Simulating Nontimber Forest Product Management in Tropical Mixed Forests

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1 # Abstract

2 Models of tropical mixed forests for simulation of multiple-use forest management are of

3 importance because of the significance of both timber and nontimber forest products (NTFP) to

4 large numbers of rural poor. Models capable of accurately simulating multiple-use forest

5 management and their impacts could be used to address questions such as, how much of a given

6 NTFPs can be extracted before jeopardizing production of other products, and how should

7 NTFPs be extracted or silvicultural treatments applied to increase timber and NTFP production?

8 Based on a literature review, we observed that (1) there is practically no integration between

9 studies that focus on timber and those of NTFPs and (2) in most cases, the limitations of

10 common NTFP modeling approaches are rarely acknowledged. We identify key processes that

11 require empirical data collection and suggest modifications to models to better represent

12 multiple-use forest management.

13

14 Keywords: nontimber forest products, modeling, simulation, sustainable forest management,

15 tropical forestry

16

17 # Introduction

18 Timber extraction is currently an important economic activity in the Brazilian Amazon.

19 However, a variety of other forest products are also important economically, such as seringa

20 latex (*Hevea brasiliensis*), Brazil nut (*Bertholletia excelsa*, Figure 1), heart of palm, and açaí

21 fruit (both from *Euterpe oleracea*, Figures 2 and 3) (Wong, et al. 2001). Moreover, many other

22 forest products without significant market value are important to the well being of rural families.

23 Since the seminal article from Peters (1996), non-timber forest products (NTFP) have emerged

1   as an important alternative for rural development and conservation interests. NTFP extraction is

2   usually lower impact compared to timber logging; it need not cause plant mortality, compact soil,

3   increase erosion or result in any modification in forest structure or functioning (Peters 1996).

4

5   Although forests are a source of timber and NTFP, there is a distinct dichotomy between

6   modeling studies that simulate timber production and those that simulate NTFP production in

7   mixed tropical forests. Part of this dichotomy can be explained by species specificity; most

8   NTFP are species specific or are specific to a small group of species, and many species can be

9   used for timber. The operational timing of NTFP production may also differ from timber

10   production. Both of these factors result in the adoption of different spatial and time scales in

11   NTFP studies when compared to timber studies. For example, because NTFP species are

12   generally found in low density in tropical mixed forests, NTFP species dynamics studies

13   typically encompass a larger spatial scale, in which only one or a few species are monitored. On

14   the other hand, timber productivity studies are typically conducted in permanent plots (1 ha or

15   less) in which all trees are measured regardless of species. Moreover, the monitoring of NTFP

16   collection and of many ecological processes of interest (e.g., flowering, fructification, leaf

17   growth, exudates production) demand frequent data collection (Wong et al. 2001), whereas the

18   ecological processes normally monitored for timber productivity studies (growth, mortality and

19   recruitment) are assessed in up to 5-yr intervals between measurements.

20

21   The objective of this paper is to analyze the potential for developing new multiple use forest

22   management models. This review focuses on tropical mixed forest studies that monitor and/or

23   simulate NTFP tree species dynamics and does not address other types of NTFP such as

1 epiphytes, lianas, mushrooms, and animal products, or NTFP extraction resulting in tree

2 mortality. To facilitate the discussion of our results, different NTFP are grouped following the

3 classification of Peters (1996): exudates (e.g., latex and resins), reproductive propagules (e.g.,

4 fruits, nuts and seeds) and vegetative structures (e.g., leaves, barks, roots and stem).

5 Why simulate multiple use forest management?

6 Currently, most simulation analysis of NTFP focuses on evaluating the impact of NTFP

7 extraction on the population and/or determining a sustainable level of extraction. However, these

8 models can also be used to compare different alternatives of management in relation to

9 productivity and profitability. For example, different product trade-off scenarios could be

10 evaluated for species that generate multiple products (e.g., copaíba [*Copaifera spp.*], andiroba

11 [*Carapa guianensis*] and sucuuba [*Himanthus succuba*]). Timber extraction could be

12 scheduled once tree production of oil, resins or fruits was in decline (Peters 1996). NTFP

13 extraction can also affect the production of the other products. Heart of palm harvest, for

14 instance, has been shown to increase the production of fruits on remaining ramets of açaí

15 (Weinstein and Moegenburg 2004).

