Forest Ecology and Management 400 (2017) 139–149

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Annual biomass increment of Xerophytic thickets and sustainability of woody charcoal production in southwestern Madagascar

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ARTICLE INFO

Article history:
Received 1 March 2017
Received in revised form 26 May 2017
Accepted 28 May 2017

Keywords:
Biomass
Productivity
Charcoal
Shrub
Semi-arid
Growth rings

ABSTRACT

The sustainability of woody charcoal production activity is analysed in xerophytic thickets in southwestern Madagascar. The above ground biomass productivity of xerophytic thickets and the biomass corresponding to woody charcoal production in the Soalara-Sud commune were estimated and compared. All individuals >3 cm diameter in 40 4×4 m^2 plots were harvested for above ground biomass measurements. Four treatments, defined by soil type (lixisol and calcisol) and distance from villages (near $\leq$ 4 km; far > 4 km), were tested. The growth rings, assumed to be annual, of the shrub trunk with the largest diameter, presumed to be the oldest specimen on each 4×4 m^2 plot, were counted to estimate the duration of biomass production on the plot. Above ground biomass productivity was estimated by the ratio between above ground biomass and growth rings number. The mean above ground biomass productivity varied between 0.38 and 0.99 t ha^{-1} year^{-1} of dry mass according to the four treatments. It did not vary significantly with soil type and increased with distance from villages on lixisol where woody charcoal is produced. The total above ground biomass of xerophytic thickets used for woody charcoal production on the current woody charcoal production site is around 862.55 t year^{-1} of fresh matter, equivalent to 107.82 t of woody charcoal. However, the effective woody charcoal production on the study site in 2013 was equal to 600.90 t, which is higher than the woody charcoal production allowed by the xerophytic thickets above ground biomass productivity. Consequently, woody charcoal production activity in the study site is unsustainable and will result in the disappearance of mature individuals belonging to species used for woody charcoal production in less than 15 years. Once this occurs, woody charcoal production will be moved to other xerophytic thickets on calcisol.

1. Introduction

Dry forests in western Madagascar are characterised by their high flora and fauna endemicity (Moat and Smith, 2007). Furthermore, they have high socio-economic value through the goods and services that they provide: (i) timber for building houses and pirogues, (ii) medicinal plants, (iii) food (tubers, honey and meat from hunted animals), (iv) fuelwood and woody charcoal and (v) land for agricultural use (slash-and-burn agriculture) or goat pastures. Woody charcoal (WC) is used exclusively to cook daily meals in the absence of alternative energy sources. Demand for charcoal is increasing with the growth of towns on the west coast (Girard, 2002; Minten et al., 2013; Gardner et al., 2015). The removal of wood to produce woody charcoal is the second most important cause of dry forest degradation in western Madagascar (Casse et al., 2004; Masezamana et al., 2013; Minten et al., 2013) after slash-and-burn agriculture (Blanc-Pamard et al. 2005; Raharimalala et al., 2010). WC production negatively impacts the structure of Malagasy dry forests, especially above ground biomass, tree/shub density and plant height (Randriamalala et al., 2016, 2017). However, it does not affect either dry forest regeneration or diversity (Randriamalala et al., 2016, 2017).

This study examines socio-environmental issues related to the sustainability of forest exploitation by tackling the little known case of xerophytic thickets (XT) in southwestern Madagascar. XT are dry forests located in the coastal zone of southwestern Madagascar, the

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http://dx.doi.org/10.1016/j.foreco.2017.05.049
0378-1127/

driest part of the island (Randriamalala et al., 2016). WC production degrades these thickets (Raoliarivelo et al., 2010; Masezamana et al., 2013; Randriamalala et al., 2016, 2017), but the activity is an important source of income for the local population (Raoliarivelo et al., 2010; Masezamana et al., 2013). WC consumed by the town of Toliara comes essentially from surrounding XT (Masezamana et al., 2013; Gardner et al., 2015). Two actions were proposed to make WC production in the southwestern forest of Madagascar sustainable (Andrianarivony et al., 2008): (i) the transfer of forest management to local communities forming associations of WC producers, and (ii) the reorganization of the WC production chain. The first action consists of local communities and the regional direction of water and forest coming together and building a spatial forest management plan which defines forest exploitation modes (location and area of WC production sites and definition of the duration of the exploitation cycle). The second action consists mainly in setting production quotas by the WC producer associations and in increasing the efficiency of traditional charcoal kilns. However, the lack of data on annual biomass increment (forest productivity) is limiting the effectiveness of such initiatives. In fact, a condition of sustainable forest exploitation is that the weight of wood removed annually is lower than annual woody biomass increment. The absence of accurate data on forest productivity leads to the delimitation of WC production sites based on unverified assumptions. One, for example, is that a rotation must last 30 years. It is thus essential that forest woody productivity be estimated.

