# Mapping Socio-biodiversity: Do Old Modelling Tools Suit New Challenges?

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Abstract: This work shows an original use of classical methods in land change modelling. The aim of this study is to model yields (productivity) and economic importance (annual rents) of rubber and Brazil nut in the Brazilian Amazon. Biophysical variables related to rubber and Brazil nut yields as well as market access (commercialization) were used to model favorability of productivity using Weights of Evidence (WofE) method. To favorability of productivity were assigned yields base on case study data. The economic model then combines the map of yields with output prices and costs of collection, processing, and transport to estimate annual rents per hectare for a specific forest plot. For estimating transport costs we used cost friction surface modelling tools. Our results show that yields for Brazil nut averages 8.19±7.41 kg $ha^{-1}year^{-1}$ and rent averages US$ 5.05±7.49 $ha^{-1}year^{-1}$. Rubber average yields is of 3.53 kg/ha/year and rubber rents average US$ 0.56±0.7$ha^{-1}year^{-1}$. Coupling biophysical and economic models allowed us to explore which environmental and governance improvements are needed to avoid deforestation and forest degradation in the Brazilian Amazon. Our results also show that despite some methodological issues and the recurrent call for "new" modelling approaches for addressing the complexity of socio ecological systems, "old" modelling tools such as Weight of Evidence and Cost Friction Surface, are still suited for addressing the challenge of mapping socio-biodiversity.

## 1 MAPPING SOCIO-BIODIVERSITY

Amazon forest biodiversity in Brazil lives together with a variety of sociocultural groups. Traditional communities in Amazon use and trade raw materials of surrounding forests as part of their livelihoods. There is a rich case study based research illustrating complexity and diversity of extractivist landscapes across the Brazilian Amazon (MMA, 2009). Although rich in detail, local case studies provide a fragmented view of extractivist landscapes in the Brazilian Amazon and do not account for fluxes and migration of people and products across the biome (Hecht, 2013). Therefore, mapping and modelling extractivist landscapes at the Amazon´s scale would need to deal with a huge variability and complexity of extractivist systems . Empirically informing spatially explicit models with social survey data then becomes a limiting factor. Thus, despite acknowledging the importance of Non-Timber Forest Products (NTFP) for securing local forest communities livelihoods, there is little information on how productivity and rents of different NTFP are geographically differentiated across the Brazilian Amazon(Homma, 2008). In order to contribute to fill in this gap, we developed a systematic approach to map yields and annual rents of two famed NTFP namely rubber and Brazil nut.

Brazil nut and rubber extraction are important components of Amazon´s socio-biodiversity (MMA 2009). In order to overcome methodological issues for mapping productivity and rents across the Brazilian Amazon biome we couple biophysical and economic modelling approaches. Biophysical variables related to rubber and Brazil nut productivity were used to model favorability of productivity using Weights of Evidence (method. The favorability of productivity was then transformed into yields based on case study data. Then, the socio-economic model combines the map of yields with output prices and costs of collection, processing, and transport to



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estimate annual rents per hectare for a specific forest plot (equation 1).

Rent=(Qxy*Pn)-(Qxy*CTprdn)-(Qxy*Ctrn_dz)) (1)

Where Qxy is the simulated production for a cell with coordinates (x,y) in kg-1ha-1; Pn and CTprdn correspond to respectively, selling price and the cost of production in US$/kg of product n and the cost of secondary transportation (Ctrn) of the product n by means (dz) from the location (x,y) to the nearest cooperative.

Although this approach has limitations it is suitable to explore the ways in which "old" modelling tools such as the Weights of Evidence and Cost Friction Surface are able for addressing the new challenges of mapping socio-biodiversity.

# 2 NEW CHALLENGES, OLD TOOLS?

There has been a call for "new" modelling approaches to tackle de specificities of bonded socio-ecological systems at broad spatial scales (Rounsevell and Arneth, 2011, Rounsevell et al., 2012). Despite acknowledging the need to develop novel modelling approaches we assess whether or not "old" and well-known modelling tools such as the Weights of Evidence and Friction Surfaces, are suited for mapping both ecology (yields) and economy (rents) of extractivist landscapes. A flowchart of the methodological framework is presented in appendix.

## 2.1 Weights of Evidence

The method of Weight of Evidence (WofE) has been widely used for mapping prospective mineral areas (Payne et al., 2015), risk of landslides (Poonam et al.), fire risk and modelling habitat suitability (Fan et al., 2011). We did a search in Science Direct database using as keywords "Weight of Evidence" and "mapping" and we found 2,396 results (in February 2017).

In this work, we applied the Continuous Weights of Evidence method (Soares Filho et al., 2009) for modeling favorability of productivity of rubber and Brazil nut. The models begin by simulating the yields of Brazil nut and rubber in the Brazilian Amazon. To do so we integrated a set of biophysical variables by using the Weights of Evidence method. We used bioclimatic and biophysical variables (Nunes et al., 2012, Jaramillo-Giraldo et al., 2017) as well as time-series (1994-2013) of production data from Brazilian Statistics office (IBGE). We used the IBGE maximum production in each municipality as a surrogate for production capability based on the assumption that if a municipality was able to produce and trade such a quantity in a particular year, over the 20-year period, it still holds that production potential. Correlated variables were removed from the model.

