

Evidence on scaling forest restoration from the Atlantic Forest Restoration Pact in Brazil

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This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

The study entitled "Scaling forest restoration in the tropics: evidence from Brazil's Atlantic Forest Restoration Pact" has performed a robust analysis of the effects of a program of incentives to promote restoration within private land in Brazil. To do that, they have worked with post-matching differences-in-differences estimation to compare the trajectories of parcels of land adhered to the program (treatment) with similar parcels non-adherent (control).

I believe the work is original and highly relevant to the interface between Conservation Science and Policy, by evaluating and discussing the effectiveness and pathways to upscale ecological restoration, with obvious applications in the real world. One of the key features of this work is having a large dataset of areas undergoing restoration and a clear intervention. They were also careful enough to support their choices of co-variables for matching by interviewing relevant stakeholders. Overall, the data and methodology are adequate and give support to the main conclusions and the quality of the study is satisfactory.

I have, however, some issues that need to be addressed by the authors if this manuscript is to be published.

The manuscript lacks definitions of key terms that are important for a broader audience, both terms from the restoration science and from the Brazilian legislations regulating restoration within private land.

I also think that in some cases there is a disconnection between the main text and the supplementary material. Some information from the supplementary material needs to be brought to the main text but mostly, the Supp. Mat. deserves to be more emphasized in the main text, directing the reader interested in more details.

I did not find any data or code, so I was not able to evaluate this aspect of the work.

My specific comments to the text are as follows:

Main text

Introduction

1st. paragraph

It would be useful to have references of how much land is privately owned to support the claim that forest restoration needs to include it (line 4).

The study has not been introduced yet nor the restoration program. This phrase needs to be reformulated. Perhaps: restoration programs can offer assistance(...)(line 9) and add some reference, for instance:

<https://www.sciencedirect.com/science/article/pii/S0169534722001719>

Similar to what? To the referred program, similar among themselves in general? I also think there is something missing here, like: While restoration initiatives are expanding rapidly due to....complete (ref!), there is little evidence regarding their effectiveness to ...deliver what? this need to be cleared said (line 10).

2nd. paragraph

Because the article aims for a broad audience, I suggest some short definition of terms such as natural regeneration and assisted Regeneration. And why this depends on locality.

"(...)requires private landowners to preserve natural vegetation(...)": to preserve and restore if this required preserved area is not present. This need to be explained.

I also suggest mentioning the more up-to-date name: Brazil's Native Vegetation Protection Law, also known as the Forest Code. And refer to the supplementary material for more details.

Also include a range. Just substantial is too vague.

3rd. paragraph

I think you can be clearer on what do you mean by opportunity costs. Land opportunity cost?

Enforcement probabilities is also too vague. Legislation enforcement concerning mandatory forests within property...

4rd. paragraph

"(...) depending on the proportion of area (...)" of which area? property? some other domain? not clear?

I realized later this is explained in the results. But it needs clarification here to, or a reformulation to a more general statement.

Results

1st. paragraph

"(...)By contrast, in the Amazon region much more land is public or in indigenous territories. (...)". I think this is not very relevant.

"(...)Nearly 90% (roughly 1.1 million km²) of the BAF (...) over the last 500 years(...)". Reference?

I think you should add something about the relevance of reversing this trends for ecosystem services, since so many people live on the BAF, and also to reduce species extinction on this biodiversity hotspot.

3rd. paragraph

"(...)A complication for our analysis is that land area units (grid cells) may be partially or fully supported by PACTO (Figure B2) (...)". It would be easier why this happens with a bit more context. Something like: Because our units of analysis were 2ha in size, a complication of our analysis is...

Legend Figure 3.

Estimated is redundant.

proportion of our units of analysis treated

4th. paragraph

Excluding control cells withing 500m of the treatment makes the effect relevant. Could it be also due to some neighbour effect where landowners not enrolled with pacto also decide to undergo restoration when they see benefits from their neighbours?

Legend Figure 4.

I would not use the word "plots". It would also be interesting to explain what the time-varying controls are. Also, instead of mentioning the cell, I would say something like our unit of analysis and explicitly say its size. I would also avoid et cetera.

5th. paragraph

If I understood correctly, 5000 ha is the restoration that can be attributed exclusively to the treatment effect, but there could be more areas restored than that, right? Otherwise, it's not very clear to me why not computing the total restored areas from the images.

Drivers of restoration success: benefits and costs to landowners and institutional context

2nd. Paragraph

The benefits are perhaps not obvious so it would be good to give some examples here, like you did for the costs.

"(...)Brazil's economic powerhouses (agriculture, cattle, and logging)". Is it logging or forestry?

"(...)Since the opportunity cost of land is high (e.g., cattle farming earns an average of \$100/ha/year [12]), restoration (...)". This seems like a low opportunity cost, compared to other agricultural activities. Alo, one could claim that most restoration should for that reason target pasturelands.

Active restoration also needs to be defined.

3rd. Paragraph

I think this paragraph needs further development. What is the role of each of those stakeholders? Why having all of them is important? For ex. why NGOS are necessary?

Since this is explained further down, maybe a brief explanation on the necessity of all those actors, which will be further developed on the paragraph to come. I also think that part of the reason of having diverse stakeholders is explained in the next paragraph.

5th. paragraph

I suggest briefly explaining what a Legal Reserve is and referring to the supplementary material for further details.

I also I think there is something missing which is the effect of both the FC and the "Lei da Mata Atlantica", which makes deforestation illegal. This can be seeing as an additional risk to restoration, since the landowner will not be able to clear the land back again.

6th. paragraph

The CAR requires some context for non-Brazilians and readers unfamiliar with the details of the legislation in general. Same comment as for the Legal Reserve.

What kind of credit? bank loans for agricultural activities? How does this work? be more specific.

I am not sure what you mean by water restoration.

Heterogeneity in impacts consistent with key drivers of success

"(1/km to city)". I did not understand why you have considered distance as a ratio.

2nd. Paragraph

This effect seems also connected with land opportunity cost. was that included in the model? By isolating the effect of o.c., the effect of the state itself would be more clear.

3rd. Paragraph

I wonder if fines per capita is the best way of considering the importance of fines. The number of fines probably depend more on the number of properties -- or the area of the state - than on its population, especially because most of the population is located in cities.

Figure 6.

This figure made me think if the total area under restoration, as part of the PACTO or not, would also follow this pattern.

Because a smaller effect could also mean that both treatment and control are more similar .e.g. are restoring areas. Can you test for that?

Also review the legend. The text could be improved.

Discussion

1st. paragraph

"There are two exceptions to this (...)." This is a very strong statement, consider attenuating it.

Also, not clear if the second exception is the Chinese program.

2nd. paragraph

Be specific about the resolution:

via 30m resolution satellite imagery, such as the ones we used for this study...

"Restoration in later-enrolled cells will (...)" Review tense.

"(...) due to concerns about that the measurement error in the outcome is likely to exceed the useful information for these very small parcels." This sentence is not very clear. It needs rephrasing.

3rd. paragraph

Our dataset sounds better.

4th. paragraph

But how about land opportunity cost as in land value? This could be estimated spatially explicitly and probably has very different patterns in different states.

5th. Paragraph

There is a very long and useful discussion in the supplementary material that deserves to be mentioned in here to direct the reader.

Materials

1st. paragraph

The fact that multiple parcels can be managed by a single landholder needs to be added to the limitation discussion as landowner's behaviour can affect the effectiveness.

Methods

In the supplementary material, the authors mentioned that the importance for water provision is also used to choose areas for the PACTO. If this is the case, and also considering that according to the landowners water is associated with forests – what could motivate restoration -- shouldn't a variable capturing this be included as covariable for matching?

2nd. paragraph

"(...) higher(...)" in altitude

"(...) farther from cities (...)"

If the matching was done by municipality, how come the controls could have different municipalities ID than the treatment?

3rd. Paragraph

How about the other co-variables described in 4.4? were they included in the matching or not?

Post-matching regression

2nd. And 3rd paragraphs

Most of those paragraphs would be better placed in Results and Discussion sections.

Supplementary material

Table A. My perception is that is more usual to add the notes information together with the table title. In addition, the Note is not very clear, I suggest some rewriting: e.g. it is no clear what (1), (2) and (3) represent.

Extended methods

1st. paragraph

I would say additional methods.

Be more specific of what you mean by spatial issues.

Matching and difference in difference estimation

1st. paragraph

Add some reference on the goal of matching.

"Clearly, the treated group has a much higher propensity for restoration going into the treatment period (...)" I suggest something like: Even before the treatment event.

2nd. Paragraph

Is protected area a binary category? or some proportion? Clarify how this variable was accessed.

