Filtering of water pollutants by riparian vegetation: bamboo versus native grasses and rice in a Lao catchment

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Although bamboo is sometimes planted in riparian areas to conserve soil and water, a Southeast Asian study suggests that it may not be the best ground cover for this purpose.

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Located at the interface of terrestrial and aquatic habitats, riparian zones have an important role in filtering and trapping of sediment and dissolved and sediment-borne pollutants. The effectiveness of riparian vegetation in filtering pollutants depends on several factors, including structure, composition and density of ground and canopy cover. In the humid tropics of Southeast Asia, the use of bamboo species – which provide important non-wood forest products (NWFPs) – has also been recommended for soil and water conservation. However, evidence of bamboo's effectiveness in this regard is limited.

This article reviews current knowledge on the water-related functions of vegetation in riparian areas. It then focuses on the results and main conclusions of research carried out in a headwater catchment in the north of the Lao People's Democratic Republic to compare fluxes of water and sediment across riparian sites covered with bamboo and native grass (Vigiak *et al.*, 2008). The study also compared the filtering properties of natural riparian vegetation with those of cultivated upland rice.

SEDIMENTS AND POLLUTANTS

In Southeast Asia, increasing population pressure on the land is causing very rapid land-use changes: cultivation on sloping land is intensifying, while in most countries forest cover is shrinking. Shifting cultivators must recultivate the same land more frequently, which disrupts the cultivation-fallow cycle of their traditional farming system. The consequences are losses of soil fertility and crop yield, accelerated erosion on hillslopes and higher sediment deliv-

Bamboos are important non-wood forest products in Southeast Asia, for food (shoots) and for building material and handicrafts (stems)

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In the traditional shifting cultivation system of mountainous Lao People's Democratic Republic, the landscape is a mosaic of cultivated fields, secondary vegetation and forest remnants; cultivation of annual crops on steep slopes is associated with high sediment yields

ery to streams (Roder, Phengchanh and Maniphone, 1997; Chaplot *et al*., 2005). In forested catchments, compaction of soil on logging roads and skid trails may reduce water infiltration and augment surface erosion (Sidle, Tani and Ziegler, 2006). As sediments are carriers of nutrients and pollutants, the increase of sediment delivery to streams has negative impact on the livelihoods and health of downstream populations.

Provision of safe water is usually a main objective of natural resource management policy. Good water quality can be achieved by reducing emission of pollutants at the source, e.g. by proper management of agricultural or forestry activities, and/or by placing natural filters in the landscape to prevent pollutants from reaching the streams. Control of water pollutants is more effective near the pollution sources, i.e. in headwater catchments, where wetlands and riparian zones may be extremely effective pollutant filters.

RIPARIAN ZONE FUNCTIONS

A riparian zone, strictly defined, comprises only the vegetation in a stream channel and along the river banks; however, the term has recently been used more broadly to include the part of the landscape adjacent to a stream that exerts a direct influence on stream and lake margins and the water and aquatic ecosystems associated with them (Karssies and Prosser, 1999). In the landscape, riparian habitats are corridors located at the interface of terrestrial and aquatic ecosystems. They act as conduits, filters or barriers controlling flows of water, sediments and nutrients. Ensuring riparian ecological functions such as filtering of polluted overland and subsurface flows, stabilization of stream banks and control of in-stream habitats is an important part of sound natural resource management (Mander and Hayakawa, 2005).

Many subsistence and income-generating activities that are integral parts of rural household economies are undertaken in riparian zones. In the Lao People's Democratic Republic, naturally occurring and cultivated bamboos found in riparian zones are important sources of food (shoots) and of raw materials for housing and handicrafts (de Beer and McDermott, 1996). Forest remnants along the stream provide wildlife habitat and are popular sites for game hunting and fishing. Relatively flat topography and the availability of water for irrigation make riparian land attractive for cultivation. Bananas are often cultivated along headwater streams. Recently, the increasing demand for produce for the growing urban market has enticed farmers to convert riparian land into orchards. Vegetable gardening is mainly a dry-season activity; however, the upper reaches of headwater streams are also cultivated during the rainy season, either for vegetables or upland rice. The effects of these land-use changes on stream water quality are largely unknown.