Based on case studies, we selected 12 variables (Figure 1) and then calculated their influences ($W^+$) to determine the spatial probability of productivity

$$P\{Productivity_{x,y}|V_1 \cap V_2 \cap V_3 \cdots \cap \cdots \cap \cdots V_j\} = e^{\Sigma W^+ V_n}/1 + e^{\Sigma W^+ V_n} \quad (2)$$

Where $P$ is the probability of productivity at location $x,y$ given a series of spatial variables and $W^+{}_{Vn}$ is the weight of evidence of category n of variable $V_j$ (Bonham-Carter, 1994). Favorability was then transformed into yields by applying a PDF transformation so that the new distribution matches the PDF of yields from the case study areas in Acre (CSR, 2011, Jaramillo-Giraldo et al., 2017). The

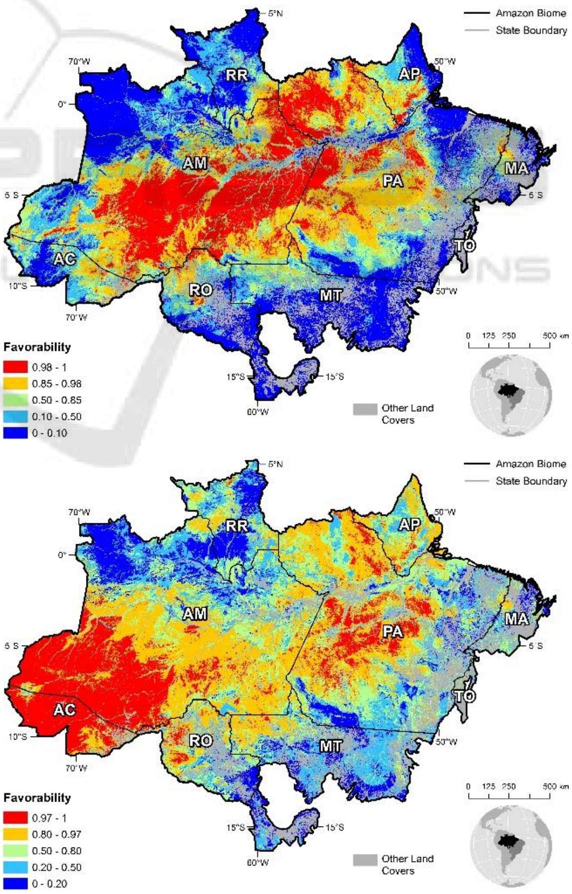


Figure 1: Result of the Continuos Weight of Evidence for maping favorability of productivity for Brazil nut (top) and Rubber (bottom).

study by Nunes et al. 2012 and Jaramillo et al 2017 used fieldwork data on tree occurrence and productivity for estimating Brazil nut and rubber tree density and yields. We used Nunes' and Jaramillo yield distribution function for extrapolating the yields from Acre to the Brazilian amazon.

In order to better understand the results of this approach we organize semi structured interviews with a variety of stakeholders. In total, we interviewed 30 people in Acre including 6 extrativists, 10 NGOs, 10 governmental bodies as well as professors at the Acre Federal University (UFAC, Universidade Federal do Acre). In Pará, we interviewed 9 extractivists, 2 cooperatives, 5 governmental bodies, 2 researchers and 1 Brazil nut exporting industry. In these contacts and from partnerships with local institutons we included in the analysis socio-economic data from over 10, 500 extractivist families.

### 2.2 Cost Friction Surface

Similarly to the WoE the use of cost friction surfaces is widespread in environmental sciences. A search in the Science Direct using keywords as "friction surface" and "mapping" delivered 680 results. We used the location of communities in the Brazilian Amazon for calculating the area of influence of each community that gathers Brazil nut and rubber (we selected the communities inside the municipalities where production was recorded by IBGE). By doing so, we estimated the transport costs from any point in the forest to the nearest community (Figure 2).

The second stage consists in transporting NTFPs from the storehouse in the communities to the nearest cooperative. We used the cooperative location (also built on the basis of field work) for calculating the "area of influence" for each one of the cooperatives that work with Brazil nut and Rubber.

In order to estimate transportation costs, the model uses a map of roads and navigable rivers. First, it calculates a cost friction surface (cost per kg and km), and then produces an accumulated cost from point of collection in the forest to the village and then to the cooperative (final destination), according to the type of road/waterway and mode of transport (boat, truck, donkey/motorcycle).

Accumulated transport cost (including transport across the forest as well as to the nearest cooperative) ranges from 0 to US$ 3.80 per kg (Figure 2).

This means that places farther than 200 km from cooperatives or point of sale, it is not worth collecting nut.