3rd. Paragraph

"(...) in the denominator of the outcome (...)"

4th. Paragraph

"(...) consistent with our main findings (...)"

5th. Paragraph

"Cell fixed effects eliminate the influence of observable fixed confounders like slope, elevation, and bioclimate is eliminated as well as that of all unobserved fixed confounders". This sentence is confusing, consider rewriting.

6th. Paragraph

"Clustering also alleviates spatial autocorrelation to the extent that landscapes are vary over larger, rather than finer, areas, like municipalities such that within municipality variation of landscape features is low". This sentence also needs rewriting.

Figure B1

The classes seem more a reclassification of Mapbiomas than original classes from the database.

Table B4.

The 0.25 threshold is based on what? This threshold seems very important as in the next table, both variables reflecting restoration are the ones that have the largest normalized differences between control and treatment.

Table B8

Not clear what are land surface categories, nor geology and bioclimate.

Table B9

There is one column missing.

Supporting policies: the Forest Code and the CAR

Some of this information needs to be in the main text and then you can refer to this section for further info.

Here you need to define what are Legal Reserves and APPs.

Role of PACTO

Why restoration in the tropics is complex needs reference.

Role of Local NGOs

I think the case of the rural settlement was never mentioned before so this needs a bit more context.

Legal Compliance and Enforcement

Small landowners are also dismissed of restoring LR, what can help explain their lack of awareness of restoration obligations.

2nd. Paragraph

BAF was not defined before in the supp. Mat.

5th. Paragraph

I was not aware that there was a size threshold for landowners in the CAR. Is that a fact?

Figure F5

Is that restoration or the treatment -- adherence to pac

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

Nature Communications

Scaling forest restoration in the tropics: evidence from Brazil's Atlantic Forest Restoration Pact

General Comments

This interesting and relevant research focuses on a well-known and large-scale restoration programme and network in the Brazilian Atlantic Forest that aims to promote forest restoration by supporting private landowners in different ways. The work is novel and important as it brings to light i) the role of a large-scale restoration programme that could be used as a model around the globe and ii) the opportunities and obstacles for these types of initiatives to have positive impacts on restoration. The work shows that the PACTO was responsible for promoting net forest restoration inside its partner areas when compared to control areas. The manuscript also includes an interview component, complementing the results and discussions around obstacles related to conservation in private lands.

The research methods are sound, being considered among the most robust methods for impact evaluation, and the work presents interesting results and discussions that are relevant to a wide community. Yet, there are some improvements in text flow, clarity of methods and connection of quantitative and qualitative analysis that should be made.

I detail below some problems and suggestions for improvement.

1. The text is somehow repetitive. For example, the research objectives were presented in more than one place, written in different ways. Some parts of methods (maybe due to methods subsections) are also repetitive and sometimes confusing. More will be mentioned about this below.

2. Interviews: It is great that the authors included a qualitative analysis based on interviews to complement quantitative ones, and I find it a great opportunity to make the article more robust and interesting. However, several improvements need to be made, such as:

a. There is no description of the questions asked in the interviews. These should be stated in the SM so the soundness of this part of the analysis can be evaluated. More details about questions, and how these were applied are important for the type of information that needs to be collected. b. In the article, authors mention that the interviews are for understanding the drivers and mechanisms of PACTO for restoration. But it is not very clear how the quantitative analysis and these will be integrated. Important to make it clear.

c. There is no information about the interviews in the Methods part of the main article.

d. Throughout the results, it is hard to know what information comes from the respondents, other articles, or authors opinions/perceptions. These need to be referenced.

e. Results from interviews are mainly described in the SM, and are extremely interesting, adding a soul to the manuscript, and allowing the reader to understand the perception of actors in the field. Of course, there is a balance regarding the amount of information you include in the main manuscript, but I think the main text would benefit immensely by including some more findings from the interviews.

f. Based on the above, I suggest the authors have a section where they can provide more details about what interviewees said and relate it to the quantitative results and relate to the context (very well presented in the SM) in the results and maybe discussion. The amount of information that should be included can be balanced with the removal of repetitive text.

3. Introduction:

a. 1st Paragraph talks about "private benefits". Can authors explain what it means?

b. 2nd paragraph has a description about PACTO, but it is still unclear how it works (it will only become clear later in the text). So the next paragraphs can be better understood, it would be important to include more detailed information about PACTO here.

c. 3rd paragraph. At the end of it, the authors mention opportunity costs and enforcement probabilities, but this only gets clear later in the text (and maybe in the SM). Needs some more explanation.

4. Results

- a. 2nd paragraph could use some information that is currently in the SM to be clearer, such as more details on the choice of studying the period before 2009.
- b. Figure 2: can you include in this figure the subset of the areas that were evaluated? It would be interesting to see if they are concentrated in one state or region.
- c. I would also suggest the design sampling method with the grid cells presented in SM should also be placed in the main text.
- d. The results for 2019 are quite drastic, particularly as we are seeing data from inside the treated parcels. The authors haven't discussed anything about that, and although it might be related to the deforestation in the Bolsonaro period, it would be interesting to know how this has affected the areas inside PACTO partners. It might elucidate something about how the context or current policies can influence a program's action.

5. Section on drivers of restoration success (Results)

- a. It is not clear where the framework comes from and what it states. I suggest moving some information from the SM.
- b. As mentioned earlier, it is hard to know where the information comes from: interviews, context or literature. I suggest including more information about the interviews, if necessary, explaining some of the context as done in the SM. Otherwise, it is hard to make a connection to the main goal of the article and with the factors that might influence restoration.
- c. Figure 6. Are the environmental fines used in Figure 6 related to forest code compliance only? Or general state-applied fines for any environmental aspects?

6. Discussion: I think it can be improved by connecting better to the findings from the interviews and context.

7. Materials and methods

- a. I suggest restructuring the methods subtopics, as they are quite repetitive and confusing. Do you need an overview section? I would replace it with a figure. My suggestion for the sections is: i) data and study area, ii) forest cover data, iii) matching (including covariates for matching). It is important to differentiate what was covariates for matching and for regression, why you chose each of them for both analyses, and why they are different (this is something that gets confused throughout the text and in the SM), iv) difference in differences with details; v) interviews! There is no information about the interview part, from which state they were, questions asked, etc.
- b. 1st paragraph (item 4.2) it is still not clear who own the land and who restores it. It must be stated earlier, and why the importance of explaining roles in the PACTO network.
- c. 2nd paragraph (Methods). You could estimate the number of parcels in the same property using the CAR. It would be interesting to see if the analysis was made with a great number of the parcels belonging to the same owner. Could this somehow impact the analysis, and how?
- d. Why have you used PA coverage as a covariate? Why not exclude the PA areas from the analysis? Also, why haven't you used SNUC data as it is in some cases more reliable than WCMC one? The WCMC one might include also IL, for example. Would it be appropriate to include them?
- e. Why a buffer of 500m? Is it enough for spillover effect?

(Remarks on code availability)

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

I have carefully read the new revised version of the manuscript and the authors responses to my previous comments. I believe the manuscript has been substantially improved, and the authors have satisfactorily addressed my concerns.

However, one of the questions I raised on the first round of review was related to the proxy used in the manuscript to access land opportunity cost: distance to urban centres. I have argued that this variable could fail to capture some nuances. For instance, different states having very different land opportunity costs as in land value and forgone production at the same distance to an urban centre. While I am convinced by the authors responses and supplementary analysis that using a different variable would probably not change the overall results and is not central to this work, they have also mentioned that the main reason for not using revenues from agriculture or land value was the lack of data. I would like to share some examples of previous works on related fields that have managed to deal with the data limitations and to produce spatial explicitly layers of opportunity cost. For instance, by using land value data:

Strassburg, B. B. N. et al. Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nat Ecol Evol* 3, 62–70 (2019).

Land value data is currently available for different states and land uses from the federal government:

Or using expected revenues:

Niemeyer, J., Barros, F. S. M., Silva, D. S., Crouzeilles, R. & Vale, M. M. Planning forest restoration within private land holdings with conservation co-benefits at the landscape scale. *Science of The Total Environment* 135262 (2019) doi:10.1016/j.scitotenv.2019.135262.

Those methods can guide future analysis or help with sensibility testing for the robustness of using distance to urban centres as a proxy.

In addition, I have some minor additional comments.

First section of Results

First session of results feels more like methods than results. I suggest incorporating to the previous session. For instance, the 1st paragraph of this session could be merged with the 2nd paragraph of the introduction to justify why there is such a coalition. Also, lots of the 2nd paragraph content was already said on the introduction.

