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Erosion Control in the Tropical Rainforest Catchments using Modified Intensive Rehabilitation

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Abstract. Tropical rainforests in Indonesia is currently managed by Intensive Forest Management System (IFMS), characterized by selective timber harvesting and intensive rehabilitation to enrich standing stock. This study conducted quantitative evaluations on catchment scale impacts of IFMS during each selective logging (SL) and intensive rehabilitation (IR) stage. SS concentrations were measured in three headwater catchments located in tropical rainforests of the Bukit Baka Experimental Catchments, Central Kalimantan, Indonesia. While no forestry operation was conducted in catchment A, operations based on IFMS were conducted in catchments B and C. A combination among the great surface disturbance by skid trails, large tree extraction ratio, and high slope angle of catchment B resulted in the greatest SS. During the post-IR period, SS concentration of catchment B did not show decreases in comparison with that during the post-SL period. In catchment C, increases in SS concentration were observed during the post-IR period. Thus, this study indicated that IR of IFMS was not effective to decrease SS concentration in the initial stage of the post operation period, but the modified intensive rehabilitation with considering the contour and topography potential*ly significant to control erosion.*

Keywords: tropical rainforest, intensive rehabilitation, paired catchment, suspended sediment, erosion control

1 Introduction

Tropical rainforests in Indonesia is currently managed by Intensive Forest Management System (IFMS), characterized by selective timber harvesting and intensive rehabilitation to enrich standing stock. In this operation, 15-20% of whole area is manually striped for intensive rehabilitation. Forest biomass and litter are left over the forest floor, and typically about 200 seedlings per hectare are planted. An expected standing stock at the end of a 30-year rotation is approximately 400 m3 per hectare [1-2]. Details on IFMS are described by [3-5].

IFMS potentially increases forest potency through the intensive rehabilitation, but on the other hand, it increases line clearing area (i.e., open area) for the intensive rehabilitation. Reductions in vegetation cover from forest clearing likely change sediment yields from catchments. Evaluations of the intensive rehabilitation method of IFMS have been rarely conducted whereas several previous studies have focused on impacts of the selective logging [6-11]. Therefore, a need exists to clarify responses of tropical rainforests managed under IFMS. This study employs the paired catchment method for investigating the effectiveness of modified intensive rehabilitation to control the impact on erosion.

2 Methods

2.1 IFMS conducted in paired catchment studies

No forestry operation was conducted in catchment A. Regular IFMS was conducted in catchments B, while IFMS with modified intensive rehabilitation based on contour topography was conducted in catchment C (Fig. 1). Data obtained in the pre-treatment period were used for calibrations to establish the hydrological relationships between the control and treated catchments. For each stage of IFMS, the data following a specific operational period were used in the analysis.

In the SL operational period, 4-m wide skid trails were constructed in catchment B and C (Fig. 1). In the IR operational period, a 3-m wide strip of rehabilitation was conducted in catchments B and C. In catchment B, intensive strip-rehabilitation was conducted, which is a standard rehabilitation method that uses a North–South direction to establish the planted lines as shown in Fig. 1a. Spacing between each planting line was 20 m. In catchment C, intensive contour-rehabilitation was conducted, which is a modified rehabilitation method that considers catchment topography (as shown in Fig.

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1b) and was expected to reduce impacts on surface runoff and soil erosion.

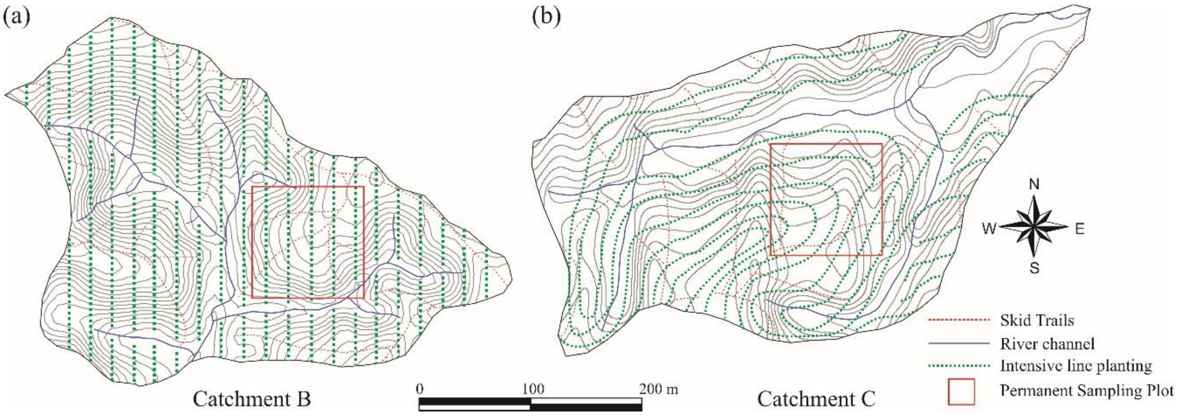

Fig. 1. Implementation of IFMS conducted in catchments B and C

Table 1. Number of trees and tree canopy cover in catchments A, B, and C based on PSP measurements.