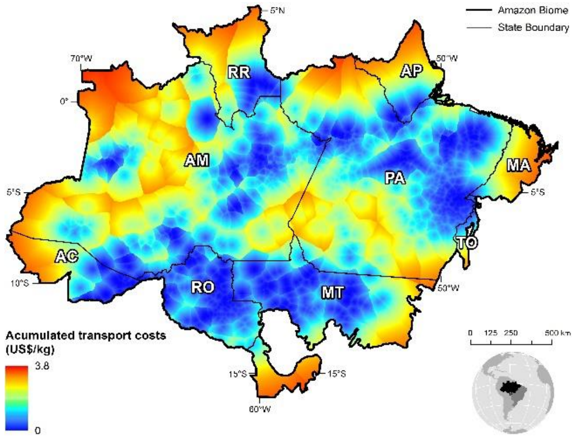


Figure 2: Accumulated transport costs: from the forest to the community and from community to cooperative.

## 3 YIELDS AND RENTS

Our Brazil nut yields in the vast majority of areas (99%) of the Brazilian Amazon situate between 0 to 30 kg per ha-1year-1, although there are locations where yields can reach 152 kg per ha (1% of the biome) The annual rents of Brazil nut, presented as the Equivalent Annual Annuity (EAA), range from US$ 0 to 46 ha-1year-1 (Figure 4.17), with average rents of US$ 5.05 ha-1year-1 (Table 1).

Table 1: Rents for Brazil nut.

| Rent Brazil nut | (US$/ha) |
|---|---|
| Minimum | 0.00 |
| Maximum | 46.00 |
| Mean | 5.05 |
| Variance | 56.24 |
| Standard deviation | 7.49 |

Rubber extraction in the Amazon is not profitable in areas of low productivity even with subsidies to guarantee a minimum price to rubber tappers. In the presence of governmental subsidies, rents average US$ 0.56 $ha^{-1}year^{-1}$, varying from 0 to US$ 6.13 $ha^{-1}year^{-1}$ (Table 2).

Table 2: Rents for rubber.

| Rent Rubber | (US$/ha) |
|---|---|
| Minimum | 0.00 |
| Maximum | 6.13 |
| Mean | 0.56 |
| Variance | 0.57 |
| Standard deviation | 0.76 |

# 4 CONCLUSIONS

Although it is widely acknowledged that Non-Timber Forest Products (NTFP) are central for securing forest communities livelihoods, there is little information on how important features of extractivist landscapes such as yields and rents are geographically differentiated across the Amazon Biome. In order to fill this gap, we have developed a systematic approach to monetize values for non-timber forest products across the Brazilian Amazon using spatially explicit assessments. The information that such assessments provide enables comparisons between the natural, physical and human capitals, and hence their contributions to the society's welfare.

This work shows an original use of classical methods in land change modelling. Using WofE and friction surfaces we mapped both yields and rents for rubber and Brazil nut across the Brazilian Amazon. With such a goal we collapsed the diversity and complexity of extractivist landscapes into simplified, but meaningful, approximations. Developing such models to the point of being operational is a long term objective and this analysis is still developing. Despite some limitations namely in data availability, these modelling tools such as Wof E and friction surface tools revealed to be able for representing the complex economy of extractivist landscapes at the biome scale. While Weight of Evidence was useful for geographically differentiating productivity, cost friction surfaces allowed us at geographically differentiating transport costs. However, although we find these tools useful and well suited for the purpose of our study we did not compare them with other modelling tools in order to gauge their performance. This needs further work.

Our modelling approach estimates yields and annual rents from the extraction, of rubber and Brazil nut collection. We found that the annual values for rubber and Brazil nut are relatively low. Rents for Brazil nut averages US\$ 5.05 $ha^{-1}year^{-1}$ while rubber extraction in the Amazon is not profitable in areas of low productiviy. In areas with yields above the mean (yields $\geq$ 3.53 kg $ha^{-1}year^{-1}$), and in the presence of governamental subsidies, rubber rents average US\$ $0.56\pm0.7$ $ha^{-1}year^{-1}$.

Our results show that areas that systematically presented higher annual rents are located nearby villages/towns with better access and larger population. These areas, by contrast, are also the areas with higher rates of deforestation. Thus, it seems likely that factors that locally influence the rents also drive forest conversion. However, NTFP development in the form of better markets, improved infrastructure and higher product demand and/or prices, could provide an alternative to forest conversion to agriculture, and hence be an ally of forest conservation. Unfortunately, this is not the current situation.

The results of this study allow us to question the effectiveness of "narrow" market chains based on specific products. We need thus to explore possible policy contexts for enhancing the value of the Amazon forests within a more holistic approach that focuses on the forest as an entity providing multiple ecosystem services. So far, the narrow market chains of sustainable timber and NTFPs were unable to do the job they were meant for because they do not aggregate values to the products that are of paramount importance to sustain local livelihoods. As a result, "new" solutions are required.

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# APPENDIX

Methodology: Flowchart