Forest cover loss in Sumatra and Kalimantan, Indonesia: Accurate maps and annual trends derived from time-series analysis of multi-resolution optical remote sensing

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ABSTRACT
The Indonesian islands of Sumatra and Kalimantan are a hotspot of rapid forest cover loss (FCL) with implications for carbon dynamics, biodiversity, and local livelihoods. Mapping of Indonesian forest cover loss has been limited due to persistent clouds. We mapped annual FCL 2000-2008 per forest land use zone using data from the Landsat 7 and MODIS sensors. FCL 2000-2008 totaled 5.39 Mil. Ha and has slowed since a peak in 2006. Riau and Central Kalimantan provinces accounted for 47% and 45% of total FCL. Within the official forest land use zones, 9% of FLC occurred where clearing is prohibited. Results illustrate the potential for reducing FCL in Indonesia via effective enforcement of existing forest land use designations, verified using remotely sensed data. Operational satellite monitoring of national-scale forest dynamics will also serve for the detection of displacement and the assessment of permanence in response to changes in forest governance.

KEYWORDS
Tropical forest, deforestation, REDD+, deforestation drivers, remote sensing, Landsat, MODIS

1 INTRODUCTION
The Indonesian island groups of Sumatra and Kalimantan are a hotspot of rapid forest cover loss (FCL) with implications for carbon dynamics, biodiversity, and local livelihoods (Curran et al. 2004; Gullison et al. 2007). The UN Reducing Emissions from Deforestation and Forest Degradation in Developing countries policy framework (REDD+) aims to reward developing nations in the tropics for reducing deforestation and forest degradation (COP16/CMP6 2010), which is considered a cost effective way of mitigating anthropogenic greenhouse gas emissions (IPCC 2007). The recently formed Norway-Indonesia REDD+ Partnership has as its goal the reduction of such emissions in Indonesia (Government of Norway and Indonesia 2010).

Establishing baseline information for such an initiative is required, and includes quantifying forest change within officially allocated forest land uses. Indonesia has three official forest land use zones: production forest (including regular production, limited production, and conversion), protection forest and conservation forest (Law Republik Indonesia 1999). Permanent and temporary clear cutting are only allowed in conversion and regular production, and restricted in limited production forests. Clearing is prohibited within conservation and protection forest (Ministry of Forestry Indonesia 2003).

To date, synoptic mapping of Indonesian forest cover extent and change using remotely sensed data has been limited due to persistent cloud cover. It has therefore been difficult to achieve an understanding of where, when and how much forest cover has changed. Only by understanding the spatial and temporal patterns of forest change is it possible to understand drivers and develop effective policies for reducing deforestation and/or degradation. However, improved methods (Broich et al. 2010) and data policies (Woodcock et al. 2008) have overcome limitations posed by cloud cover and enabled large area FCL mapping.

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2 METHODS
Using remotely sensed data, we mapped annual FCL 2000-2008 per forest land use on Sumatra and Kalimantan. These maps were generated automatically using data from the Landsat Enhanced Thematic Mapper Plus (ETM+) and MODerate Resolution Imaging Spectroradiometer (MODIS) sensors. ETM+ data were used to accurately map FCL 2000-2008 (Broich et al. 2010). Annual MODIS-derived FCL maps were used to allocate ETM+-mapped FCL to individual years (Broich et al. In Review). Forest was defined as >25% canopy cover of trees >= 5 m in height. FCL was measured without regard to forest land use, and included plantation and palm estate change dynamics.

3 RESULTS
Our findings indicate that FCL 2000-2008 totaled 5.39 million hectares, or 5.3% of the land area, with 73% of FCL occurring within official forest land uses. The map of 2000-2008 FCL in Sumatra and Kalimantan and regional trends are shown in Figure 1A&B. Findings include:

1) FCL does not follow allocated forest use zones. Within the official forest zones, 73% of all FCL occurred in zones permitting permanent or temporary clear-cutting, i.e. conversion and production. However, 9% of FCL occurred in zones where clearing is prohibited: 6% in watershed protection, and 3% in biodiversity conservation. An additional 19% of FCL occurred in limited production forests where cutting is restricted. (Figure 1C).

