This document summarizes all changes made in the manuscript:

1- Affiliation of the author 'Marisol Toledo' changed to:

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2- Supplementary material

According to Referee #3 and the Editor, we have included the 2 adjacency matrix (S1 Guarayos and S2 Tapajos) in the Supplementary Material.

3- Anonymous Referee #1

Authors' responses to review comments are in ***red, bold, italics.***

Received and published: 3 June 2019- Changes made and submitted by the authors: 10 July 2019
References to lines and pages have been updated (4 December 2019) to match the final version of the text (it includes changes made according also to Referee #2 and #3).

**General comments:

The paper presents a novel methodology for the analysis of interactions between the socio-economic and environmental aspects of a region. It is tested in two different regions with similar problems linked to deforestation. The paper addresses relevant scientific questions within the scope of NHESS, presenting novel concepts and tools, which are usable in other contexts in the world. The methods used are clearly explained and the results support the interpretation and conclusions of the paper. The description of the data, the methods used, the calculations made and the results obtained are sufficiently complete and accurate to allow their reproduction. The title clearly and unambiguously reflects the contents of the paper, while the abstract provides a concise, complete and unambiguous summary of the work done and the results obtained. The overall presentation is well structured, clear and easy to understand by a wide and general audience. The paper is, as a whole, of a high quality, although some aspects could still be improved.

Thank you very much for the review and positive feedback.

**Specific comments:

Regarding the structure of the paper, section 2.1 Description of the study area should be part of the introduction, not of the methodology section.

Thank you for this comment. We agree that the description of the study area is not really part of the methodology. We have added a new point '2 Description of the study area' that goes after '1 Introduction' and before '3 Methodology'. Authors think that it is better not to merge Sections '1 Introduction' and '2 Description of the study area' because they present self-contained information that goes from the general to the specific.

The paper is very well written, with detailed explanations of the method and the results. However, it would improve readability if some parts were shortened. The introduction and the study area description, for example, are too long and contains irrelevant information that could be deleted, such as mean annual temperatures or precipitation, which are not needed and it is sufficient to know the type of climate for the purpose of the article.

Good suggestion. We have deleted irrelevant information and shortened the introduction (from 58 to 51 lines) and the description of the study area (from 64 to 38 lines) to improve readability. See sections 1 and 2 of the revised manuscript.

Some additional information on the scenario selection should be included. In section 2.4, it should be explained why are those scenarios selected and how are they translated into the models? In particular, the 'climate change' scenario is too simplistic and it should not be presented as a scenario itself but only as an important element to analyse together with the development scenarios (as it is mentioned in page 9, lines 4-5).

Thank you for the observations. We have now described the selection process used for the scenarios (Pg 7 line 29- Pg 8 lines 1-6). Following your suggestion we have now provided a more extended explanation of the translation of these scenarios into the model (Pg 7: lines 7-12). Further, we have also removed the climate change scenario as being an independent scenario and just defined it as an additional element for the scenarios.

Page 6, line 23: the authors mention two focus groups per study area without justifying why. Please briefly clarify why 2 focus groups were organised instead of one, which could have avoided the merging phase. It is also not clarified if the 2 focus groups were similarly composed, in terms of stakeholder groups.

Agreed. We have clarified the organization (Pg 5: lines 26-28) and composition of the focus groups (Pg 5: lines 28-31).

Page 7, lines 11-15: it is not clear what the 'centrality' concept is; please add a short clarification.

Agreed. Done (Pg 6: lines 26-28).

Page 8, line 1: it would be easier to understand the equation elements with a very small figure containing the components (ci, cj) with the edges and the weights in a visual way.

Although we agree that inclusion of this information (ci, cj) may provide greater support to the work, however an adequate explanation of such information would require an extension section and we believe would probably be more confusing than aiding. The values for the edges and weights of the components are included in Figures 4 and 5.

for Page 8, line 26: how are values between 0-1 determined?

We have now better explained how these values were determined: "Following Reckien (2014), we translated each scenario into the analysis through the manipulation of individual component state vector values (A of Eq. 1: Sect. 2.3.2). (Table 3). For each scenario, we identified components which we assumed would be directly affected by the scenario implementation. For these selected components, their values were fixed between 0-1, depending upon the scale of the scenario's impact. If we assumed a strong increase in the selected component, its state vector value was set to 1, whilst a strong decrease was set to 0. Intermediate values represent less intense increases or decreases. All other components had their values set to 0."

Page 10, lines 15-24: The paragraph is presented as facts, but this is the perceived view of stakeholders and it does not mean it is a demonstrated truth. Please rephrase so that it is clear that authors are presenting the reality perceived by stakeholders.

Agreed. Done (Pg 9: lines 26-33 and Pg 10 lines 1-2).

Table 1: the list of stakeholder groups is long and not easy to understand by outsiders. It would be easier for the reader if the table added a column (or some other feature) classifying them by wider types of stakeholder groups, such as 'farmers, environmentalists, local government: : :.'.

Very useful comment. Done. In Table 1, a column has been added with the stakeholder group (policy/administration, private sector, non-governmental organization, research)

Table 3: I would remove the climate change scenario, as explained in previous comments

Agreed. Done.

**Technical corrections:

Page 5, line 32, add "concept" after "FCM".
Thank you. Done. Pg 5: line 3

Page 6, line 2, add "called" before "nodes".
Thank you. Done. Pg 5: line 6

Page 6, line 3, add "The weight of" before "these relationships".
Thank you. Done. Pg 5: line 8

Page 6, line 13, replace "scare" by "scarce".
Thank you. Done. Pg 5: line 17

Page 9, line 32: remove 'and problems', it is redundant.
Thank you. Done. Pg 9: line 11

Page 11, line 7: remove 'them' after 'studies'.
Thank you. Done. Pg 10: line 18

Page 13, line 9: introduce ‘situation of’ (or something similar) between ‘worsen’ and ‘region’.
Thank you. Done. Pg 12: line 18

Page 13, line 25: move ‘absent or ineffective’ before ‘social and governance’.
Changed by ‘weak social and governance support structures’. Pg 12: line 34

Page 13, line 27: replace ‘are’ by ‘is after ‘deforestation’.
Thank you. Done. Pg 13: line 2

Table 2: font size is too small for reading
Agreed. Font sized has been increased

Figures 4, 5: font size of the maps’ elements is too small
Agreed. Font sized has been increased

4- Anonymous Referee #2 Pei-Lin Yu

Received and published: 12 September 2019- Changes made and submitted by the authors: 4 November 2019

1. Initial paragraph or section evaluating the overall quality of the discussion paper ("general comments").
Scientific Significance: The manuscript represents a substantial contribution to the understanding of natural hazards and their consequences through the use of the network analysis called Fuzzy Cognitive Mapping.
Scientific Quality: The scientific and/or technical approaches and the applied methods are largely valid in my judgment, although I am not a network analyst. The authors seem to ’lump’ two very different communities together for comparative purposes; would benefit from describing the cultural/ethnic/socioeconomic makeup of the focus groups sampled. In addition, the importance of linguistic and cultural variability in understanding of terms such as climate change should be clearly addressed.
Presentation Quality: The scientific data, results and conclusions are presented in a clear, concise, and well-structured way.

Authors sincerely thank the referee for the review, constructive comments and positive feedback. Suggested improvements are much appreciated and they have been addressed below.

2. Individual scientific questions/issues ("specific comments").

P. 2 Lines 10-15. Consider updating this introduction with urgency of environmental degradation such as the recent megafires in Amazon.
Good suggestion. Agreed and included (Pg. 2: lines 6-7)

P. 4 line 4, worth mentioning that Brazilian governance structure demonstrates the volatility of politics in Amazonian countries, and the relative disengagement of the larger global community. This could also be discussed briefly on p. 14, line 15-16.

Thank you. We have added a sentence about it in the introduction (Pg. 2: lines 5-6) because we think that it is in fact very important, but applicable to all the Amazonian countries, not only Brazil. In addition, we believe this has already been touched upon within the discussion (Pg 14, line 35-Pg 15 line 2).

P. 5 Line 10. What is the cultural background/ethnicity of these ribeirinhos? Seems that these communities in Bolivia and Brazil would likely have some important differences.

Thanks for highlighting this. We were instructed to reduce the content concerning the communities by a previous reviewer. However, as suggested, we have clarified the background of the 'ribeirinhos' in Pg. 4, lines 16-17, in Section 2 'Description of the study area', and included relevant information in Pg. 4: lines 10-12 and line 24 .

The studied communities (Guarayos in Bolivia and Ribeirinhos in Brazil) are culturally different, but their conditions are largely similar. Both live at the edge of the agricultural frontier, are reliant upon natural resources for incomes, face high levels of poverty, and are increasingly threatened by outside forces. The differences perceptions of the present situation in Guarayos and in Tapajos are already included in the different FCMs developed during the workhops (Figures 4 and 5).

P. 12 Lines 10-15. With regard to climate change it's possible that there are cultural, linguistic, inter-group, or even individual differences in perceptions of the meaning of the term 'climate change'. Please address this.

Agreed. We have included this caveat in the text. "This finding may also reflect the distinct cultural and linguistic meaning or representations of climate changes (e.g drought, flooding) across the two sites." (Pg 13: lines 9-10).
However, we should point out that the FCMs are group maps and therefore 'agreed' or 'consensual' maps developed during the workshops. Discussions between stakeholders were carefully guided by a facilitator, who helped to reach consensus. These types of exercises are not meant to identify (individual) contrasting views, to do so it is better to develop individual FCMs or other methodologies. Also, as part of the FCM methodology (Pg 5) a number of components considered to be representing similar features were merged. Therefore, components like reduced rains or increased droughts are included under this catch-all phrase of climate change. We agree that the need for highlighting linguistic and cultural distinctions is definitely relevant, but we don't believe it will have greatly affected the results here.

P. 13-14. In discussion mentions unanticipated results for climate change which reinforces my comment above. In my experience conducting climate change oriented interviews with indigenous gardeners of the sub-tropics, interviewees stated clearly that climate change is not relevant because 'the weather is always changing'. Thus it's worth asking if concepts of climate change amongst Western scientists might not apply to traditional communities.

Interesting point. We completely agree that cultural perspectives will have a considerable impact on perceptions of concepts like climate change. However, it does not apply to our study. As is common with the Fuzzy Cognitive Mapping method, similar components are grouped together. The stakeholders in both Brazil and Bolivia mentioned an array or terms (e.g.

increasing drought, reduced rains, increasing floods, weather instability), but they decided during the workshops to use the word ‘climate change’ to catch all terms. Further, in follow up meetings (Varela-Ortega et al., 2014) stakeholders validated this combination as being accurate to the current situation.

3. Compact listing of purely technical corrections at the very end ("technical corrections": typing errors, etc.). Not included.

Table 3 has misspelling ’focusses’

The manuscript has been written in British English, making this spelling appropriate.

P. 14 Section heading: I think it should read "Effecting Change..."

Thank you, we have change the word ‘affecting’ by ‘encouraging’ . Section heading 5.2 in Pg. 13.

5- Anonymous Referee #3

Received and published: 2 October 2019- Changes made and submitted by the authors: 4 November 2019

We thank Reviewer 3 for the many insightful comments and suggestions.

General Comments:

1. The paper presents two interesting case studies from Amazon countries, where the FCM approach was adopted to understand the perceptions of local actors about their environmental context. As result, different networks and scenarios were present to debate how local actor from each region could reacts to the sustainability and development challenges.

2. In the introduction section, the narrative conducts the reader to the importance of two groups of stakeholders in Bolivian (Guarayos indigenous communities) and Brazilian Amazon (Tapajós riverine communities). An important point in this kind of modeling approach is the choice of stakeholders to represent the multiplicity of actors and perceptions for tackling the problem analyzed. Considering this, some questions come up:

- Do the authors think that the riverine and indigenous communities were well represented in the groups of stakeholders that participated in the workshop?

Good point. Yes, riverine and indigenous communities were well represented in the workshops. See Table 1. In both cases (Guarayos in Bolivia and Tapajós in Brazil), key representatives of the indigenous communities (with the ability to make and to influence decisions) attended the workshops. E.g., in Guarayos (Bolivia), several representatives of the Organisation Centre of Guarayo Native People (COPNAG), which is the most powerful and influential indigenous association in the region attended the workshops. Similarly, in Tapajós (Brazil), the representative of all indigenous communities of the Flona (who lived in Communidade do Maguari) attended the workshop, together with other indigenous community heads. Indigenous communities were reached by the local teams of the ROBIN project (IBIF in Bolivia, and EMBRAPA in Brazil; researchers of both teams are co-authors

of the paper), which are great connoisseurs in the area and have long experience working with indigenous communities.

- Do the cognitive maps represent the vision of these groups?

Yes. The maps include the vision of these groups. In fact, in Brazil, the representative of all indigenous communities of the Flona presented the FCM obtained in the plenary

3. The description of the study area is long. The authors could be more focused on providing elements to support the research questions and the results (especially, the scenarios). For example, the social, cultural and political contexts experienced by stakeholders that can influence the networks structures or different responses to scenarios.

Agree, thank you. Following your suggestion (and other similar from other reviewers) we have deleted irrelevant information (e.g., mean annual temperatures or precipitation; we have been told that it is sufficient to know the type of climate for the purpose of the article) and focused this section on the description of the socio-economic, cultural, and political context. In addition, as suggested by one of the reviewers, the description of the case study has been now separated from the methodology section. We have added a new point '2 Description of the study area' that goes after '1 Introduction' and before '3 Methodology'.

4. Regarding the description of the study area, details of temperature, precipitation and vegetation are not relevant in this section, unless they are used in the design of climate change scenarios (that would be interesting).

We have deleted this information. See previous comment (point 3).

5. The section 2 should focus a little more on describing the workshops. Given that the stakeholder participants within each case study seem to be diverse and present even contrasting view on development and conservation, some issues need to be clarified, such as:

Thank you very much for noticing this. We have made some changes following your suggestions (see below)

- How the authors selected the stakeholders groups?