RIPARIAN VEGETATION AS SEDIMENT FILTER

The effectiveness of riparian vegetation in filtering pollutants depends on the nature of the pollutant. Retention of sediments is usually higher than retention of sediment-bound pollutants, because most sediment-bound pollutants are usually attached to finer particles which are more difficult to retain; and dissolved contaminants are reduced the least (Karssies and Prosser, 1999). Riparian vegetation mainly filters sediments through the following mechanisms (Karssies and Prosser, 1999; Mander and Hayakawa, 2005):

- by enhancing infiltration (i.e. reducing runoff volume) and increasing

Growing demand from urban markets entices farmers to establish vegetable gardens on riparian land along the Mekong River (Luang Prabang, Lao People's Democratic Republic)

Bamboos have important riparian ecological functions, such as shading and control of water temperature and in-stream habitats (left); however, because of their scant ground cover, they do not appear to be very effective in trapping hillslope runoff water and sediments (right)

surface roughness (i.e. reducing run-off velocity), which favour sediment settling out – with effectiveness depending on many factors, such as rainfall characteristics and riparian topography;
- by protecting the stream banks and riparian soils from direct erosion;
- by filtering solid particles;
- by adsorbing pollutants;
- by taking up nutrients before they reach the watercourse.

Soil in riparian areas also adsorbs pollutants, and microbes in the soil take up nutrients.

Infiltration is by far the most important mechanism filtering incoming hillslope surface flows. However, when subsurface flows are sizeable, seepage and saturation flows can hinder infiltration (McKergow *et al.*, 2004).

The effectiveness of riparian vegetation in trapping sediments depends on many factors, such as incoming flow rates, sediment particle size, hydrologic and topographic settings of the riparian area, and vegetation cover and type (Karssies and Prosser, 1999).

EFFECTIVENESS OF DIFFERENT VEGETATION TYPES

Density, height and type are the most important characteristics affecting the capacity of vegetation to retain sediments in riparian land (Karssies and Prosser, 1999).

The density of the vegetation is important, particularly at ground surface, because the vegetation stems offer resistance to overland flow, thus reducing flow velocity and favouring particle settling. Vegetation should be uniformly dense; stoloniferous grasses (those spread by lateral stems, called stolons, which creep over the ground and give rise to new shoots along their length) and creeping grasses are the best, whereas tussocks may concentrate flow (Karssies and Prosser, 1999). A minimum of 45 percent ground cover is recommended for effective buffers. Vegetation height should be at least 10 to 15 cm; it must be high enough to avoid submergence from overland flow.

The effect of vegetation type is more controversial. Grass may be more effective than woody vegetation in reducing bank erosion and trapping sediments, but grass requires active management because succession processes tend to favour woody vegetation (Lyons, Trimble and Paine, 2000). Grass filters colonize new sediments quickly so they are not removed by subsequent runoff; grass filters should be perennial, resistant to flooding and drought, able to grow after partial inundation, and not invasive of other ecosystems (Karssies and Prosser, 1999).

Unless undergrowth is dense, forest is considered the least effective buffer because stems are dispersed and flow often gets concentrated into rills, thus becoming more erosive. Litter works only as a temporary store: it traps sediments, but these are flushed out by subsequent runoff (Karssies and Prosser, 1999; McKergow *et al.*, 2004). However, trees and shrubs can provide other benefits to streams, such as shade and control of water temperature, which affect primary production and in-stream habitat (Lyons, Trimble and Paine, 2000). Forest should therefore be bordered by a grass strip to trap sediments from adjacent fields. For the southeastern United States, Sheridan, Lowrance and Bosch (1999) recommended forest riparian buffers composed of three zones: a grass filter strip adjacent to fields, whose main function is to spread surface runoff as sheet flow; a first forested zone where infiltration and sedimentation occurs; and a second forested zone to protect and stabilize stream banks.

Bamboo stands frequently occur near streams. Their bushy structure and close canopies ensure good shading of the stream, but the understorey vegetation may be sparse. In the southwestern and midwestern United States, the native bamboo species *Arundinaria gigantea* was found to be an effective filter for sediment, nitrogen and phosphorus (Blattel *et al.*, 2005; Schoonover *et al.*, 2006). Yet few other field studies have addressed the effectiveness of bamboo in filtering sediments.

