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The economic value of sustainable seed and timber harvests of multi-use species: An example using *Carapa guianensis*

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ABSTRACT

The future of tropical forests may lie in integrating different revenue sources, such as timber, non-timber products and environmental services, to make standing forests more economically competitive with other land uses such as pasture. Therefore, analytical techniques that couple economic models with ecological understanding are an increasingly important tool to promote forested landscapes. This study explores the potential revenue associated with different harvest strategies of the multipurpose tropical tree *Carapa guianensis*, a species valued for both the high quality oil extracted from its seeds and its mahogany-like timber. We calculated the equal annual equivalent (EAE), a measure of profitability that annualizes net present value, of revenues and costs associated with simulations of sustainable seed and timber harvests. Our specific objectives were (1) to simulate and compare the revenue from ecologically viable seed and timber harvests of *C. guianensis* in stochastically varying environments; and (2) to calculate the EAE of revenues and costs from seed and timber harvest under different market prices and different oil extraction methods. We found profits from both timber and seed harvest of *C. guianensis* for oil production, though only when seed presses were available for oil extraction; manual oil extraction had negative returns due to intensive labor requirements. Combined profits from *C. guianensis* press-extracted seed oil and timber harvests were economically competitive with other common forest use activities that provide communities with cash profits. Combining extraction of NTFPs with timber may provide continuous income while forests recover volume between timber harvests. Combining this income with harvest of other resources in the context of multi-use management may be an economically viable management strategy in similar forests in Amazonia.

1. Introduction

The future of tropical forests may lie in integrating different revenue sources, such as timber, non-timber products and environmental services, to make standing forests more economically competitive with other land uses such as cattle production. Logging is currently critically important in Amazonian regional economies because of the high present value associated with single-entry extraction (AIMEX, 2005; Pereira et al., 2010). However, logging has significant drawbacks: it often leads to long-lasting forest damage (Veríssimo et al., 1992), can increase forest flammability (Alencar et al., 2004; Nepstad et al., 1999), and encourages conversion of forest to other land uses (Asner et al., 2005; Fearnside, 2005).

Management of non-timber forest products (NTFP) has also been touted as an economically-viable forest management option. NTFPs typically contribute significantly to the subsistence livelihoods of forest residents and provide cash income that adds to the perceived value of standing tropical forest (Chopra, 1993; Gunatilake et al., 1993; Marshall et al., 2003), though harvests for cash rarely lift communities out of poverty (Morsello, 2006). In addition, NTFP (vs. timber) extraction usually results in comparatively less ecological damage (Ticktin, 2004), although NTFP overharvesting does occur (Gaoue and Ticktin, 2009), and can cause resource degradation and affect species persistence (Peres et al., 2003; Ticktin, 2004).

If linked, however, multiple-use forest management could combine potential cash benefits, pooling the income periodically available from timber harvests within a backdrop of steady income from NTFP harvest. Proponents of diversified forest management highlight the fact that integrating multiple forest values provides a social and financial edge over timber-dominant management models (Panayotou and Aston, 1992; Salick et al., 1995; Scherr et al., 2003). Indeed, multiple-use management of tropical forests is not a new concept (Panayotou and Aston, 1992; Salick et al., 1995), but rather is the standard in most smallholder and community managed forests (Whitmore, 1990). The combined extraction

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of xate (*Chamaedorea* spp.) and timber in community forests in Guatemala is one successful example of multiple-use management (Guariguata et al., 2008) management for chicle, honey, game and timber in Mexico is another (Snook, 2000). There are, however, still multiple ecological, social, and economic barriers to widespread successful implementation (García-Fernández et al., 2008; Ros-Tonen et al., 2008).

While there is a growing body of literature on the economics of timber harvest (Boltz et al., 2001; Merry et al., 2009) and cash returns from individual NTFPs (Avocèvou-Ayisso et al., 2009; Varghese and Ticktin, 2008), there is still limited research on the compatibility of timber with non-timber forest management for cash (though see Guariguata et al., 2008; Guariguata et al., 2010; Menton et al., 2009; Snook, 2000). Most studies have highlighted the ecological benefits of diversification, but have not incorporated the economic opportunities and trade-offs associated with multiple use management (though see Boscolo and Vincent, 2003; Menton et al., 2009). Quantifying revenue from harvests is particularly important in cases where an individual species provides multiple economic benefits, generating a potential conflict in deciding whether to prioritize one use over another. Such "conflict of interest" is common in the Amazon where nearly half of timber species have NTFP value (Herrero-Jáuregui et al., 2009; Martini et al., 1994). A comparison of revenue generated by individual tree harvests for timber and/or seed collection would allow forest managers to choose a strategy that best meets their economic objectives.

We provide one such comparison using the multipurpose tropical tree *Carapa guianensis*, a species valued for both the high quality oil extracted from its seeds (Shanley and Medina, 2005) and its mahogany-like timber (Mabberley, 1987; McHargue and Hartsorn, 1983). Pure *C. guianensis* seed oil is used for medicinal applications (Rodrigues, 1989), with value-added products including soaps, shampoos, candles and insect repellent torches (Shanley and Medina, 2005). This economic potential has prompted the Brazilian government to highlight *C. guianensis* as one of its priority species for sustainable development (MMA et al., 2009).