Catchment	Number of trees*			Tree canopy cover (%)		
	Natural	Post-SL	Post-IR	Natural	Post-SL	Post-IR
A	206			95%		
B	218	135	80	88%	60%	55%
C	170	102	81	79%	56%	51%

* Diameter > 20 cm (at 1.3 m above land surface)

Changes in forest canopy cover were monitored in a permanent sampling plot (PSP) established in each catchment, as shown in Fig. 1. The PSP is used for the long-term observation of forest growth, including measurements of diameter increment, volume increment, and stand structure dynamics. The PSP consisted of one square hectare of forest area located in the middle slope of each catchment. Measurements were counted under the natural condition, and during the post-SL and -IR periods (Table 1).

Based on the PSP measurements, the SL operation greatly decreased forest canopy cover by reducing the number of trees. The IR operation also significantly reduced the number of trees and canopy cover. Under the natural condition, canopy cover in the three catchments ranged 79–95%. Catchment C had the smallest canopy cover of the three catchments. In the post-SL and post-IR periods, the difference in canopy cover between catchments B and C was reduced to 4%.

2.2 Paired catchment observation and analysis

Precipitation was monitored with an interval of 15 min using an automatic tipping-bucket rain gauge located near the three catchments. The discharge rates were measured using 90° V-notch weirs (0.9 × 1.4 × 3m) and water-level loggers (HOBO U-20) with a time interval of 15 min at each catchment outlet. The observed runoff hydrograph was divided into direct runoff and base flow using a straight-line method [12].

At each weir, sediment concentration was measured using a rising stage suspended sediment sampler [13]. Rising stage suspended samplers work on the siphon principle from the inlet-pipe to bottle samples. In this method, water samples including suspended sediment were collected at each water level. A rising stage was installed at a sidewall of the weir and attached to 60 inlet pipes (3.5 mm in diameter with a distance of 1 cm for each pipe). The inlet-pipe connected to a number of bottles (260 ml in volume) arranged on top of each other in frame, installed near the rising stage. Each bottle is fitted with a two-hole stopper, one hole for the sample inlet and one for the air exhaust. Suspended sediment samples were collected during storm rainfall occurrences.

3 Results and Discussions

3.1 Suspended sediment hysteresis loops

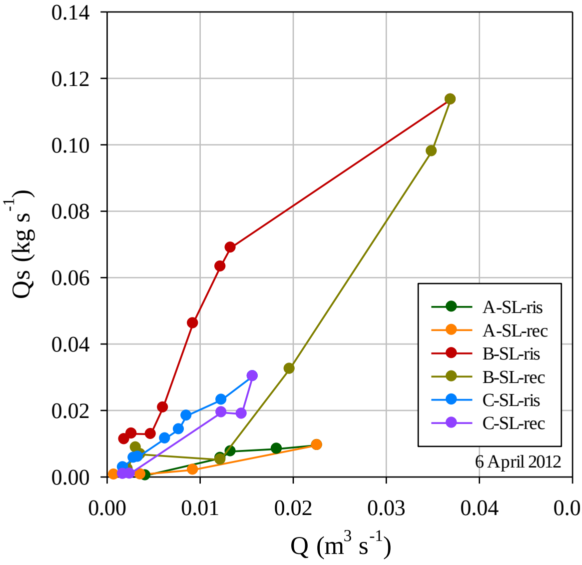

Fig. 2. Water discharge (Q) and suspended sediment discharge (Qs) relationship of catchments A, B, and C observed in the post-SL period. (ris=rising-limb; rec=recessing-limb)