Then, I suggest a concise paragraph on the introduction right before the last paragraph with the relevant information from paragraphs 2 and 3 of this section summarising what was done and then starting the results with the next sessions.

Maybe even eliminating the subtitle results and starting with:

Drivers of restoration success: benefits and costs to landowners and institutional context
(I leave it to the authors whether or not they consider this last suggestion adequate).

Legend Figure 1

You could include the % of area under PACTO in each state in the legend, e.g. Bahia (32% of parcels) and so on.

Drivers of restoration success: benefits and costs to landowners and institutional context

Lines 121-123: This sentence should be reframed to sound more like a result than methods. For example: The interviews contributed/gave us an understanding of the restoration environment and drivers of impact. And then be placed on the beginning of the next paragraph.

Lines 127- 128: The sentence directing the reader to the Supp. Mat. would be better right after when the forest code is mentioned, between brackets. As it is, it breaks the fluidity of the reading.

Also, the following sentence "Because of these rules" is not very clear. Because of the sanctions imposed by the legislation, which include fines and ..., according to (...)?

Figure 4:

The legend on the left panel is partially erased.

Heterogeneity in impacts consistent with key drivers of success

Line 243: land or property size rather than landowner size.

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

This study, "Scaling forest restoration in the tropics: evidence from Brazil's Atlantic Forest Restoration Pact" presents compelling evidence that assistance to landholders to restore forests on their lands can indeed have influence on landscape-level regeneration. The large dataset is impressive and covers a critical area both for conservation and human livelihoods. I commend the authors on this work and believe it will make a valuable contribution to Nature Communications.

My only substantial concerns are that the post-intervention time-scale is short for classification of actual "Forest restoration" and the 2019 cutoff date seems arbitrary at this point. I would normally want to see more interrogation of the map products to determine that they are indeed capturing reforestation satisfactorily. Here I find that the robust statistical approach provides a convincing case that there is indeed a significant treatment effect in growth captured by the maps regardless of any measurement error. Nonetheless, I would suggest the authors exercise a little more caution in labeling this growth as "forest restoration". It would also be beneficial to extend the analysis a few years beyond 2019. I assume that this was the last year available when the analysis was first conducted. However, MapBiomas seems to now have maps available through 2022 if not 2024 at the link cited. Extending the analysis a few years would help contextualize the 2019 results – is this year indeed an outlier or is it part of a longer trend extending through Bolsonaro's term? (if so, the impact would indeed largely be reversed). A few additional years of analysis would also help to allay concerns that the regrowth is not actually forest or

cannot yet be perceived in the satellite images if the actual treatment started later. If it is too difficult to rerun the full analysis with the more recent MapBiomass product, I suggest at least running a sub-analysis (included in the appendix) to show that 2019 is indeed an outlier.

Minor issues:

Line 96: "the total area is roughly twice the land area of the District of Columbia in the United States" – I am not sure this is the most helpful illustration of the size for most readers and can perhaps be dropped altogether.

Figure 3: Note says "treated (red line) and untreated (blue line)" but legend and story have it the other way around.

Figure 4: "dots indicate this treatment effect evaluated at 25, 50, 75, and 100% coverage of the analysis units in a restoration parcel". Clarify what is meant by "coverage" here. I assumed it meant vegetative coverage until reading the methods much later.

Line 347: Change "coverage categories" to "land cover categories" for clarity.

Figure 6: It seems that this could be presented in a single figure, with the fine value as the X axis (and state labels inserted where they fit along that axis). The only reason for not doing so that I can see is that the clean gradient shown in the top figure would be muddled, but then this gradient is misleading.

Line 370 – 375: The temperature and precipitation data are discussed here with the matching variables but are not used in the matching analysis. I believe they are used as covariates in the regression analysis. This should be clarified here.

Table B5: Post-Matching Means: Maybe specify here that Net forest recovery (ha), 2010-2019 is the dependent variable and thus not matched here.

Overall, this is a very nice piece and I thoroughly enjoyed reading it.

(Remarks on code availability)

The code is not yet available at the link provided. I understand that it will be uploaded there upon publication.

Version 2:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Dear authors,

Thank you for your thoughtful revisions in response to the previous round of peer review. I have the updated version of your manuscript, and I appreciate the effort you have put into addressing the comments and improving the clarity and rigour of your work.

I find the study to be well-conducted and the conclusions well-supported by the evidence provided.

At this stage, I do not have any further concerns, and I am pleased to recommend your manuscript for publication. I believe it will make a valuable contribution.

Best regards,

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

I have read the revised version of "Scaling forest restoration in the tropics: evidence from Brazil's Atlantic Forest Restoration Pact" and agree that the authors have addressed all of the concerns I expressed in my previous comments except for one (regarding Fig 6).

I appreciate the extra work taken to evaluate the more recent MapBiomass data and think that showing this updated analysis adds to the value of this analysis. While I am not as optimistic as the authors about how the new trend line will extrapolate to subsequent years, I understand that this is beyond the scope of this research.

My only pending concern is that Fig 6A still does not have a quantitative x axis (as seems implied by the point sequence). I do not understand why the x axis cannot be the fine amount -- essentially moving Sao Paulo and Minas Gerais before Espitito Santo and Rio de Janiero. Not doing so seems misleading (even if B provides the data for the correct interpretation - why require the reader to do this task mentally?)

Also, I was able to access the code at the link now and don't see the code related to the MapBiomass analysis. Can that code be included?

Outside these small requests, I think this manuscript is ready for publication and will make a great contribution to Nature Communications.

(Remarks on code availability)

I do not have Stata, so did not review the code specifics. However, it looks to me that the code related to the MapBiomass data extraction/prep is not included at the link provided. It would be ideal if this code could be included.

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Thank you to both reviewers for your very thoughtful comments. We think that they have significantly improved the paper and hope that you find this to be the case as well. We have put original comments in *italics* and our responses in [unitalicized blue font](#).

Responses to reviewer 1:

The study entitled “Scaling forest restoration in the tropics: evidence from Brazil’s Atlantic Forest Restoration Pact” has performed a robust analysis of the effects of a program of incentives to promote restoration within private land in Brazil. To do that, they have worked with post-matching differences-in-differences estimation to compare the trajectories of parcels of land adhered to the program (treatment) with similar parcels non-adherent (control).

I believe the work is original and highly relevant to the interface between Conservation Science and Policy, by evaluating and discussing the effectiveness and pathways to upscale ecological restoration, with obvious applications in the real world.

One of the key features of this work is having a large dataset of areas undergoing restoration and a clear intervention. They were also careful enough to support their choices of co-variables for matching by interviewing relevant stakeholders.

Overall, the data and methodology are adequate and give support to the main conclusions and the quality of the study is satisfactory.

I have, however, some issues that need to be addressed by the authors if this manuscript is to be published.

The manuscript lacks definitions of key terms that are important for a broader audience, both terms from the restoration science and from the Brazilian legislations regulating restoration within private land.

I also think that in some cases there is a disconnection between the main text and the supplementary material. Some information from the supplementary material needs to be brought to the main text but mostly, the Supp. Mat. deserves to be more emphasized in the main text, directing the reader interested in more details.

I did not find any data or code, so I was not able to evaluate this aspect of the work.

[Thank you very much for your thoughtful and thorough review of the manuscript. We appreciate your evaluation of the contributions of the work and relevance for policy. Your comments have significantly improved the quality and readability of the paper. We have sought to better define key terms and to improve the connection between the main text and the SI by substantially editing the results section.](#)

[The text has changed quite significantly as a result of your suggestions, and so we have included both a clean version of the final manuscript and a pdf-compare version with the original one. Regarding the data and code availability, we have created a Dataverse entry for the datasets and code, and we plan to make them available upon publication. However, we are happy to provide you access to the data and code sooner should you require it for your review. We respond to each of your comments individually below.](#)

Main text Introduction 1st.paragraph: It would be useful to have references of how much land is privately owned to support the claim that forest restoration needs to include it (line 4).

We have modified this paragraph to include the following citations that support this claim:

Mo et al (2023): Estimates the differences between current and potential carbon stocks, globally, by land-use, highlighting pasture and agriculture.

Shyamsundar et al (2023): Estimates the amount of low-cost restorable land that is owned by smallholders.

Sparovek et al (2019): Estimates that 44% of Brazilian land is privately owned.

The study has not been introduced yet nor the restoration program.

Thank you for this point. We now define PACTO in the first paragraph and in the abstract.

This phrase needs to be reformulated. Perhaps: restoration programs can offer assistance(...)(line 9) and add some reference, for instance: <https://www.sciencedirect.com/science/article/pii/S0169534722001719>

We have reformulated the statement on program assistance to reflect that programs offer landowners assistance when barriers are high. Further, we have added the following citations on restoration incentives and costs: Pashkevich et al (2022), Brancalion et al (2019).