Agree. We have clarified this. See page 5, lines 25-31 and Table 1

How conducted the process of identifying the components to be included in the model? How do the participants identify the degree of influence between components (high, medium, etc.)?

Agree. This has been explained in more detail in the manuscript. See page 6, lines 1-10

What were the most important components mentioned in the workshops?

The most important components are those reflected in the FCMs, and particularly those with the highest page rank (see Figures 4 and 5).

- It is unclear how component values were obtained during the workshops (were individual or group responses?).

Agree. They were group responses. This is now specified on page 6, lines 1-2 'the FCM developed represented stakeholder group knowledge' (Ösezmi and Ösezmi, 2004), and on page 6 line 11, FCMs are 'group maps'.

How have the authors converted the cognitive maps in the adjacent matrix? I mean, how the strength of the interactions among components (the weighted values) was defined?

The strength of the interactions among components was defined by the stakeholders in the workshops as described on page 6, lines 1-10

How the contrasting view of the problem was converted in a single value of influence? I suggest the authors to provide the ranges of model parameters/variables presented during the workshops to show contrasting views.

The FCMs are group maps and therefore 'agreed' or 'consensual' maps developed during the workshops. Discussions between stakeholders were guided by a facilitator, who helped to reach consensus. These types of exercises are not meant to identify contrasting views, to do so it is better to develop individual FCMs or other methodologies. Furthermore, the objective of the paper was not to dig on individual/contrasting views, but to have a clear picture of the common vision of the present in two communities (Guarayos and Tapajos) from different countries (Bolivia and Brazil), living on the edge of the agricultural frontier and confronting similar problems.

6. Scenario section (2.4) is not clear. The authors could provide more details about the scenario conception and the stakeholders' contribution.

Agree. Thank you. We have made some changes following your suggestions (see below)

- How were climate change identified by stakeholders (changes in temperature, extreme climate events, precipitation, river level, floods, forest fires, soil erosion, etc.) and how were they translated it to the model?

As is common with the Fuzzy Cognitive Mapping method, similar components were grouped together. The stakeholders in both Brazil and Bolivia mentioned an array or terms (e.g. increasing drought, reduced rains, increasing floods, weather instability), but they decided during the workshops to use the word 'climate change' to catch all terms. Further, in follow up meetings (Varela-Ortega et al., 2014) stakeholders validated this combination as being accurate to the current situation.

Following the suggestion of one of the reviewers, we have removed the climate change scenario as being an independent scenario and just defined it as an additional element for the scenarios. Also, following your comment, we have now provided a more extended explanation of the translation of these scenarios into the model (Pg 8: lines 7-18).

The climate change scenarios are the same for the two study sites?

Yes

What climate changes were considered to be impacted by deforestation?

Increasing drought, reduced rains, increasing floods, weather instability

- Conservation strategies were resumed in one strategy in the Tapajós case study (Environmental Monitoring). It is not clear if the scenario components were defined in the workshop by the stakeholders or by the authors. Anyway, I see as a problem reducing conservation strategies in a unique and passive action of monitoring. By doing this, conservation strategies may seem to have low impact to achieve desired changes, in comparison with the governance and techno-social reform.

The scenarios were first proposed by the authors, based on literature review, and then further defined by the stakeholders taking into account the limited number of factors included in the FCMs. We agree that the conservation scenario in the Tapajós case study may seem to be too reductionist, but stakeholders identified improved monitoring as the key environmental aspect to achieve a successful conservationist future. Stakeholders think that many conservation policies have already been developed and put in place, but their effectiveness has been limited due to insufficient monitoring and enforcement. Also, stakeholders think that a lot more remains to be done for improving institutional and governance systems, to protect traditional communities, support technical training, etc. Many aspects could be improved in this regard that could have positive impacts in the region. This is why the governance and techno-social scenario include changes in several components and the conservation scenario only in one.

7. The authors show in figure 2 that FCM was validated in the second workshop. How the validation procedure was carried out? Can the same participants in the first workshop validate the FCM they created themselves?

The people who participated in the second workshop are not exactly the same as those who participated in the first workshop. We were very careful to count with the same group of stakeholder, but the key representatives varied in some cases (due to agenda issues or changes in governmental bodies). Thus, the FCMs were validated by the same groups of stakeholders, not exactly by the same participants.

In the second workshop, the validation was performed by showing the stakeholders the processed FCM, including the dynamic analysis, and discussing with them the results. In both cases, Guarayos in Bolivia and Tapajos in Brazil, the main components of the FCMs remained unchanged, but stakeholders decided to change (increase/decrease) the strength of some links among components (e.g., in Guarayos, stakeholders decided to increase the weight given to the links 'illegal mining → soil erosion'; 'illegal mining → contamination').

8. In the Dynamic analysis of FCM (3.2), some interesting results could be presented in respect to the model dynamics during the calculation to achieve the baseline situation. Does the system's identity remain the same after steady state analyses is conducted?

Yes, the systems' identity remains the same. The steady state analysis considers the current situation of all variables. It is used to measure how a variable is changing (increasing, reducing, or stable based upon the value) in the system and you can also compare across variables (i.e whether deforestation is increasing, whilst forest law implementation is reducing) within the system. However, the system remains the same as the weighting applied to each variable is identical; the 'identity' would only change with the application of the scenarios, where the current situation of the system is altered. The iterations (calculation) of the model dynamics are irrelevant, the final result is what it is important and it is shown in Figures 6 and 7.

- Do the authors think that there is a relation between FCM complexity and the diversity of indigenous and riverine communities in the group of stakeholders?

No, we think that there is not such a relation. Key representatives transmitted a common voice for the indigenous and riverine communities. This is quite frequent; they used to have a common voice to make theirselves heard.

Specific comments:

Page 2: Include more recent citations in introduction.
Agree. Done

Page 5, Line 6: 'dense moist and wet forest types'. I suggest you include a classification system for the Amazon vegetation to describe the forest types.
Agree, defined now as dense terra firme (upland) tropical moist forest

Page 5, lines 7-9: I suggest you mention the decree n_ 73.684, February 19 of 1974.
Agree, included

Page 5, Line 10: Cite data source (reference) in respect to the number of 'ribeirinhos' and 16 communities mostly along Tapajós river.
Following the suggestion of another reviewer, we have deleted the number of communities and further specified the ethnical background of this riberirinhos

Page 6, Lines 20 – 25: How were focus groups defined?
This has now been detailed in Pg. 5, lines 26-31.

Page 7: Last paragraph: I suggest to present the adjacent matrix in the supplementary material.
Fist response (November 2019) → We have tried to include the adjacency matrix as Tables in the Supplementary material, but it has been impossible, they are too big (29 lines x 29 columns in Guarayos, 32 lines x 32 columns in Tapajós). They are illegible
According to the Editor's comments (December 2019) → We have included the 2 adjacency matrix (S1 Guarayos and S2 Tapajos) in the Supplementary Material.

Page 9: How much components were included in the model by the workshop participants?
This is specified in Table 4 (second line), in Guarayos 29, in Tapajós 32

Examining the sustainability and development challenge in agricultural-forest frontiers of the Amazon Basin through the eyes of locals

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Abstract

The Amazon basin is the world's largest rainforest and the most biologically diverse place on Earth. Despite the critical importance of this region, Amazon forests continue inexorably to be degraded and deforested for various reasons, mainly a consequence of agricultural expansion. The development of novel policy strategies that provide balanced solutions, associating economic growth and environmental protection, is still challenging, largely because the perspective of those most affected- local stakeholders- is often ignored. Participatory Fuzzy Cognitive Mapping (FCM) was implemented to examine stakeholder perceptions towards the sustainable development of two agricultural-forest frontier areas in the Bolivian and Brazilian Amazon. A series of development scenarios and a climate change scenario(including climate change) were explored and applied to stakeholder derived FCM, with climate change also analysed.. Stakeholders in both regions perceived landscapes of socio-economic impoverishment and environmental degradation driven by governmental and institutional deficiencies. Under such abject conditions, governance and well-integrated social and technological strategies offered socio-economic development, environmental conservation, and resilience to climatic changes. The results suggest the benefits of a new type of thinking for development strategies in the Amazon basin, and that continued application of traditional development policies reduce the resilience of the Amazon to climate change, whilst limiting socio-economic development and environmental conservation.

Key words: agriculture expansion, deforestation, stakeholder perception, fuzzy cognitive mapping, sustainable development strategies, Amazon basin.

1 Introduction

The Amazon basin is a one of the richest terrestrial biodiversity hotspotsthe world's richest biological reservoir, and a globally significant carbon sink, a leading supplier of agricultural commodities (Lapola et al., 2014), and home to millions (INE, 2014). Since the 1960's, deforestation and forest degradation has weakened the basin's natural function, causing a substantial loss of biodiversity, provision of ecosystem services, and changes in local and global weather patterns (Harris et al., 2012; Haddad et al., 2015; Zemp et al., 2017). (Haddad et al., 2015; Brandon, 2014; Harris et al., 2012). Weak governments and political instability in Amazonian countries have reduced capacity to halt deforestation and related expansion of illegal activities. Recent increases in deforestation and megafire clearances reinforce the continued threatened state of the basin (Global Forest Watch, 2019). In addition, climate change wouldwill most likely lead to increased drought in the Amazonia, which will pose a further threat to the sustainability of the region (Malhi et al., 2008; Guimberteau et al., 2017). . The contemporary basin is the product of prolonged socio-natural interactions (Ioris, 2016), with environmental destruction and degradation increasingly commonplace (Foley et al., 2007). This degradation constitutes a threat to threating biodiversity (Haddad et al., 2015), ecosystem service provision (Brandon, 2014), and climate change mitigation (Haddad et al., 2015; Brandon, 2014; Harris et al., 2012). These environmental changes have been driven by agricultural and other extractive activities (Hosonuma et al. 2012), which have expanded to profit from the basin's resources (Weinhold et al., 2013). These changes are so widespread that Davidson et al. (2012) describe the basin as a region in transition. Furthermore, the basin is threatened by climate change, with temperatures having already increased at least 1°C since the 19th century (Victoria et al., 1998). Continued environmental degradation and climatic changes could increase regional weather pattern variability (Spracklen and Garcia-Carreras, 2015), and threaten both biodiversity (Phillips et al., 2009), and agricultural activities (Oliviera et al., 2013). Further, fFuture scenarios suggest a continuation of the current basin'sis precarious state (e.g. Folhes et al., 2015; Tejada et al., 2016), with Lenton (2011) proposing that ecological tipping points could be reached.

Agricultural and extraction Aactivities are often pointed outcited as responsible for the current state ofenvironmental major drivers of deforestation and forest degradation in the Amazon basin in the basin the basin (Hosonuma et al., 2012; García et al., 2019).

These activitiesy have, in many cases, been supported by policies to encourage rural development wthose lasting benefits are unclear (Rodrigues et al. 2009; Celentano et al, 2012; Oliviera et al., 2013; Weinhold et al., 2015). (Diversi, 2014)., Iand in some instances these have catalysed socio-economic improvements (Le Tourneau et al., 2013). However, the long-term developmental benefits of such activities are unclear (Rodrigues et al. 2009; Celentano et al, 2012; Weinhold et al., 2015)., with Ioris (2016) positsing that developmental improvements from extracionist activities are far from universal and are

~~overshadowed by long-term environmental costs. P~~Policies~~ that solely ~~concentratinge upon agricultural intensification and resource extraction may provide ~~only marginal ~~economic gains (Le Tourneau et al., 2013; Ioris, 2016), ~~and ~~but may also have negative long-term ~~be responsible for ~~social and environmental ~~negative effects~~impacts ~~in a long-term perspective~~ (Weinhold et al., 2015). Conversely, ~~approaches~~conservation policies ~~conservation policies~~aimed at preserving and restoring ~~to preserve existing ~~forest ecosystems ~~and restore lost tree cover ~~have been implicated as drivers of negative socio-economic changes ~~impacts ~~(Chomitz, 2007; Carr, 2009; Guedes et al., 2014). These findings point toward the trade-offs in rural development objectives (McNeil et al., 2012), which increasingly focus upon socio-economic development through extracionist activities, or environmental conservation that excludes them. This dichotomy has dominated the political and developmental discourse of the Amazon for decades, with Nobre et al. (2016) suggesting they represent the basin's established development model.

The ~~bleak ~~state and outlook of the Amazon basin, along with the limitations of the entrenched development policies, beg the question as to whether other options exist to transition the basin towards a sustainable, less conflict-ridden state. Nobre et al. (2016) promote a "third-way", driven by investment in technical and social capital, catalysing a localised industrial revolution. Guedes et al. (2014) offer that increased access to technical assistance may permit communities to develop more sustainable livelihoods, converting natural capital to social~~ capital~~. Lapola et al. (2014) infer that technological improvements along with sustainable land management could drive ~~a ~~sustainable land use shifts~~ in land use in the Brazilian Amazon~~. A further possibility may lie in the results of recent analyses, ~~(e.g. Weinhold et al., 2015; Caviglia-Harris et al., 2016)~~which ~~. These analyses ~~suggest that socio-economic development in forest frontier regions of Brazil has uncoupled from environmental exploitation and degradation, due to policy development and implementation (e.g. Weinhold et al., 2015; Caviglia-Harris et al., 2016)~~(Lapola et al., 2014; Caviglia-Harris et al., 2016)~~. Tritsch and Arvor (2016) ~~suggest~~ propose that recent improved governance structures have begun to address competing rural development goals. Godfray et al. (2011) and Newton et al. (2013) advocate that governance and institutional improvements could provide a balance between conservation, development, and climate change mitigation. The implementation of such reforms, or similar strategies could offer an interesting discussion point to reassess the emphasis of rural development policies. However, consideration of novel strategies would be reliant upon modelling and testing, offering scope for scenario development and application. The development of such scenarios could aid in quantifying the impacts of potential strategies in improving factors within the three main rural development dimensions, social, economic, and environmental, whilst simultaneously mitigating climate change.