BAMBOO VERSUS GRASS VERSUS RICE

To assess the efficiency of sediment trapping by naturally occurring or cultivated riparian vegetation, a field experiment was conducted in a small headwater catchment of northern Lao People's Democratic Republic (Houay Pano catchment, Luang Prabang Province). High sediment yields (more than 10 tonnes per hectare per year) have been associated with annual crops in this catchment (Chaplot *et al.*, 2005).

The headwater catchment receives an average of about 1 300 mm of rain per year, most of it during the monsoon season that lasts from mid-May to mid-October. The catchment is representative of the no-input slash and burn system of Southeast Asia. Over the past 30 years, the fallow period has been reduced from 10 to 15 years down to 2 to 5 years (Lestrelin and Giordano, 2006). Altitude ranges from 400 to more than 800 m. The main stream reach is a second-order perennial stream of irregular but steep topography. Riparian zones are mainly of convex or convex-concave shape, steep and narrow. Stream banks are high and steep.

More than 43 percent of the riparian areas along the Houay Pano stream are covered by a grass and shrub vegetation dominated by *Microstegium ciliatum* (referred to here as "native grass"). Bamboos, especially *Dendrocalamus* sp. and *Cephalostachium virgatum*, cover 19 percent of the riparian areas. Native grass and bamboo sites differ in ground and canopy cover (Table 1); therefore different performance in sediment filtering was expected. The remaining riparian areas in the catchment are covered with banana (15 percent), forest (15 percent), cassava (6 percent) and napier grass (a cultivated fodder species, *Pennisetum purpureum*) (3 percent).

TABLE 1. Average characteristics of riparian naturally occurring vegetation type, estimated from 3 m x 3 m plots during the 2005 rainy season (July–October 2005), Houay Pano (n = 12)

Vegetation type	Canopy cover (%)	Ground cover (%)	Density of grass stems (n/m²)	Grass biomass (g/m²)	Undergrowth height (m)
Native grass	85	88	355	435	0.75
Bamboo	70	39	64	45	0.27

TABLE 2. Characteristics of the riparian sites for monitoring of water and sediment fluxes, Houay Pano catchment, Lao People's Democratic Republic

Year/site	Vegetation type	Slope (%)	Width[a] (m)	Upslope land use
2005				
NG1	Native grass	16	11.6	3 years fallow
NG2	Native grass	58	10.4	Teak
BB1	Bamboo	20	8.8	2 years fallow
BB2	Bamboo	70	7.9	Banana
2006				
NG3	Native grass	75	5.1	2 years fallow
R_NG	Upland rice	65	7.0	2 years fallow
BB3	Bamboo	49	3.9	Banana
R_BB	Upland rice	48	5.2	Banana

[a] Width is the horizontal distance of the monitored buffer zone.

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In headwater mountain catchments of the northern Lao People's Democratic Republic, riparian areas are steep and narrow; clearance of this land for cultivation of rice or other annual crops may have serious negative impact on water quality

For two rainy seasons, volumes of surface water runoff and runoff sediment concentration entering and exiting bamboo and native grass riparian sites were measured by means of open troughs (Vigiak *et al.*, 2008). Two bamboo and two native grass sites were monitored in 2005, and one each in 2006. The sites differed in topographic settings, upslope conditions and buffer width. In 2006, vegetation adjacent to the riparian sites was cleared and upland rice was established for use as a reference and to assess the effect of clearance and cultivation in riparian land (Table 2).

Figure 1 shows the total runoff volumes and sediment load entering and exiting the native grass and bamboo riparian sites during the monitoring periods. Two native grass sites reduced the volume of water; these sites had less runoff exiting than entering. In the third, runoff out only slightly exceeded runoff in. All three bamboo sites had more water exiting than entering, which showed that infiltration of rainfall and incoming runoff was limited. Sediments were more concentrated in the runoff exiting the riparian sites than in that entering, particularly under bamboo vegetation. Bamboo sites were therefore sources of sediment to the stream, while native grass was generally a sediment sink.