16

17 Single-species population dynamic models could be used to simulate some trade-offs. However,

18 there are many questions that can only be answered with a model capable of simultaneously

19 simulating a variety of forest tree species. For example, some NTFP species (e.g., the liana *titica*)

20 depend on tree species (e.g., Plowden 2001; Plowden et al. 2003), and, consequently, NTFP

21 management depends on timber management. Moreover, timber extraction may benefit some

22 species, such as piquiá (*Caryocar villosum*) (Shanley et al. 2002), and silvicultural treatments for

23 timber can become economically viable if done simultaneously with NTFP extraction (Salick et

1   al. 1995). Although more complex, answering questions that involve the interaction between

2   different species is integral to managing forests for multiple use.

3   # Forest dynamic models

4   The majority of forest dynamics models focus exclusively on timber production and only more

5   recently have models been developed for NTFP (Wong et al. 2001). We briefly review their

6   general characteristics, as summarized in Table 1.

7   ## NTFP Models

8   Matrix population models group individuals belonging to the same population into different size

9   or age classes and/or reproductive stages. The construction and application of matrix population

10   models in forestry is described in Vanclay (1994). In matrix modeling, the latent dominant

11   eigenvalue, λ, indicates if a population at the stable size class distribution is in equilibrium ($\lambda =$

12   1), increasing ($\lambda > 1$) or decreasing ($\lambda < 1$) in size (Peters 1996).

13

14   Matrix models of single NTFP species have been the main tools used to determine the

15   sustainable level of NTFP extraction. Extraction is simulated by changing model parameters;

16   changes associated with $\lambda < 1$ are interpreted as non-sustainable for NTFP extraction. The choice

17   of which matrix parameters to modify depends on the product being extracted. For example, fruit

18   collection might be modeled through a reduction in fecundity coefficients while exudate

19   extraction can be simulated by decreasing growth rates or increasing mortality rates (Peters

20   1996; Wong et al. 2001).

21

1   One criticism of matrix modeling is that fixed mean rates are usually adopted in models applied

2   to conservation biology (Fieberg and Ellner 2001), ignoring measurement and sampling errors

3   and natural spatial and temporal variability (Wisdom et al. 2000). Fixed rates do not allow for

4   effects of environmental changes, such as an increase in competition or suppression (Peters

5   1996; Wong et al. 2001; Ticktin et al. 2002). For example, significantly different projections can

6   result from matrix models calibrated with data from an unlogged population versus data from a

7   logged population (Ticktin et al. 2002; Ticktin 2004).

8

9   The accuracy of matrix population models depends on correctly estimating the transition rates

10   (matrix elements). The impacts of different methods and intensities of management are typically

11   simulated through modifying transition rates. However, modified rates are often hypothetical and

12   are not based on experimental or empirical data (Wong et al. 2001). Moreover,

13   elasticity/sensitivity analyses generally assume absence of correlation between the different

14   transition rates (e.g., Zuidema and Boot 2002), which is an untenable assumption. Some

15   researchers also point out theoretical issues in using λ to define sustainable extraction levels.

16   Because λ has inherent variation, it may not be significantly different from 1 and therefore

17   confidence about the estimated maximum sustainable extraction level is low.

18

19   Finally, nearly all models used to simulate NTFP extraction are single-species population

20   dynamic models (Ticktin 2004). More complex modeling techniques, however, are required to

21   simulate multiple forest species and uses.