However, in analysing the Amazon basin, development strategies and scenario development, it is easy to ignore the perspective of those most likely to be affected- local stakeholders. ~~Local perspectives can be drowned out by the largely expert derived knowledge base that dominates the understanding of the Amazon basin. ~~Stakeholder involvement can provide new interpretations to previously studied problems, improve the understanding of complex situations, reduce unforeseen consequences of policy implementation, and empower local communities (Folhes et al., 2015; Olazabal and Pascual, 2016). ~~Application of scenarios to stakeholder derived information may broaden the understanding of localised issues within the~~

~~basin and highlight the effectiveness of traditional and novel development strategies in addressing such issues.~~ A number of methods are available to incorporate stakeholder perspectives into such analyses (e.g. Verburg et al., 2014), including Fuzzy Cognitive Mapping (FCM). FCM involves the development of a visual representation (map) of perceptions of a given system ~~or situation~~ (Kok, 2009) and permits the application of scenarios to these maps (~~e.g.~~ Vasslides and Jensen, 2016).

Using stakeholder derived information collected from workshops performed in forest frontier communities of the Bolivian and Brazilian Amazon (the province of Guarayos in Bolivia and the Tapajós National Forest in Brazil), this paper aims to identify how such communities perceive the present state of their region using FCM. In general, deforestation and the expansion of the agricultural frontier in Bolivia have been less well studied than in Brazil, probably due to its relatively recent development (Pacheco, 2006; Killeen et al., 2008). However, increasing efforts are being made to study both parts of the Amazon basin. Further, this analysis will apply development ~~and climate~~ scenarios (including climate change) to these ~~cognitive maps~~FCM, analysing how each region reacts to the sustainability and development challenge, changing socio-economic, political, and climatic conditions.

2 Description of the study area

~~The Amazon basin is the largest tropical rainforest in the world. It covers an area of approximately 6 million km^2, extends over eight South American countries, and consists of wide mosaic of ecosystem and vegetation types.~~ Given the size of the Amazon basin~~region~~, two study sites with similar problems ~~have been~~were selected within the framework of the ROBIN[1] project. Firstly, the Province of Guarayos (20,029 km^2~~, covering the municipalities of Ascensión de Guarayos, El Puente, and Urubichá~~), in the northwest corner of the Department of Santa Cruz in lowland Bolivia; the second, the Tapajós National Forest (5,449 km^2) ~~bound by the Tapajós River, the Cupari River, and the Santarém-Cuiabá highway (BR-163),~~ in the western part of the State of Pará (municipalities of Belterra, Placas, Rurópolis and Aveiro), in northern Brazil (Fig. 1).

Figure 1 here

~~Both study sites provide representative examples of the threats that endanger the Amazon basin. Despite this, these threats are highly conditioned by the specific characteristics for each region, which offers an interesting perspective for comparison.~~ The Province of Guarayos (henceforth Guarayos) is located ~~at the southernmost extent of Amazonian rainforest in Bolivia,~~ in the transition zone between the humid Amazon forest and the dry Chiquitano forest. ~~The climate is tropical, with a mean annual temperature and precipitation of approximately 22°C and 1600 mm. This region, like all southern Amazon regions, is~~

[1] The research project ROBIN (The Role of Biodiversity in Climate change Mitigation) (2011-2015), funded by the European Union Seventh Framework Programme under grant agreement No 283093, aims at quantifying interactions between terrestrial biodiversity, land use and climate change potential in tropical Latin America. More information can be found at https://cordis.europa.eu/project/rcn/100815/reporting/.

prone to changes in precipitation and is expected to be most affected by rainfall declines caused by climate change (Malhi et al., 2008). It has a tropical climate and In Guarayos, half of the territory is covered by natural forests. It hosts important protected forest areas, recently created, such as the 'Reserva Nacional de Vida Silvestre Ríos Blanco y Negro' (dating from 1990) created in 1990, which are hugely important in terms of biological diversity. In the vicinity of theses protected areas lives the Guarayos indigenous community (a branch of the Guaraní), whose livelihoods depend on fishing, hunting, and gathering fruit, as well as the cultivation of rice, pineapples, bananas, manioc, and other crops. The extraction of wood is limited. In spite of significant efforts to promote formal sustainable forest management at the community and industrial level, with, only informal timber networks have been developedin place (Albornoz et al., 2008). Since 1996, land is collectively owned and managed by the Guarayos through a 'community land of origin' (TCO, by its Spanish acronym), which has contributed to the sustainable conservation and utilisation of forests. However, the legal uncertainty surrounding the system of land tenure in Bolivia, coupled with the increasingly frequent arrivals of outside investors in the area, mainly large-scale farm operators in the area, have resulted in highly conflicted situations, with illegal appropriation of TCO common llands and environmental degradation (deforestation, contamination, habitat destruction, soil degradation, etc.) (Killeen et al., 2008; Stavenhagen, 2009). Agricultural is main employer for the Guarayos, being the major source of income for households, in this region of elevated poverty. Soya dominates both winter and summer cultivation, followed by sunflower, maize, rice, and sorghum (INE, 2015).Between 2001 and 2012, the population of Guarayos almost doubled to 48,301 inhabitants. Currently, Aagriculture is the primary economic activity, with almost 50% of the working population employed in agricultural activities (INE, 2011), with . Of the total arable land (4% of the province's land surface area), soya dominating es both winter and summer cultivation, followed by sunflower, maize, rice, and sorghum (INE, 2015). In general, deforestation and the expansion of the agricultural frontier in Bolivia has been less well studied than in Brazil, probably due to its relatively recent development and it being concentrated in the Department of Santa Cruz to the east (Pacheco, 2006; Killeen et al., 2008). The socio-ecological implications of the expansion of agricultural frontier in this region are huge, with increasing efforts being made to study this part of the Amazon basin.

The Tapajós National Forest (henceforth Tapajós) is located at the heart of the Amazonian rain forest in Brazil. In this region, theThe climate is humid tropical; the mean temperature is 26°C and annual precipitation averages approximately 1,820 mm. The dry season lasts roughly two months, falling between August and October, with rainfall of < 60 mm month $^{-1}$ (IBAMA, 2004). and Tthe natural vegetation is dense terra firme (upland) tropical moist forest dominated by dense moist and wet forest types with emergent trees (Dubois, 1976). TapajósTapajós is the second oldest conservation unit in the Brazilian Amazon. It has been protected since 1974 (Decree nº 73.684, February 19 of 1974), when it was officially designated as a 'National Park', and is classed as an IUCN category VI protected area (protected area with sustainable use of forest resources and scientific research) (IBAMA, 2004). Most of the population livess along the Tapajós River, in well organised communities of 'ribeirinhos' (or Caboclos, which derived from theintermingling between the first European colonialists and the Amerindian populations).

The area is home to 5,000 'ribeirinhos' (traditional South American populations living near rivers), distributed across 16 communities mostly along the Tapajós River. These communities are well organised and have historically been very active in governance processes. During the 30-year period (1980-2010), the traditional riverine populationthey held an important resistance movement to avoid eviction and gain land tenure and resource rights. This movement was . This movement was a pioneering in Brazil and led to a commercial community forest management system that has has attracted both national and international attention (Bicalho and Hoefle, 2015). Despite this, these communitiesthe 'ribeirinhos' face difficult living conditions, with poor access to social services. (education, health, etc.). Logging is the main economic source of employment and revenue for the population, who subsist on very low incomes subsidised by small-scale subsistence farming activities (manioc, beans, and corn), fishing, hunting, and non-logging activities (eco-tourism and the sale of wood-latex-leather handicrafts).. Most residents are dependent on government transfer payments (Hoefle, 2016)As a result, most residents are dependent on government transfer payments (Hoefle, 2016). Although forestry exploitation in Tapajós is mostly carried out in a sustainable way, by the local population, growing concerns regarding the conservation of protected areas have recently emerged. The environment and the protected areas inhabited by the 'ribeirinhos' are increasingly threatened External pressures on these protected areas are increasingly being applied by private forestry companies to acquire concessions,the expansion of intensive agriculture and cattle grazing areas coming mainly from the neighbouring Cerrado, and the development of infrastructure (highways and dams) for the acceleration of growth (Fearnside, 2007; Gibbs et al., 2015; Verburg, 2014; Fearnside, 2015; Gibbs et al., 2015).

In general, deforestation and the expansion of the agricultural frontier in Bolivia has been less well studied than in Brazil, probably due to its relatively recent development (Pacheco, 2006; Killeen et al., 2008). However, increasing efforts are being made to study both parts of the Amazon basin.

The bordering Santarém-Cuiabá (BR-163) and Transamazonian (RB-230) highways, planned to be reconstructed, are considered major corridors of deforestation as they stimulate migration and exportation of livestock, soybean, minerals (gold), and forestry products via the Amazon River (Fearnside, 2007). Beyond this, the Tapajós River is at the centre of some of the most recent and dynamic hydroelectric development activity in Brazil (Fearnside, 2015). In 2012, the Brazilian government approved a law (No. 12,678) to enable the construction of the São Luiz do Tapajós mega dam, which would have reduced the geographical limits of the Tapajós National Park by 11,990 ha. This particular project was highly criticised and finally cancelled in 2016, but similar ones are still planned and threaten the study area.

2 3 Methodology

2.1 Description of the study area

The Amazon basin is the largest tropical rainforest in the world. It covers an area of approximately 6 million km^2, extends over eight South American countries, and consists of wide mosaic of ecosystem and vegetation types. Given the size of the region, two study sites have been selected in the framework of the ROBIN[2] project. Firstly, the Province of Guarayos (20,029 km^2, covering the municipalities of Ascensión de Guarayos, El Puente, and Urubichá), in the northwest corner of the Department of Santa Cruz in lowland Bolivia; the second, the Tapajós National Forest (5,449 km^2) bound by the Tapajós River, the Cupari River, and the Santarém-Cuiabá highway (BR-163), in the western part of the State of Pará (municipalities of Belterra, Placas, Rurópolis and Aveiro), in northern Brazil (Fig. 1).

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2.23.1 Participatory development of FCMs

The FCM concept is attributed to Kosko (1986) who provided the fuzziness to earlier cognitive mapping techniques (Tolman, 1948; Axelrod, 1976). Maps developed from FCM visualise components and their causal relationships within a system (Kok, 2009) as perceived by an individual, or group. This mapping can be developed through participatory interviews or workshops, where components (called nodes, concepts or vertices) representing features of the system are identified, and causal relationships (links, connections or arcs) between them are defined through weighted and meaningful directed linkages (Gray et al., 2015). The weight of Tthese relationships range from -1 to +1 (Özesmi and Özesmi, 2004) and define the scale of influence (positive or negative) that one component has upon another.

The causal networks developed from FCM have considerable flexibility for analysis in a range of fields (e.g. Papageorgiou et al., 2013) and support scenario development (e.g. Kok, 2009). The methodology can incorporate multiple stakeholders' perspectives and knowledge (Gray et al., 2015) through combination of multiple maps into one 'community' map (Fairweather, 2010) or development of a single map by a group of stakeholders (Varela-Ortega et al., 2014), aggregating and incorporating distinct perspectives of different groups into a single vision. Participatory development of FCMs can improve communication through the development of an open, neutral, and informal forum for participants to give their opinions. The FCM methodology can incorporate both measurable (e.g. deforestation) and qualitative concepts (e.g. awareness of environmental problems). FCM can provide useful output for data scarce problems or in areas where data it is difficult to obtain and can be complementary to quantitative models (Olazabal and Pascual, 2016). The results of FCM are semi-quantitative and can only be interpreted relative to other values within the system (Kok, 2009).

In this study, we use FCMs to visualise the perceptions of local stakeholders concerning the direct or indirect interactions of variables that influence the state of the local environments in both Guarayos and Tapajós. The steps implemented as part of the methodology are illustrated in Fig. 2.

Figure 2 here

In each of the case studies, two stakeholder workshops were held within the framework of the ROBIN project. In the first, and following the author's previous experience from a large EU project (SCENES) (Kok and van Vliet, 2011), we facilitated two focus groups of 12 to 15 persons each to ease the process of producing FCM. As much as possible, the two focus groups were equally balanced in terms of gender, age, and stakeholder group representation. ~~, consisting of diverse groups of stakeholders providing a heterogeneous perspective (Table 1).~~Each stakeholder group included representatives from the policy and private sectors, non-governmental organisations and scientists, thus covering a broad range of expertise on agro-forestry issues (Table 1).

Table 1 here

Each focus group developed its own FCM. Thus, the FCM developed represented stakeholder group knowledge (Ösezmi and Ösezmi,2004). Participants were invited to offer their perspectives on the present state of the environment in the region and what they considered to be the key features and processes inherent to it. First, every participant was asked to write up to three factors in cards that they considered to contribute most to the present situation and explained their choices with the rest of the group. Following discussion, similar factors were clustered and new factors were identified and added to the original selection. After a final selection of factors was chosen, participants established links (arrows) among them and identified the sign of the links: positive (+) when an increase in one factor causes an increase in the other; and negative (-) when an increase in one factor causes a decrease in the other. Finally, they assigned values to these links indicating how strong they were using a scale within the range 0 (very weak) to ± 1 (very strong).

~~Participants discussed and identified the components, causal component connections, and the weights of these connections in the development of the maps.~~

After the first stakeholder workshop and following Ösezmi and Ösezmi (2004), the two group maps from each case study were combined into one ‘Case Study FCM’. As part of the combination process, components identified as representing similar features were merged, where possible. However, in combining components, conflicting connections were identified, normally involving the wording “Lack of…” In these cases, and following Vasslides and Jensen (2016), wording of the more prevalent component was kept, and connection weights were inverted appropriately.

The combined FCM was presented in the second workshop for enrichment, validation, and interpretation. Once the ‘Case Study FCM’ was agreed, a discussion on possible futures and sustainable strategies was held, serving as input for scenario development and simulation. To ensure continuity, care was taken that similar stakeholders (or stakeholder groups) were present in the second workshop.

~~2.~~3.2~~3~~ FCM analysis

The two ‘Case Study FCMs’ were analysed following Reckien (2014) and Olazabal and Pascual (2016) considering their structure, dynamics, and the impacts of scenarios on their dynamics.