Similar to what? To the referred program, similar among themselves in general? I also think there is something missing here, like: While restoration initiatives are expanding rapidly due to. complete (ref!), there is little evidence regarding their effectiveness to deliver what? this need to be cleared said (line 10).

Thanks for pointing out the lack of clarity here. We have modified this sentence to read: “Although such initiatives are expanding rapidly worldwide (Meli et al. 2017), there is little empirical evidence regarding their ability to generate additional forest relative to a plausible comparison group of properties.” We have also added citations to a meta-analysis (Meli et al 2017) and a review paper on forest restoration (Vincent et al. 2021).

2nd. Paragraph: Because the article aims for a broad audience, I suggest some short definition of terms such as natural regeneration and assisted Regeneration. And why this depends on locality.

“(...)requires private landowners to preserve natural vegetation(...)”: to preserve and restore if this required preserved area is not present. This need to be explained.

I also suggest mentioning the more up-to-date name: Brazil's Native Vegetation Protection Law, also known as the Forest Code. And refer to the supplementary material for more details.

Also include a range. Just substantial is too vague.

We have substantially rewritten the introduction and have responded to these two comments in the revised version in paragraphs 2 and 3.

3rd. paragraph: I think you can be clearer on what do you mean by opportunity costs. Land opportunity cost?

We now address this with the specific economic definition of this term in paragraph 5 (the foregone profits from alternate uses of land). We include further discussion of opportunity costs on page 7:

“Because restoration directly precludes highly profitable land uses, like agriculture, and cattle ranching, the main implicit cost is the foregone profits from alternate uses, or the opportunity costs of restoration.”

Enforcement probabilities is also too vague. Legislation enforcement concerning mandatory forests within property...

We have modified this to: “the risk of legal sanction for violating minimum native vegetation requirements.”

4rd. paragraph: “(...) depending on the proportion of area (...)”. of which area? property? some other domain? not clear?

I realized later this is explained in the results. But it needs clarification here to, or a reformulation to a more general statement.

We agree that a more general statement is useful in the introduction. We now write in the fourth paragraph: “Our analysis compares restoration outcomes for land that received support from a PACTO implementer after 2009 to similar land units that did not.” In the final paragraph, we explain the treatment effect as: “Over this period, we estimate that forest cover increased by 9-21 percentage points on average in PACTO supported land relative to the counterfactual.”

Also please note that we have made edits throughout the introduction section with the goal of improving clarity.

Results

1st. paragraph: “(...)By contrast, in the Amazon region much more land is public or in indigenous territories. (...)”. I think this is not very relevant.

“(...)Nearly 90% (roughly 1.1 million km²) of the BAF (...) over the last 500 years(...)”. Reference?

I think you should add something about the relevance of reversing this trends for ecosystem services, since so many people live on the BAF, and also to reduce species extinction on this biodiversity hotspot.

We have eliminated the Amazon sentence, added a citation on the 90%, and included the following sentence (with citations):

“Conserving and restoring the remaining fragments of the forest may help protect unique species in danger of extinction in addition to providing important carbon, erosion, and watershed function services.”

3rd. paragraph: “(...)A complication for our analysis is that land area units (grid cells) may be partially or fully supported by PACTO (Figure B2) (...)”. It would be easier why this happens with a bit more context. Something like: Because our units of analysis were 2ha in size, a complication of our analysis is...

Thank you, we have adjusted this phrasing.

Legend Figure 3.: *Estimated is redundant. proportion of our units of analysis treated*

We edited the legend for clarity.

4th. Paragraph

Excluding control cells within 500m of the treatment makes the effect relevant. Could it be also due to some neighbour effect where landowners not enrolled with pacto also decide to undergo restoration when they see benefits from their neighbours?

We apologize that our writing here was confusing, and this seems to have led to a misinterpretation of what we found. In our main estimation, we exclude possible controls within 500m so that our results are not contaminated by the potential leakage effects from restoration. Leakage effects to immediately adjacent areas might occur because a single landowner shifts land use within their property (restoring land in one area and deforesting in the adjacent area). This type of negative leakage could result in an overestimate of the true impacts if we do not exclude nearby cells from the possible control set. Positive or negative leakage could also occur if neighboring landowners decide to restore or deforest based on learning or information sharing from their neighbors. Given the difficulty of getting people to restore in the first place, it seems unlikely that neighboring landowners would engage in more restoration without support. Nonetheless, if there were positive spillovers, they could reduce the magnitude of our estimated results if we do not exclude nearby properties from the comparison.

In order to check that our results are not driven by the exclusion of these neighboring cells or our choice of a 500m zone, we compare estimates under different assumptions. We find that we get very similar point estimates if we include or exclude controls from within 500m, which suggests that there is not local leakage and that this estimation choice is not driving the results. In the new version of the manuscript we also exclude cells within 1000m as a robustness check. Here we also see no differences in results, which indicates that there were not meaningful positive or negative local spillovers.

We have clarified our spillover analysis in the 4th paragraph of the subsection entitled “*Participation in PACTO induced additional restoration*” in the Results section. We hope this more clearly describes our results with respect to spillovers.

Legend Figure 4.: I would not use the word “plots”. It would also be interesting to explain what the time-varying controls are. Also, instead of mentioning the cell, I would say something like our unit of analysis and explicitly say its size. I would also avoid et cetera.

Thank you, we have adjusted the legend accordingly.

5th. Paragraph: *If I understood correctly, 5000 ha is the restoration that can be attributed exclusively to the treatment effect, but there could be more areas restored than that, right? Otherwise, it’s not very clear to me why not computing the total restored areas from the images.*

Yes, this is correct. The 5000 ha is our estimation of the additional restoration that can be attributed to the program. It is a calculation based upon the treatment effect estimation, so it is relative to the behavior in the counterfactual cells; not an absolute measure of how much land was restored within the boundaries of the PACTO supported parcels (which could be assessed from the images as the reviewer notes). On average, there is a positive rate of net forest recovery among the control group as well, so there could be additional areas restored. More importantly, as we state in the text, we are looking only at a subsample of the land that is supported by PACTO, so we are very likely understating the total effect of the program. We have clarified this in the text at the end of the “Participation in PACTO induced additional restoration” section and in the second paragraph of the discussion section.

Drivers of restoration success: benefits and costs to landowners and institutional context

The series of comments for this section, along with recommendations by reviewer 2, was essential to getting us to better integrate the interview results into the paper. It was a challenge to rewrite this section without greatly expanding the space dedicated to it (given the strict length requirements of the journal), however we have sought to clarify each of these points. Overall, we hope that the revised version does the following:

Better articulates benefits and costs of restoration

Connects benefits and costs to specific examples and illuminates the value of the interviews.

Generates hypotheses that are then tested in the heterogeneity tests section.

2nd. Paragraph

The benefits are perhaps not obvious so it would be good to give some examples here, like you did for the costs.

We have sought to substantially rewrite this section. In the revised version we describe specific potential benefits including reduced risk of government sanction, access to agricultural credit, additional income, and increased environmental quality or ecosystem service flows.

“(….)Brazil’s economic powerhouses (agriculture, cattle, and logging)”. Is it logging or forestry?

This sentence is no longer part of the paper.

“(…)Since the opportunity cost of land is high (e.g., cattle farming earns an average of \$100/ha/year [12]), restoration (….)”. This seems like a low opportunity cost, compared to other agricultural activities. Alo, one could claim that most restoration should for that reason target pasturelands.

This specific sentence is no longer part of the paper. We agree that restoration often targets pasture or degraded land and that point is included in the paper.

Active restoration also needs to be defined.

The introduction now briefly defines active restoration (direct seeding or planting young trees). Active restoration is further discussed and defined in the third paragraph of the “Drivers of restoration success” section.

3rd. Paragraph

I think this paragraph needs further development. What is the role of each of those stakeholders? Why having all of them is important? For ex. why NGOS are necessary?

Since this is explained further down, maybe a brief explanation on the necessity of all those actors, which will be further developed on the paragraph to come. I also think that part of the reason of having diverse stakeholders is explained in the next paragraph.

We have substantially rewritten the introduction and this section with an eye towards clarifying the role of PACTO and the implementing partners. We have also sought to reduce repetition throughout the text.

5th. paragraph

I suggest briefly explaining what a Legal Reserve is and referring to the supplementary material for further details.