C. guianensis timber and seed harvests can be mutually compatible: this species displays a concave relationship between trunk diameter and seed production with peak production in individuals 35–45 cm diameter at breast height (dbh) (Klimas, 2010), suggesting that the largest individuals could be harvested for timber, leaving mid-sized individuals for seed production while maintaining positive population growth (Klimas, 2010). This relationship has been observed in other species (Kainer et al., 2007; Soehartono and Newton, 2001) but does not necessarily hold true for all individuals. Local communities who have extensive knowledge of their forests can identify individual trees that are high and low fruit producers, guiding which larger diameter trees are best targeted for seed production or timber harvest, respectively.

We use *C. guianensis* as a model species to compare revenue generated by individual tree harvests for timber and/or seed collection. We calculate the equal annual equivalent (EAE), a measure of profitability that annualizes net present value (NPV), of revenues and costs associated with simulations of sustainable seed and timber harvests. Our specific objectives were (1) to simulate and compare the revenue from ecologically viable seed and timber harvests of *C. guianensis* in stochastically varying environments; and (2) to calculate the EAE of revenues and costs from (a) standing timber harvest and (b) seed harvest under different market prices and extraction methods.

2. Methods

Sustainable *C. guianensis* harvest simulations are based on a stochastic population matrix model parameterized with demographic data collected in the southwestern Amazonian state of Acre, Brazil (Klimas, 2010). Such matrix models are powerful tools used to identify population trends and responses to management regimes (Caswell, 2001; Crowder et al., 1994), including setting limits for both timber (Olmsted and Alvarez-Buylla, 2002) and non-timber (Hernández-Apolinar et al., 2006; Ticktin, 2004) harvests that are compatible with continued population existence (Nantel et al., 1996; Ratsirarson et al., 1996). The underlying transition matrix used in these population viability analyses also possesses the ecological underpinnings for application in an economic model (Buongiorno and Gilless, 2000).

Here we used two seed and timber harvest scenarios simulated by Klimas (2010), both of which were considered ecologically sustainable based on a projected population growth rate (λ) that was greater than or equal to one, indicating an increasing or stable population (Caswell, 2001). These include (1) combined harvest of 10% seeds and 100% harvests of all individuals $\geqslant$50 cm dbh for standing timber; and (2) harvest of 30% of seeds. We also include economic analysis of standing timber harvest of all individuals $\geqslant$40 cm dbh.

2.1. Study site and field measurements

We carried out field measurements within the 1200 ha experimental forest of the Brazilian Agricultural Research Corporation (Embrapa) in the eastern portion of the state of Acre (latitude 10°01′28″S and longitude 67°42′19″W). Average annual temperature was 24.5 °C with a dry season from June to August (INMET, 2008). The region has rolling topography including occasionally inundated areas and upland habitat (*terra firme*). Occasionally inundated forests are potentially flooded for a short period during the rainy season in contrast to the more commonly studied flooded forests (varzea) that are consistently and more severely flooded each year. Soils were red and yellow ultisols (Rodrigues et al., 2001) *C. guianensis* densities were 25 individuals $\geqslant$10 cm dbh per hectare (Klimas et al., 2007). Occasionally inundated forests had an average total volume of 218.53 m^3 and 149.51 individuals dbh $\geqslant$30 cm. Common species included *Bertholletia excelsa*, *Dipterix* sp., and *Apulea* sp. In contrast, *terra firme* forest had an average volume of 143.56 m^3 and an average of 112 individuals dbh $\geqslant$30 cm per hectare; common species included *Ceiba* sp., *Hura creptans*, *Rheedia floribunda*, *Manilcara* sp., and *Claricia recemosa* (d'Oliveira, 1994). *Terra firme* soils were plintosols (Rodrigues et al., 2001), and *C. guianensis* densities were comparatively lower at 14 individuals $\geqslant$10 cm dbh per hectare (Klimas et al., 2007).

We inventoried and monitored survival of all individuals $\geqslant$10 cm diameter at breast height (dbh) from 2004 to 2009 in four 400 × 400 m (16 ha) plots. Two of the plots were established where the majority of the environment was upland dry (*terra firme*) forest and the other two were in occasionally inundated forest. We recorded canopy position (dominant, co-dominant, intermediate or suppressed), spatial coordinates, and initial diameter at breast height (dbh) for each tree in 2004 (Klimas et al., 2007). We installed dendrometer bands on a random subset of over 500 trees stratified by dbh and forest type to measure annual growth during 2004–2009. We also made notations of any abnormalities that affected trunk form, such as evidence of a previous burn, forked trunks (a potential indication of prior insect attack), and damaged or absent crowns for consideration when calculating expected revenue from *C. guianensis* timber. Within the larger 16 ha plots, we randomly installed 32 10 × 10 m subplots to measure annual survival, diameter and height increment of individuals $\leqslant$10 cm dbh throughout the 2004–2009 study period. See Klimas et al. (2007) for detailed methods.

We also quantified seed production over a 5-year period (2004–2009) using a randomly selected subset of trees (ranging from 39 to 103 individuals per year) in each forest type. Seed production was quantified weekly during 5–17 week "peak" periods in