~~2~~3.~~3~~2.1 Structural metrics

As FCM are considered complex networks, the structural metrics here used to analyse them are complex network parameters commonly applied in the literature (see Table 2). Further, we also include two novel metrics for the measurement of centrality in FCM analysis: page rank (PR) and betweeness (Bw). ~~The goal of C~~centrality is used to determine the importance or influence of a given node in the network. This concept was first introduced in sociology to quantify the influence of an individual in the whole social network (Freeman, 1978). In the two networks analysed (FCM of Guarayos and Tapajós) the ties among nodes have weights assigned to them, therefore the FCM are considered weighted networks and the centrality measures are weighted as well.

Table 2 here

Bw was first introduced by Freeman (1977) to quantify the control that an individual can achieve on the communication between other humans in a social network. PR was named after Larry Page (Page, 1999), ~~one of the founders of Google,~~ and is used by Google Search to rank websites in their search ~~rengine r~~esults. While Bw measures the influence of a node within a network by calculating the number of times a node acts as an intermediary along the shortest path between two other nodes, PR calculates the probability of visiting each node if we were randomly ‘surfing’ the net.

~~2~~3.~~3~~2.2 Dynamic analysis

Besides the structural metrics of Table 2, the dynamic behaviour of the maps was also analysed to gain an insight into how components interact with each other, over ~~various~~ multiple iterations (Gray et al., 2015). This analysis permitted comparison between the steady state values (Kosko, 1994) for each component, as well as the simulation of scenarios.

To calculate the steady state values and perform the dynamic analysis, each Case Study FCM was converted into an adjacency matrix (Tables S1 and S2), which was then multiplied by a state vector A (Eq. 1) over various iterations (k). According to Kok (2009), this calculation results in four potential dynamic outcomes: components return to zero, components continuously increase/ decrease, components continuously cycle, and components stabilise at a fixed value.

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j\neq i \\ j=1}}^{N} A_j^{(k)} w_{ji}\right) \qquad (1)$$

Where $A_i^{(k+1)}$ is the value of the component C_i at iteration k +1; $A_i^{(k)}$ is the value of component C_i at iteration k; $A_j^{(k)}$ is the value of the component C_j at iteration k; and w_{ij} is the weight of the connection between components C_i and C_j.

The state vector A initially sets values for all components to 1 (Olazabal and Pascual, 2016), assuming all components are equally important and is multiplied against the adjacency matrix. The resultant vector is transformed to a logistic expression f, binding values between 0 and 1 (Kosko, 1986). This output vector is once again multiplied against the adjacency matrix, producing bound results between 0 and 1. This process is repeated until the dynamic outcome becomes evident, usually after 20-30 iterations (Kok, 2009).

Output (steady state) values close to 0 are representative of a strong decrease in the component, whereas values closer to 1 represent a strong increase (Reckien, 2014). The steady state values were interpreted as the current state of each component within the system (map) and were used as a baseline for interpreting the impacts of the scenarios.

~~2~~3.~~4~~ 3 Scenario development

~~Five scenarios were developed~~ Development of scenarios can provide a useful mechanism to evaluate the localised impacts of potential policy implementation. In the present study, scenarios that mimic traditional rural development policies are compared with novel policy strategies, to analyse the system impacts on Guarayos and Tapajós. We designed and implemented four scenarios (Table 3). Two to~~to identify how Guarayos and Tapajós may react to the conditions of four development strategies and to climate change (Table 3). The four development strategies~~ ~~were characterised to~~ replicate the ~~traditional~~ binary development strategies traditionally applied in the region~~s applied in conflicting agricultural-forest frontier areas~~: agricultural development (Scenario 3); and ~~(~~environmental conservation~~, associated with~~ (S~~s~~cenario 4)~~3 in Table 3; and agricultural development, scenario 4) (Nobre et al., 2016)~~. A further~~,~~ ~~with two~~ two~~others~~ scenarios were developed: techno-social reforms (Scenario 1) to replicate Nobre et al. (2016) 'third- way' for rural development; and ~~characterising~~

governance reforms (S~~s~~cenario 2)~~1)~~ cited by stakeholders to be fundamental for sustainable futures in the region (Varela-Ortega et al., 2015).~~and~~ ~~techno-social reforms (scenario 2)~~We also analysed the cumulative effects of climate change on each of the scenarios~~.~~. ~~Further, a climate change scenario (scenario 5) was applied to analyse the impact of climatic changes on the current state of the system. Although addressing similar concepts and themes, the scenarios differ in their application and characterisation across the case studies due to differences in the mapped systems' constituent structure.~~

~~To analyse the impacts of the scenarios, the same calculation as for the baseline (Eq. 1: Sect. 2.3.2) was performed. However, unlike the baseline, where the state vector for each component was fixed at 1, the scenarios fixed the values of certain components within state vector. Those components included within the scenario (Table 3)~~Following Reckien (2014) and based on discussions with stakeholders, we translated each scenario into the analysis through the manipulation of individual component state vector values (*A* of Eq. 1: Sect. 2.3.2). (Table 3). For each scenario, we ~~identified~~different components were identified as being~~which we assumed would be~~ directly affected by the scenario implementation. For these selected components, ~~had their values fixed~~ their values were fixed ~~at a set value~~ between 0-1, depending upon the ~~assumed~~ scale of the scenario's impact~~s of the scenario on that component~~. ~~If we assumed a~~A strong increase in the selected component was translated by ~~, its~~ a state vector value ~~was set to~~of 1, whilst a strong decrease was set to 0. Intermediate values represent less intense increases or decreases.~~. All other components had their values set to 0 within the state vector (Kosko, 1986). If for example 'Lack of Government Coordination' was included within an improved governance strategy, its value would be set lower than that the steady state value of the baseline, characterising the assumption that the strategy will reduce the impact of this component.~~ All other components had their values set to 0. ~~The five scenarios, their description, the components, and the fixed values are presented in Table 3.~~

Table 3 here

The output values for components under each scenario were then compared to their baseline values, with differences suggesting the relative impacts of each scenario. Further, the effects of the four development scenarios were also tested under the conditions of climate change~~scenario~~, where the climate change component was fixed to 1.~~.~~

To determine the wider impacts of the scenarios on the system, cumulative impacts for each scenario were analysed. To do so, components were categorised as positive, negative, or neutral (Reckien, 2014; Olazabal and Pascual, 2016) (Supplementary Table ~~S1~~S3). Categorisation of components was based upon the perception of the role that each component would have in developing more sustainable regions. Components were categorised to recognise the equal importance of a reduction in a negative component, as an increase in a positive one, when considering the cumulative impacts of the scenarios. As with Reckien (2014), an aggregated impact value was calculated as the sum of: increases in positive components and decreases in negative components (from baseline to scenario).

It should be noted that the output results of FCMs are semi-quantitative. As such, outcomes can only be used to determine impacts on components, relative to other components, rather than absolute changes (Özesmi and Özesmi, 2004; Kok, 2009).

Impact comparisons can only be made within the system and cannot be compared with absolute indicator values (Reckien, 2014; Devisscher et al.,2016).

~~3~~ 4 Results

~~3~~4.1 Structure analysis of FCM

Analysis of the two Case-Study FCMs demonstrated structurally similar systems (Table 4), with divergent contents (Fig. 3, 4 and 5).

Table 4 here

The two maps have comparable component numbers and similar densities of 0.052 (Guarayos) and 0.048 (Tapajós). The density difference may suggest that stakeholders in Tapajós perceive greater causal relationships between components. According to Özesmi and Özesmi (2004) this may offer greater possibilities to elicit change within Tapajós, compared to Guarayos. The complexity of the Guarayos map (0.57) was almost double that of Tapajós (0.33), suggesting that Tapajós is a more hierarchical system (Özesmi and Özesmi, 2004), with more transmitting components. This hierarchical lean is reflected in the components of the Tapajós map (Fig. 5), dominated by political and institutional concepts~~ and problems~~, whilst the Guarayos map (Fig. 4) appears more heterogeneous.
A first look at the results obtained in Bw and PR (Table 4) shows that the maximum Bw value in Guarayos is double than in Tapajós, 0.21 and 0.09 respectively, as we observed with Complexity. In both cases the highest Bw corresponds to Deforestation. Meanwhile PR maximum values are more similar in both case studies being higher in Tapajós than in Guarayos. Studying the values distribution for both metrics (Bw and PR) in percentage of components, it is possible to compare both cases. With respect to Bw (Fig. 3a), the highest six values are quite differentiated from the rest, in Guarayos showing a range from 0.05 till 0.21. These correspond with ordinary components: Agricultural Expansion, Climate change, Illegal logging, Lower crop yields and Deforestation. In the case of Tapajós, there is only one differentiated value corresponding to Deforestation. With respect to PR (Fig. 3b), both cases present several differentiated values that are visualized in the network (Fig. 3 and 4) for a deeper analysis.

Figure 3 here

Figure 4 here

Figure 5 here

Stakeholder perceived Bboth systems areas dominated by environmental problems, with deforestation and biodiversity loss having the highest page rank value in Guarayos and Tapajós. It is also important to note, the importance of poverty and low crop yields in Guarayos and forest products value and population purchasing power in Tapajós. For stakeholder Iin Guarayos, , deforestation is the most influential component (highest outdegree, see Table S2S4) driving climate change, soil erosion, and biodiversity loss (Figure 4), whereas in Tapajós deforestation was perceived asis the most influenced component (highest indegree, see Table S35) affected by amongst others: infrastructure projects, lack of public policy, and agricultural expansion (Fig. 5). In Tapajós, stakeholder depicted a lack of efficiency in policies for subsistence farmers as the factor with enacts the greatest influence (highest outdegree, see Table S35), causing incomplete production chains, lack of technical capacity, and access to viable economic activities (Fig. 5). Components including contamination and biodiversity loss were found in both maps to have high indegrees (see Tables S24 and S35), suggesting their sensitivity to other components.

In Guarayos and Tapajós the aggregated page rank of the component groups was dominated by the environmental and economic groups, followed by political, social, and technical. In both maps, the environmental grouping is the most heavily influenced and sensitive group with the highest group indegree values. The components identified as transmitters (square components) were largely political and economic, mostly defined as ineffective or with negative connotations, with the use of words such as “Lack of...”or “Poor...” The influence of these components in driving the situation in both regions (Fig. 4 and 5) is supported by their outdegree values (Tables S24 and S35). The sensitivity of environmental components was once again demonstrated by the majority of receiver components (diamonds) being environmental.

Despite the differences in components within each map there was still overlap between them, with 15 of the 61 total components representing similar concepts (environmental degradation, worsening socio-economic situations, and poor governance). This suggests that despite the maps being developed in distinct regions and with unique stakeholders, there is some continuity in the problems that afflict both regions and potentially the basin as a whole.

34.2 Dynamic analysis of FCM

43.2.1 Baseline situation

Dynamic analysis of the aggregated maps (Fig. 6 and 7) demonstrate significant overlap, despite the ~2000km that separate the case studies them. Both regions (Guarayos and Tapajós) are characterised by worsening environmental degradation and apparently bleak socio-economic opportunities for local communities, coupled with low institutional safeguards.

Figure 6 here

Figure 6 characterises Guarayos as a region where environmental degradation is high, facilitated by low (and declining) application of the forest law and poor (and worsening) compliance with land zoning, coupled with low socio-economic opportunities. The system is dominated by increasing contamination, deforestation, loss of biodiversity, soil erosion, fires, poverty and agricultural expansion.

Figure 7 here

The situation in Tapajós (Fig. 7) depicts a similarly degraded system, where environmental conditions are deteriorating, facilitated by limited economic opportunities, and poor environmental monitoring. Tapajós is dominated by loss of environmental services and biodiversity; and increasing contamination, deforestation, infrastructure projects, and agricultural expansion. Contrarily, socio-economic opportunities for locals are apparently diminishing with reducing value of forest products and limited access to viable economic activities. Further, monitoring of environmental degradation is inhibited by limited environmental monitoring.

~~3~~4.2.2 Scenario outcomes

Figure 8 establishes the aggregate effects of the four development strategies ~~and the climate scenario~~ on the mapped system. The values for the components fixed within each scenario have not been included, to highlight the subsequent systemic impacts of changes to components fixed within each strategy.

Figure 8 here

The governance strategy was responsible for the greatest ‘desired’ change in both Guarayos and Tapajós, with the ~~climate change scenario~~agricultural development strategy causing the biggest ‘undesired’ change. The techno-social and conservation strategies also resulted in desirable changes. ~~However, application of the agricultural development strategy worsened the situation in both regions. Guarayos is more heavily influenced by climate change than Tapajós, which considering the page rank of climate change in both systems (Fig. 4 and 5) may have been expected.~~
A more detailed description of the individual impacts of the scenarios on components in both systems is given below, with the extent of component changes shown in Supplementary Fig. 1 and 2. In general, implementation of these strategies results in greater changes to individual components in Guarayos than in Tapajós, which may be attributable to the higher density of the Guarayos map.
The *governance strategy* results in the greatest systemic relative changes and some of the greatest changes to individual components. This may demonstrate the integrated nature of governance components and their connectivity within both systems. The strategy encourages reductions in environmental degradation across the two systems including deforestation, logging, and forest fires. It also drives socio-economic improvements reducing poverty, increasing access to financial aid

and viable economic alternatives, improving population purchasing power in Tapajós and reducing the inequality of benefits in Guarayos. In Tapajós, it also elicits considerable improvements in the technical capacity of the region.

The *techno-social strategy* encourages a suite of positive changes to both systems, reducing environmentally degrading activities, whilst providing simultaneous economic development. In Guarayos poverty is reduced, along with reductions in contamination, deforestation, illegal hunting, and logging. The strategy provides similar reductions in environmental degradation in Tapajós, with large reductions in deforestation and fires, whilst increasing population purchasing power and improving the value of forest products. Further, it also encourages greater social organisation and political participation, demonstrating a potentially beneficial unforeseen knock-on effect of such reforms.

