Forest Ecology and Management 400 (2017) 396–407

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Using tree-ring data to improve timber-yield projections for African wet tropical forest tree species

Peter Groenendijk [a,b,c,*], Frans Bongers [a], Pieter A. Zuidema [a]

[a] Forest Ecology and Forest Management Group, Wageningen University, P.O. Box 47, 6700AA, The Netherlands
[b] Departamento de Botánica, Escola Politécnica Superior, Universidade de Santiago de Compostela, Lugo 27002, Spain
[c] Department of Plant Biology, Institute of Biology, University of Campinas – UNICAMP, P.O. Box 6109, 13083-970 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 26 April 2017
Received in revised form 29 May 2017
Accepted 30 May 2017
Available online 20 June 2017

Keywords:
Growth projections
Minimum logging diameter
Logging cycle
Future crop trees
Sustainable forest management
Timber volume

ABSTRACT

Worldwide, over 400 million hectares of tropical forests are set aside for timber production. Several certification schemes exist to ensure more sustainable exploitation and large areas of production forests are currently certified. Under such schemes, logging companies are required to evaluate whether species are not overexploited and, if necessary, adapt their logging activities. However, the data needed to project exploitation intensities – growth, mortality and regeneration rates of trees – are scarce or nonexistent. Tree-ring analysis provides lifetime species-specific growth data that can be used to allow or improve the projections of timber availability during following logging cycles. In this study, we integrated growth data from tree rings with logging inventory data to forecast timber yields in the next harvest round for four timber species in Cameroon. We compared projections using tree-ring data with projections using fixed growth rates, as set by law and customarily applied in Cameroon. Additionally, we assessed the effect of increasing logging cycles and of using filed-based species-specific logging intensities on the next cycle's yield projections. Under current logging practices, timber volumes available at next logging cycles are projected to be 21–36% of the volumes obtained at first harvest. Simulations using fixed rates often resulted in lower yields with lower volume ingrowth from trees that were below minimum cutting diameters in the first harvest. Lengthening the logging cycle increased yield predictions during the next harvests, but yields were still not sustained over time. This problem can be resolved by using species-specific logging intensities, which led to projected yields of up to 73% of the initial harvested volume. The growth data provided by tree-ring analysis allows conducting such species-specific projections and thus helps to provide the knowledge base necessary for sustainable forest management. Yet, the low overall yields are a concern to forest conservation, as loss of economic value may lead to conversion of forests to other land uses.

1. Introduction

Tropical forests harbour a rich biodiversity and hold almost half of the world's terrestrial biomass (Pan et al., 2011). Simultaneously, these forests are an important source of timber and large tracts of tropical forest – 403 million hectares – are being logged or have been assigned for logging in the near future (Blaser et al., 2011). In many tropical countries, forestry legislation aim to ensure logging operations do not affect long-term economic, societal and ecological functions of forests (Estève, 2001), and often require the development of management plans prior to exploitation (Nasi et al., 2006). Several international certification schemes (e.g., FSC, PEFC, OLB, etc.) have also been set up to evaluate the sustainability of logging, guarantee socio-economic benefits and safeguard the future of forest areas. Currently, the area of logging concessions with some form of certification accounts for only 8% of the world's forests, with only a small worldwide increase in area between 2005 and 2010 (Blaser et al., 2011). The area of certified forests in Africa has, however, more than tripled in the same period, from 1.48 to 4.63 million hectares (Blaser et al., 2011).

Under certification schemes, logging is usually performed in polycyclic logging systems, in which the largest individuals in a forest parcel are selectively logged and the parcel is allowed to regrow for several years, i.e., for the length of the logging cycle. Logging cycle length may be either fixed by national legislation (typically 20–40 years) or adjusted per forest type (Nasi et al.,

* Corresponding author at: Department of Plant Biology, Institute of Biology, University of Campinas – UNICAMP, P.O. Box 6109, 13083-970 Campinas, SP, Brazil.
E-mail addresses: peterg@unicamp.br (P. Groenendijk), Frans.Bongers@wur.nl (F. Bongers), Pieter.Zuidema@wur.nl (P.A. Zuidema).

http://dx.doi.org/10.1016/j.foreco.2017.05.054
0378-1127/

2006). Additionally, only one part of all potentially exploitable trees can be logged (i.e., there is a maximum logging intensity) and a species-specific minimum diameter threshold to log trees (Minimum Cutting Diameter, MCD) is also usually set (Nasi et al., 2006). Logging companies are required to evaluate whether the combination of logging cycle length, intensity, and MCD results in the sustainable exploitation of a species.

In many countries in the Congo Basin in Central Africa, sustainability of exploitation is assessed using stock recovery rate calculations (Picard et al., 2009). These calculations use the vital rates (i.e., growth and mortality) and current population structure of a species to forecast the number of trees available for harvest after one logging cycle, compared to the number harvested at the first logging round (Durrieu de Madron et al., 1998). To attain sustainable stocks, recovery rates should equal 100%. If needed, the MCD of a species is increased, as cycle length and maximum logging intensity are often fixed by law (e.g., in Cameroon at 30 years and 80%, respectively). Alternatively, assessments of sustainability of exploitation can also be performed on logged volumes instead of on the number of trees. Such timber-yield projections provide an indication whether exploited volumes can be sustained in the next harvest round (Brienen and Zuidema, 2006) and thus provide a more complete picture of timber exploitation. Despite their relevance, such calculations exist only for a limited set of tropical tree species worldwide (Putz et al., 2012) and they are nearly absent for African species (De Ridder et al., 2013). This shortage of studies is worrisome, given the importance of sustainable management for conserving forested areas and maintaining biodiversity of tropical forests (Edwards et al., 2011; Putz et al., 2012).

