# Oil palm plantation land use is associated with elevated stream temperature and suspended solids concentration in Kalimantan, Indonesia

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## Background

- Oil palm is developing rapidly throughout the tropics, especially in Southeast Asia.
- This perennial crop (~25-30 yr rotation) is grown in extensive plantations (~130 km$^2$ per plantation).
- Plantation expansion converts mainly forested lands, including logged forests and mixed agricultural systems.
- Deforestation typically leads to increased sediment concentration and elevated stream temperature.
- Compared to intact forest to agriculture transitions, conversion of non-intact yet forested land uses (e.g., logged forests) to perennial plantations may impart distinctive outcomes on tropical freshwater stream ecosystems.

## Study Sites

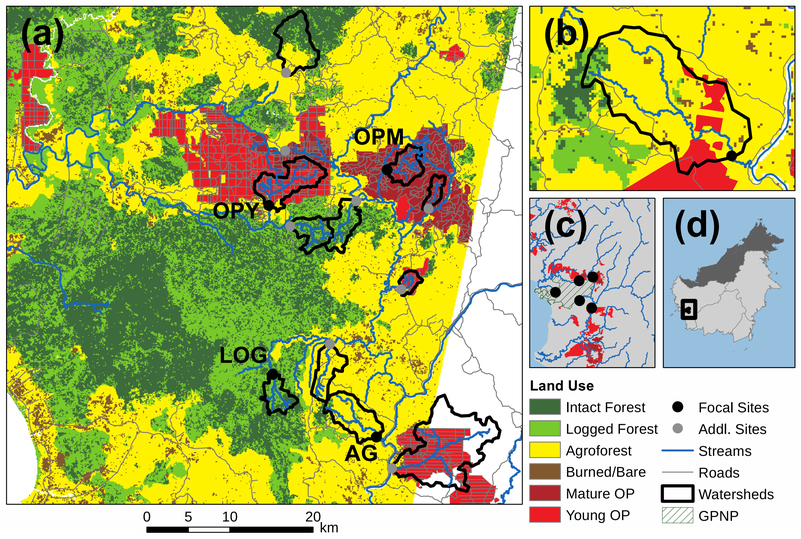


**Fig. 1.** Study region in Ketapang District, West Kalimantan, Indonesia. (a) Land use in 2008, with focal stream sample sites indicated by black circles and text labels, and eight supplementary sites denoted with grey circles. (b) In July 2011, clearing for oil palm commenced in the agroforest watershed; by June 2012, ~14% of the watershed was converted. (c) The study region is centered around Gunung Palung National Park (GPNP) in the Pawan River watershed of (d) the island of Borneo.

## Methods

- In West Kalimantan, Indonesia, we assessed streams draining watersheds characterized by four land uses: logged forest, mixed agroforest, and young (<3 yr) and mature (>10 yr) oil palm plantation.
- In four intensively sampled focal streams, we quantified total suspended solids (TSS, mg L$^{-1}$) concentration and stream temperature (°C) using high-frequency submersible sonde measurements during month-long intervals between 2009 and 2012.
- Temperature and sediment data were also collected across eight additional catchments with variable elevation, slope, area, and climatic conditions during four one-week periods in 2008 and 2009.
- Focal streams were field mapped and canopy cover was visually estimated at the stream center every ~500 m.
- Regional land use change was quantified by applying image segmentation and nearest-neighbor classification to Carnegie Landsat Analysis System-Lite (CLASlite) fractional cover data derived from a timeseries of Landsat imagery.