The *conservation strategy* has limited impacts across the two systems, fomenting change only on environmental components. In Guarayos it reduces deforestation, whilst in Tapajós it reduces deforestation as well as other environmental degrading activities including; forest fires, logging, deforestation, and biodiversity loss.

The *agricultural development strategy* encourages substantial differences in the responses of the two systems. In Guarayos, crop yields improve with the expansion in both agriculture and grazing expansion, and results in reductions in poverty. Further, it also encourages positive environmental change with reduced illegal logging, hunting and fishing. However, in general environmental conditions worsen greatly with for example deforestation increasing, along with contamination, soil erosion, loss of biodiversity and destruction of pampas. In Tapajós, the rural development strategy results in no socio-economic benefits, but encourages considerable environmental degradation with deforestation, forest fires, loss of environmental services and biodiversity and contamination all increasing.

~~The *climate change scenario* suggests that without immediate reforms to mitigate or adapt, the situation in Guarayos and Tapajós will worsen into the future.~~

Figure 9 demonstrates the sensitivity of the systems under each scenario, whilst experiencing continued climate change, with some scenarios demonstrating greater resilience than others.

Figure 9 here

Figure 9 reveals that the governance reforms (and to a lesser extent techno-social reforms) may provide the most effective and resilient means of instigating regional improvements, even under climate change. Guarayos is more heavily influenced by climate change than Tapajós, which considering the page rank of climate change in both systems (Fig. 4 and 5) may have been expected. In Guarayos, the effect of climate change was so great that despite the conservation strategy the overall state worsened, compared with the baseline. In Tapajós, the impacts of climate change were still notable, but not to such an extreme extent as to further worsen the situation of the region. In both Guarayos and Tapajós, the agricultural development strategy offered the least resilient development strategy.

~~4~~5 Discussion

54.1 The Amazon as mapped by Stakeholders

The utility and flexibility of Fuzzy Cognitive Mapping to elicit a stakeholder-derived interpretation of the present state of two forest frontier regions of the Amazon basin has been demonstrated in this analysis. FCM afforded the combination of knowledge from regional experts and local community members, offering the opportunity to improve and enrich the understanding of these regions, whilst providing a low-resolution demonstration of their present state. We also outline the potential to include novel network analysis metrics into parsing out the current situation of the Amazon. The highest values in PageRank and Betweeness are useful to detect the key components in the network. The use of FCM also facilitated the use of scenarios to analyse how these regions may react to development strategies, and climate change.

Despite the two maps reflecting systems on opposite sides of the Amazon basin, they yielded strikingly similar results. Stakeholders in both Bolivia and Brazil mapped systems plagued by environmental degradation, with weak social and governance support structures absent or ineffective, inhibiting local community benefits. The perceived lack of effective governance is apparently incongruent to the contemporary literature, which suggests recent improvements in the governance model (World Bank, 2016). The presence of inequality, poverty, and deforestation are is consistent with the paradox of poverty in resource rich systems (Ioris, 2016), with stakeholders appearing to characterise the same "...landscapes of impoverishment..." as Ioris (2016, p. 187). Stakeholders in both Bolivia and Brazil identified similar barriers to development, with poor governance and conflicting policy measures inhibiting widespread socio-economic development, and hindering environmental conservation, supporting previous findings (Simmons et al., 2007). Further, the inconsequential nature of climate change for stakeholders in both cases was unexpected, considering its already noted impacts (Victoria et al., 1998) and potential future impacts (e.g. Malhi et al., 2008; Spracklen and Garcia-Carreras, 2015). This unanticipated outcome may support the findings of Brondizio and Moran (2008), who suggest that the memory of climatic changes is short-lived. This finding may also reflect the distinct cultural and linguistic meaning or representations of climate changes (e.g drought, flooding) across the two sites. However, Varela-Ortega (2014) found that stakeholders considered climate change a fundamental component in the future of both regions and in Tapajós in the present.

45.2 Affecting Encouraging positive change in the Amazon

Implementation of the suite of scenarios affected substantial and variable changes. Governance and institutional reforms appear to offer the most effective means of transitioning Amazonian regions towards more sustainable 'desirable' states, even under the conditions of climate change. The positive effects of governance and institutional reforms are unsurprising considering the constraining effect (McNeil et al., 2012) that poor governance can have in inhibiting sustainable development, with its effects well documented in the Amazon (e.g. Rodrigues-Filho et al., 2015). The results evidence the liberating effect that improving institutional capacity can have in instigating desirable social, economic, and environmental change. These multi-dimensional benefits apparently confirm the transversal nature of institutions and governance in the context of sustainable development (McNeil et al., 2012). The positive impacts of governance have precedence in the Amazon, where institutional and governance improvements have encouraged environmental conservation (Nepstad et al., 2014; Tritsch and Arvor, 2016) and socio-economic development (Caviglia-Harris et al., 2016). Further, the literature widely supports the need for strong governance and institutions with Müller (2014), Verburg et al. (2014b), and Høiby and Zenteno-Hopp (2014) contending that the likelihood for long-term environmental conservation is slim under poor governance conditions. Lapola et al. (2014) promotes the need for policy enforcement and institutional support to encourage sustainable development, whilst Guedes et al. (2014) propose that pathways towards future environmental conservation can be founded upon investments in local institutions.

Techno-social reforms also represent an alternative strategy, driving environmental protection, economic development, and social improvements. In Brazil, the difference in desired change between this strategy and governance reforms was minimal, suggesting its considerable potential. These results support the vision of Nobre et al. (2016), where rural development is encouraged through social and technological reforms, with both environmental and social components improving. The implementation of this scenario suggests that investments in technical capacity building and social reforms may reverse the poverty traps (Reardon and Vosti, 1995) in which stakeholders mapped both regions appear to be locked. Investments in social and technical reforms may have wider unforeseen benefits, improving societal attitudes towards natural capital conservation (Salahodjaev, 2016), aiding in flattening environmental Kuznet´s curves (Tritsch and Arvor, 2016), and driving positive changes in agricultural methods (Assunção et al., 2013). Many of these points are suggested in the results of this analysis. However, this strategy was admittedly found to be susceptible to climate change, more so than the institutional reforms.

Traditional developmental strategies relying upon conservation or extractionist policy implementation have driven trade-offs across the Amazon (Le Tourneau et al., 2013). The impacts of these binary choices can be stark, with decision makers having to make substantial compromises between environmental conservation and agricultural development (e.g. Manners and Varela-Ortega, 2018). The application of the conservation strategy had limited system wide impacts, resulting in environmental improvements, but offering little opportunity for socio-economic development, potentially confining local communities to conditions of poverty and limited development. Further, implementation of such a narrow strategy was found to be particularly susceptible to climate change. The application of this strategy, or one similar, may have little chance of providing sustainable rural development without concomitant offering of economic alternatives for locals, or the need for systems like Payments for Ecosystem Services to potentially alleviate poverty and encourage conservation (Pinho et al. 2014). Tejada et al. (2016) found that limiting future environmental degradation, specifically deforestation, in the Bolivian lowlands without offering new economic alternatives is unlikely.

The results also outline the negative effects of a strategy solely focussing upon agricultural development, with the long-term benefits limited, especially under climate change. This strategy improved social factors like poverty and inequality (in

Bolivia), but at a cost to local ecosystems in both Bolivia and Brazil. The outcomes of this scenario appear consistent with the literature, suggesting that purely agriculturally orientated strategies, without supporting policies may result in limited economic benefits for locals (Rodrigues et al. 2009; Ioris 2016) and some environmental costs (Weinhold et al., 2015). Further, these results appear not to demonstrate the uncoupling of agricultural development from environmental degradation as identified in Brazil (Caviglia-Harris et al., 2016). However, focussing solely upon the local-scale economic and social benefits of such extractive strategies, as touched upon by Celentano et al. (2012), may ignore their wider national developmental benefits.

In summary, application of the two traditional scenarios for rural development (agricultural development and environmental conservation) demonstrate the trade-offs in their application and their ability to improve regional economic, social, and environmental conditions. Development of new strategies concentrating upon governance and techno-social reforms could instigate positive shifts in the trajectory of these regions, even under the effects of climate change. However, moving from the modelled world to the real, where implementation of such strategies requires: consideration of social acceptability; likelihood of implementation; willingness of politicians and institutions to reform; coherence with current policy landscapes; and funding availability may result in complications. Despite improvements in governance across many Amazonian countries in recent decades (World Bank, 2016), implementation of the governance reform may be challenging, especially under increasingly turbulent political landscapes, exemplified by Brazil. Further, potentially intangible (in the short-term) and time-consuming governance and institutional reforms may be unpalatable for voter conscious and electioneering administrations. Governments wanting to appear proactive in terms of rural development may consider other, more palpable options. The benefits of institutional reforms may only be reaped in the long-term, by which time governments may have changed and the benefits of change lost for the implementing administration. This may highlight the space for market-based interventions to encourage more sustainable development (e.g Nepstad et al., 2014; Gibbs et al., 2015). Beyond this, strategies aimed at techno-social reforms may garner less systemic positive changes but offer more tangible actions for voters and governments alike, whilst fomenting positive change, even under worsening climatic conditions. However, the financial implications of such reforms must be considered, with them likely requiring significant and long-term public or private investments. However, such funding is invariably scarce (Ferraro and Pattanayak, 2006).

~~5~~6 Conclusions

The use of FCM to visualise the perceptions of stakeholders across the Amazon basin has shown that on both sides of the basin, landscapes of socio-economic impoverishment and environmental degradation are present, driven to varying degrees by governmental and institutional deficiencies. Even under such abject conditions, these processes have been modelled to be theoretically reversible through application of governance and well-integrated technical and social reform strategies. These strategies were found to encourage positive regional changes even under the pressure of climatic change. However, what is apparent in both regions is that a continuation of the current rural development programmes cannot continue, with these results showing that concentration on only conservation or agricultural development policies would reduce the resilience of both regions to climate change, whilst also providing limited socio-economic development and continued environmental degradation.

Author contribution

The conceptualisation and methodology design were done by CVO (PI of Spain's research team in the ROBIN project) and IB. The development and implementation of the stakeholder workshops were done by IB, CVO, LGM and MT. AT carried out the mathematical analysis of FCM. RM performed the simulations and supported the scenario development and processing of results. IB and RM prepared the manuscript with contributions from all co-authors.

Competing interests

The authors declare that they have no conflict of interest.

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List of tables

Table 1: Stakeholder workshops held in Guarayos (Bolivia) and Tapajós (Brazil).

Case Study	Workshop	Nº Stakeholders	Stakeholder Groups Represented
Guarayos (Bolivia)	First: 30th January 2013	30	Organisation Centre of Guarayo Native People (COPNAG), Forestry Services, Tropical and Agricultural Research Centre (CIAT), Arado Foundation, Farmers Federation, Indigenous Forestry Association, Rio Blanco and Rio Negro Wildlife Reserve, Guarayos Timber Association (AMAGUA), Authority and Social Control of Forest and Land (ABT), Guarayos Indigenous Women Centre (CEMIG), Development Area Program (PDA), Guarayo Cattle Association (AGUAGUA) and Ascensión Inter-Ethnicity Centre (CIEA)
	Second: 18th June 2014	27	Autonomous Government of Santa Cruz (GDASC), Department of Protected Areas (DIAP), Department of Agriculture (SEDACRUZ), Indigenous Guarayos Women' Centre (CEMIG) Las Misiones Radio, Radio Guaguazuti, Central Organisation of Native Guarayo Villages (COPNAG), Department of Natural Resources (DIRENA), Indigenous Guarayos Forestry Asscoaition (IRARAI) and the Community Centre Urubichá (CECU)
Tapajós (Brazil)	First: 27th November 2013	23	Ministry of Agriculture (MAPA), The Federal University of Western Pará (UFOPA), Chico Mendes Institute for Biodiversity Conservation (ICMBIO), Hope Foundation (IESPES), EMBRAPA Eastern Amazon, Tapajós Community Leaders, The Nature Conservancy (TNC) and Luiz de Quieroz College of Agriculture (ESALQ-USP)
	Second: 28th November 2013	26	Ministry of Agriculture (MAPA), The Federal University of Western Pará (UFOPA), Chico Mendes Institute for Biodiversity Conservation (ICMBIO), Hope Foundation (IESPES), EMBRAPA Eastern Amazon, Tapajós Community Leaders, The Nature Conservancy (TNC) and Luiz de Quieroz College of Agriculture (ESALQ-USP)

Case Study	Workshops	Nº Stakeholders	Stakeholder Group	Name of stakeholder
Guarayos (Bolivia)	First: 30th January 2013	30	Policy/Administration	Autonomous Government of Santa Cruz (GDASC) Authority and Social Control of Forest and Land (ABT) Forestry Services Department of Natural Resources (DIRENA) Department of Agriculture (SEDACRUZ)
			Private sector	Indigenous Guarayos Forestry Association (IRARAI) Farmers Federation Guarayos Timber Association (AMAGUA) Guarayos Cattle Association (AGUAGUA)
	Second: 18th June 2014	27	Non-governmental organisation	Organisation Centre of Guarayo Native People (COPNAG) Guarayos Indigenous Women Centre (CEMIG) Ascensión Inter-Ethnicity Centre (CIEA) Rio Blanco and Rio Negro Wildlife Reserve
			Research	Tropical and Agricultural Research Centre (CIAT) Instituto Boliviano de Investigación Forestal
Tapajós (Brazil)	First: 27th November		Policy/Administration	Ministry of Agriculture (MAPA) Federal Government Agency- Chico Mendes Institute for Biodiversity Conservation (ICMBIO) Institute of Technical Assistance and Rural Extension

2013	23		(EMATER)
Second:28th November 2013	26	Private sector	Flona Tapajós-Communidade do Maguari Soybean production company
		Non-governmental organisation	Indigenous Communities (Flona Tapajós-Communidade do Maguari) Hope Foundation (IESPES) The Nature Conservancy (TNC)
		Research	The Federal University of Western Pará (UFOPA) EMBRAPA Eastern Amazon Luiz de Quieroz College of Agriculture (ESALQ-USP)

Table 2: Structural metrics of Fuzzy Cognitive Maps analysed.

