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Changes in sediment discharge resulting from commercial logging in the Sungai Lawing basin, Selangor, Malaysia

F. S. LAI, M. J. LEE & S. MOHD RIZAL
Department of Forest Management, Universiti Pertanian Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

Abstract This study assesses effects of logging on sediment yield in a steep, tropical catchment in Malaysia. The Sungai Lawing basin, 4.7 km^2 in area with total relief of 1035 m, is one of many hilly basins undergoing commercial logging. Rainfall, streamflow, and water quality data were collected from August 1988 to July 1989, when the basin was undisturbed. Monitoring continued from October 1992, when a licence permitted logging in the lower basin. The highest suspended sediment concentration of 1988-1989 was 2126 mg l^{-1}. Concentrations increased with logging in 1993 to as much as 19 920 mg l^{-1} during a September storm. The 1993 suspended sediment load was 1129 t km^{-2} compared with 54 t km^{-2} for 1988-1989. Bed load increased from 125 t km^{-2} $year^{-1}$ to 414 t km^{-2} $year^{-1}$ for the same study period. Mean particle size of bed sediment during the period of study decreased.

INTRODUCTION

The need to understand hydrological processes in tropical rainforests is reflected by the increasing recent study of catchments of various sizes and land use changes (Bruijnzeel, 1990; Vegas-Vilarrubia *et al.*, 1994). Of interest is the effect of logging on sediment yield in forest basins. In Malaysia, past reports on sediment yield (e.g. Douglas, 1968; Peh, 1981; Baharuddin, 1988; Douglas *et al.*, 1992; 1993) mostly concentrated on the suspended load and dealt with lowland basins. Few data are available for sediment loads of upland catchments that now face much pressure from development, logging in particular. We report on changes in suspended and bed load yields of the Sungai (Sg.) Lawing, a steep upland basin, before and during commercial logging.

MATERIALS AND METHODS

The study basin

The study basin of Sg. Lawing, 4.7 km^2, is in Selangor, longitude 101°56′E and latitude 3°10′N (Fig. 1). The stream, fourth order by Strahler's classification, is one of many tributaries of the Sg. Langat, whose headwaters drain the western flank of the Main Range. The Sg. Langat flows southwest into the Straits of Malacca in the west coast.

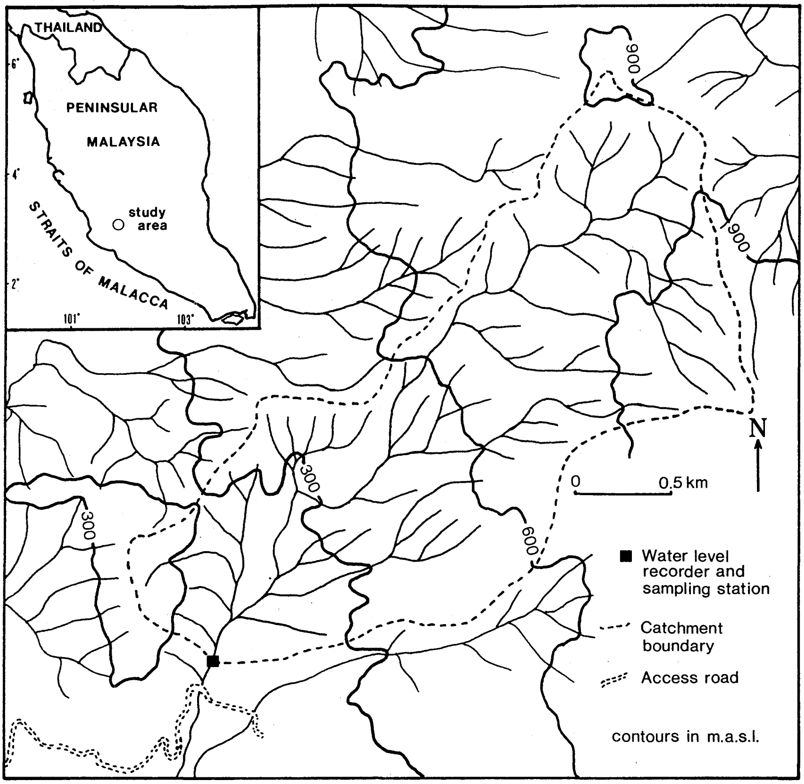

Fig. 1 Map of study basin.