This is now briefly explained in the introduction: “The country's key forest policy is the federal “Forest Code,” formally known as the Native Vegetation Protection Law (NVPL) of 2012. This law requires all landowners in the BAF to set aside 20% of their land as a “Legal Reserve” of native vegetation conservation, with additional requirements for ecologically-important areas (such as riparian zones) known as “Areas of Permanent Protection” (APPs) \cite{Brancalion2016}.” We also give further explanation in the supplementary materials.

I also I think there is something missing which is the effect of both the FC and the "Lei da Mata Atlantica", which makes deforestation illegal. This can be seeing as an additional risk to restoration, since the landowner will not be able to clear the land back again.

The 2006 Atlantic Forest law certainly warrants inclusion as it is important legal context that drives landowner behavior in our sample states. We have included the following text in the supplementary materials (to which we have moved the details about Legal Reserves and legislation in general):

“The 2006 Atlantic Forest Law further restricts land use in the Brazilian Atlantic Forest by making restoration legally irreversible. This law makes restoration a unique and possibly unappealing land use choice by removing the option for landowners to return restored land to pasture, agriculture, or timber in the future. However, the 2012 Forest Code included a provision (Article 81) that any land being regenerated in accordance with the 2006 law qualifies for a Legal Reserve or the environmental reserve quota (CRA) program. While the restored areas remain irreversible, this provision increased the appeal of restoration by putting land partially back into economic use or eligible for compensation. The restored forest in a Legal Reserve can be used to generate income under sustainable conditions, like agroforestry.”

We also include the following footnote about the CRA: “Under the CRA program, landowners may be compensated for restored land areas that are in excess of the minimum area required by the Forest Code.”

6th. paragraph

The CAR requires some context for non-Brazilians and readers unfamiliar with the details of the legislation in general. Same comment as for the Legal Reserve.

We have included more detail about the CAR in the Supplemental Materials. Specifically, we write “The Environmental Rural Registry (CAR) continues to be a critical component of the 2012 revision because of its impact on landowner compliance with the Forest Code. The CAR is a national registry designed to increase compliance (among other goals) by mapping and monitoring rural property holdings, which are subject to environmental laws. Property owners are required to register their land with the CAR and to provide information on property boundaries and locations of APPs and LRs. In return, compliant landowners gain access to credit and rural financing programs.\footnote{See Articles 29 and 41 of the Native Vegetation Protection Law.}”

What kind of credit? bank loans for agricultural activities? How does this work? be more specific.

We have added text and a footnote in this section to clarify that we mean access to government-supported credit programs, including agricultural credit, agricultural insurance, and some other types of tax credits. This is part of the Native Vegetation Protection Law.

I am not sure what you mean by water restoration.

We are referring to potential increases in water quantity (due to changes in microclimate / shade) and to changes in water quality (due to less erosion and sedimentation of streams or water bodies).

Heterogeneity in impacts consistent with key drivers of success

“(1/km to city)”. I did not understand why you have considered distance as a ratio.

This is a transformation that allows for a non-linear relationship with distance, which is greater the closer a piece of land is to the city. This may capture greater opportunity costs close to cities. We have noted this rationale in the revised text.

2nd. Paragraph

This effect seems also connected with land opportunity cost. was that included in the model? By isolating the effect of o.c., the effect of the state itself would be more clear.

We agree that it would be ideal to separate the mediating impacts of opportunity cost and institutional context. Unfortunately, we do not have direct measures of land opportunity cost at the grid cell or property level. There are measures of agricultural revenues at the state level, but there is not corresponding data on input costs, so these do not give an accurate measure of foregone profits that could be used to test for heterogeneity by opportunity cost directly. The state level heterogeneity results are estimated from a model that includes unit-level fixed effects, which controls for underlying land quality and other factors that do not change over time. However, state-level differences could also be the result of change in institutional factors or changes in opportunity cost that are specific to that state. The additional data on fines per state and the regressions using distance as a proxy for opportunity cost indicate that both plausibly matter. We have sought to clarify these results in the text.

3rd. Paragraph

I wonder if fines per capita is the best way of considering the importance of fines. The number of fines probably depend more on the number of properties -- or the area of the state - than on its population, especially because most of the population is located in cities.

In our original figure we showed both fines per capita and fines per ha of forest. We agree that these don't quite capture the importance of forest fines. In the revised paper, we calculated the hectares of forest per *rural* population for the denominator, and kept the value of forest fines in the numerator. This measure will be higher if forest per person tends to be smaller (because of a smaller denominator), reflecting the expectation of more fines if there are more properties. It will be higher if there are more fines, all else equal. We use this revised measure in Figure 6 and include the previous figure in the Supplementary information section.

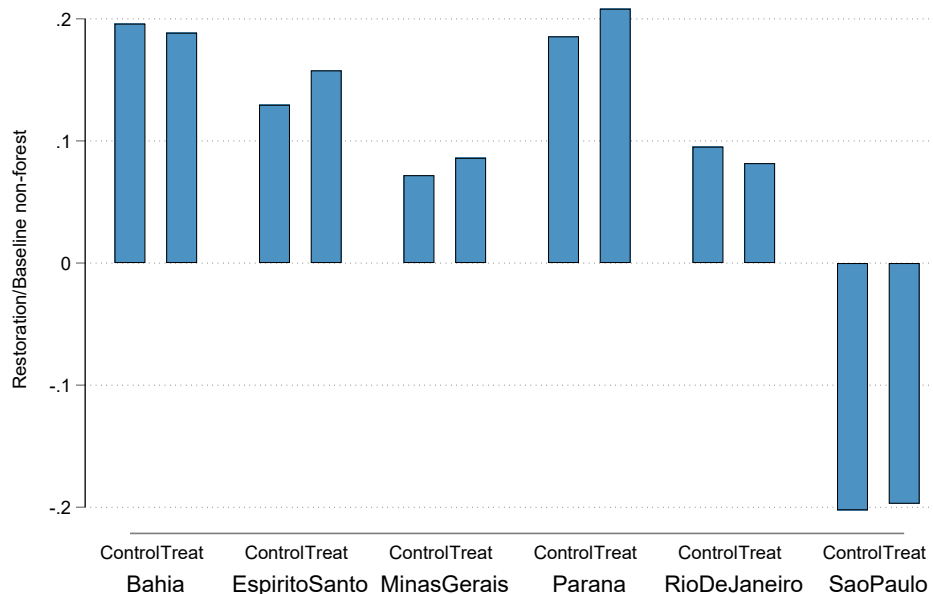
Figure 6. : *This figure made me think if the total area under restoration, as part of the PACTO or not, would also follow this pattern. Because a smaller effect could also mean that both treatment and control are more similar .e.g. are restoring areas. Can you test for that?*

Also review the legend. The text could be improved.

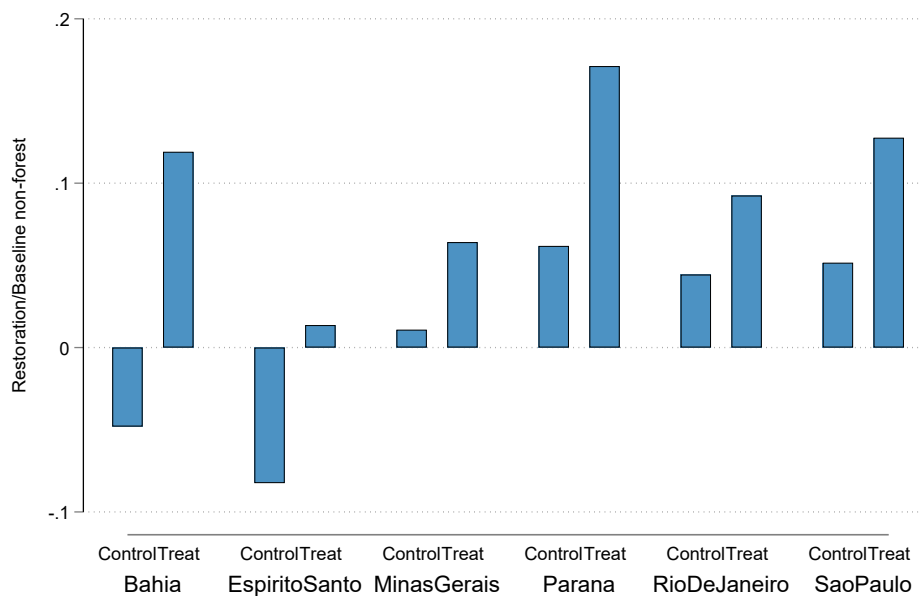
We apologize for possible confusion here. We have modified the legend to explain that the markers shown are coefficients on the interaction term between having a unit treated and being in the post period. This interaction effect is explicitly testing whether or not restoration was relatively different between treatment and control after the PACTO intervention. The treatment effect it is exactly the mean difference in restoration in treatment parcels relative to controls in the post-period, compared to the same difference in the pre-period.

