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Long term natural forest management and land-use change in a developing tropical catchment, Sabah, Malaysia

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Abstract The Segama River catchment in Sabah, East Malaysia embraces a range of land-use types typical of forested land undergoing development in this region. A long term research programme based at the Danum Valley Field Centre (DVFC) monitored suspended sediment transport in the upper Segama and in three nearby small forested catchments, one of which was commercially logged in 1989. Following the disturbance, there was rapid regrowth of secondary vegetation and within three years sediment production had declined significantly and was more comparable with the undisturbed forest areas. At the next scale of monitoring suspended sediment concentrations in the Segama are elevated as a result of the mosaic of forest patches at different stages of use and recovery, but overall, they remain lower than in the downstream part of the catchment, outside the working timber concession. The lower Segama consists of large tracts of commercial plantation, agricultural plots and remnants of degraded forest – all maintaining a potential to generate high volumes of sediment. This paper makes a preliminary comparison of the existing downstream sediment data with patterns of disturbance recorded at the scale of the annual cutting coupe.

INTRODUCTION

Extensive areas of Southeast Asia are presently undergoing a sequence of change that, depending on a complex of management issues, can end in deforestation. Land-use change often starts with the selective cutting of timber from production forest followed by a period of regeneration before the next harvest. Alternatively, logged forests could be deleted from the production inventory and converted to other land uses. Managed conversion would typically be to plantation forestry and agriculture. More subtle degradation may occur by various combinations of small scale permanent and shifting agricultural encroachment into the once production forest. This generalized trend of land-use change may be coupled with generalizations about location. Coastal and nearby forests were converted fairly early in this century, often by colonial efforts, leaving the remaining forests in the less accessible and often steeper hinterland. Whatever the fate of the forests, the landscapes of the region will consist of vast areas with changing land-use, all with the potential to accelerate natural erosion rates. It has been well established at a local level that commercial logging and clearing operations in Southeast Asia are usually associated with dramatic increases in sediment production (Douglas *et al.*, 1993). However, long term erosion rates from forests logged for a second time or converted to plantation have yet to be accurately assessed.

This paper will examine the existing sediment data from different locations within the Sungai (Sg) Segama catchment (4576 km^2). Erosion data from plots of both disturbed and undisturbed forest will be examined alongside small catchment data. Processes occurring at this scale immediately reflect the logging disturbance. Results will then be linked to suspended sediment data recorded at two stations further downstream (721 and 2450 km^2).

Selective harvesting operations

Long term natural forest management in the region requires the well managed felling of trees followed by a period of regeneration. Within the main timber concession of the study area, forest is harvested by annual blocks (coupes) of around 2000-3000 ha which have progressed steadily westwards (Fig. 1). The forests are cut following a modified Malayan Uniform System of selective felling with a rotation cycle of 65 years. The subsequent viability of the coupe will depend upon a number of factors including the intensity of the first cut and the amount of associated damage. In many parts of the region logs are extracted by bulldozer, resulting in a mosaic of disturbance ranging from severe along the tractor trail to undisturbed in the interstitial patches.

Study site

Situated between 4°50′ and 5°00′ degrees north of the equator, the catchment receives predominantly convectional rainfall averaging 2699 mm (1986-1994) as measured at the Danum Valley Field Centre (DVFC) and 2063 mm (Lahad Datu; 1960-1983) as it nears the drier eastern seaboard of Sabah (Marsh, 1995). Most of the upper catchment occupies a rugged terrain with several major summits; the highest of which is Gunong Tribulation at 1280m. For the purposes of this study the catchment is arbitrarily divided at the existing gauging stations of DVFC and Limkabong (Fig. 1).

The lower Segama, coinciding with the Segama valley and extending to the coastal plain, is dominated by extensive tracts of predominantly oil palm plantation agriculture. Upstream of Limkabong, the middle Segama comprises some plantations along the northern bank with limited smallholder agriculture along the riparian native reserve zone. The remaining forest concession has been systematically cut by annual coupes progressing westwards from 1970 until 1993 when operations left the catchment. The perimeter of the south bank was also logged pre 1983 and mostly remains as degraded forest.