The basis for calculating timber yields is ultimately the ecological information on the vital rates for each exploited species (e.g., growth rates, regeneration and survival), which is commonly obtained from monitoring trees in Permanent Sample Plots (PSPs). Plot data has limitations when used to estimate species-specific growth rates and tree ages, especially for commercial tree species (Picard et al., 2010). Commercial species usually occur in low densities per hectare (Poorter et al., 1996; Hall et al., 2003) and, combined with the relative small size (typically one hectare) and short monitoring period of most PSPs (typically a few years to a few decades), this implies that vital-rate data is collected for only a very small number of trees of these commercial species. Thus, for many commercial species, accurate and long-term data on survival, ages and growth rates are lacking or of poor quality.

Tree-ring analysis offers a reliable and relatively fast tool to assess tree ages (at logging) and to measure growth rates covering the entire life-span of trees. These data have been used to improve calculations of future timber yields (Brienen and Zuidema, 2006; Schöngart, 2008) and assess the sustainability of timber exploitation for several species in South America (Brienen and Zuidema, 2006; Schöngart, 2008; Rozendaal et al., 2010). Despite the long-known potential for tree-ring analysis in Africa (Mariaux, 1967), such calculations exist for only one African species (i.e., *Terminalia superba*; De Ridder et al., 2013). Given the strong increase in demand for timber from Africa and the increase in certified African forests (Blaser et al., 2011), it is important that such calculations are performed for more species.

Tree-ring derived growth data has the additional advantage that it documents the persistent growth differences between individuals: it shows which individuals are the consistently fast-growing, and which the slow growers. These growth differences among individuals within a species lead to large variation in tree ages at harvestable sizes, and fast-growing trees contribute disproportionally to future timber yields (Brienen and Zuidema, 2007; Rozendaal et al., 2010). Including persistent growth-differences in timber yield predictions provides more realistic estimates of future yields compared to calculations using fixed growth rates (Brienen and Zuidema, 2007), thus improving the assessment of logging sustainability. Finally, tree ring data can also be used to determine the size range of future crop trees, which may attain harvestable sizes in one logging round trees and thus need to be protected or tended.

In this study, we use tree-ring data for four Cameroonian tree species to project future timber yields. For each of these species we use the observed size distribution in a logging concession and combine this with growth data to predict future yields under five distinct logging scenarios. The scenarios are based on the current Cameroonian national logging legislation, but vary in the growth data being used (legally fixed or tree-ring based), the length of the cutting cycles (the current 30-year cycle used in Cameroon or cycles of 40 and 60 years), and in the logging intensities (maximum allowed intensity or an intensity that is based on *in situ* timber availability). We address the following questions:

– Under current logging regulations, what proportion of timber extracted at first harvest will be available in the next standard harvest round for four timber species in Cameroon and do these proportions change when using legally fixed or tree-ring based growth rates?
– How do these proportions change for the different species when increasing logging-cycle lengths to 40 and 60 years?
– What is the effect of changing the logging intensities on future timber yields?

We collected lifetime growth data for four timber species in Cameroon using tree-ring analysis and used a bootstrapping approach to simulate future timber yields. We then compared different logging scenarios: from a base model following the parameters set by Cameroonian legislation (MINEF, 2001) to alternatives based on tree-ring growth data, varying logging cycle lengths and applying field-based logging intensities. Additionally, we determined the diameter ranges of future crop trees and assessed the number of years trees have grown between reaching MCD and being logged, an indication of how long wood volume has 'accumulated' after trees passed MCD.

2. Materials and methods

2.1. Study area

Samples were collected inside the adjacent 2011 and 2012 cutting blocks of the FSC-certified (Forest Stewardship Council) logging concession 11.001, of Transformation REEF Cameroon (TRC, 2008). This concession lies in the Southwest Region of Cameroon, adjacent to Korup National Park (Fig. 1), at approximately 5°23′N, 9°10′E. Although a large area in the North-west of the concession was previously exploited in the 1980s, our sampling area consisted of primary forest without signs of major disturbances or previous exploitation. The vegetation consists of semi-deciduous Guineo-Congolian lowland rainforest (~200 m a.s.l.; cf. White, 1983) dominated by Leguminosae–Caesalpinioideae, with a canopy height of ca. 40 m (and emergent trees up to 53 m). Regional climate is equatorial, with a unimodal rainfall distribution and a dry season from December to February (monthly rainfall <100 mm). Total annual precipitation averages ~4000 mm (Nchanji and Plumptre, 2001) and mean annual temperature averages 26.7 °C (range: 25.7–29 °C). See the climatic diagram (Mamfé weather station; cf. Walter and Lieth, 1960) in Fig. 1.

2.2. Study species, sample collection and ring measurements

In the period of June 2010 to May 2012 we collected samples of four timber species known to produce annual growth rings