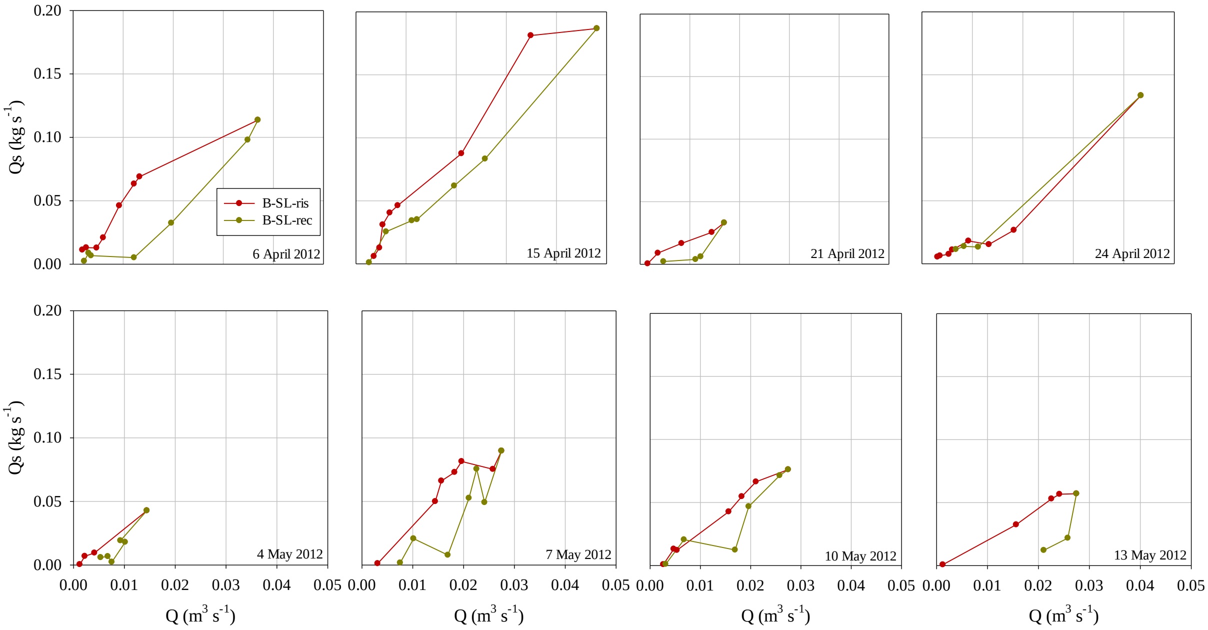

Fig. 3. Water discharge (Q) and suspended sediment discharge (Qs) relationship for catchment B during the post-SL period.

Fig. 2. shows the results of suspended sediment (SS) measurements conducted for a storm event (i.e., during the post-SL period). The figure indicates that catchment B produced a clear clockwise hysteresis loop in the water discharge (Q) and SS discharge (Qs) relationship. This means that SS concentration for the rising-limb (SL-ris) was greater than SS concentration for the recessing-limb (SL-rec). Hysteresis was not so clear for catchments A and C.

As shown in Fig. 3, during the post-SL period, catchment B produced clear hysteresis loops in Q and Qs relationships for most of the storm events. Again, no clear hysteresis was found for catchments A and C during the same period. Fig. 3c showed that catchment B had higher Qp than catchment C. It is likely that the greater amount of surface runoff as well as the higher slope gradient of catchment B produced larger ability for transporting SS. Therefore, in catchment B, the amount of sediment sources probably is the controlling factor for SS discharge; while large amount of SS material was washed away in rising-limbs of storm hydrographs, the SS concentration in the recessing-limb decreased because of lacks sediment sources. On the other hand, in catchment C, the ability of SS transporting by surface flow probably is the controlling factor. Consequently, the relationships between Q and Qs in catchment C were similar in both of rising- and recessing-limbs (Fig. 3).

During the post-IR period, hysteresis became unclear in catchment B. In catchment C, no hysteresis loop was observed during the post-IR period as well. The IR operation left the biomass litters in the forest floor, which leads to increases in the surface roughness and works as traps of the flowing SS material. Therefore, we consider that the IR operation reduces ability of SS transporting. Consequently, SS discharge during the post-IR period was not controlled by the amount of sediment source but by the transporting ability, which resulted in the diminishing of hysteresis in catchment B.

3.2 Suspended sediment concentration

Fig. 4 shows the relationship between Q and Qs for each catchment and each IFMS operation period. For catchment B, data obtained during the post-SL period were divided into the rising- and recessing-limbs, due to the clear hysteresis as shown in Figs. 2 and 3.