You raise an interesting point, which is how the overall rates of restoration in the different states may compare to each other. We do not directly test this point, because we do not calculate restoration outcomes for any of the entire areas, as we were focused on trying to isolate the potential causal impact of PACTO.

Indeed, because the matching works well, the restoration rates for treatment and control groups are very similar in the pre-period. You can see this by looking at the means of the outcome variable in treatment versus control units prior to 2009 by state:



Over the post 2009 period, the restoration rates among treatment and control diverge, as is expected if the PACTO support is having an impact. For example, in Bahia the PACTO enrolled properties saw strong reforestation while the control properties lost forest:



Our main estimation is based on the difference of these differences and also controls for temperature and precipitation (which affect the remotely sensed outcomes substantially), removes the secular time trend, and controls for time-invariant features via the fixed effects. Because of this, the treatment effect estimated is not precisely the same as shown in these figures. However, we can see above that within our treatment and control areas, restoration has generally decreased over the study period, but that treatment units have had relatively better restoration outcomes than controls (which is also the point of Figure 3 in the paper). We do not see that the impacts are driven by the type of pattern you suggest, e.g. that smaller impacts are occurring in states where there is generally a lot of restoration already happening on control properties.

Discussion

1st. paragraph: "There are two exceptions to this (...)." This is a very strong statement, consider attenuating it.

We changed this wording to "Studies in Chile and China provide some related insights. . ."

Also, not clear if the second exception is the Chinese program.

Yes, we were referring to China's program but agree with amending the statement. We have clarified this in the text and rewritten this paragraph.

2nd. Paragraph: Be specific about the resolution:

via 30m resolution satellite imagery, such as the ones we used for this study... "Restoration in later-enrolled cells will (...)". Review tense.

"(...) due to concerns about that the measurement error in the outcome is likely to exceed the useful information for these very small parcels." This sentence is not very clear. It needs rephrasing.

We have amended this paragraph as suggested. It can now be found in the SI in our discussion on unit of analysis.

3rd. paragraph: Our dataset sounds better.

We have changed this.

4th. Paragraph: But how about land opportunity cost as in land value? This could be estimated spatially explicitly and probably has very different patterns in different states.

Yes, land values are clearly likely to be very important in the success of restoration. Our exploration of the relationship between distance to city and restoration effectiveness attempts to address this. There is not data available at the parcel level, or at any level, on agricultural, pasture, and forest profits (revenues minus costs). This would be the idea way to probe the issue of opportunity cost. Other options might be actual land values, but these are also not available. To clarify that we agree that opportunity cost is a key factor in restoration success, we have modified the relevant paragraph. The new paragraph is the third paragraph of the discussion section.

5th. Paragraph: There is a very long and useful discussion in the supplementary material that deserves to be mentioned in here to direct the reader.

Thank you for this suggestion, we now direct readers to the SI in this paragraph (now the third paragraph of the Discussion).

Materials: 1st. paragraph: The fact that multiple parcels can be managed by a single landholder needs to be added to the limitation discussion as landowner's behaviour can affect the effectiveness.

As a result of this comment and others below, we have significantly restructured the materials and methods section. We discuss correlated behavior in section 4.3 of the paper, in the paragraph below equation one. We note, "Standard errors are clustered at the municipality level, allowing cells to be spatially correlated within municipality and across time. We cluster standard errors because it is possible that a single landowner may manage multiple restoration parcels and PACTO implementers may work on several nearby parcels. Clustering accommodates this by allowing for correlation of the errors within the clustering unit. Therefore, clustering at the municipality level is a more conservative approach than clustering at the property level."

Methods

In the supplementary material, the authors mentioned that the importance for water provision is also used to choose areas for the PACTO. If this is the case, and also considering that according to the landowners water is associated with forests – what could motivate restoration -- shouldn't a variable capturing this be included as covariable for matching?

This is a good point and we agree. We do match on the presence of water within a unit, which is one of the categories that is available within the MapBiomass layers. This was described as "land surface type"; we have now noted specifically in the "Other covariates" section that our matching covariates include the presence of water.

2nd. paragraph

“(…) higher(…)” in altitude “(…) farther from cities (…)”

If the matching was done by municipality, how come the controls could have different municipalities ID than the treatment?

We apologize for the confusion and we have rewritten substantial portions of this text with the goal of better describing the matching process. We use exact matching by municipality in combination with propensity score matching to ensure that no control matches are located in different municipalities than the treated observation with which they are matched.

3rd. Paragraph

How about the other co-variables described in 4.4? were they included in the matching or not?

We list the matching variables in the 2nd paragraph of section 4.2.

Post-matching regression

2nd. And 3rd paragraphs

Most of those paragraphs would be better placed in Results and Discussion sections.

We have sought to better explain the empirical strategy in the main text, before we get to the materials and methods. Unfortunately, the word limit on the main text (excluding methods, references and figures) is 5,000 words. Thus, we have tried to leave technical detail in the methods section or SI and structured the main text to be more accessible to a non-technical reader. The fifth paragraph of the introduction gives a summary of the empirical strategy in an accessible manner.

Supplementary material

Based on your comments and those of the other reviewer, we have thoroughly edited the supplementary material section with an eye towards clarity and removing repetition or unnecessary information. We hope you will find this section improved.

Table A. My perception is that is more usual to add the notes information together with the table title. In addition, the Note is not very clear, I suggest some rewriting: e.g. it is no clear what (1), (2) and (3) represent.

The journal instructions read: “Each table should be prepared using the Table menu in Word or the table environment in TeX/LaTeX and accompanied by a short title sentence describing what the table shows. Further details can be included as footnotes to the table.” We think that our formatting reflects these instructions but can change this if requested by the reviewer or editor.

(1)-(6) are column numbers that are referred to in the note. Each column is a separate estimation. We have modified the table note, and all of the table notes, to clarify that each column represents a separate estimation.

Extended methods

1st. paragraph: I would say additional methods. Be more specific of what you mean by spatial issues.

We have made these modifications by editing this section.

Matching and difference in difference estimation 1st paragraph: Add some reference on the goal of matching.

We added a reference to King et al. 2019. In addition, in the main paper text we cite similar quasi-experimental evaluations of conservation interventions that use a matching plus regression approach including Alix-Garcia et al. 2015, Wendland et al. 2015, Heilmayr et al. 2016, and Blackman et al. 2016.

“Clearly, the treated group has a much higher propensity for restoration going into the treatment period (...).” I suggest something like: Even before the treatment event.

Thank you, we made this change.

2nd. Paragraph: Is protected area a binary category? Or some proportion? Clarify how this variable was accessed.

Yes, this is a binary category for any overlap of the grid cell with a protected area.

3rd. Paragraph: “(...) in the denominator of the outcome (...)”

Changed accordingly.

4th. Paragraph: “(...) consistent with our main findings (...)”

Changed accordingly.

5th. Paragraph: “Cell fixed effects eliminate the influence of observable fixed confounders like slope, elevation, and bioclimate is eliminated as well as that of all unobserved fixed confounders”. This sentence is confusing, consider rewriting.

We have reworded this sentence as follows: “Cell fixed effects eliminate the influence of characteristics that do not change over time. These include important determinants of land productivity like slope, elevation, and bioclimate.”

6th. Paragraph: “Clustering also alleviates spatial autocorrelation to the extent that landscapes are vary over larger, rather than finer, areas, like municipalities such that within municipality variation of landscape features is low”. This sentence also needs rewriting.

This section has been edited. Clustering is discussed in Section 4.3, as noted above.

Figure B1: The classes seem more a reclassification of Mapbiomas than original classes from the database.

These are the original “high level” classes from MapBiomas, although they can also be broken down into detailed subcategories. For example, non-vegetated area includes beaches, urban areas, mining, and other non-vegetated areas.

Table B4.: The 0.25 threshold is based on what? This threshold seems very important as in the next table, both variables reflecting restoration are the ones that have the largest normalized differences between control and treatment.

The normalized difference is a measure of how different the covariate distributions are for treated and control units. A commonly used threshold for a substantial difference is greater than 0.25 standard deviations. We now include a standard reference for this threshold (Imbens 2009). To clarify, table B4 shows the covariate and outcome variable means and normalized differences prior to matching. In that table, we expect there to be differences in both outcome variables and covariates because we haven't yet conducted the matching. Table B5 shows the covariate and outcome variable means after matching. Here, we expect that if we have achieved good balance in the matching, there will not be normalized differences greater than 0.25 for any of the matching covariates or pre-treatment outcomes. We do, however, expect that if there is a positive treatment effect of the program, there will be meaningful differences in post-treatment outcomes (net forest recovery 2010-2019 and forest recovery 2010-2019). The results are consistent with these expectations.