The terrain of Sg. Lawing is predominantly hilly and steep, 0.40, with a maximum height difference of 1035 m and maximum relief at 1210 m. From a hypsometric curve derived for the basin, Sg. Lawing falls into the non-equilibrium stage of the erosion cycle. Streams have steep gradients characterized by pool-riffle sequences. The catchment falls into the hydrological region of Kuala Kerai-Ulu Langat (no. 65), as demarcated by the Drainage and Irrigation Department, Malaysia (Goh, 1974). The Kuala Kerai-Ulu Langat hydrological region is underlain mainly by granite, with pockets of shale, schist, volcanic flows, pyroclasts and tuffs. This hydrologic region lies within 30% of the peninsula, where potential runoff is 500 to 1000 mm. The Kuala Kerai-Ulu Langat unit covers 17% of the peninsula in one continuous area and occupies much of the Main Range region, which is mostly forested and generally rugged, sharing much the same topography as that of the study area. The results obtained from this study should be generally applicable to the region.

Climate

The climate is the equatorial type of Peninsular Malaysia, which has high but uniform annual temperature, humidity and rainfall. A general climatic pattern of southwest and northeast monsoons affecting rainfall largely determines the generation of runoff and sediment transport in catchments. The rainfall pattern of the study area has two distinct maxima each year. Rainfall distribution is strongly influenced by major airstreams across Peninsular Malaysia that produce four annual "seasons" (Dale, 1959): (a) northeast monsoon of November or early December through March; (b) inter-monsoonal of April and May; (c) southwest monsoon of June through September or early October; and (d) inter-monsoonal of October through early November.

Geology

The geology of the study catchment is that of the Main Range batholith (Tjia, 1988; Gobbett & Hutchinson, 1973), derived from granitic magma intruded into anticlinal folds of the Malay Peninsular during late-Triassic to early-Jurassic time (Van Benmelen, 1949). Roe (1953), however, believed that the granite may have been emplaced during the Jurassic, Cretaceous or early Tertiary. Based on radiometric dates from granite samples in southern Thailand and parts of the peninsula, Burton & Bignell (1969) believed that the Main Range is Triassic or older. Presently, the Main Range runs northwest to southeast in Peninsular Malaysia.

Soils and vegetation

Soil surveys conducted throughout Malaysia have been chiefly for agricultural purposes, often with specific crops in mind. Soils in steep terrain have been mapped as a steepland unit (Paramanathan, 1987); soil in the Sg. Lawing catchment is of the steepland type. Soils over granitic material are typically well drained. Due partly to the steep terrain, the soils are relatively weaker in structure and development than in the lowlands nearby. The transition from weathered soils to bedrock is small, particularly in areas of igneous rocks (Nossin & Levelt, 1967).

Vegetation of the Sg. Lawing catchment is characterized by the Hill Dipterocarp species. The inventory of tree species at two plots nearby, in Sg. Batangsi and in Sg. Chongkak, suggest dominance of "meranti bukit" *Shorea platyclados*, which is the characteristic tree of the Upper Hill Dipterocarp Forest (Burgess, 1969).

Logging

Logging in the lower half of the Sg. Lawing basin started in January 1993. About 40%, or 180 ha, of the catchment was affected. The logging method was typically that used elsewhere, with crawler tractors employed to construct roads and skid trails, and haul logs. Felling was on a selective basis under the Selective Management System, where dipterocarps of 50 cm diameter at breast height (dbh) and non-dipterocarps of 45 cm dbh were felled.

Field instrumentation

To understand the hydrology and sediment transport of the catchment, a wide range of parameters was measured, including data from the installation of rainfall and automatic water level recorders and automatic water samplers. The USDH-48 Depth Integrating sampler was used for stream sampling and a locally-made Helley-Smith sampler was used for bed load.

RESULTS AND DISCUSSION

Suspended load

The peak suspended sediment concentration sampled before logging was 2126 mg l^{-1} at a discharge of 0.676 $m^3\ s^{-1}$, or 0.144 $m^3\ s^{-1}\ km^{-2}$, on 5 September 1989. A high of 19 920 mg l^{-1} occurred during a storm of 9 September 1993 at 0.248 $m^3\ s^{-1}\ km^{-2}$. These concentrations for the two study periods, however, may not have been the maxima that occurred. As continuous records are unavailable, sediment concentrations at unsampled discharges have to be estimated. Gaps in the sediment sample record make the sediment rating curve method the most suitable. The most common method to develop a sediment rating curve is to use least-squares regression of instantaneous values of concentration on discharge. Transformation yields a power function describing the non-linear relation between sediment and discharge:

$$S = aQ^b \tag{1}$$

where S is suspended sediment in mg l^{-1}, Q is discharge in $m^3\ s^{-1}$, a is the intercept and b is the slope

