Supplemental Material

1.0 Study Sites

Since 1999 when the methodology for estimating carbon emissions from selective logging was first developed, we have applied it in forest concessions in six different countries: Bolivia and Belize (unpublished data available from authors), Republic of Congo (Pearson et al. 2006a), Brazilian Amazon (Pearson et al. 2006b), Indonesia (Pearson et al.2007, Brown et al. 2011) and Guyana (Goslee et al. 2012). All 13 tropical forest concession areas (five in Indonesia, four in Guyana, and one each in other countries) are located in tropical moist climate zone and are subject to a wide range of extraction rates (Table 1). The dominance of specific timber species differed between sites: 98% of all harvested trees in Guyana were of *Chlorocardium rodiei*, 69% of all harvested trees in Congo were *Entandrophragma cylindricum* , and no one species represented more than 38% of the harvested trees in Bolivia. In Indonesia 90% of all harvested trees was represented by the genus *Shorea.*

2.0 Field Measurements

2.1. Timber extraction. At each site, the volume of the extracted log was calculated by multiplying the log length by the average of the cross-sectional areas at the base and crown ends of each log. Biomass of the commercial log was calculated by multiplying the estimated volume by the wood density. A species-specific density was used when available or a mean wood density was used when the species was not known or had no published wood density value. The following mean values were used: 0.57 Mg m^{-3} for Asian species, 0.58 Mg m^{-3} for African species, 0.60 Mg m^{-3} for Latin American species (Reyes et al. 1992); or country specific density in the case of Guyana of 0.67 Mg m^{-3}.

The area of the logging gaps was estimated as the area with unimpeded direct vertical penetration of light. A best approximation was made of the shape of the gap, and the necessary dimensions to estimate the area were recorded (gap area was not recorded in Bolivia or Belize).

2.2. Logging damage factor. We estimated the total aboveground biomass of the felled tree by applying a general biomass allometric equation for tropical moist forests that incorporates DBH (diameter at breast height) and wood density (from Chave et al. 2005). The biomass of the tree crown and stump was estimated by subtracting the biomass of the extracted log from the estimated total aboveground biomass of the felled tree.

Damaged trees were those trees that were severely impacted by the felled tree, ultimately leading to their death. Damaged trees were classified as either a snapped stem or uprooted. The DBH of all damaged trees with a DBH> 10 cm was measured. Aboveground biomass of incidentally damaged trees was estimated using Chave et al. (2005).

Below ground biomass of the felled and damaged trees was based on the linear equation for forests and woodlands given in Mokany et al. (2006; root biomass = 0.26 * shoot biomass, R^2=0.78). We used this form of the equation as it allowed us to estimate the belowground biomass of individual trees.

During the felling of a large timber tree it is possible that large branches could be broken off from neighboring surviving trees. The biomass carbon of the branches was also estimated based on volume estimation and application of the region-specific default wood density (see above). The extent of this type of damage was very limited—through careful inspection in each plot we recorded such events in only 4 plots in Bolivia, 0 plots in Belize, 1 plot in Congo, 3 plots in Brazil, 15 plots in Indonesia, and 17 plots in Guyana.

The total damage in a logging gap was calculated as the sum of the above- and below-ground biomass of the crown and stump of the felled tree, plus the biomass of snapped and uprooted trees and large broken branches.

2.3. Skid trails, roads and logging decks. In Congo and Indonesia, the emissions from roads, skid trails and logging decks were estimated at the concession level, whereas in Guyana it was at the national level.

In Congo, the length of a sample of skid trails was measured and all trees snapped or uprooted along the length of skid trails were measured at breast height and their biomass estimated using the Chave et al. (2005) equation. Ten skid trails totaling 3.8 km were measured to provide an estimate of the dead tree biomass per km.

In Indonesia and Guyana, skid trails were created by the operators using bulldozers (also known as crawler tractors). In this case the impact of skid trails was estimated per unit of length of the trails with the assumption that all trees with DBH less than 50cm in Indonesia, and 35 cm in Guyana in the path of the skidder were killed (based on personal communications with concessionaires and concessions' field team). In Indonesia, skid trail length was recorded in remotely sensed imagery (Brown et al. 2011). In Guyana, skid trail length was obtained from pre-harvest management plans required by the Guyana Forestry Commission (GFC) from concessionaries planning harvesting operations. In this case, we used the average annual total length of skid trails planned to extract the average annual recorded production of logs for the most recently reported 5-yr period from 2006 to 2011.