Structural Metric	**Definition**	**Source**
Outdegree *(od(vi))*	Cumulative total of transmitted connection weights from each component (horizontal cumulative sum within adjacency matrix).	Wasserman and Faust 1994
Indegree *(id(vi))*	Cumulative total of received connection weights to each component (vertical sum within adjacency matrix).	Wasserman and Faust 1994
Receiver variables *(R)*	Components that receive connections from other components but does not influence others through outward connections (components with zero *od(vi)*)	Özesmi and Özesmi 2003
Transmitter variables or drivers *(T)*	Components that solely influences other components through outward connections but does not receive connections (components with zero *id(vi))*	Özesmi and Özesmi 2003
Ordinary variables *(O)*	Components that both influence and are influenced upon within the system	Özesmi and Özesmi 2003
Density *(D)*	Number of connections (C) divided by the maximum number of possible connections between a number N of components $$D = \frac{C}{N(N-1)}$$	Devisscher et al. 2016; Hage and Harary, 1983
Complexity *(CM)*	Number of receiver components *(R)* divided by the number of transmitters *(T).* A receiver being a $$CM = \frac{R}{T}$$	Devisscher et al. 2016; Özesmi and Özesmi 2004
Betweeness *(Bw)*	Betweenness is a centrality measure of influence of a node within a network. This measure quantifies the number of times a node acts as an intermediary along the shortest path between two other nodes.	Freeman, 1977; Brandes, 2001
Page Rank *(PR)*	Used to determine a node's relevance or importance. PageRank value for a node u is dependent on the PageRank values for each node v contained in the set Bu (the set containing all nodes linking to node u), divided by the number L(v) of links from page v. $$PR\,(u) = \sum_{v \in B_u} \frac{PR(v)}{L\,(v)}$$	Page et al., 1999; Berkhim, 2005; this study

Table 3: Overview of the simulated scenarios.

Scenario	Description	Case Study					
		Guarayos			Tapajós		
		Component	Value change (with respect to steady state baseline)	Scenario fixed value	Component	Value change (with respect to steady state baseline)	Scenario fixed value
1. Governance Reform	Introduces institutional and governance improvements to the system, with policies widely implemented and governmental communication and efficiency improved	Lack of understanding, application and coordination of laws	Decrease	0.4	Lack of governmental co-ordination	Decrease	0.4
		Poor administration by community leaders	Decrease	0.3	Lack of efficiency in policies for subsistence Farming	Decrease	0.4
					Lack of public policy	Decrease	0.4
2. Techno-Social Reform	Considers a system in which investments are made in technical and social capital through capacity building, improvements in education and protection of traditional communities.	Lack of awareness of environmental problems	Decrease	0.2	Lack of environmental awareness	Decrease	0.2
		Land encroachment	Decrease	0.3	Lack of technical training and assistance	Decrease	0.3
		Loss of subsistence agriculture by Guarayos Communities	Decrease	0.3	Technical and productive capacity	Increase	0.8
					Lack of protection of traditional communities	Decrease	0.3
3. Agricultural Development	Encourages extractionist activities, such as agricultural expansion, encouraged to improve the socio-economic conditions of each region.	Agricultural expansion	Increase	0.9	Agricultural expansion	Increase	0.9
		Application of agricultural Law	Increase	0.8	Use of agrochemicals	Increase	0.9

		Agricultural intensification	Increase	0.8			
4. Conservation	Focusses solely upon conserving the environment, with no consideration of socio-economic development.	Compliance with land zoning	Increase	0.8	Environmental monitoring	Increase	0.8
		Application of forest law	Increase	0.8			

Table 4: Guarayos and Tapajós fuzzy cognitive maps indices. Standard deviations shown in brackets and maximum values of the centrality indices.

Indices	Guarayos	Tapajós
Components	29	32
Transmitters	7	9
Receivers	4	3
Ordinary	18	20
Connections	44	50
Average Connection Weight (SD)	0.57 (0.26)	0.61 (0.22)
Connections per Component	1.52	1.56
Density	0.052	0.048
Complexity	0.57	0.33
Betweeness	0.21	0.09
PageRank	0.13	0.17

List of figures

Figure 1: Location of the case study sites (the Province of Guarayos in Bolivia and the Tapajós National Forest in Brazil). Case studies shaded in brown. The Department of Santa Cruz (Bolivia) shaded in dark blue and the State of Pará (Brazil) in dark green. The extent of the Amazon Basin is outlined in red.

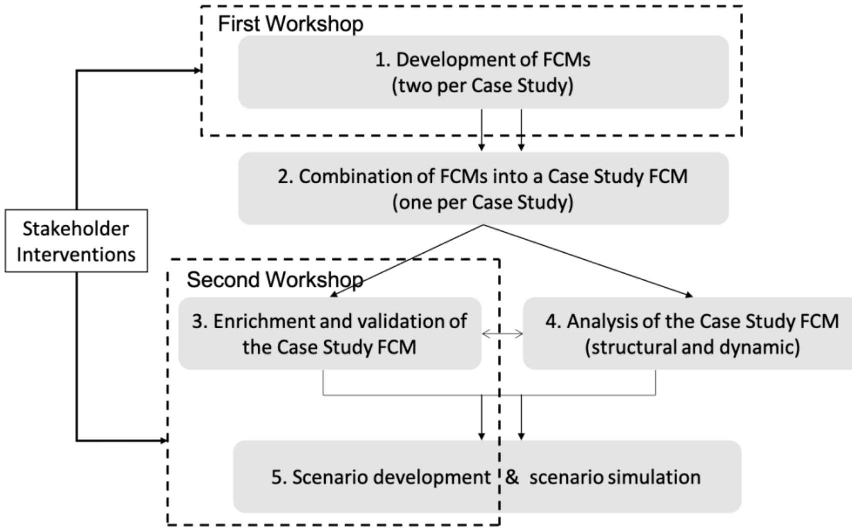

Figure 2: Methodological steps in the research.

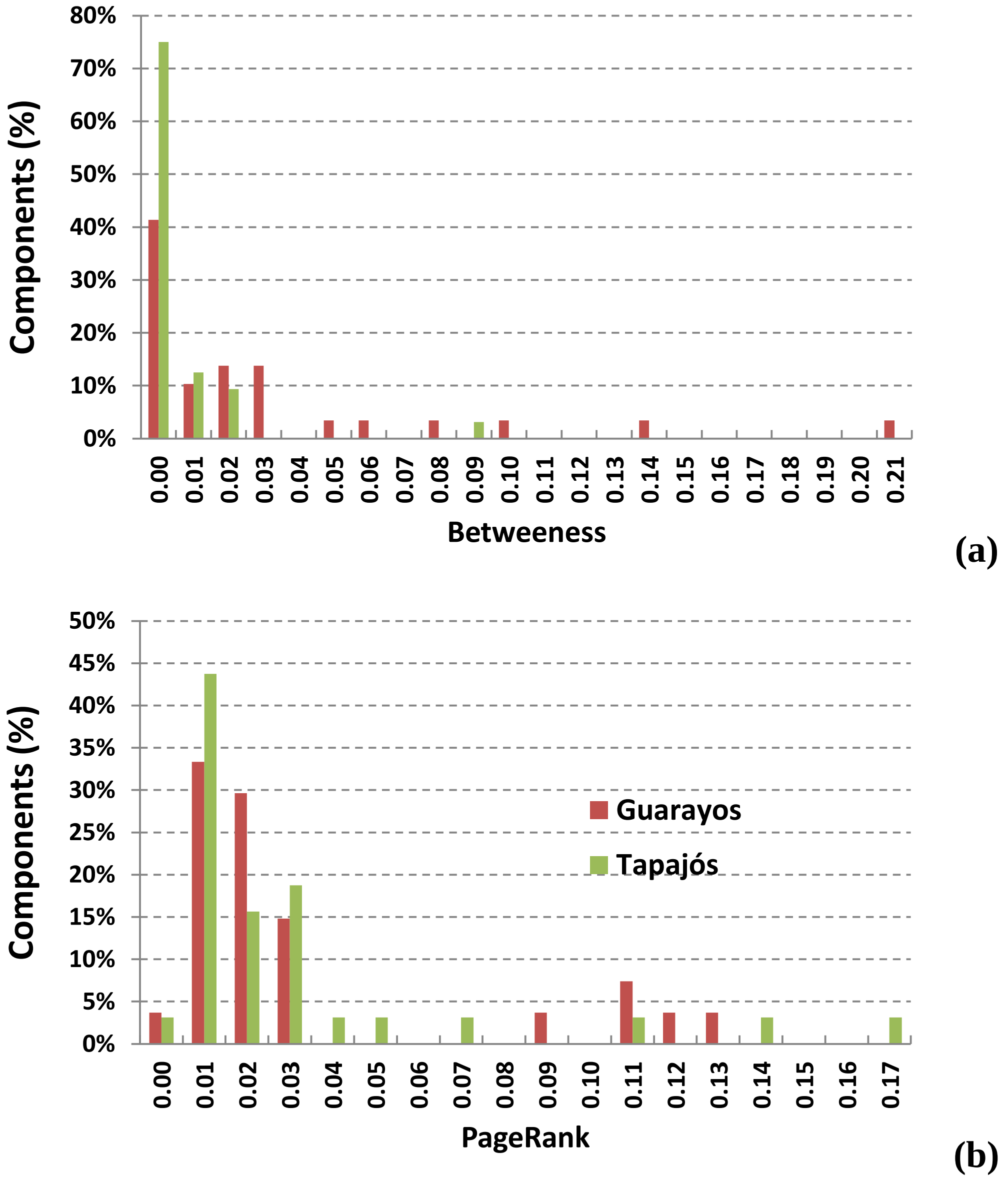

Figure 3: Frequencies of Betweeness (A) and PageRank values (B) in both case studies: Guarayos (red) and Tapajós (green)

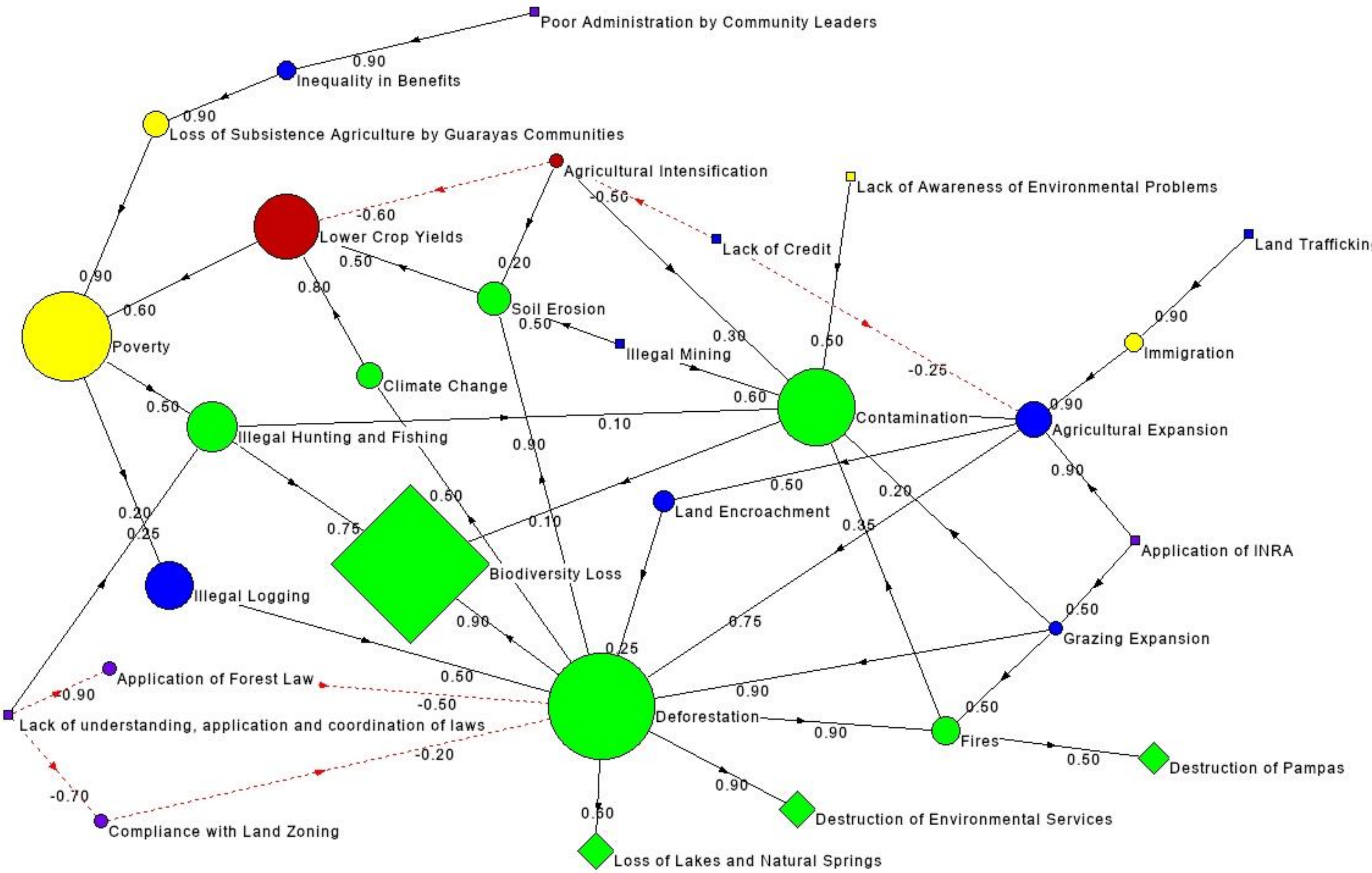

Figure 4: Network visualization of the Case Study FCM developed by stakeholders in Guarayos. Size of each component represents their page rank. Solid black lines represent positive connection weights and red dotted lines negative. Shape of each component represents its type (square=transmitter, circle=ordinary and diamond=receiver) and colours their grouping (green=environmental, blue=economic, yellow=social, purple=political/ institutional and red=technical).