Due to variations in sediment concentrations at the same discharges on the rising and falling limbs of storm hydrographs, however, several types of rating curves were compared before using a procedure for computing the sediment loads. Between the two approaches of calculating sediment loads, the method separating rising and falling concentrations gave values closer to those observed in the field than did a single transport curve (Lai, 1993). In the total load calculation, half-hourly hydrographs were assembled to compute sediment discharge. Sediment rating curves for 1988-1989 were straightforward only when one combination of rising and falling rating was used. When logging started, the relation between discharge and sediment concentrations differed, even over short periods. This is understandable as roads and skid trails were constructed where felled trees were transported from the area. Eight sets of rising and falling rating curves were used in the suspended load computation.

Prior to logging, sediment concentrations obtained for storms in October through December 1992, appeared similar to the range of the 1988-1989 study period. The sediment concentrations only appear to increase by middle February 1993, because January is normally a dry month. It is evident that rainstorms are important in transporting sediment from sources to streams, the amounts depending on intensity of the storms and the supply of sediment. Consequently, several rating curve changes were adopted to generate more reliable estimates. From monthly load computations, higher loads were exported from April onward, peaking in September at 465 t km^{-2} (Fig. 2). The total load for 1993 increased 21 fold compared to the previously undisturbed state.

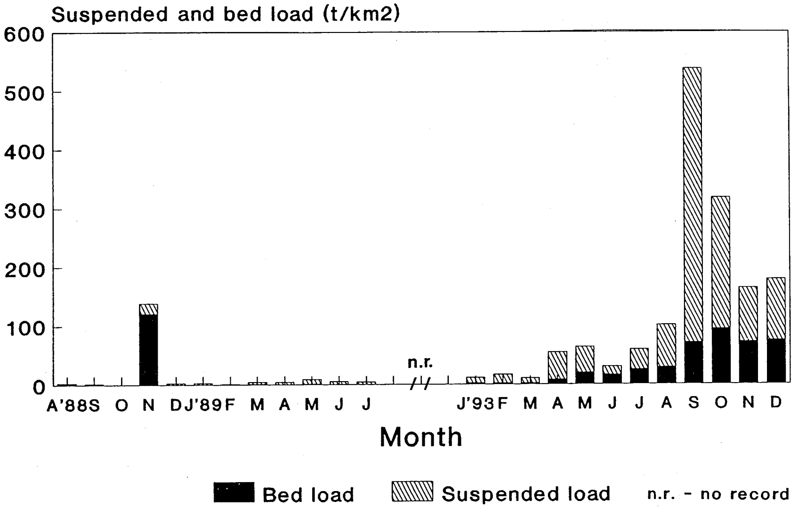

Fig. 2 Monthly suspended load and bed load before logging (August 1988 through July 1989) and during logging (1993).

Bed load

Bed load data were collected from three subsections of the stream about 10 m downstream from the gaging station. We assume that samples from each subsection represent the total bed load transport in the respective segments. Total bed load transport was therefore the sum of the transport rates calculated for the three sections. In all samples of both study periods, bed load movement was uneven across the stream and mobilization of bed sediment varied considerably.

Bed load yield calculation

Bed load was computed from single rating curves based on the bed load measurements made. Far fewer measurements are available for the bed load regressions than for suspended sediment. Having determined a rating curve, bed load discharge was computed for the study catchment using a single rating against mean daily discharges instead of half-hourly hydrographs. Half-hourly hydrographs gave high load estimates because this method assumes consistent delivery of bed material corresponding to instantaneous streamflow (Lai, 1993). In reality, however, a correspondence does not occur as previous authors have shown (e.g. Beschta, 1981; Reid & Frostick, 1987). The use of mean daily discharge values, by which peak discharges are depressed, cancels the high peak outputs of the hydrograph technique. In the context of this study, values derived from using mean daily discharge appeared more accurate and thus were used in bed load analysis.