To create logging decks, forest operators entirely clear patches of forest. Such patches were clearly apparent in the imagery for Indonesia and Guyana. In Congo, however, logs were piled on the margins of roads that were wider than in the other sites and thus the area of decks and roads were combined into one value. No field measurements of logging decks were made in Indonesia or Guyana because their area was obtained from the satellite imagery.

The infrastructure factors given in Eq. 3 are based on the carbon stocks of the unlogged forest. We obtained their carbon stocks by establishing nested circular plots in each forest concession area that had not yet been logged. The field measurement and calculation procedures we used are described in Pearson et al. (2005). Diameters at breast height were recorded and biomass was calculated using the equation of Chave et al. (2005) based on DBH and wood density. The belowground biomass was estimated using the median root:shoot ratio for tropical moist forests (0.235 for forests with aboveground biomass of >125 $Mg.ha^{-1}$) given in Mokany et al. (2006).

2.4. Area of logging infrastructure. In Guyana, the area of roads and decks were captured together in national remote sensing analysis (Guyana Forestry Commission and Poyry Forest Industry 2011). In Congo and Indonesia, the area of roads and logging decks was estimated either from satellite or aerial imagery.

Aerial digital imagery: Digital aerial imagery was collected at a height of 2000 m above ground over logged areas in Congo. The area captured by the imagery for our analysis was 12.5% of the total area of the active 2004 concession (11,800 ha). All imagery was collected in the visible bands (red, green, blue) at a rate of about 2 images per second. This high rate of image collection yielded overlap of 70-80% between each image and its neighbors, making stereo interpretation possible. For more details on the collection system and analysis see Brown et al. (2005).

We identified logging gaps by digitizing polygons that completely enclosed the resulting areas of bare ground, visible slash and other debris, and low, scrubby growth (Figure 1). The skid trails used for log extraction were often visible beneath the forest canopy, and these trails were digitized as simple line features everywhere that they were visible. When the location could be confidently interpolated, it was digitized (visible on either side of a large tree, for example). The third category that we digitized was roads and logging decks that were delineated as polygons and were free of any type of vegetation.

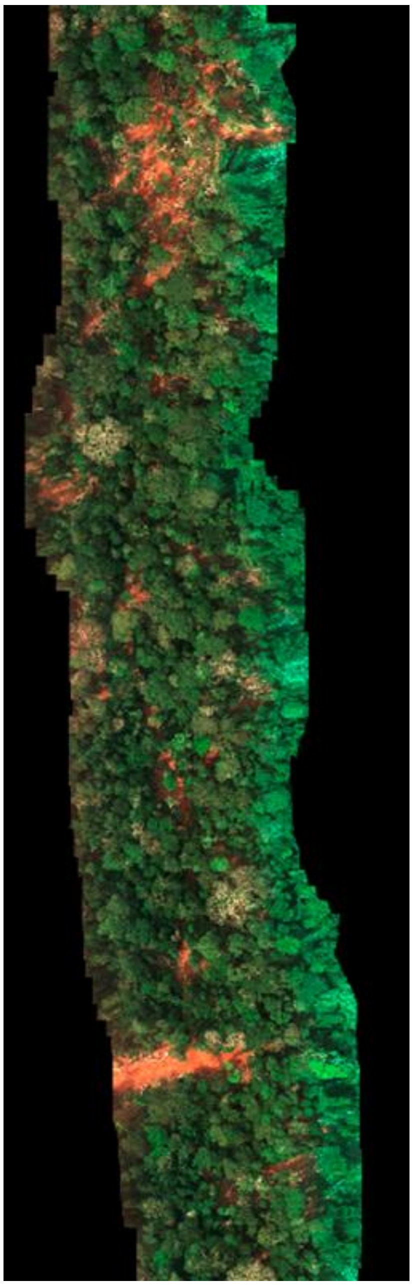

Figure 1. Aerial image of a transect at the Republic of Congo site illustrating a road, skid trails and logging gaps.

Satellite imagery: In Indonesia, high resolution images from the WorldView-2 satellite with 0.6 m resolution were acquired that covered 70% of the 2010 logging area inside one of the study concessions (details are given in Brown et al. 2011). All skid trails, logging decks and roads were identified and digitized. Measurements of the width of skid trails and roads and area of the decks were made in the imagery to obtain the total length and area of skid trails and roads, and area of decks covered by the satellite images. Data on the total extraction rate for the concession area covered by the imagery were obtained from the concession operator.

In Guyana, the area of logging roads and decks was obtained from a country-wide forest-cover change assessment for the period 2006-2010 based on medium to high resolution satellite imagery (Guyana Forestry Commission and Poyry Forest Industry 2011).

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