2) FCL is spatially concentrated. Riau and Central Kalimantan provinces accounted for 47% and 45% of total FCL in Sumatra and Kalimantan, respectively (Figure 1B). Sebangau National Park (NP) in Central Kalimantan accounted for 35% of all FCL in NPs. The majority of Sebangau's FCL occurred in moderate El Nino years, indicating human-induced fire as a principal cause (van der Werf et al. 2008) (Figure 1D).

3) Total FCL has slowed since a peak in 2006 (Figure 1B).

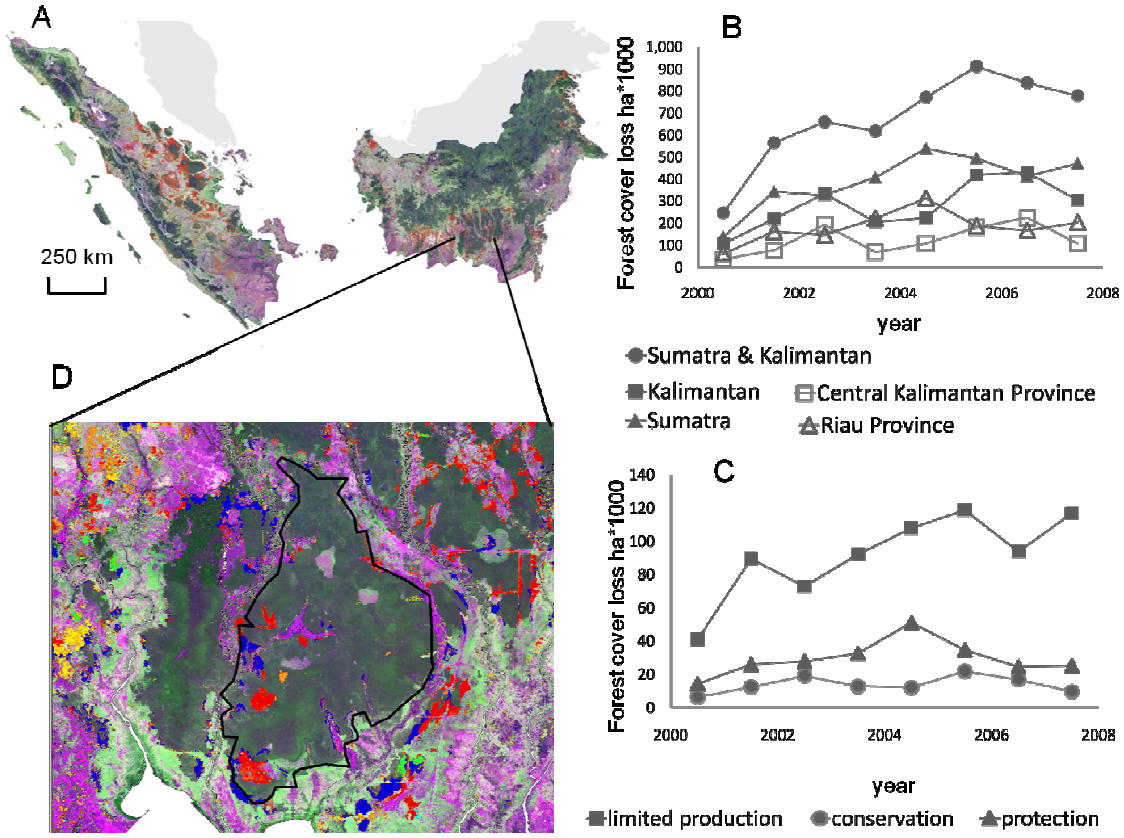

Figure 1 (A) Forest cover loss for Sumatra and Kalimantan 2000-2008 (red); (B) disaggregated by year and region; (C) disaggregated by year and forest land use where clearing is not permitted; (D) zoom of Sebangau NP color-coded by year of FCL (red=2002-03, blue=2006-07);

4 CONCUSIONS

Quantifying the spatial and temporal variation of forest change within Indonesia is possible and necessary in light of the ambitious goals of the Norway-Indonesia REDD+ Partnership (Government of Norway and Indonesia 2010). Results of this analysis illustrate the significant potential for reducing FCL in Indonesia via effective enforcement of existing forest land use designations (Minstry of Forestry Indonesia 2008), verified using remotely sensed data. Operational satellite monitoring of national-scale forest dynamics will also serve for the detection of displacement and the assessment of permanence in response to changes in forest governance.

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