The northeastern and central northern sections of the upper Segama fall within the 438 km^2 undisturbed dipterocarp rain forest of the Danum Valley Conservation Area. Access roads from the south extended into the upper catchment during the 1970s and

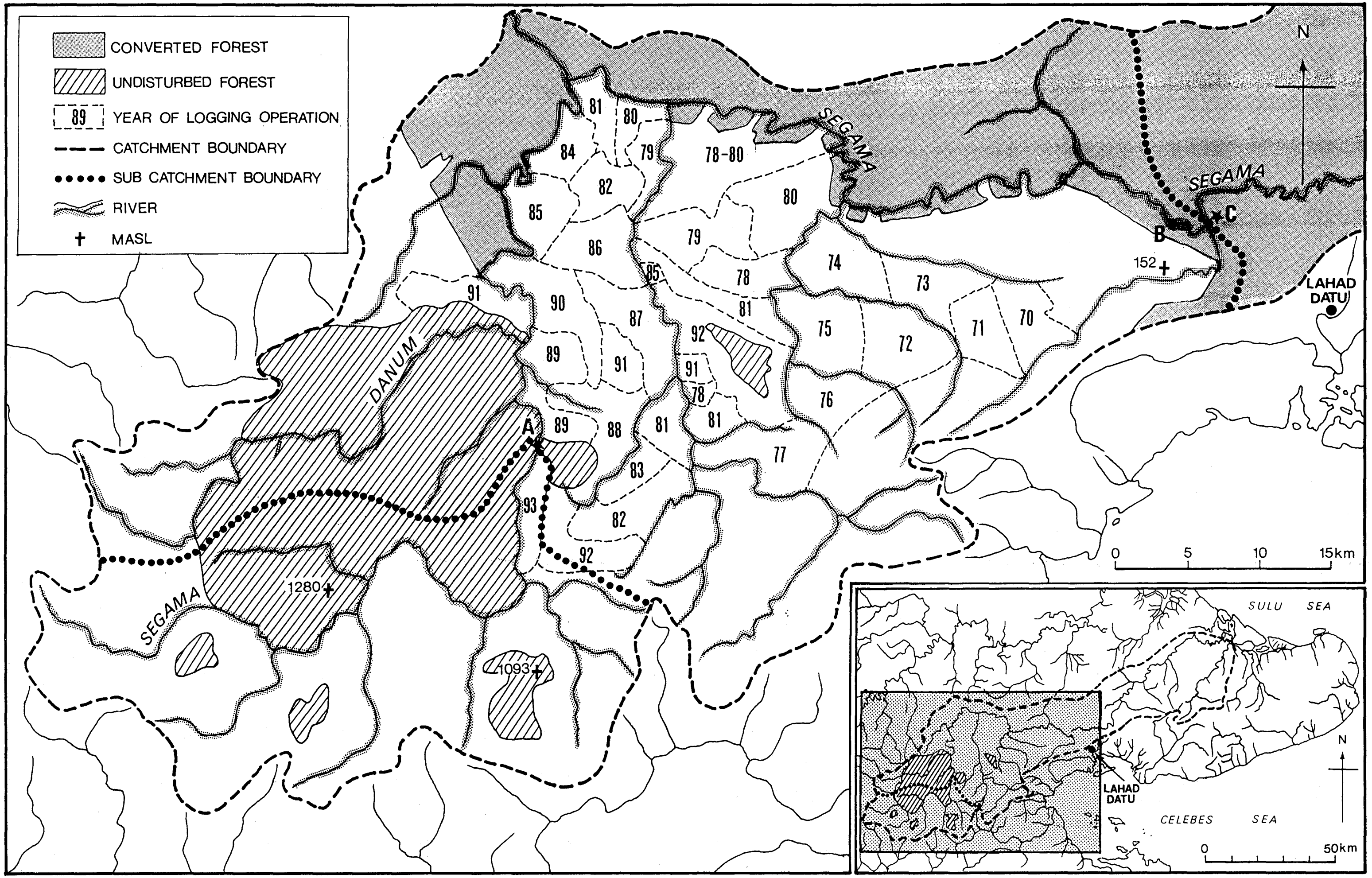

Fig. 1 Sketch map of land use in the Sg Segama catchment. The logging coupes of the major concession holder are outlined as are some of the main deleted areas. Blank areas represent earlier logged over forest (A: DVCF, upper catchment divide; B: Limkabong, middle catchment divide; C: Segama bridge).

early 1980s resulting in the logging of nearby forests, although a number of undisturbed patches do exist along the steep unworkable ridges (Marsh, 1995).