1   Timber extraction models

2   In general, models used to simulate timber extraction simultaneously describe the behavior of all

3   tree species in the forest. Although these stand-level models can be used to describe a whole-

4   stand or size class, individual tree models allow a more detailed description of stand

5   development and underlying biological and ecological interactions. Also, instead of grouping

6   trees by size class, the behavior of each tree is predicted separately based on the unique

7   conditions it experiences. These models have potential to simulate conditions distinct from those

8   found in calibration data (e.g., to predict forest reaction to an alternative logging system and

9   silvicultural treatments), because they incorporate mechanistic processes and external drivers of

10   the forest state rather than the forest state by itself (Boot and Gullison 1995).

11

12   Individual tree models represent all trees in the forest above a given minimum measurement,

13   generally 5-10 cm diameter. A recruitment sub-model is used to estimate the probability of a new

14   tree with the minimum measurement "appearing" (e.g., Chambers et al. 2004; Gourlet-Fleury et

15   al. 2005). Many of the intermediary ecological processes such as flowering, pollination,

16   production, dispersion (primary, secondary, etc.) and germination of seeds are not explicitly

17   represented. Because of the great number of tree species in tropical mixed forests, species are

18   frequently grouped. While this reduces the number of parameters and increases the data available

19   to estimate the parameters, there is no consensus regarding the ideal number of groups or the

20   variables and methods used to determine them (e.g., Vanclay 1994; Kohler and Huth 1998;

21   Phillips et al. 2002).

22

1   In comparison with matrix modeling, stand-level individual tree models do not have a simple

2   built-in indicator of sustainability. The evaluation of sustainability depends on the criteria and

3   time frame adopted. To parameterize individual tree models for the simulation of NTFP

4   production, many questions need to be answered carefully. We briefly discuss some of these

5   questions, suggest how potential obstacles and pitfalls may be overcome (see summary in Table

6   1), and present a conceptual model for multiple-use forest management (Figure 4).

7   # Modeling NTFP production

8   To incorporate NTFP into stand models, data must be collected that better describes the relevant

9   ecological processes (reproduction, growth, etc.) and how this production is influenced by

10   competition from surrounding trees. In individual tree models competition is often described

11   with indices based on neighboring tree characteristics such as height, diameter, basal area, or

12   distance (Vanclay 1994).

13

14   Although past studies of NTFP population dynamics have measured many variables, such as

15   diameter, height, leaf production rate, liana load, and crown form, they have done so only on the

16   species of interest (e.g., Olmsted and Alvarez-Buylla 1995; Ratsirarson et al. 1996; Wadt et al.

17   2005; Kainer et al. 2006). Even when environmental indicators are included, such as crown

18   position, forest phase and luminosity index (e.g., Nakazono et al. 2004), they are frequently

19   categorical and not easily adapted to individual tree models. On the other hand, measuring local

20   competition intensity with surrounding tree characteristics (e.g., recording DBH for trees within

21   a given radius from the tree of interest) demands excessive field time and therefore, faster

22   alternative methods must be developed.

1 Reproductive propagule production

2 Simulation of reproduction is complicated by a variety of factors, including propagule

3 production periodicity and variability, the size of the individual at sexual maturity and the sex of

4 the plant (for dioecious species). For instance, the diameter of a tree at sexual maturity is a

5 standard parameter used in modeling fruit and/or seed production (Chave 1999); however, in the

6 absence of adequate data, we might assume that individuals reach sexual maturity when they

7 reach ⅓ to ½ their maximum size (e.g., Pinard et al. 1999).

8

9 Many tropical tree species have supra-annual fruit production cycles (Wong et al. 2001; Shanley

10 et al. 2002). In the absence of specific tree data, models of fruit production could operate in a

11 supra-annual cycle, with a given proportion of trees starting the cycle in each year. Alternatively,

12 one could assume a high variability in production, with a constant proportion of the population

13 not producing any fruit. For example, a relatively constant proportion of Brazil nut trees (7.5%)

14 do not give fruits in any given year (Zuidema and Boot 2002).