Table B8: Not clear what are land surface categories, nor geology and bioclimate.

These refer to the USGS data presented in the materials and methods section. We have added a note to the table notes indicating the source of the data.

Table B9: There is one column missing.

We apologize, this was a mistake in the table note. The "full" results are in the previous table. This table shows results for each state in the sample. We have updated the table note to reflect this.

Supporting policies: the Forest Code and the CAR: Some of this information needs to be in the main text and then you can refer to this section for further info. Here you need to define what are Legal Reserves and APPs.

We have updated this section to provide better definition of these terms. They are introduced in the main text now in the third paragraph of the introduction and explained further in the supplemental information.

Role of PACTO: Why restoration in the tropics is complex needs reference.

We have included two references here.

Role of Local NGOs

I think the case of the rural settlement was never mentioned before so this needs a bit more context.

We have moved our mention of rural settlements to the first paragraph of the "Field interview insights" section. In that paragraph, the following context for rural settlements has been added as a footnote: "Rural settlements are comprised of agricultural plots that are managed independently. They are part of the National Agrarian Reform Program and are distributed to families in vulnerable situations. They are managed by the National Institute of Colonization and Agrarian Reform (INCRA), which supports development initiatives in these areas\cite{Pereira2022}."

Legal Compliance and Enforcement: Small landowners are also dismissed of restoring LR, what can help explain their lack of awareness of restoration obligations.

We now mention this fact in this section.

2nd. Paragraph: BAF was not defined before in the supp. Mat.

We now define it here.

5th. Paragraph: *I was not aware that there was a size threshold for landowners in the CAR. Is that a fact?*

Thank you for pointing this out. The threshold was based on a comment during an interview. But, in fact, the NVPL mandates that all rural properties and possessions must register with CAR. We have removed this assertion and changed the language to only refer to size as a criterium for enforcement: “Clients of NGO 1 may be landowners not registered with CAR or too small to be a priority for enforcement agencies, reducing the legal incentive to restore.”

Figure F5: Is that restoration or the treatment -- adherence to pacto – that is less effective?

This figure represents the interaction between the treatment effect and proximity to cities. It demonstrates that the treatment effect is lower closer to cities, especially within 10 km of distance. Our theoretical framework and the interview information suggests that this is likely because this land is more valuable in alternative uses. This may mean that follow through on restoration initiatives is less and they are less effective. Unfortunately, we cannot know what the mechanism is for sure without further field visits to a substantial number of these parcels. We highlight in the discussion section that it would be interesting in future work to learn more about variation in treatment by landholding size.

Responses to Reviewer 2:

General Comments: This is an interesting and relevant research that focus on a well know and large-scale restoration programme and network that takes place in the Brazilian Atlantic Forest and that aims at promoting forest restoration by supporting private landowners in different ways. The work is novel and important as it brings to light i) the role of a large-scale restoration programme that could be used as model around the globe and ii) the opportunities and obstacles for these types of initiatives to have positive impacts on restoration. The work shows that the PACTO was responsible to promote net forest restoration inside its partner areas, when compared to control areas. The manuscript also includes an interview component, complementing the results and discussions around obstacles related to conservation in private lands.

The research methods are sound, being considered among the most robust methods for impact evaluation, and the work presents interesting results and discussion that are relevant to a wide community. Yet, there are some improvements in text flow, clarity of methods and connection of quantitative and qualitative analysis that should be made.

I detail below some problems and suggestions for improvement.

Thank you very much for your careful reading of the paper. We are glad that you found the evaluation methods to be valid and the findings relevant to a broad community. We have revised the paper substantially in light of your suggestions and think that this has improved the flow and clarity. We hope that you will find the same.

The text is somehow repetitive. For example, the research objectives were presented in more than one place, written in different ways. Some parts of methods (maybe due to methods subsections) are also repetitive and sometimes confusing. More will be mentioned about this below.

We appreciate your attention to the flow of the manuscript. We have reassessed the overall structure of the manuscript and made changes throughout with the goal of increasing clarity and reducing repetition. We provide additional responses to your specific points below.

Interviews: It is great that the authors included a qualitative analysis based on interviews to complement quantitative ones, and I find it a great opportunity to make the article more robust and interesting. However, there are several improvements that need to be made, such as:

There is no description of the questions asked in the interviews. These should be stated in the SM so the soundness of this part of the analysis can be evaluated. More details about questions, and how these were applied are important for the type of information that needs to be collected.

Yes, we agree with you and we have now included the interview questions as an appendix. Following semi-structured interview methods, these conversations were open, and so the questions served more as a guide than a protocol. They also varied depending upon the actor and we have included the different sets of questions in the appendix. Hopefully being able to see these questions will help clarify the process for readers.

In the article, authors mention that the interviews are for understanding the drivers and mechanisms of PACTO for restoration. But it is not very clear how the quantitative analysis and these will be integrated. Important to make it clear.

We have substantially rewritten the results section as well as a large part of the discussion section in order to more clearly illuminate the links between the qualitative and quantitative work, and also to highlight conclusions that come specifically from the interviews. We see the qualitative interviews as integrated with our quantitative analysis because: 1) They help to identify possible context-specific factors influencing adoption of restoration or serving as barriers to restoration. This then informs our choice of matching variables in the quantitative analysis. 2) They help to identify potential mechanisms through which PACTO works, and this allows us to generate testable hypotheses about when and where the program may be more or less effective. We have sought to clarify these points throughout the revised text.

There is no information about the interviews in the Methods part of the main article.

This is also an important point. Although there was reference to these interviews in the main text and a figure describing who was interviewed, we agree that more information was needed. We have now included a section on the interviews in the methods that explains what we did and how the analyses are integrated.

Throughout the results, it is hard to know what information comes from the respondents, other articles, or authors opinions/perceptions. These need to be referenced.

We have entirely rewritten the section of the results that uses the interviews in combination with our theoretical framework in order to clarify the sources of the information.

Results from interviews are mainly described in the SM, and are extremely interesting, adding a soul to the manuscript, and allowing the reader to understand the perception of actors in the field. Of course, there

is a balance regarding the amount of information you include in the main manuscript, but I think the main text would benefit immensely by including some more findings from the interviews.

We appreciate this suggestion and have sought to integrate more of the interview information into the second section of the results and also in the discussion.

Based on the above, I suggest the authors have a section where they can provide more details about what interviewees said and relate it to the quantitative results and relate to the context (very well presented in the SM) in the results and maybe discussion. The amount of information that should be included can be balanced with the removal of repetitive text.

Yes, we have sought to better integrate key information from the interviews into the main manuscript.

Introduction:

1st Paragraph talks about “private benefits”. Can authors explain what it means?

We mean this in the sense of who gets the financial or environmental benefits of restoration. “Private benefits” are those that accrue to landowners (profits, for example, or localized changes in water). “Public benefits”, in contrast, are those that go to other people in society. In the context of restoration, these benefits would include carbon sequestration, biodiversity, or regional watershed protection. To try to avoid field-specific jargon, we have substituted “long-term profits or improved local water availability” for private benefits in the first paragraph.

2nd paragraph has a description about PACTO, but it is still unclear how it works (it will only become clear later in the text). So the next paragraphs can be better understood, it would be important to include more detailed information about PACTO here.

We have rewritten the introduction to provide more detail about how PACTO works. Specifically, we have emphasized that PACTO is a regional knowledge-sharing network that supports government and non-governmental organizations which implement forest restoration. We also refer to the organizational figure (Figure 1) so that readers have an earlier pointer to this information.

3rd paragraph. At the end of it, the authors mention opportunity costs and enforcement probabilities, but this only gets clear later in the text (and maybe in the SM). Needs some more explanation.

We have modified this paragraph to specifically outline that we test for heterogeneity by distance to city (a proxy for opportunity cost, or the foregone profits from alternate uses of land) and state entity (because the risk of legal sanction for violating minimum native vegetation requirements varies by state and was highlighted in the interviews as a key factor driving restoration uptake and maintenance activities).

Results

2nd paragraph could use some information that is currently in the SM to be clearer, such as more details on the choice of studying the period before 2009.

We have explained in greater detail here the comparison that we are making (enrolled versus unenrolled before and after 2009), and hope that this will not be redundant as per your point 1 above.

Figure 2: can you include in this figure the subset of the areas that were evaluated? It would be interesting to see if they are concentrated in one state or region.