EXPERIMENTAL DESIGN AND RESULTS

Erosion plots and small catchment studies

A series of small bounded runoff ploffs with Gerlach trough type collecting systems were established in undisturbed and disturbed forest close to DVFC (Sinun *et al.*, 1992). The data presented here are from an undisturbed site immediately upstream from DVFC feeding into the 1.7 km^2 Sg W8S5, and from a disturbed site within the 0.5 km^2 Sg SB catchment nearby but downstream of DVFC. The Sg W8S5 plot values are comparable to other nearby erosion plot values and are considered representative for undisturbed forests in the vicinity. The disturbed plot, located directly on a bulldozer trail yields extreme values that are only generally representative of other similarly travelled logging paths and certainly cannot be applied to the catchment as a whole (Table 1). The limitations of erosion plot data (Evans, 1995) are enhanced by the uneven nature of disturbance in selectively logged forests, where bulldozer skid trails make up only a portion of the catchment. Skid trail density in nearby forest averaged 200 m ha^{-1} (Pinnard, 1994). If annual weighted averages for skid trail and undisturbed forest are calculated, values of 1308 and 200 t km^{-2} are obtained for 1989 and 1990, which are considerably lower than the measured catchment yields. The bounded nature of the plot prevented the development of gullies and therefore underepresented erosion rates, as they were a common feature along adjacent skid trails.

Daily and storm event sampling of Sg W8S5 and Sg SB allowed good estimates of suspended sediment yields and these are compared with the undisturbed and disturbed plots respectively. Details of the monitoring programme over a period of 51 months post harvesting are given in Greer *et al.* (1995) and are summarized in Table 1. The most active period of erosion during the experimental period was during the first three years.

Table 1 Estimated rates of erosion, Sungai Segama, Sabah.

Site	Area of sample	Sediment yield (t km^2 year^{-1}) for year:				
		1989	1990	1991	1992	1993
Disturbed sites						
Plot (logged forest)	10 m^2	19 050	1050			
Sg SB	0.5 km^2	3 200	1994	830	78	283
Sg Segama at DVFC	721 km^2		ND			
Sg Segama at Limkabong	2450 km^2	448* (average 1983-1989)				
Undisturbed sites						
Plot Sg W8S5	20 m^2	175	146			
Sg W8S5	1.7 km^2	76	68	61	38	38

*Murtedza (1992)

There is a steady but reasonably fast recovery of the catchment condition, but during extreme events or as result of small land slides associated with disintegrating access roads, large volumes of sediment may still enter the system.

Natural erosion rates as measured on the plots are high compared to the undisturbed catchment suspended sediment yields and are 2.3 and 1.7 times greater for year one and two of the study respectively. Comparing the weighted average of disturbed and undisturbed erosion plot values with the disturbed site explains only 0.4 of the amount measured at the catchment level in the first year and 0.1 in the second, suggesting that erosion rates in other parts of the catchment must be greater than those measured in the experimental plot. Obviously plot studies alone need to be combined with other survey methods to produce more realistic estimates. Comparing the disturbed catchment yields with the disturbed erosion plot figure alone does, however, give some indication of the amount of temporary in-catchment storage, as plot values are six times greater in the first year but are only half the amount for the second year indicating that degree of on site recovery.

Sg Segama at DVFC

Commercial logging operations took place in the upper part of the catchment at undetermined dates during the 1970s and early 1980s with the last activity in 1983 (Marsh, 1995) and at least 34% of the catchment above DVFC remains undisturbed. Therefore daily suspended sediment measurements (1988-1995) represent values for a disturbed but recovering catchment (Fig. 2). Erosion from the logged catchments at a local level would gradually decrease, following a pattern of recovery similar to the Sg SB catchment study. As would be expected there is a poor relationship between sediment concentration and discharge, with much of the variation attributable to the often localized rainfall and the distribution of logged and unlogged forest.

In 1992, 8 km^2 of the annual coupe (representing about 1.1% of the upper catchment), extended into the catchment above DVFC and in 1993 a further 19 km^2

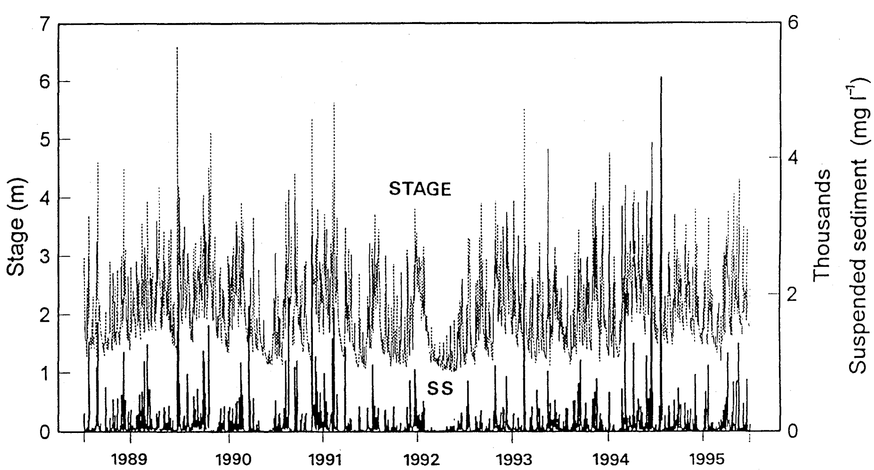

Fig. 2 Daily stage and suspended sediment recorded at DVFC, Sg Segama.