| Land Use | Area (ha) | Elevation (m) | Slope (°) |
|---|---|---|---|
| **Logged Forest** | **1316** | **89 (42-313)** | **6.1 (0-30)** |
| LOG1* | 1148 | 128 (52-441) | 8.6 (0-31) |
| LOG2 | 1336 | 70 (37-271) | 5.1 (0-32) |
| LOG3 | 1465 | 68 (36-227) | 4.7 (0-28) |
| **Agroforest** | **2074** | **133 (22-642)** | **8.4 (0-33)** |
| AG1* | 2297 | 103 (19-519) | 7.0 (0-31) |
| AG2 | 2454 | 220 (27-909) | 13 (0-40) |
| AG3 | 1471 | 77 (19-497) | 5.5 (0-26) |
| **Young Oil Palm** | **3496** | **54 (21-217)** | **3.7 (0-20)** |
| OPY1* | 2621 | 41 (19-91) | 2.3 (0-10) |
| OPY2 | 495 | 62 (30-109) | 4.8 (0-16) |
| OPY3 | 7372 | 58 (15-450) | 4.1 (0-34) |
| **Mature Oil Palm** | **922** | **47 (26-102)** | **3.9 (0-14)** |
| OPM1* | 1283 | 47 (27-104) | 3.0 (0-13) |
| OPM2 | 561 | 47 (25-99) | 4.8 (0-15) |
| OPM3 | n/a | n/a | n/a |

**Table 1.** Characteristics of 12 sample watersheds, with bold rows indicating means for each land use treatment, and asterisks denoting focal watersheds. Oil palm streams were characterized by lower elevation and slope compared to logged and agroforest streams. OPM3 watershed parameters are unavailable because the area was too flat for characterization using ArcGIS hydrology tools.

## Acknowledgements

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## Questions

1. **Do streams draining watersheds dominated by intact forest, logged forest, mixed agroforest, young oil palm plantation (<3 yr) or mature oil palm plantation (>10 yr) differ in temperature and sediment concentration?**
2. **What are the potential biophysical drivers of these differences?**

## Focal Stream Comparisons: Temperature and Total Suspended Solids

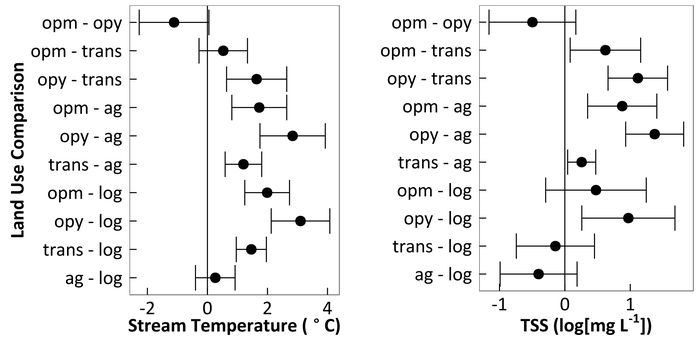



**Fig. 2.** Confidence intervals generated from multiple comparisons of focal watershed land use treatment means of stream temperature (°C) and total suspended solids concentration (TSS, mg L$^{-1}$) from generalized least squares models that account for correlated errors and unequal variances. The filled black circle indicates the mean difference between land uses. If the 95% confidence interval intersects with zero, no significant difference between land use treatments is detected. Land use treatment is a critical predictor of all response variables. After oil palm development commenced in the agroforest watershed, this stream experienced greater temperature and TSS concentration. The young oil palm stream is warmer and more turbid than logged and agroforest streams.