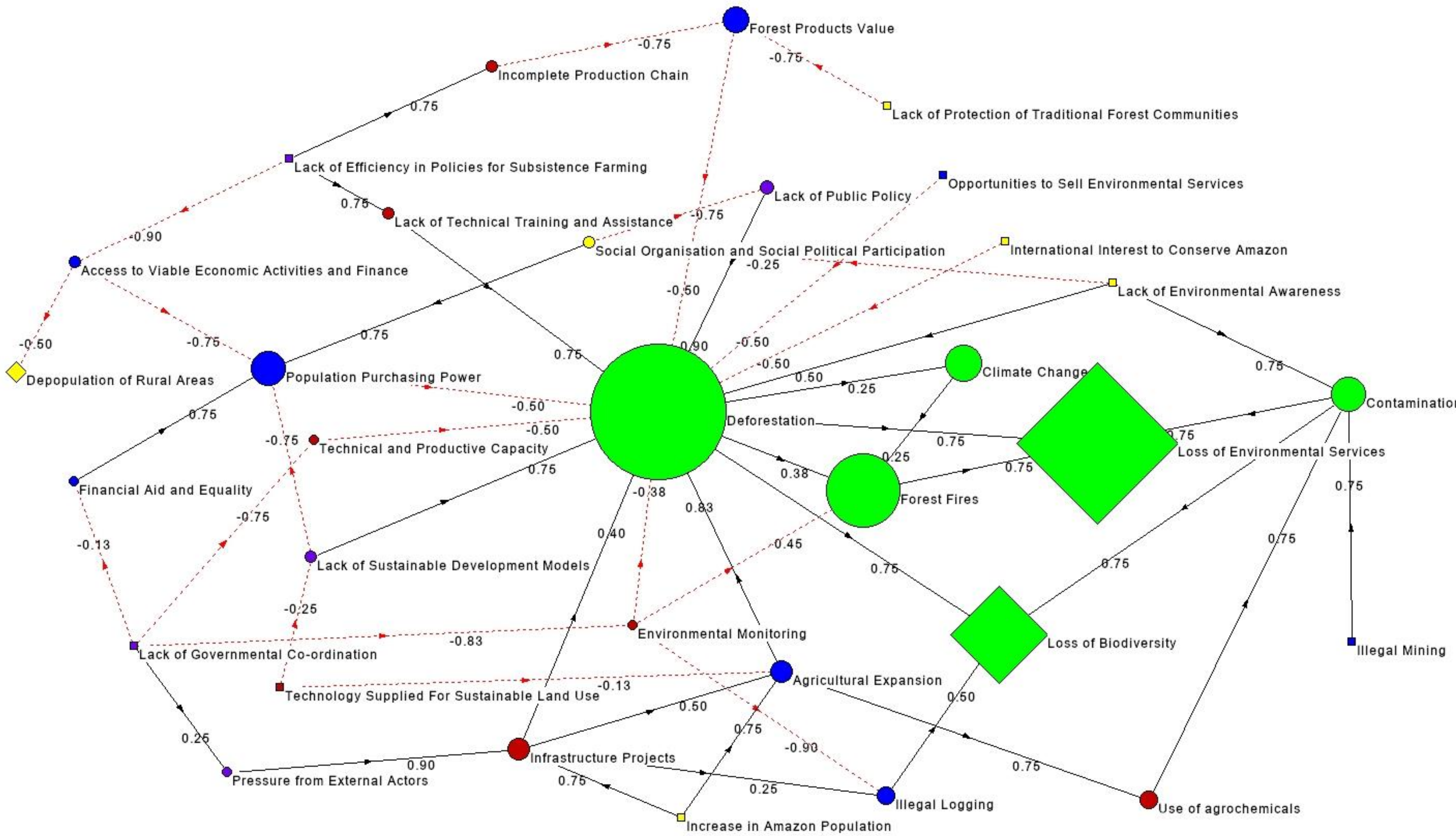

Figure 5: **Network visualization of the Case Study FCM developed by stakeholders in Tapajós. Size of each component represents their page rank. Solid black lines represent positive connection weights and red dotted lines negative. Shape of each component represents its type (square=transmitter, circle=ordinary and diamond=receiver) and colours their grouping (green=environmental, blue=economic, yellow=social, purple=political/ institutional and red=technical).**

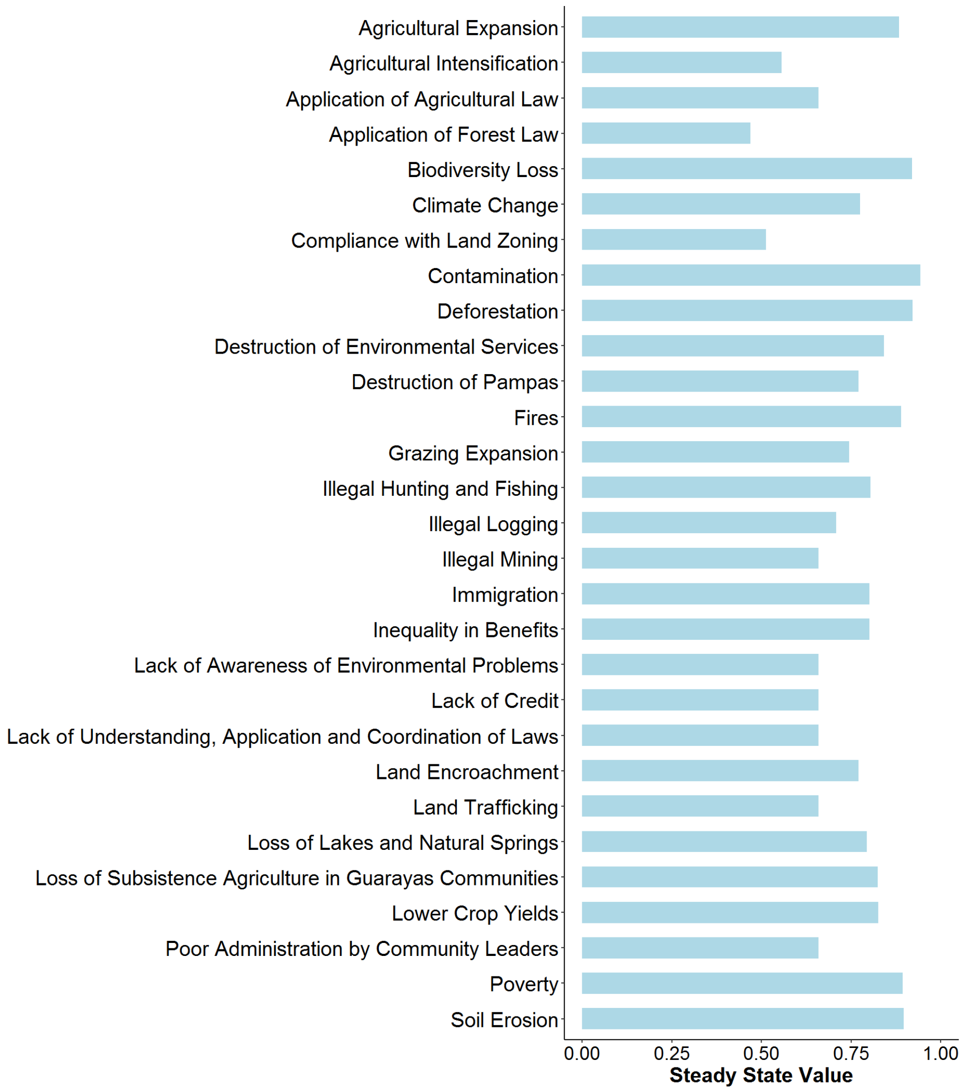

Figure 6: Component values for Guarayos Case Study FCM under steady state 'baseline' conditions. Values close to 0 represent a strong decrease in the component, whilst values closer to 1 represent a strong increase.

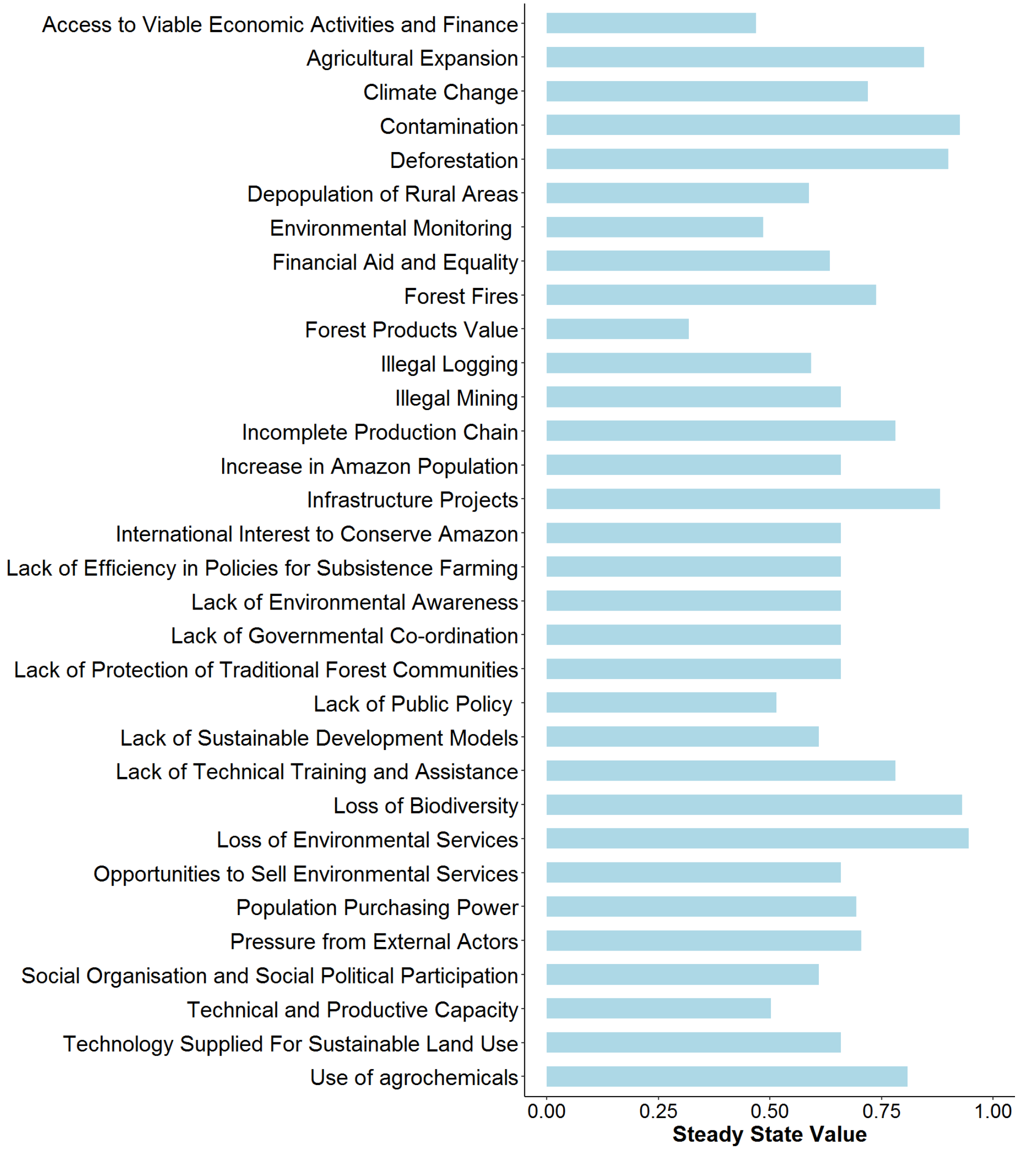

Figure 7: Component values for Tapajós Case Study FCM under steady state 'baseline' conditions. Values close to 0 represent a strong decrease in the component, whilst values closer to 1 represent a strong increase.

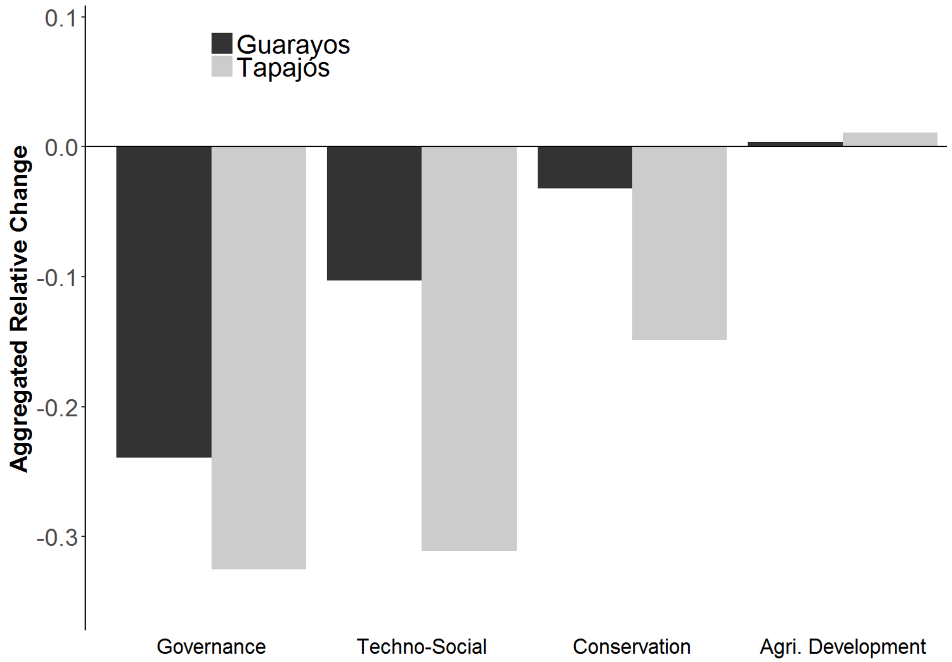

Figure 8: Aggregated relative change and response of scenarios, compared with baseline. Negative values represent a 'desirable' change in the system. Positive values represent an 'undesirable' change in the system.