Both vegetation types, however, were much better filters than upland rice. Figure 2 shows "box-and-whisker" plots of the ratio of sediment concentration in the outflow measured in adjacent plots between upland rice (sites R_BB and R_NG) and bamboo or native grass (BB3 and NG3, respectively) in 17 events during the 2006 monsoon season. The graph shows that runoff exiting upland rice always had higher concentration of sediments than the adjacent plots. Indeed, the sediment concentration in runoff exiting upland rice sites was, on average, three times higher than that in runoff exiting the adjacent bamboo site, and nine times higher than that in runoff from the native grass site.

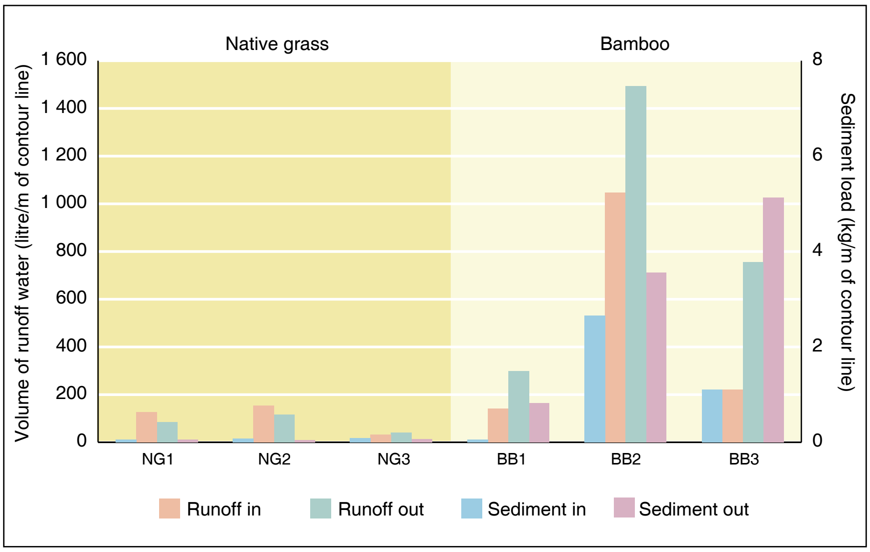
MANAGEMENT IMPLICATIONS

Sediment retention measured in riparian sites in Houay Pano catchment was low. The natural setting of riparian land in this headwater catchment – steep, narrow and clayey – severely limits the possibility of trapping sediment and pollutants *in situ*. Seepage was frequently observed during the study, as is common in riparian zones in the humid and wet tropics (McKergow *et al.*, 2004; Sidle, Tani and Ziegler, 2006). Seepage inhibits infiltration and the resistance of soil to detachment and transport, while possibly triggering landslides and streambank collapse.

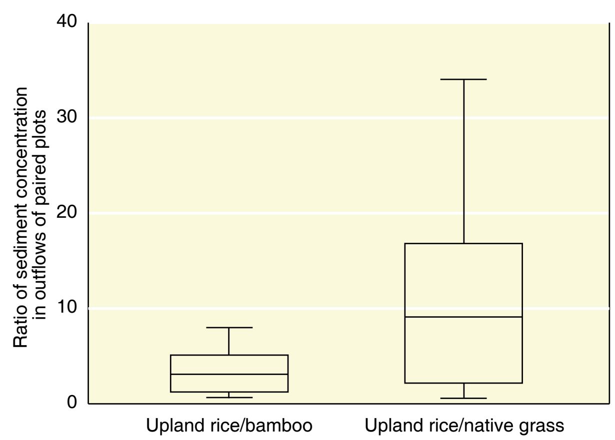
Cultivation of annual crops in this environment leads to high sediment yields (e.g. Chaplot *et al.*, 2005). Given the findings of this study, it is not appropriate to rely exclusively on the filtering capacity of riparian vegetation to enhance water quality. Proper management of riparian land cannot replace proper management of sloping land, but it is essential where cultivation of slopes is intensified.

In northern Lao People's Democratic Republic, riparian land offers important opportunities for income generation for the rural population. Relatively gentle slopes and the presence of water for irrigation make riparian land particularly appropriate for cultivation of vegetables, which fetch increasing prices on the market. However, because of the proximity to streams, the use of riparian land affects water quality. The present study showed that cultivation of upland rice on riparian land led to increased sediment concentration in surface runoff flowing into the stream.