## Multiple Watershed Replicates: Consistent Results

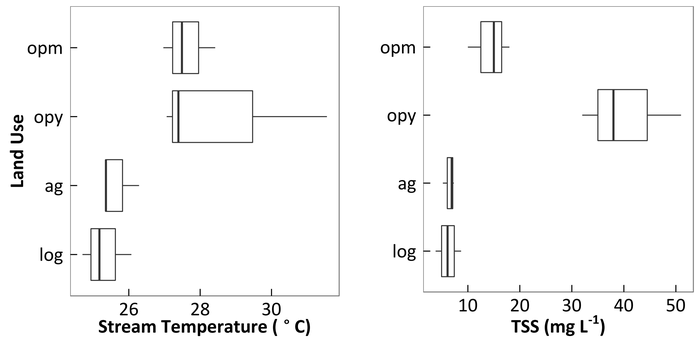
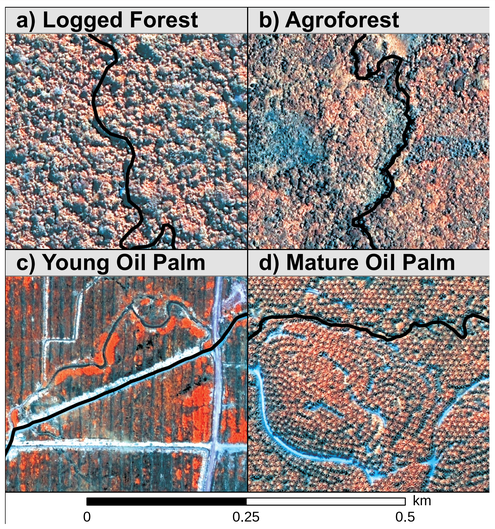



**Fig. 3.** Stream temperature (°C) and total suspended solids (TSS, mg L$^{-1}$) measurements across four focal and eight supplementary catchments ($n$ = 3 replicates per land use), sampled 8-16 August and 20-27 November 2008, and 11-16 April and 30 July to 9 August 2009. Black bars represent median values, hinges are 25$^{th}$ and 75$^{th}$ percentiles, and whiskers are the greatest (least) value 1.5x the interquartile range. While these results may not capture peak annual flow events and do not control for variable precipitation, they provide additional support for the finding that oil palm land use is associated with elevated temperature and TSS concentration. Notably, TSS concentration remains elevated even under mature plantation land use.

## Roads and Riparian Buffers

**Fig. 4.** High-resolution (0.6 m) Quickbird satellite imagery. Stream locations are shown with black vector; vegetation appears red. (a-b) Large trees extend to the edge of the logged forest stream, while trees are typically present to the agroforest stream edge. Skid trails and dirt footpaths dominate these land uses. (c-d) The young oil palm stream was diverted and little vegetation remains, while palms are planted to the mature oil palm stream edge. Although recovery of soil hydraulic properties, increased interception and evapotranspiration, and plantation management may inhibit sediment export with oil palm maturation, we suspect that dense plantation road networks – with frequent road/stream intersections that enable runoff to drain directly to streams – drive sustained high TSS concentration.



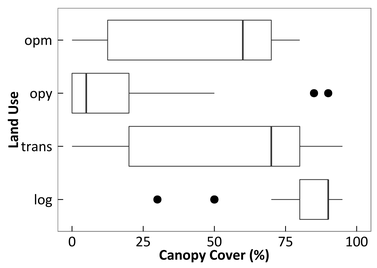




**Fig. 5.** Riparian stream reach canopy cover estimated at four focal watersheds. Radiative flux accounts for most heat inputs to freshwater streams, with lesser contributions from friction and sensible heat transfer. Thus, riparian vegetation cover plays a critical role in stream water temperature regulation because it moderates radiative inputs. We hypothesize that reduced stream shading is an important driver of observed greater stream temperatures in oil palm plantations compared to other land uses.

## Conclusions

- Temperature in focal oil palm streams was significantly greater (~1°C to >3°C) than in agroforest and logged forest streams.
- Young and mature oil palm streams had the lowest canopy cover (12% and 45%, respectively) compared with 81% cover in the logged forest stream.
- Focal logged forest and agroforest streams had significantly lower TSS concentration than the young oil palm stream.
- Across 12 regional streams, young and mature oil palm land uses generated 2- to 6-fold greater mean TSS concentration than logged forests and agroforest.
- Watersheds with similar area, slope, and elevation to those studied here occupy approximately 23% of Kalimantan's land area.
- Thus, our findings inform potential hydrologic outcomes of continued expansion of oil palm plantations in Kalimantan.