15 Resins, gums, and exudates production

16 The extraction of resins, gums and exudates is closest to the ideal of sustainable NTFP use

17 (Peters 1996), and represents a large proportion of total NTFP. However, models of these

18 products are still rare (Ticktin 2004). One reason may be that the mechanisms of production and

19 the physiological function of many of these products are still unknown. For instance, generally, it

20 is believed that resins help heal tree wounds. Experiments with breu (*Protium spp.*), however,

21 showed that fungus and insect attacks stimulated resin production (Plowden 2001). In this case,

22 production modeling would necessarily involve estimating the probability that a tree suffers an

23 attack from those agents.

1

2 Another reason that exudates are rarely modeled may be variability of management methods.

3 Forest management by small farmers and industrial management differ drastically because of the

4 variety of extraction and management techniques used and the flexibility of production (Padoch

5 and Pinedo-Vasquez 1996). For example, copaiba oil (*Copaifera spp.*) might be extracted semi-

6 annually to biannually through one or two holes, which could have diameters from 1.5 to 5 cm

7 (Plowden 2001). This variability is a considerable obstacle in production modeling; however,

8 one alternative is to model only the most usual or most extreme methods (e.g., best case: low

9 intensity and low frequency extraction vs. worst case: high intensity and high frequency

10 extraction).

11

12 Some evidence suggests that the history of NTFP extraction of a given tree determines its current

13 production. For example, tree productivity has been observed to drop after successive extractions

14 of copaiba oil (Copaifera spp.; Plowden 2001). In this case, modeling current and future

15 production would require knowing NTFP extraction histories by tree and NTFP replacement

16 rate. If replacement rate is low and NTFP extraction frequent, successive extractions may cause a

17 decrease in or cessation of production.

18 Vegetative structure production

19 Vegetative structures include products such as leaves, stems, roots, bark and apical buds (Peters

20 1996). In principle, allometric functions to estimate the quantity of NTFP could easily be

21 developed. However, it is also important to evaluate the rate at which these structures are

22 replaced. Most studies assume that extraction results in tree mortality and thus the replacement

23 rate of individuals that stay alive is unknown (e.g., Olmsted and Alvarez-Buylla 1995), or they

1 assume that individuals that remain alive after extraction completely recover vegetative

2 structures between harvests (Ticktin et al. 2002). Extraction methodologies for vegetative

3 structures can also vary considerably, and consequently, the most usual or most extreme methods

4 need to be simulated.

5 Environmental factors

6 Factors that influence production of reproductive propagules, exudates, and vegetative structures

7 include liana load (e.g., Kainer et al. 2006), crown form (e.g., Wadt et al. 2005), stem hollows

8 (e.g., Plowden 2001), and climate (Olmsted and Alvarez-Buylla 1995; Wong et al. 2001).

9 However, there are multiple obstacles to include these factors in individual tree models. For

10 instance, there is a huge gap in our knowledge regarding factors in crown form determination

11 and presence/size of stem hollows. Also, though many NTFP are lianas (e.g., Plowden et al.

12 2003) and liana load decreases host tree growth and vigor (e.g., Gerwing 2001), there is no

13 standardized method to measure lianas (Wong et al. 2001; but see Gerwing et al. 2006).

14 Moreover, the few long-term data available are not sufficient to simulate the life cycle of lianas

15 and their interaction with trees. Finally, although climate variables have been widely recognized

16 as an important factor affecting seasonal fruit production (Wong et al. 2001), climatic models are

17 complex and have their own level of associated uncertainty.

18 # Simulating NTFP extraction impact

19 To provide a more realistic representation of the impact of NTFP extraction in individual tree

20 models, a rigorous empirical approach to determine extraction impacts on population dynamics

21 is required. As an example, a conceptual model representing multiple-use forest management is

22 given in Figure 4. Depending on the NTFP, its extraction might affect one or more ecological

1   processes simultaneously. The main challenge lies in integrating the different time scales

2   between NTFP extraction (i.e., days and months) and their impact on demographic variables

3   such as growth, mortality and recruitment (i.e., years and decades) (Peters 1996).