1
Volume of runoff water and sediment load entering and exiting native grass and bamboo sites, Houay Pano catchment, Lao People's Democratic Republic, 2005 and 2006 monsoon seasons



2
"Box-and-whisker" plot of ratios of sediment concentration in outflow, Houay Pano catchment, 2006 (n = 17)



Central line indicates median value; upper and lower edges (hinges) of the box indicate 25th and 75th percentile values; whiskers extend 1.5 times the spread of hinges to show the extent of the sampled population.

Native grass was the best vegetation cover for filtering surface water inflows and thus reducing sediment delivered to streams. Bamboo, although a source of valuable products for local communities, was not effective in reducing sediment pollution to streams, whether it was naturally occurring or planted. As these results contrast with those of Schoonover *et al*. (2006), further research is needed to confirm the effect of bamboo on soil and water conservation and water quality.

The study addressed only one aspect of the relationship between riparian vegetation and water quality. Bamboo effects on bank erosion protection and in-stream habitats are not well understood. It is therefore recommended, as advocated in the United States (Sheridan, Lowrance and Bosch, 1999), that the establishment or management of bamboo stands in riparian zones be coupled with the establishment or maintenance of a grass strip uphill from the watercourse to enhance the trapping of sediments. ◆

Bibliography

Blattel, C.R., Williard, K.J., Baer, S.G. & Zaczec, J.J. 2005. Abatement of ground water phosphate in giant cane and forest riparian buffers. *Journal of the American Water Resources Association*, 41(2): 301–307.

Chaplot, V., Coadou le Brozec, E., Silvera, N. & Valentin, C. 2005. Spatial and temporal assessment of linear erosion in catchments under sloping lands of northern Laos. *Catena*, 63: 167–184.

de Beer, J.H. & McDermott, M.J. 1996. *The economic value of non-timber forest products in Southeast Asia.* Amsterdam, the Netherlands, Netherlands Committee for the World Conservation Union (IUCN). 2nd ed.

Karssies, L.E. & Prosser, I.P. 1999. *Guidelines for riparian filter trips for Queensland irrigators*. CSIRO Land and Water Technical Report 32/99. Canberra, Australia, Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Lestrelin, G. & Giordano, M. 2007. Upland development policy, livelihood change and land degradation: interactions from a Laotian village. *Land Degradation and Development*, 18: 55–76.

Lyons, J., Trimble, S.W. & Paine, L.K. 2000. Grass versus trees: managing riparian areas to benefit streams of central North America. *Journal of the American Water Resources Association*, 36: 919–930.

Mander, U. & Hayakawa, Y. 2005. Purification processes, ecological functions, planning and design of buffer zones in agricultural watersheds. *Ecological Engineering*, 24: 421–432.

McKergow, L.A., Prosser, I.P., Grayson, R.B. & 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.

Roder, W., Phengchanh, S. & Maniphone, S. 1997. Dynamics of soil and vegetation during crop and fallow period in slash-and-burn fields on northern Laos. *Geoderma*, 76: 131–144.

Schoonover, J.H., Williard, K.W.J., Zaczek, J.J., Mangun, J.C. & Carver, A.D. 2006. Agricultural sediment reduction by giant cane and forest riparian buffers. *Water, Air and Soil Pollution*, 169: 303–315.

Sidle, R.C., Tani, M. & Ziegler, A.D. 2006. Catchment processes in Southeast Asia: atmospheric, hydrologic, erosion, nutrient cycling, and management effects. *Forest Ecology and Management*, 224: 1–4.

Sheridan, J.M., Lowrance, R. & Bosch, D.D. 1999. Management effects on runoff and sediment transport in riparian forest buffers. *Transactions of the American Society of Agricultural Engineers (ASAE)*, 42: 55–64.

Vigiak, O., Ribolzi, O., Pierret, A., Sengtaheuanghoung, O. & Valentin, C. 2008. Trapping efficiencies of cultivated and natural riparian vegetation of northern Laos. *Journal of Environmental Quality* (In press). ◆