Table 2 The relationship between stage and suspended sediment concentration; Sungai Segema at DVFC.

Year	Intercept	Slope	r^2
1988	0.1414	4.6492	0.66
1989	0.1425	4.3294	0.61
1990	0.208	4.3363	0.68
1991	0.3236	4.0779	0.64
1992	0.4385	3.4222	0.48
1993	0.4993	3.5707	0.46
1994	−0.088	4.7629	0.59
1995	−0.064	4.9046	0.6

(2.08%) was included, of which 400 ha was cut under a supervised reduced impact logging programme. Although the disturbance occured in a small percentage of the area of the Sg Segama catchment, the Segama frequently appeared yellow in colour, characteristic of disturbed rivers in the locality due to the erosion of the recently exposed lower soil layers. However, the 1992 and 1993 disturbance was not obvious on a simple time series plot; the dominant feature being the prolonged dry period (Fig. 2). Annual regression analysis of stage against sediment concentration for 1988-1995 does reveal a change in the relationship in 1992 and again in 1994 (Table 2). The 1992 change in slope must be partly controlled by the lack of high flow events, but can be explained by the higher suspended sediment concentrations at some lower stages. This additional variation in the stage-suspended sediment concentration relationship is seen in the r^2 values as the relationship weakens in 1992 and 1993, but there is evidence of recovery in 1994-1995. Again this may be explained by the areal distribution of rainfall in the upper catchment. Widespread rainfall and runoff results in the dilution of sediment runoff from disturbed sites by the less- and non-disturbed parts of the catchment. More localized convectional rainfall in the disturbed tributary catchments generates high suspended sediment concentrations eventually passing through the DVFC monitoring station as a low to medium flow. The reduction in variance, but change in slope for the 1994-1995 results has yet to be examined, but is probably attributable to the absence of distinct dry season flow for these years.

Sg Segama at Limkabong

An examination of the discharge and suspended sediment data for 1978-1994 obtained at the Limkabong gauging site (Drainage and Irrigation Department, Sabah; personal communication) is constrained by the number of samples and the irregularity of the sampling programme at this remote site, but some general observations may be made. Sediment concentration values are higher at the beginning of the data and gradually decline, whereas the corresponding discharge values at time of sampling increase (Fig. 3). The relatively large number of samples taken during the late 1980s may have some control over the trend as samples were often taken two or three times per month on consecutive days. A possible explanation of higher sediment production at the begining of the period could be provided by the intensive logging operations in the headwaters during the late 1970s up until 1983 and the conversion of some forest to plantation along

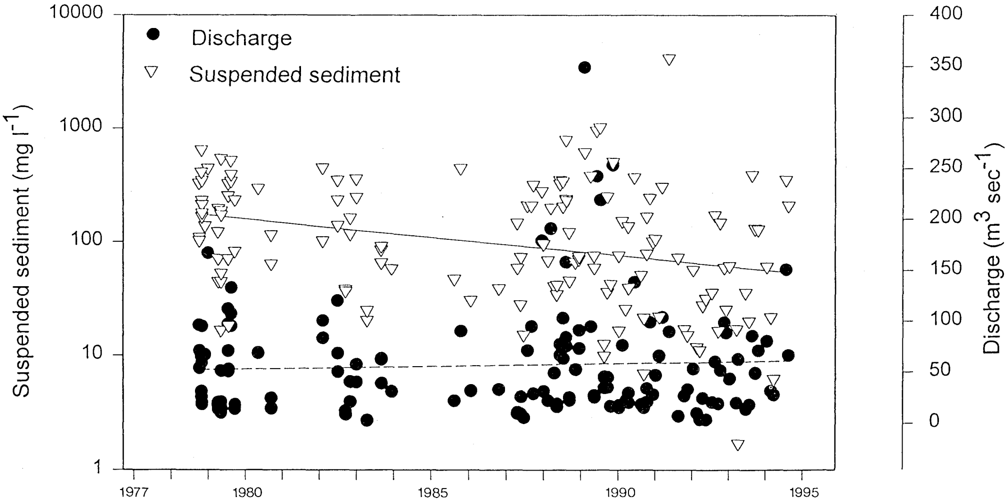

Fig. 3 Suspended sediment and discharge recorded at Limkabong, Sg Segama. Trend lines represent the regression of variable against time.

parts of the northern bank. This contrasts with the subsequent better managed and more systematic cutting operations which leave behind a mosaic of regenerating forests to buffer recently disturbed catchments. Using the sediment rating curve technique Murtedza (1992) derived a figure of 448 t km^{-2} year^{-1} for the period 1983-1989 which coincides with the cessation of logging operations in the upper catchment. Until the DVFC data are converted to discharge, erosion rates from the upper catchment cannot be compared directly with the Lower Segama. However, from the comparative concentration values given below, it would appear that rates of erosion are higher downstream as the percentage area of undisturbed forest is reduced.

