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Impacts of selective logging on above-ground forest biomass in the Monts de Cristal in Gabon

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ABSTRACT

Selective logging is an important socio-economic activity in the Congo Basin but one with associated environmental costs, some of which are avoidable through the use of reduced-impact logging (RIL) practices. With increased global concerns about biodiversity losses and emissions of carbon from forest in the region, more information is needed about the effects of logging on forest structure, composition, and carbon balance. We assessed the consequences of low-intensity RIL on above-ground biomass and tree species richness in a 50 ha area in northwestern Gabon. We assessed logging impacts principally in 10 randomly located 1-ha plots in which all trees ⩾10 cm dbh were measured, identified to species, marked, and tagged prior to harvesting. After logging, damage to these trees was recorded as being due to felling or skidding (i.e., log yarding) and skid trails were mapped in the entire 50-ha study area. Allometric equations based on tree diameter and wood density were used to transform tree diameter into biomass.

Logging was light with only 0.82 trees (8.11 m^3) per hectare extracted. For each tree felled, an average of 11 trees ⩾10 cm dbh suffered crown, bole, or root damage. Skid trails covered 2.8% of the soil surface and skidding logs to the roadside caused damage to an average of 15.6 trees ⩾10 cm dbh per hectare. No effect of logging was observed on tree species richness and pre-logging above-ground forest biomass (420.4 Mg ha^{-1}) declined by only 8.1% (34.2 Mg ha^{-1}). We conclude from these data that with harvest planning, worker training in RIL techniques, and low logging intensities, substantial carbon stocks and tree species richness were retained in this selectively logged forest in Gabon.

1. Introduction

The two million km^2 of Congo Basin forest is high in conservation value and crucial for both national development and the livelihoods of about 100 million people (de Wasseige et al., 2009; FAO, 2011). These forests are among the world's most intact and provide a variety of ecosystem services (e.g., protection of water and soil resources), support thousands of plant species, and harbor populations of many endangered animal species (Blake et al., 2007; Clark et al., 2009). Although these forests are actively used by people, they are needed to maintain viable populations of many wide-ranging species (Putz et al., 2001; Sanderson, 2006). In addition to supporting biodiversity, these forests also store and absorb substantial but seldom measured quantities of carbon (Lewis et al., 2009).

Logging by untrained and unsupervised laborers working without the aid of adequate management plans is taking a great toll on Congo Basin forests (Hall et al., 2003; Ruiz Perez et al., 2005; Cerutti et al., 2008, 2011; Ezzine de Blas and Ruiz Perez, 2008; Angelsen et al., 2009; Poulsen et al., 2009). In Gabon, for example, of the 12.4×10^6 ha of "forêt productive enregistrée" in 2008, management plans were prepared for only about a quarter of the area being logged (WRI, 2009).

Based on studies conducted in tropical forests but not in Africa, employment of reduced-impact logging (RIL) practices reduces collateral forest damage, which results in both substantial reductions in carbon emissions and increased biodiversity retention (see Johns et al., 1996; Pinard and Putz, 1996; van Rheenen et al., 2004; Putz et al., 2008a; van Kuijk et al., 2009; Putz and Nasi, 2009). RIL is a suite of techniques based on scientific and engineering principles that, in combination with worker education, training, and supervision,

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improves the efficiency of application of labor and equipment in the harvesting of industrial timber while reducing damage to residual stands (Dykstra, 2002). While definitions of RIL are imprecise and not all of these techniques are used in every site claiming to be applying RIL, studies of areas logged using some or all of these techniques in South America and Asia have shown increased forest carbon retention both immediately after logging and for decades afterwards (Putz et al., 2008b). Unfortunately, the implementation of RIL requires up-front capital investment in timber inventories, staff training, and sometimes machinery, along with substantial modifications in working practices. Logging company managers and owners are unlikely to make these investments without clear indications of their benefits. Evidence for these benefits is scarce in Central Africa where little is known about the extent to which employment of RIL could serve to preserve carbon and tree species diversity.

If poorly implemented, selective logging causes substantial damage to residual stands. Logging directly and indirectly affects all components of biodiversity, from genes to landscapes (Putz et al., 2001; van Kuijk et al., 2009). Even light selective logging affects tree species composition, densities, and size-class frequency distributions, but the deleterious environmental impacts of logging can be substantially reduced if appropriate techniques are used (Bertault and Sist, 1997; Durrieu de Madron et al., 1998; van Kuijk et al., 2009). In a selectively logged forest in Indonesian Borneo, for example, Cannon et al. (1998) found that 8 years after logging the density of trees ⩾20 cm dbh was lower than in unlogged plots but detected no difference in tree species richness. Similarly, in Southwestern Central African Republic, Hall et al. (2003) found that forest sampled 18 years post-logging had lower tree densities than either unlogged stands or stands sampled 6 months post-harvest, but did not detect difference in tree species richness.