Bed load discharge was an estimated 124.8 t in 1988-1989. The highest estimated monthly load was in the wet month of November when about 121 t km^{-2} was transported; this value was 97% of the total observed bed load transport, and about 70% of all sediment evacuated from the catchment. From field observation, the channel was greatly scoured, with considerable movement of boulders, by the storms that occurred this month. During 1993, however, bed load was about 414 t km^{-2}, a three-fold increase due to logging. Increases in bed load occurred much later than did increased suspended sediment discharge, probably because large storm runoff is needed to transport large quantities of the freshly disturbed soil into streams. By observation, bed load appeared to increase by mid-April 1993, after which much more bed material filled the numerous pools near the sampling site than before. The computation of bed load was conducted with this change in mind and a new bed load rating was applied to streamflow data from 21 April onwards.

Bed load size distribution

The bed load data suggested that availability of sediment differed across the channel due to velocity variations and the quality and supply of bed sediment; these factors have also been studied in temperate streams (e.g. Sidle, 1988). For this study, particle sizes were compared for 12 sets of bed load samples collected across the channel. Among three equally divided sections across streams, largest sizes were in mid-channel. Mean d_{50} of bed sediment at mid-channel was 0.64 mm, compared with 0.51 and 0.44 mm for the left and right, respectively (Fig. 3). Particle sizes were finer than those sampled before logging, where, at mid-channel, d_{50} was about 1 mm. This change may be due to increased movement of fine sediment, from eroded roads and skid trails, that is stored temporarily in channels, particularly as storm flow recedes.

CONCLUSION

Loads of suspended and bed sediment of the Sg. Lawing, January through December 1993, were 73.2 and 26.8% of total load, respectively. In a 1988-1989 study, however,

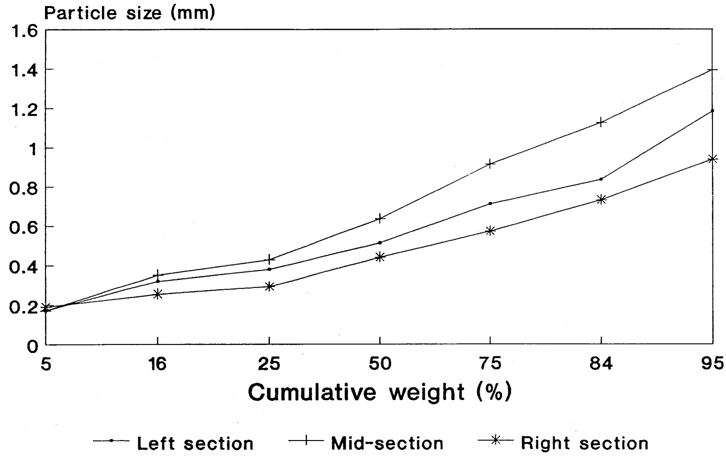

Fig. 3 Mean particle size distribution of bed load at left, right and mid-section of sampling site (n = 12).

percent yields of suspended and bed sediment and solutes were 28.3, 65.7, and 6.0%, respectively. The solute load was assumed also low during the logging phase, based on a study in two logged catchments of similar granitic bedrock (Lai, 1993).

Sediment loads for Sg. Lawing during the logging phase compare well with other logged catchments (Table 1). The 1987-1989 load for Sg. Batangsi, where logging was on-going, was about 52 times that of the undisturbed Sg. Lawing. Bed load of Sg. Batangsi was also about 30% of total load. In a study in Ulu Segama, Sabah, Douglas *et al.* (1992) reported an 18-fold increase in suspended sediment discharge from a 54 ha lowland rainforest basin 5 months after logging.

Estimated change in sediment output of Sg. Lawing is probably of the right magnitude. Results suggest that close monitoring of the sediment output of the Sg. Lawing was essential because sediment transport, especially following disturbance in small basins, differs over short time periods. These differences occur because sediment output depends on sediment supply and transport by storms. When these factors are observed and monitored, a clearer picture of catchment sediment yield changes is obtained.

Table 1 Comparison of sediment yields of upland basins in Selangor.

Catchment	Area (km^2)	Suspended load ($t\ km^{-2}\ year^{-1}$)	Bed load ($t\ km^{-2}\ year^{-1}$)	Study period	Remarks
Sg. Batangsi	19.8	2826	1264	Mar. 1987-Apr. 1989	Logging on-going
Sg. Chongkak A	12.7	2476	619	Mar. 1987-Jun. 1988	Logging ceased
Sg. Chongkak B		1335	334	Jul. 1988-Oct. 1989	April 1987
Sg. Lui	68.1	90	22	Mar. 1987-Jun. 1989	Rural basin, 80% forested
Sg. Lawing	4.7	54	125	Aug. 1988-Jul. 1989	Undisturbed
		1129	414	Jan. 1993-Dec. 1993	Logging started in January 1993

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