Sediment transfer upper-middle Segama

Starting in July 1995 a short term series of samples were taken at DVFC and correspondingly 158 km downstream at the Segama bridge, near Lahad Datu. Concentrations recorded at the bridge were generally higher than those upstream. Dilution from tributary flows downstream attenuated events from the upper catchment where high values during storm events reflect the proximity of the logging operations (Fig. 4). Likewise sediment may be contributed from downstream flows, maintaining high suspended sediment loads when there has been little or no rain in the upper catchment. More widespread rain over the catchments (i.e. early September) results in a delayed but exaggerated set of readings compared to those from the DVFC values.

DISCUSSION

The heterogenous nature of disturbance at both a local and a regional level presents a complex range of potential erosion sites with many opportunities for deposition.

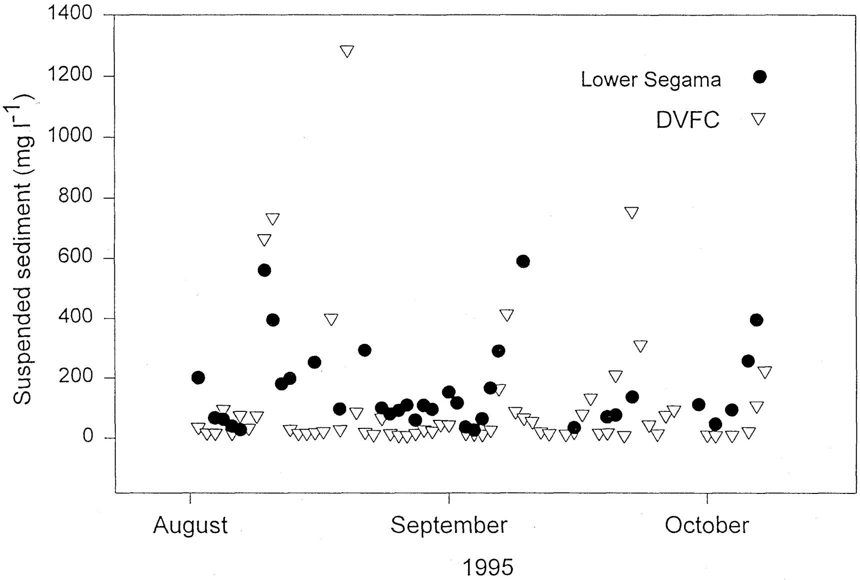

Fig. 4 Suspended sediment recorded at DVFC and the Segama bridge, Lahad Datu.

Disturbance by cutting of annual coupes causes severe impacts at a small catchment level and although the impact can be registered at the next level of monitoring (721 km^2) it is greatly reduced by the surrounding undisturbed and recovering sub-catchments. Until sediment concentration data at DVFC are converted to loads it is not possible to draw any clear conclusions on the sediment delivery processes within the catchment. However, it would appear that in the disturbed state sediment yields increase progressively through the catchment as a result of the percentage increase of land-use change. Yields from disturbed small catchments are much higher than values recorded downstream, but quickly recover to near ambient levels. It is also clear that the areal and interannual variation of climate exert considerable control on sediment yields and the relative importance of these factors in combination with land-use change needs further assessment.

The elevated erosion rates that currently prevail in the region are likely to persist. To what extent and at what level will depend upon the answer to a number of important questions. Further research on establishing long term erosion rates from plantations, in particular during replanting, as compared to recovering logged forest, will be important and may in part be an indicator of economic as well as ecological sustainability.

Cyclical forest harvesting may therefore offer a potential land-use option for the long term management of large tropical catchments in this region. Supervised and well managed commercial cutting operations, alongside complementary conservation efforts, compared to alternative land-use options would depress sediment concentration values downstream. However, on-site erosion problems and associated environmental degradation may still persist. Emphasis should be placed on working a large enough concession to permit a full rotation of coupes. This would ensure that the percentage area disturbed at any one time is buffered by the surrounding low sediment yielding areas.

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