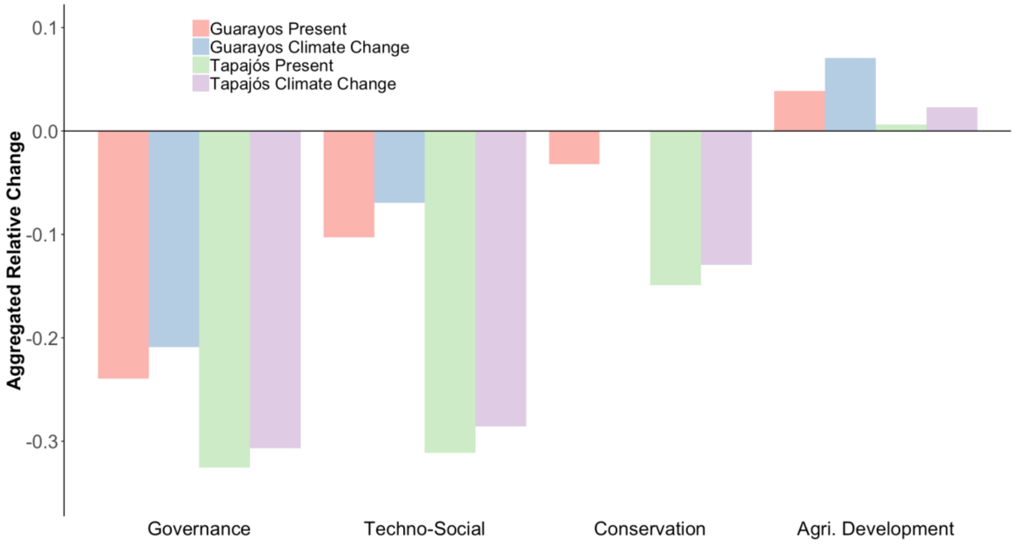

Figure 9: Aggregated relative change and response of scenarios under present climatic conditions, and climate change. Negative values represent a 'desirable' change in the system. Positive values represent an 'undesirable' change in the system.

The following supplements accompany the article

Table S1. Adjacency matrix in Guarayos

	Agricultural Expansion	Agricultural Intensification	Application of Forest Law	Application of INRA	Biodiversity Loss	Climate Change	Compliance with ILand Zoning	Contamination	Deforestation	Destruction of Environmental Services	Destruction of Pampas	Fires	Grazing Expansion	Illegal Hunting and Fishing	Illegal Logging	Illegal Mining	Immigration	Inequality in Benefits	Lack of Awareness of Environmental Problems	Lack of Credit	Lack of Understanding, Application and Coordination of Laws	Land Encroachment	Land Trafficking	Loss of Lakes and Natural Springs	Loss of Subsistence Agriculture in Guarayas Communities	Lower Crop Yields	Poor Administration by Commuity Leaders	Poverty	Soil Erosion
Agricultural Expansion	0,00	0,50	0,00	0,00	0,50	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Agricultural Intensification	0,00	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	-0,60	0,00	0,00	0,00
Application of Forest Law	0,00	0,00	0,00	0,00	0,00	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Application of INRA	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity Loss	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Climate Change	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,80	0,00	0,00	0,00
Compliance with ILand Zoning	0,00	0,00	0,00	0,00	0,00	-0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Contamination	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deforestation	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,50	0,00	0,00	0,90	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,90	0,00	0,00
Destruction of Environmental Services	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Destruction of Pampas	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fires	0,00	0,35	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Grazing Expansion	0,00	0,20	0,00	0,00	0,00	0,90	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Illegal Hunting and Fishing	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Illegal Logging	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Illegal Mining	0,00	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00
Immigration	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Inequality in Benefits	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Awareness of Environmental Problems	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Credit	0,00	0,00	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,00
Lack of Understanding , Application and Coordination of Laws	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	-0,70	-0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Land Encroachment	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Land Trafficking	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00
Loss of Lakes and Natural Springs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Loss of Subsistence Agriculture in Guarayas Communities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lower Crop Yields	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poor Administration by Commuity Leaders	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Poverty	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Soil Erosion	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00

Table S2. Adjacency matrix in Tapajós

	Access to Viable Economic Activities and Finance	Agricultural Expansion	Climate Change	Deforestation	Depopulation of Rural Areas	Environmental Monitoring	Financial Aid and Equality	Forest Fires	Forest Products Value	Illegal Logging	Illegal Mining	Incomplete Production Chain	Increase in Amazon Population	Infrastructure Projects	International Interest to Conserve Amazon	Lack of Efficiency in Policies for Subsistence Farming	Lack of Environmental Awareness	Lack of Governmental Co-ordination	Lack of Protection of Traditional Forest Communities	Lack of Public Policy	Lack of Sustainable Development Models	Lack of Technical Training and Assistance	Loss of Biodiversity	Loss of Environmental Services	Opportunities to Sell Environmental Services	Population Purchasing Power	Pressure from External Actors	River Contamination	Social Organisation and Social Political Participation	Technical and Productive Capacity	Technology Supplied For Sustainable Land Use	Use of agrochemicals
Access to Viable Economic Activities and Finance	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Agricultural Expansion	0,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00
Climate Change	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deforestation	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Depopulation of Rural Areas	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental Monitoring	-0,38	0,00	0,00	-0,90	0,00	0,00	0,00	0,00	0,00	0,00	-0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Financial Aid and Equality	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Forest Fires	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Forest Products Value	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Illegal Logging	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Illegal Mining	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00
Incomplete Production Chain	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Increase in Amazon Population	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Infrastructure Projects	0,40	0,00	0,00	0,25	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

International Interest to Conserve Amazon	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Efficiency in Policies for Subsistence Farming	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Environmental Awareness	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	-0,25	0,00
Lack of Governmental Co-ordination	0,00	0,00	0,00	0,00	0,00	0,25	-0,83	0,00	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00
Lack of Protection of Traditional Forest Communities	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Public Policy	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Sustainable Development Models	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Lack of Technical Training and Assistance	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Loss of Biodiversity	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Loss of Environmental Services	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Opportunities to Sell Environmental Services	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Population Purchasing Power	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pressure from External Actors	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
River Contamination	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Social Organisation and Social Political Participatio	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00
Technical and Productive Capacity	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Technology Supplied For Sustainable Land Use	0,00	0,00	0,00	0,00	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Use of agrochemicals	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,00	0,00	0,00

Table S~~1~~3. Preferred changes in components in Guarayos and Tapajós.

Guarayos		Tapajós	
Component	Desired Change	Component	Desired Change
Agricultural Expansion	Decrease	Access to Viable Economic Activities and Finance	Negative
Agricultural Intensification	Neutral	Agricultural Expansion	Negative
Application of Agricultural Law	Positive	Climate Change	Negative
Application of Forest Law	Positive	Contamination	Negative
Biodiversity Loss	Negative	Deforestation	Negative
Climate Change	Negative	Depopulation of Rural Areas	Negative
Compliance with Land Zoning	Positive	Environmental Monitoring	Positive
Contamination	Negative	Financial Aid and Equality	Positive
Deforestation	Negative	Forest Fires	Negative
Destruction of Environmental Services	Negative	Forest Products Value	Positive
Destruction of Pampas	Negative	Illegal Logging	Negative
Fires	Negative	Illegal Mining	Negative
Grazing Expansion	Negative	Incomplete Production Chains	Negative
Illegal Hunting and Fishing	Negative	Positive in Amazon Population	Negative
Illegal Logging	Negative	Infrastructure Projects	Neutral
Illegal Mining	Negative	International Interest to Conserve Amazon	Positive
Immigration	Negative	Lack of Efficiency in Policies for Subsistence Farming	Negative
Inequality in Benefits	Negative	Lack of Environmental Awareness	Negative
Lack of Awareness of Environmental Problems	Negative	Lack of Governmental Co-ordination	Negative
Lack of Credit	Negative	Lack of Protection of Traditional Forest Communities	Negative
Lack of Understanding, Application and Coordination of Laws	Negative	Lack of Public Policy	Negative
Land Encroachment	Negative	Lack of Sustainable Development Models	Negative
Land Trafficking	Negative	Lack of Technical Training and Assistance	Negative
Loss of Lakes and Natural Springs	Negative	Loss of Biodiversity	Negative
Loss of Subsistence Agriculture in Guarayos Communities	Negative	Loss of Environmental Services	Negative
Lower Crops Yields	Negative	Opportunities to Sell Environmental Services	Positive
Poor Administration by Community Leaders	Negative	Population Purchasing Power	Positive
Poverty	Negative	Pressure from External Actors (agribusiness)	Negative
Soil Erosion	Negative	Social Organisation and Social Political Participation	Positive
		Technical and Productive Capacity	Positive
		Technology Supplied for Sustainable Land Use	Positive
		Use of Agrochemicals	Neutral

Table S~~2~~4. Component Indices for Guarayos

Component	Outdegree	Indegree	Page Rank	Betweeness	Component Type
Agricultural Expansion	1.75	2.05	0.037	0.056	Ordinary
Agricultural Intensification	1.10	0.50	0.015	0.008	Ordinary
Application of Forest Law	0.50	0.90	0.014	0.007	Ordinary
Application of INRA	1.40	0.00	0.011	0.000	Transmitter
Biodiversity Loss	0.00	1.75	0.117	0.000	Receiver
Climate Change	0.80	0.50	0.026	0.030	Ordinary
Compliance with Land Zoning	0.20	0.70	0.014	0.007	Ordinary
Contamination	0.10	2.55	0.080	0.009	Ordinary
Deforestation	4.70	3.10	0.110	0.217	Ordinary
Destruction of Environmental Services	0.00	0.90	0.026	0.000	Receiver
Destruction of Pampas	0.00	0.50	0.024	0.000	Receiver
Fires	0.85	1.40	0.031	0.034	Ordinary
Grazing Expansion	1.60	0.50	0.015	0.010	Ordinary
Illegal Hunting and Fishing	0.85	0.75	0.053	0.021	Ordinary
Illegal Logging	0.50	0.20	0.050	0.083	Ordinary
Illegal Mining	1.10	0.00	0.011	0.000	Transmitter
Immigration	0.90	0.90	0.020	0.020	Ordinary
Inequality in Benefits	0.90	0.90	0.020	0.019	Ordinary
Lack of Awareness of Environmental Problems	0.50	0.00	0.011	0.000	Transmitter
Lack of Credit	0.75	0.00	0.011	0.000	Transmitter
Lack of Understanding, Application and Coordination of Laws	1.85	0.00	0.011	0.000	Transmitter
Land Encroachment	0.25	0.50	0.021	0.000	Ordinary
Land Trafficking	0.90	0.00	0.011	0.000	Transmitter
Loss of Lakes and Natural Springs	0.00	0.60	0.026	0.000	Receiver
Loss of Subsistence Agriculture in Guarayos Communities	0.90	0.90	0.028	0.034	Ordinary
Lower Crop Yields	0.60	1.90	0.068	0.098	Ordinary
Poor Administration by Community Leaders	0.90	0.00	0.011	0.000	Transmitter
Poverty	0.70	1.50	0.092	0.139	Ordinary
Soil Erosion	0.50	1.60	0.035	0.044	Ordinary

Table S~~3~~5. Component indices for Tapajós.

Component	Outdegree	Indegree	Page Rank	Betweeness	Component Type
Access to Viable Economic Activities and Finance	1.25	0.90	0.014	0.002	Ordinary
Agricultural Expansion	1.58	1.38	0.028	0.016	Ordinary
Climate Change	0.25	0.25	0.046	0.000	Ordinary
Contamination	1.50	2.25	0.043	0.005	Ordinary
Deforestation	2.13	7.00	0.164	0.088	Ordinary
Depopulation of Rural Areas	0.00	0.50	0.017	0.000	Receiver
Environmental Monitoring	1.73	0.83	0.013	0.005	Ordinary
Financial Aid and Equality	0.75	0.13	0.013	0.001	Ordinary
Forest Fires	0.75	1.08	0.089	0.002	Ordinary
Forest Products Value	0.50	1.50	0.033	0.011	Ordinary
Illegal Logging	0.50	1.15	0.023	0.002	Ordinary
Illegal Mining	0.75	0.00	0.011	0.000	Transmitter
Incomplete Production Chain	0.75	0.75	0.014	0.001	Ordinary
Increase in Amazon Population	1.50	0.00	0.011	0.000	Transmitter
Infrastructure Projects	1.15	1.65	0.027	0.017	Ordinary
International Interest to Conserve Amazon	0.50	0.00	0.011	0.000	Transmitter
Lack of Efficiency in Policies for Subsistence Farming	2.40	0.00	0.011	0.000	Transmitter
Lack of Environmental Awareness	1.50	0.00	0.011	0.000	Transmitter
Lack of Governmental Co-ordination	1.95	0.00	0.011	0.000	Transmitter
Lack of Protection of Traditional Forest Communities	0.75	0.00	0.011	0.000	Transmitter
Lack of Public Policy	0.90	0.75	0.017	0.003	Ordinary
Lack of Sustainable Development Models	1.50	0.25	0.016	0.004	Ordinary
Lack of Technical Training and Assistance	0.75	0.75	0.014	0.005	Ordinary
Loss of Biodiversity	0.00	2.00	0.083	0.000	Receiver
Loss of Environmental Services	0.00	2.25	0.140	0.000	Receiver
Opportunities to Sell Environmental Services	0.50	0.00	0.011	0.000	Transmitter
Population Purchasing Power	0.50	3.00	0.041	0.013	Ordinary
Pressure from External Actors	0.90	0.25	0.013	0.004	Ordinary
Social Organisation and Social Political Participation	1.50	0.25	0.014	0.002	Ordinary
Technical and Productive Capacity	0.50	0.75	0.013	0.002	Ordinary
Technology Supplied For Sustainable Land Use	0.38	0.00	0.011	0.000	Transmitter
Use of agrochemicals	0.75	0.75	0.023	0.006	Ordinary

Figure S1. Relative change of individual component values in Guarayos under the conditions of the ~~five~~ four scenarios compared with baseline.

Figure S2. Relative change of individual component values in Tapajós under the conditions of the ~~five~~ four scenarios compared with baseline.