Tree harvesting unavoidably opens canopy gaps, reduces overall canopy cover, and disturbs soil surface. In Bolivia, for example, Jackson et al. (2002) found that planned harvesting of 4.3 trees ha^{-1} (12.1 m^3 ha^{-1}) opened the canopy over 25% of their study area. In eastern Brazil, Johns et al. (1996) found canopy reduction of 10% after planned logging of 4.5 trees ha^{-1} (37 m^3 ha^{-1}). In the semi-deciduous forest of Mbaïki, Central African Republic, Durrieu de Madron et al. (2000) reported 14–22% of area disturbed due to the harvest of 2.6–4.0 trees ha^{-1} (mean = 118 cm dbh). These results show that the harvest of even small numbers of large trees results in substantial canopy opening.

Selective timber harvesting degrades forests in the sense that it results in reductions in carbon stocks that will need to be accounted for if a reduced-emissions from deforestation and forest degradation (REDD; Angelsen et al., 2009) program is implemented. If Congo Basin countries are to benefit from REDD and REDD-like programs, data will be needed on the carbon consequences of logging. To fill some of the gaps in knowledge about the effects of logging on forest structure, composition, and above-ground biomass in Africa, we measured the damage resulting from felling and skidding due to low-intensity RIL in Gabon.

2. Methods

2.1. Study site

This study was conducted in the Monts de Cristal region of northwestern Gabon (0°20’N; 10°20’E; Fig. 1) in the 477,033 ha logging concession of Société Equatoriale d’Exploitation Forestière (SEEF). The natural vegetation of this region is dense humid evergreen rainforest (Fuhr et al., 1998; Sunderland et al., 2004). The long-lived pioneer *Aucoumea klaineana* Pierre (Burseraceae) is the most common tree species. The soils are mostly oxisols, the climate is tropical with a long dry season (July–September), annual rainfall is 2000–2400 mm (Leonard and Richard, 1993), and average temperatures are 24–26 °C (Sunderland et al., 2004).

Logging in what is now the SEEF concession started in the 1950s but due mostly to the undulating topography, elevation (689 m above sea level), and inaccessibility, harvesting was extremely light and spatially patchy until SEEF started more thorough exploitation in 2000. Although we lack maps or other information about the history of the study site, we found no evidence of earlier episodes of harvesting in our study plots.

Timber extraction in SEEF is selective with *A. klaineana* alone making up about 60% of the total volume. At the time of this study the concessionaire was preparing management plans for the entire concession with the intention of attaining Forest Stewardship Council (FSC) certification (Ricordo 2010, pers. comm.). With this goal in mind, SEEF allocated 250 ha to the Tropical Forest Foundation (TFF) and FORM International for training, demonstration, and research on RIL as part of an International Tropical Timber Organization project. In this area, harvestable trees of 27 commercial species were tagged, mapped, measured (dbh; diameter at breast height of 1.4 m or above buttresses), and identified to species. Prior to harvesting a total of 104 ha in July 2009 and January–February 2010, skid trails were planned by TFF on the basis of topographic and stock maps prepared by an inventory crew. Each feller received one week of training in directional felling techniques conducted by a professional trainer contracted by TFF. Trees were felled using chainsaws (Stihl MS 880) and yarded by a trained worker with a tracked skidder (Caterpillar D527); both operations were coordinated and supervised by TFF. Logging intensity in the 104 ha (0.82 trees ha^{-1} and 8.11 m^3 ha^{-1}) was within the typical range (0.7–4 trees ha^{-1}) for Central Africa (Durrieu de Madron et al., 1998; Ruiz Perez et al., 2005).

2.2. Plot-based measurements

Prior to harvesting we established ten permanent 200 × 50 m (1 ha) plots at random locations in 50 ha of the area to be subjected to RIL to capture variability in logging impacts. All trees ⩾10 cm dbh in each plot were measured, tagged, mapped, classified according to stem quality and crown position (suppressed, side-lighted, sub-dominant, co-dominant and dominant; see Hall et al., 2003), and assessed for the presence or absence of lianas. Trees were identified to the species level where possible based on vegetative characteristics. Voucher specimens were collected for species that could not be identified in the field and then identified at the National Herbarium in Libreville.

2.3. Damage assessment

Logging damage was assessed in the 1-ha sample plots using methods well-established in the literature (e.g., Johns et al., 1996; Whitman et al., 1997; reviewed by Putz et al., 2008b). Damage to roots, boles, and crowns were ranked on a scale from minor to very severe. Crown damage was recorded as severe (>66% crown loss), moderate (33–66% crown loss), or minor (<33% crown). Bole damage was recorded as severe (broken bole), moderate (>100 cm^2 of bark removed), or minor (<100 cm^2 of bark removed). Uprooted trees were recorded as such. Root damage was recorded as major (>10% of surface roots injured) or minor (<10% of surface root injured). Crown, bole, and root damage were attributed to felling and/or skidding.

The soil surface area disturbed by skid trails and skidder activities in logging gaps was measured in the entire 50 ha study area. Skid trails were assigned to one of three categories based on the number of logs skidded (one log per pass): primary > 10; secondary 2–10; and, tertiary 1. Skid trail widths were measured every 10 m.