On the international level, assessments of forest productivity are essentially associated with tree plantations (Singh and Toky, 1997; Lodhiyal and Lodhiyal, 1997, 2003), humid forests (Chave et al., 2001, 2008; Hertel et al., 2009; Vasconcelos et al., 2012) and mangroves (Hossain et al., 2008; Komiyama et al., 2008). The methods generally used are diachronic (observing the same plots states at two periods t0 and t1), indirect and based on allometric equations. In contrast, few biomass increment assessments have been made in semi-arid ecosystems, and those which have been conducted generally concern only a few species and not the entire ecosystem (Paton et al., 1998; Mbow et al., 2013). In Madagascar, the woody productivity of dry secondary forests was assessed in the northern region using dendrochronological methods to evaluate their potential as sources of timber and fuelwood (firewood and charcoal; Lopez, 2004). It was shown that an exploitation cycle of 15 years associated with a mean exploitable diameter of 10 cm can be sustainable (Lopez, 2004).

This study aims to assess the sustainability of WC production in XT in southwestern Madagascar by comparing annual woody biomass removal and increment. We address the following question: is the woody charcoal production of XT a sustainable activity? In other words, is the annual removal of woody biomass undertaken in the framework of this activity lower than the annual increment of woody biomass?

2. Method

2.1. Study site

The study site, located on the Mahafaly plateau, Soalara-Sud commune, Toliara II District, in southwestern Madagascar (Fig. 1), was previously described by Randriamalala et al. (2016). The semi-arid climate of the study site is defined by a short rainy season (<500 mm) followed by a ≥9 months dry season (Raoliarivelo et al., 2010).

2.2. Practices of woody charcoal production on the study site

The production of woody charcoal (WC) on the study site was already described by Randriamalala et al. (2016). This activity is an important source of income for the local population. The entire production is exported by pirogue to the town of Toliara (Raoliarivelo et al., 2010; Masezamana et al., 2013; Ramaroson, 2014), about 25 km away by sea (Fig. 1).

Current WC production sites in the study area are located in the eastern part of Soalara commune at a distance of less than 4 km from nearby villages (Randriamalala et al., 2016). WC is only produced on degraded XT growing on lixisol, in an area estimated to be 8399.70 ha (shape file and GIS data of Randriamalala et al., 2015).

Fuelwood, which is used for cooking, is also collected from sites near villages, both on lixisol and cacisol. However, the corresponding woody biomass was not estimated in this study, which focuses only on WC. In fact, as firewood is gathered generally through the selective collection of dead and fallen branches rather than the falling of entire trees, the use of fuelwood rarely threatens sustainable forest management (Casse et al., 2004; Minten et al., 2013).

2.3. Annual woody charcoal (WC) production

Sacks of WC from Soalara-Sud commune unloaded at the Mahavatsy II harbour in Toliara were counted during 10 non-consecutive days in November 2013. This month belongs to a period (September–November) corresponding to a peak in the annual production of WC in Soalara-Sud Commune (Raoliarivelo et al., 2010). An overestimation of the amount of WC production is expected. In fact, all of the WC from the study site is taken to Toliara by pirogue and unloaded at this harbour (Raoliarivelo et al., 2010; Masezamana et al., 2013; Ramaroson, 2014). Six WC sacks were chosen randomly and were weighed to calculate the mean weight of the sacks, which all have the same size. WC production of the Soalara commune in 2013 was estimated by Eq. (1):

$$\mathrm{WCP} = \mathrm{E(NS)} \times \mathrm{E(SW)} \times \mathrm{ND}, \quad (1)$$

where E(NS) is the mean daily number of WC sacks unloaded at the harbour (10 observations), E(SW) is the mean weight of a WC sack (6 observations) and ND is the number of days that WC sacks are unloaded. The ND value is 313 because WC sacks arrive at the harbour every day except Sunday (ND = 365–52 = 313; Pers. Obs.).

2.4. Woody biomass productivity

2.4.1. Above ground biomass measurements

Field work was conducted in March 2012. Twenty $20 \times 20\ m^2$ plots were randomly sampled along soil type and disturbance gradient characterised by distance from villages (Table 1). An inventory of all shrubs and lianas belonging to overstory vegetation (≥1.3 m height) was drawn up in each plot (Randriamalala et al., 2016). Surveys conducted with local guides enabled the identification of species fit for WC production (Appendix A) and the calculation of the proportion of WC species on each plot. Two $4 \times 4\ m^2$ plots were randomly sampled on the $20 \times 20\ m^2$ plot to evaluate above ground biomass (AGB) using the destructive total harvest method. Every plant on each $4 \times 4\ m^2$ plot was cut at ground level and sorted into two subsets (diameter ≤3 cm and >3 cm) before weighing. Vegetal samples from the two subsets were collected and oven-dried at 85 °C during 72 h to estimate their humidity rate.

2.4.2. Age estimation

To estimate the age of each plot, the trunk with the biggest diameter on each $4 \times 4\ m^2$ plot was harvested. It was assumed that this trunk belonged to the oldest plant on each plot. As dendrochronology methods can be applied to shrubs (Liang et al., 2012; Xiao et al., 2012; Srur et al., 2013; Zimowski et al., 2014; Oddi and Ghermandi, 2015), the rings of the largest shrub trunk