



## Viability of combined timber and non-timber harvests for one species: A *Carapa guianensis* case study

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### ABSTRACT

There is growing consensus that sustainable use has a significant role to play in global conservation. Tropical forests are no different, and managing them for multiple products is envisioned as a preferable alternative to timber-dominant management models. Limited research, however, has tested coupling timber and non-timber harvests in multiple-use species for both economic gain and long-term species conservation. We employ matrix population models and the extinction time cumulative distribution function to examine one such species, *Carapa guianensis*. We investigated sustainable harvests of *C. guianensis* in two forest types in which it occurs naturally in western Amazonia, testing whether differences between forest types affect population responses to harvest under measured environmental stochasticity regimes. Our results indicated that some *C. guianensis* populations may be suitable for extraction of seeds, timber, or a combination of both. In upland or *terra firme* forest sites, model projections suggested that no tested levels of seed and timber extraction were sustainable. In contrast, we found the potential for compatibility between seed and timber harvest in occasionally inundated forests. In these sites, which are ecologically similar to wet areas where *Carapa* thrives throughout its range, our results suggested that 10% annual seed harvests were compatible with 100% timber harvests of trees  $\geq 50$  cm twice a century, the equivalent of approximately two trees per hectare. Application of this research approach to other economically important tropical species could increase the diversity of Amazonian management and conservation options.

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### 1. Introduction

There is growing consensus that sustainable use has a significant role to play in nature conservation globally (Heywood and Iriondo, 2003; Nepstad et al., 2009). While preservation via protected areas is a cornerstone of conservation (Brooks et al., 2009) and an essential part of any strategy to conserve tropical forest diversity, protected areas inevitably include an incomplete set of the regional biota and are often embedded in a modified and fragmented landscape. Even if protected areas are locally effective, they encompass only 9.8% of tropical forests and 11.1% of Amazonia (Schmitt et al., 2009). Even so, managed forests, protected or not,

can provide important conservation benefits, including provision of ecosystem services (Daily, 1997) and species habitat for biodiversity conservation (Lamb et al., 2005; Scales and Marsden, 2008). Recognizing and increasing the conservation value of lands outside protected areas is a necessary component of any long-lasting conservation effort (Harvey et al., 2008; Ros-Tonen et al., 2008).

Managing forests for services and products that yield economic benefits is an effective way to encourage forest persistence and biodiversity conservation, with potential benefits for diverse groups, including private landowners, forest residents, indigenous groups and smallholders. Indeed, economic benefits from managed harvests may be necessary to maintain forest cover on privately owned lands at high risk of deforestation (Zarin et al., 2007). The Brazilian government has recognized this potential synergy between conservation and sustainable forest development by expanding the country's conservation units (Campos and Nepstad, 2006) to almost 1.5 million km<sup>2</sup> that includes both use and non-use forest reserves (MMA, 2011).

Multiple forest resources already provide concrete revenue, including timber and non-timber forest products (NTFPs). Logging

**Abbreviations:** CDF, cumulative distribution function; dbh, diameter at breast height; iid, independent and identically distributed; IPM, integral projection model; NTFP, non-timber forest product.

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provides clear economic benefits (AIMEX, 2005; Verissimo et al., 1992), although it does not provide a continuous revenue flow unless specifically managed to do so (Oliveira, 2000), which is rarely the case in the tropics. Indiscriminant one-entry logging remains the predominant form of timber extraction (Putz et al., 2000) and timber overexploitation is often linked with a strong boom and bust economic pattern (Rodrigues et al., 2009). Logged forests can be a component of multi-functional conservation landscapes for conservation values (Meijaard et al., 2005) and biodiversity (Whitmore and Sayer, 1992). Even twice-logged forest in Indonesia sustained 75% of native bird species (Edwards et al., 2011). Logging, however, has significant drawbacks: removing stems causes forest disturbance (Verissimo et al., 1992), increases forest susceptibility to fire (Alencar et al., 2004; Cochrane et al., 1999), and typically foments increased forest access and conversion (Fearnside, 2005).

In contrast, non-timber forest product (NTFP) harvest can provide a more consistent cash flow, particularly when targeting a diversity of species over the course of a year. While NTFP harvests may affect population persistence (Peres et al., 2003) and forest structure (Belcher and Schreckenberg, 2007; Ticktin, 2004), they are generally less ecologically destructive than logging. Harvests are typically easier to sustain long-term and add to the perceived value of the forest (Marshall et al., 2003), but alone, may not provide enough revenue to promote forest maintenance and biodiversity conservation, and may be insufficient to lift communities out of poverty (Morsello, 2006).