Figs. 4a, b and c show that the IFMS treatments resulted in higher suspended sediment concentrations in catchments B and C than in catchment A. In catchment B, Qs on the rising-limb during the post-SL period was greater than Qs during the post-IR period (Fig. 4a). On the recessing-limb during the post-SL period, catchment B produced lower Qs than that during the post-IR period (Fig. 4b). Overall, in catchment B, Qs during the post-SL period was similar to Qs during the post-IR period. Fig. 4c shows that during the post-SL period, catchment C exhibited slightly higher Qs than catchment A. Furthermore, the Qs of catchment C during the post-IR period was higher than that during the post-SL period.

Figs. 4d and 4e show that during the post-SL period, both the rising-limb and the recessing-limb of the Q-Qp relationship in catchment B produced higher Qs than the Q-Qp relationship in catchment C. This result indicates that the SS concentration in catchment B was greater than that in catchment C during the post-SL period. A combination of the larger skid trail area and steeper catchment topography in catchment B likely caused the greater magnitudes of SS discharge.

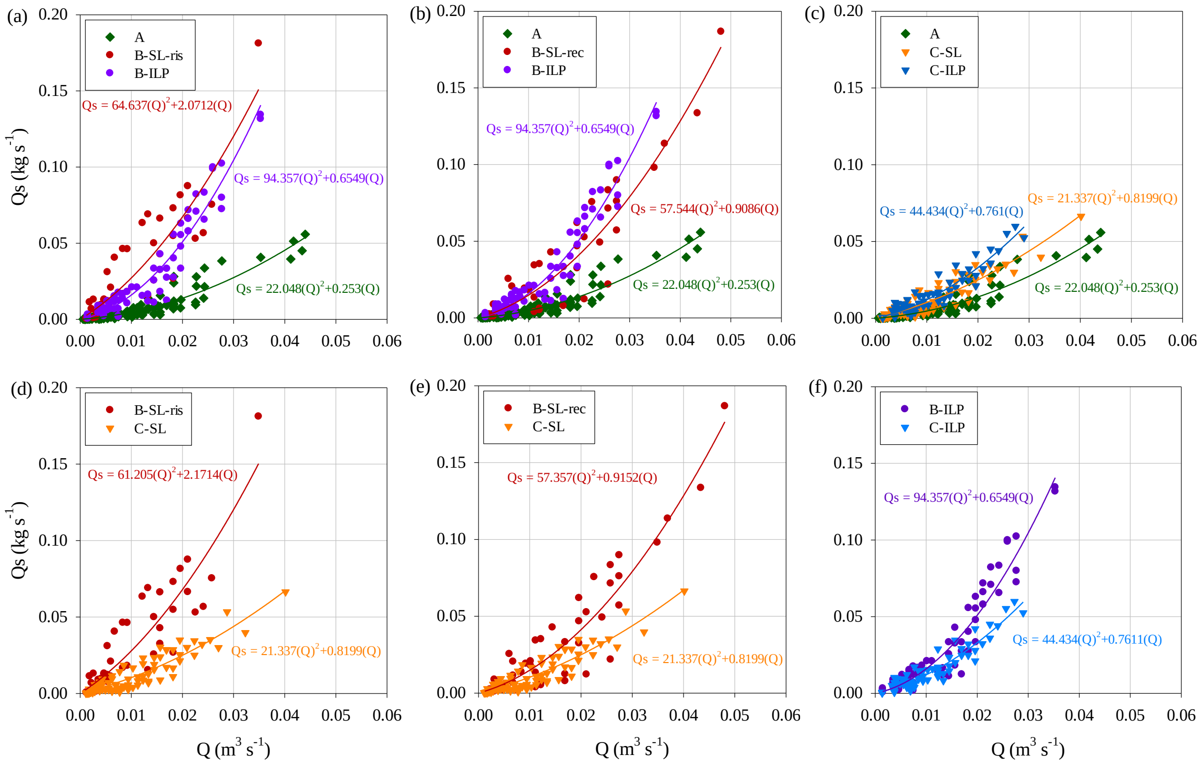

Fig. 4. Water discharge (Q) and suspended sediment discharge (Qs) relationships for the natural catchment (A), and treated catchments (B and C) during the post-SL (SL) and post-IR (IR) periods. (ris=rising-limb; rec=recessing-limb)

During the post-IR period, catchment B also produced greater Qs than catchment C (Fig. 4f). However, the differences between catchments B and C were smaller in comparison with those during the post-SL period (Figs. 4d and 4e). In catchment C, the sediment concentration during the post-IR period was slightly higher than that during the post-SL period (Fig. 4c). This increase was likely related to the addition of surface disturbance caused by IR operations. Although the manual line clearing operation left biomass litter on the forest floor, IR caused an increase in surface disturbance area and an overall decrease in canopy coverage (Table 1). Probably, effects of such disturbances outstrip effects of the biomass litter coverage in the forest floor, resulting in the increase of the SS concentration. The disturbances caused by the IR operations were pronounced in catchment C which suffered less disturbances than catchment B during the SL operation (Fig. 4d and e). Thus, our observations during the initial three months in the post-IR period suggested that the contour-rehabilitation conducted in catchment C was not effective to reduce the SS concentration of discharge water.

