of 2nd GWSO-Asia Network Meeting/Workshop, Sun Yat Sen University, Guangzhou, China, June 8-11, 2006.

Vigiak, O., Ribolzi, O., van Bresusegem, N., DuangVong, I. and Valentin, C. 2006. "Soil and water conservation efficiencies of riparian vegetation types in northern Lao PDR". *The Lao Journal of Agriculture and Forestry*. 12: 87-108.

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