4   Reproductive propagules extraction impact

5   Because reproductive propagule extraction could impact regeneration, a more complete

6   representation of NTFP species life cycle and the links between generations (e.g., adult tree

7   giving rise to new trees) must be understood. One obstacle in determining propagule extraction

8   impact on regeneration in individual tree models is that these models do not simulate the entire

9   life cycle of trees, usually representing trees only above a minimum size. However, there may be

10   lengthy time intervals between fruit production and germination, and for a seedling to attain

11   minimum size. For instance, a germinant of the timber species *Dicorynia guianensis* may need

12   60 years to reach10 cm DBH (Gourlet-Fleury et al. 2005). One solution is to represent the

13   dynamics of each utilization group (e.g., commercial timber, NTFP, non-commercial timber)

14   with different levels of detail, choosing different minimum sizes for each group, as in Gourlet-

15   Fleury et al. (2005).

16

17   Another issue is that there are few individual tree models that link tree regeneration to adult

18   population structure (i.e., with number of recruited trees dependent on number or distance to

19   adult trees). Usually it is assumed that regeneration is not seed-limited and that the appearance of

20   a new tree only depends on adequate light conditions (e.g., Kohler and Huth 1998; Chambers et

21   al. 2004; but see Chave 1999; Kohler et al. 2003). Clearly, this approach is not adequate to

22   simulate extraction impact of reproductive propagules on regeneration. One option is to model

23   the entire life cycle of the NTFP species, including primary and secondary dispersion, fecundity,

1   seed survival, germination and possible predation (e.g., Kohler et al. 2003), or simply to establish

2   a direct relation between the numbers of adult individuals and recruited trees with the minimum

3   measurement size (e.g., StoMat model; Gourlet-Fleury et al. 2005). This first option is closer to

4   reality but requires a great deal of data; moreover, the results would be difficult to interpret and

5   model tuning would be required (e.g., SELVA model; Gourlet-Fleury et al. 2005). The second

6   option requires determination of a long-term functional relationship between the numbers of

7   adult trees and recruits.

8   ## Exudates and vegetative structure extraction impact

9   Exudates and vegetative structure extraction may affect many ecological processes. Latex

10   extraction, e.g., might reduce tree growth, increase the probability of tree death, and even affect

11   flowering (Peters 1996). The experimental extraction of *Neodypsis decaryi* palm leaves was

12   found to impact the production of fruits and new leaves (Ratsirarson et al. 1996) and the

13   extraction of mature *Ischnosiphon polyphyllus* stems drastically increased mortality (Nakazono

14   et al. 2004).

15

16   In contrast to the harvest of most reproductive propagules, the extraction of exudates and

17   vegetative structures may directly influence the future production of these products by the same

18   tree. Exudates and vegetative structures may be renewed constantly by the tree for maintenance,

19   whereas reproductive propagules are replaced periodically. This is an important distinction, and

20   emphasizes the need to estimate replacement rates in the vegetative structure and exudates NTFP

21   categories. Because of this fundamental gap in knowledge, an experimental approach will be

22   essential to generate information to build adequate models quantifying NTFP extraction impact,

1   and to determine NTFP replacement rates, especially considering the variability of methods,

2   intensities and frequencies of extraction.

3   ## Model considerations

4   ### Species grouping

5   Because the biological mechanisms involved in the NTFP production and NTFP extraction

6   impact are species specific, the simulation of each of these forest products cannot be performed

7   with species groups. One solution is to maintain existing groups in an individual tree model and

8   create additional groups to represent species that produce NTFP, with each additional group

9   representing one or more species that produced a given NTFP. We found only one study that

10   used this approach, focusing on timber logging of *Dicorynia guianensis* (Gourlet-Fleury et al.

11   2005).

12   ### Spatial scale

13   The majority of economically important species in tropical forests have low density (Peters

14   1996; Shanley et al. 2002) and consequently their use spans the landscape scale. Ideally, models

15   should simulate forest management at the appropriate spatial scale. However, models require

16   information (e.g., diameter and botanical identification) from all trees present in the forest above

17   a minimum size (e.g., 5 or 10 cm diameter), which is rare in landscape scale models.