Combining these two types of forest products through multiple-use forest management is increasingly envisioned as a preferable alternative to timber-dominant management models (García-Fernandez et al., 2008). While limited research has focused on the relative compatibility of coupling timber and NTFP harvests (though see Guariguata et al., 2010, 2008; Menton et al., 2009; Snook, 2000), thoughtful harvest of multiple forest products seems increasingly necessary to compete with alternative, relatively lucrative land-use activities, like conventional logging, cattle ranching, and soy and palm oil monocultures (Butler and Laurance, 2008; Pearce, 1996; Pearce et al., 2003).

Determining ecologically sustainable harvest limits is necessary for developing appropriate forest management and conservation strategies, despite the significant challenge (Ribeiro do Valle et al., 2007). Matrix population models are powerful tools to identify population responses to management regimes (Olmsted and Alvarez-Buylla, 1995) and to set harvest limits compatible with continued population existence (Nantel et al., 1996; Ratsiraron et al., 1996). Matrix models can be used to evaluate sustainable harvest levels for timber, NTFPs or a combination of management strategies for single species. These models are potentially useful for the third to half of Amazonian timber species that also have NTFP value (Herrero-Jáuregui et al., 2009; Martini et al., 1994).

We employ matrix models to examine sustainable use of *Carapa guianensis*, one such multiple-use species, by simulating harvests in two forest types in which it occurs naturally in western Amazonia, and at different densities and abundances (Klimas et al., 2007). Our objectives were: (1) to quantitatively assess the impact of seed and timber harvests on *C. guianensis* populations in stochastically varying environments and between occasionally inundated and upland or *terra firme* forests, and (2) to simulate potential ecologically viable harvest scenarios of *C. guianensis* seeds, timber, or both.

We hypothesized that intensive seed collection would not impinge on seedling recruitment, ensuring continued species persistence. For *Bertholletia excelsa*, Wadt et al. (2007) found that high levels of seed harvest (up to 71%) were compatible with population persistence. We also hypothesized that *terra firme* forests would allow even more intensive seed harvests because seeds in this environment may be “safe-site” limited with fewer suitable

germination sites. Lower densities in this forest, compared with occasionally inundated forests, may translate into fewer suitable areas for successful germination and survival (Klimas et al., 2007). Collecting seeds that would otherwise perish would allow for increased seed harvest levels without impacting future population viability.

## 2. Methods

### 2.1. Study species

Mature *C. guianensis* (Meliaceae) trees can reach heights of 30 m (Ferraz et al., 2002) though neither tree height, nor diameter reliably predicts age (Vieira et al., 2005). Seed production is variable between years and between size classes, and peaks at 40–50 cm dbh (Klimas et al., 2012b). *C. guianensis* seed oil sells both locally and internationally. Brazil exported 200–300 tons of oil annually between 1974 and 1985 (Clay et al., 2000). Pure seed oil is used for medicinal applications, with value-added products including soaps, shampoos, candles and repellent torches (Shandley and Medina, 2005). In addition, *C. guianensis* has economic value from its high quality timber (Dayanandan et al., 1999).

### 2.2. Study site

We carried out field measurements within four 400 m × 400 m (16 ha) plots established within the 1200 ha experimental forest of the Brazilian Agricultural Research Corporation (Embrapa) in eastern Acre, Brazil (latitude 10° 01'28"S and longitude 67° 42'19"W). Average annual temperature is 24.5 °C with a dry season from June to August (INMET, 2009). Two plots were established where the majority of the environment was classified as *terra firme* and two in occasionally inundated forest (Klimas et al., 2007). All individuals ≥10 cm dbh were inventoried in these plots and tree canopy position (dominant, co-dominant, intermediate or suppressed), spatial coordinates, and diameter at breast height (dbh) were measured. Annual survival was assessed for all inventoried individuals.

### 2.3. Individual survival rates, diameter growth and seed production

Of the inventoried individuals ≥10 cm dbh, we installed dendrometer bands on a subset of over 500 trees in 2003, via a stratified random sample controlling for location (forest type) and dbh categories (Table S1). Following a 9-month period of band adjustment, annual diameter growth was monitored for this subset of trees between May and June of 2004 through 2009. We conducted measurements during the dry season to reduce variance (Sheil, 1997, 1995, but see Baker et al., 2003). Size-class dependent growth was characterized by low annual diameter increment, with high variability (Klimas et al., 2012a).

We recorded seedling and sapling location (*x*, *y* coordinates), and annual survival and growth in 32 10 m × 10 m subplots within each of the larger 16 ha plots. Seedlings (individuals <1.5 m tall) and saplings (individuals ≥1.5 m tall and <10 cm dbh) in each subplot were monitored from 2005 to 2009, between May and July. For seedlings, we annually measured basal diameter (ground level) and stem height; for saplings we measured dbh (Klimas et al., 2007), calculating annual growth increments by increases in seedling height and sapling dbh. We measured smaller saplings using digital calipers, marking the measurement location with a permanent marker to ensure year-to-year consistency. For larger saplings, we sprayed paint above and below a circular piece of metal the same size as the diameter tape, taking annual measurements by placing the diameter tape within the non-painted area.

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