4 Conclusions

During the post-SL period, the greater amount of surface runoff as well as the higher slope gradient of catchment B attributed to high ability for transporting SS, which caused hysteresis in the relationship between water discharge and SS discharge and resulted in large amount of SS production. We concluded that a combination among the great surface disturbance by skid trails, large tree extraction ratio, and high slope angle brought the greatest SS yield in catchment B.

In catchment B, SS concentration during the post-IR period did not decrease in comparison with that during the post-SL period. In catchment C, IR operations increased SS concentration slightly higher than that during the post-SL period. Thus, both catchments B and C had high SS production rate in the initial stage of the post-IR period. This was attributed to additional surface disturbances by IR operations; although the manual line clearing left biomass litter on forest floor, IR caused increases in soil disturbance area and decreases in canopy coverage. Effects of such disturbances outstripped effects of the biomass litter coverage, resulting in increases in SS concentration.

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References

1. Na’iem, M. and Faridah, E. 2006. Model of Intensive Enrichment Planting (TPTII). In: A. Rimbawanto (Eds.), Silviculture systems of indonesia’s dipterocarps forest management a lesson learned. Yogyakarta: Faculty of Forestry

Gadjah Mada University and ITTO. Technical Report: ITTO Project PD 41/00 Rev. 3 (F,M), pp. 25–36.

2. E. Farida, S.P. Widiyatno, M. Naiem, *Close to nature technique: Applied studies on dipterocarps Indonesian tropical rain forest rehabilitation,* in Proceedings of the International Conference on Sustainable Forest Development in view of Climate Change, 8-11 August 2016, Putrajaya, Malaysia (2016)
3. H. Suryatmojo, M. Fujimoto, K. Kosugi, T. Mizuyama. *Impact of selective logging and intensive rehabilitation system on runoff and soil erosion in a tropical Indonesia rainforest*, in Proceedings of River Basin Management VI, 25-27 May 2011, California, USA (2011)
4. H. Suryatmojo, M. Fujimoto, K. Kosugi, T. Mizuyama, J-SustaiN **2**, 2 (2013)
5. H. Suryatmojo, K. Kosugi, Water **13**, 17 (2021)
6. I. Douglas, T. Spencer, T. Greer, K. Bidin, W. Sinun, W. W. Meng, Philos. Trans. Roy. Soc. B – Biol. Sci **335**, 1275 (1992)
7. K. Baharuddin, N. Abdul Rahim, J. Trop. For. Sci. **7**, 2 (1994)
8. J.N. Negishi, R.C. Sidle, A.D. Ziegler, S. Noguchi, N. Abdul Rahim, Earth Surf Process Landf **33**, 8 (2008)
9. R.P.D Walsh, K. Bidin, W.H. Blake, N.A. Chappell, M.A. Clarke, I. Douglas, R. Ghazali, A.M. Sayer, J. Suhaimi, W. Tych, K.V. Annammala, Philos. Trans. Roy. Soc. B – Biol. Sci **366**, 1582 (2011)
10. R.C. Gatti, S. Castaldi, J.A. Lindsell, D.A. Coomes, M. Marchetti, A.D. Paola, F. Paparella, R. Valentini, Ecol. Res. **30**, 1 (2015)
11. P.W. Ellis, T. Goapakhrisna, R.C. Goodman, F.E. Putz, A. Roopsind, P.M. Umunay, J. Zalman, E.A. Ellish, K. Mo, T.G. Gregoire, B.W. Griscom, For. Ecol. Manag. **438**, 255-266 (2019)
12. Black, P.E. Watershed Hydrology. New Jersey: Prentice-Hall, Inc., pp. 183-205. 1991.
13. Gordon, N.D., McMahon, T.A., Finlayson, B.L. 1992. Stream hydrology. An introduction for ecologists. University of Melbourne: John Wiley & Sons, pp.179–185