18

19   To simulate NTFP on a landscape scale, one might create a forest where trees are created

20   randomly depending on the observed distribution of a number of forest variables (e.g., Chambers

21   et al. 2004). However, this approach ignores any existing spatial pattern, either of tree

22   distribution or landscape use. Another possibility would be to measure the species of interest,

1   either for timber or NTFP, at the landscape scale and to subsample the area for other species.

2   This approach would require that data collection explicitly focused on multiple-use forest

3   management and not only the NTFP species. Alternatively, simulations could be done on the

4   scale of permanent plots used for timber productivity measurement, with NTFP species

5   simulated within these plots based on information gathered in the landscape scale.

6   ## Conclusions

7   This review identifies a large gap between studies that focus on NTFP production and those that

8   focus on timber production. Much of this gap can be attributed to the different spatial and

9   temporal scales used in NTFP studies versus those of timber studies. Models that have been used

10   to simulate NTFP species dynamics are predominantly life cycle or matrix population models

11   with constant transition rates, whereas a wider range of approaches (including matrix models)

12   have been used to simulate timber production.

13

14   A new approach to data collection is required to integrate NTFP and timber management into a

15   single model framework. This includes measurement of competition experienced by NTFP trees

16   and estimation of the replacement rate of the NTFP when extraction does not result in tree

17   mortality. Moreover, the NTFP extraction effect on ecological processes should be based on

18   empirical observations or experimental results.

19

20   To simultaneously simulate timber and NTFP extraction, several modifications are suggested for

21   stand models. Stand models should be adapted to represent each NTFP species as one more

22   species group. In addition, the species of interest (not necessarily only commercial species)

23   should have a more complete and detailed representations of their life cycle. Finally, NTFP

1 simulation should be based on the most common extraction method or the simulation of the most

2 extreme methods (best and worst case scenarios). To form a more holistic view of the forest and

3 its multiple products, as well as to generate innovative management scenarios, models must

4 represent multiple uses of the forest and must integrate NTFP and timber species.

5

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Table 1. Description of differences in modelling approaches used to simulate NTFP and timber extraction. Suggested modifications in stand model to simulate multiple-use forest management are given.

Characteristics	NTFP	Timber extraction	Multiple use forest management
Modelling approach	Matrix models	Several approaches	Several approaches
Criteria of sustainability	Latent dominant eigenvalue (λ)	Constant timber production and other criteria	Constant timber and NTFP production and other criteria
Life cycle representation	More complete	Less complete	Different levels of details in life cycle representation depending on the utilization group
Interaction among species	None	Yes	Yes
Species representation	One or few species represented	Species groups with multiple species	Species groups with single and multiple species
Simulation of extraction impact	Extraction kills plant, or extraction of reproductive propagules decreases recruitment rates	Extraction kills selected tree and damages other trees; change in competition environment (which influences growth, recruitment and mortality), and change in recruitment due to the removal of adult trees (in some cases)	Timber extraction kills selected tree and damages other trees; change in competition environment (which influences growth, recruitment and mortality); and extraction of reproductive propagules decreases recruitment rates; change in mortality, growth, and replacement rate in the NTFP tree

Figure 1. Opened Brazil nut fruit encasing multiple edible nuts. (Photo courtesy of Dr. Karen Kainer, University of Florida School of Forest Resources and Conservation).

Figure 2. Grove of açaí palms in rural Amapá, Brazil. (Photo courtesy of authors).

Figure 3. Açaí fruit harvest in Acre, Brazil. (Photo courtesy of C. Klimas, University of Florida School of Forest Resources and Conservation).

Figure 4. Flow diagram showing the simulation sequence in a given time step for a conceptual model representing multiple-use forest management. A generic individual tree model would have to be modified by adding some parameters (within circles), processes and inputs (within rectangles), highlighted in blue.