The aqua colored points in the original figure are the parcels that were supported by PACTO. The tend to be concentrated towards the coast but there are a few in more westerly regions of Parana, which means that the map shows quite a lot of area where there are no parcels (particularly in Minas Gerais). To clarify, we have changed the note and selected a darker color to highlight the analysis parcels. In the Materials and Method section we also specify the percentages of the sample that come from each state.

I would also suggest the design sampling method with the grid cells presented in SM should also be placed in the main text.

We have now briefly described the unit of analysis in the results section and also placed this information about sampling design in the materials and methods section.

The results for 2019 are quite drastic, particularly as we are seeing data from inside the treated parcels. The authors haven't discussed anything about that, and although it might be related to the deforestation in the Bolsonaro period, it would be interesting to know how this has affected the areas inside PACTO partners. It might elucidate something about how the context or current policies can influence a program's action.

It is true that both the basic time trends and the event study, which uses regression analysis, demonstrate a big drop in restoration activity in 2019. We agree that this is likely due to the beginning of the Bolsonaro regime. The basic trends shown in figure 3 are actually showing what is happening inside of the PACTO lands (in blue) versus the non-PACTO matched controls (in red). The event study (now Figure 5) shows the year by year treatment effects, which are essentially the differences between the red and blue lines from figure 3 while controlling for temperature, precipitation, and fixed effects. However, it is important to recognize that the outcome variable is measured for these two figures annually, which means that the total restoration effect is the sum of all of these across the post-treatment period. So, while it is true that 2019 stopped restoration progress, it did not move it substantially backwards. The full estimated effect remains a 9-21 percentage point increase in net forest recovery as estimated in the difference in differences approach. We make this point in a new paragraph added to this section.

Section on drivers of restoration success (Results)

It is not clear where the framework comes from and what it states. I suggest moving some information from the SM.

We have entirely rewritten this section to better summarize the framework and interviews, and also to connect the quantitative and qualitative parts of the work. We have also changed Figure 4 in order to better emphasize the link between the reported results in the text and the figure.

As mentioned earlier, it is hard to know where the information comes from: interviews, context or literature. I suggest including more information about the interviews, if necessary, explaining some of the context as done in the SM. Otherwise, it is hard to make a connection to the main goal of the article and with the factors that might influence restoration.

We have expanded this section and included more of the information from the interviews. We have sought to better link the quantitative heterogeneity analysis to the qualitative work in the results section.

c. Figure 6. Are the environmental fines used in Figure 6 related to forest code compliance only? Or general state applied fines for any environmental aspects?

In Figure 6, the fines are those issued by IBAMA, which is the federal enforcement arm for environmental law. The fines we include are only those related to “flora” violations, which are those affecting native vegetation. Thus, we do not include fines related to unrelated environmental harms, like pollution or mining.

We added clarification to the end of the Data section: “Reported fines are those issued by IBAMA for flora-related violations affecting native vegetation.” We also include a footnote defining IBAMA.

Discussion: I think it can be improved by connecting better to the findings from the interviews and context.

Yes, we have edited the discussion section with this comment in mind.

Materials and methods

I suggest restructuring the methods subtopics, as they are quite repetitive and confusing. Do you need an overview section? I would replace it with a figure. My suggestion for the sections is: i) data and study area, ii) forest cover data, iii) matching (including covariates for matching). It is important to differentiate what was covariates for matching and for regression, why you chose each of them for both analyses, and why they are different (this is something that gets confused throughout the text and in the SM), iv) difference in differences with details; v) interviews! There is no information about the interview part, from which state they were, questions asked, etc.

Thank you for these suggestions. We have substantially edited the materials and methods section, including removing the overview section. Our subsections are: Unit of analysis and data sources; estimation strategy step 1: matching, estimation strategy step 2: difference in difference regression, and stakeholder interviews.

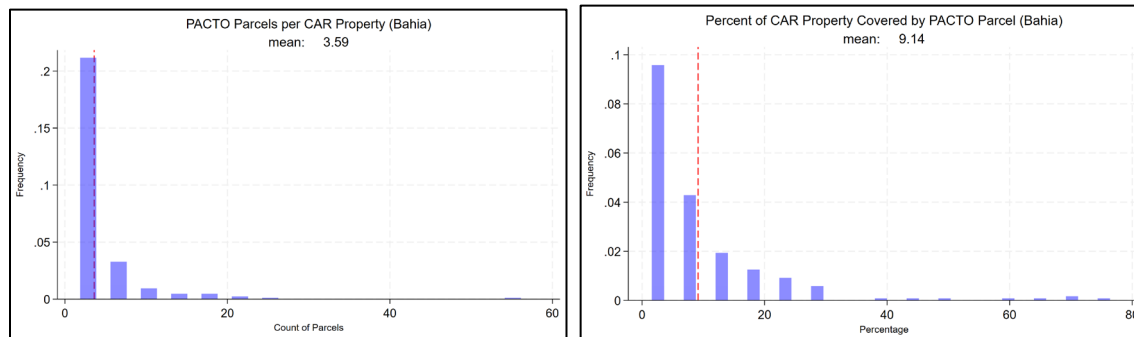
1st paragraph (item 4.2) it is still not clear who own the land and who restores. It is important it is stated earlier, and why the importance of explaining well roles in the PACTO network.

All of the land supported by PACTO is owned by private landowners who are collaborating with PACTO implementers. We have sought to clarify the roles of PACTO by revising the introduction and the results section. The PACTO implementers provide varying degrees of restoration support, as described in the text.

2nd paragraph (Methods). You could estimate the number of parcels in the same property using the CAR. It would be interesting to see if the analysis was made with a great number of the parcels belonging to the same owner. Could this somehow impact the analysis, and how?

This is a great idea. We had initially hoped to do this. However, not all parcels are registered within a CAR, or at least the CAR that are available for public download. We did obtain these boundaries for the state of Bahia, and found that on average, for parcels that did fall within a CAR, there were 3 to 4

treatment parcels within each property on average, constituting about 9 percent of the property. We made some summary figures for your perusal:



The important way that this could impact our analysis is through potential correlation in management strategies across PACTO parcels within a property. We address this (and did in the previous version as well) by clustering our standard errors, which accounts for this potential correlated error structure. Since we do not have property level information for all states, we cluster at the municipality level. Our municipality level clustering is actually more conservative than clustering at the property level, which means that results with property level clustering would likely have greater statistical significance than our current results. We explain this in section 4.3.

Why have you used PA coverage as a covariate? Why not exclude the PA areas from the analysis? Also, why haven't you used SNUC data as it is in some cases more reliable than WCMC one? The WCMC one might include also IL, for example. Would it be appropriate to include them?

Regarding the dataset choice, our protected area shapefile comes from the 2022 Version of the World Database of Protected Areas (WDPA), which is a joint product of the World Conservation Monitoring Centre at the United Nations Environment Programme (UNEP-WCMC) and the International Union for Conservation of Nature (IUNC).

To ensure that we use protected areas actually active under Brazilian law, we checked the spatial overlap between the WDPA and the SNUC to determine if WDPA excludes any active protected areas. We find that WDPA generally has high fidelity to SNUC, though there are some minor exceptions. We then checked whether these exceptions affect our results and determine that they do not. Specifically, we look at the protected areas established as of 2000 for both datasets, per our methodology. We find that non-overlaps affect less than 1% of total parcel areas, which has a negligible impact on our matching and results. We add a footnote to the end of the Data section clarifying this check.

We use PA coverage as a matching covariate because about 6% of the sample falls within PAs. We had initially wanted to test whether or not PACTO was more effective inside of PAs (it is not statistically different). However, upon your suggestion, we have also run an estimation where we exclude parcels falling inside PAs. This has no meaningful effect on the estimates.

Why buffer of 500m? Is it enough for spillover effect?

This is a good question and was also raised by Reviewer 1. The purpose of excluding potential controls from within a 500 m buffer was to avoid contamination of results from land-shifting type spillover effects within an owner's property or information spillovers to close neighbors. However, in order to test the robustness of this assumption, we also made a 1,000 m buffer and re-ran our matching scheme to exclude controls from this larger buffer (Table F14). Finally, we reran the estimation including all potential controls. We find no statistical difference between our main results (500 m exclusion buffer), results with no buffer, and results with the 1,000 m exclusion buffer. This suggests that there are not localized spillover effects, although of course it does not rule out broader economy-wide price effects of restoration. We think that in this case such effects are probably not plausible given the scale of the restoration, which is unlikely to be large enough to affect agricultural prices.

REVIEWER COMMENTS

Reviewer #1 (Remarks to the Author):

I have carefully read the new revised version of the manuscript and the authors responses to my previous comments. I believe the manuscript has been substantially improved, and the authors have satisfactorily addressed my concerns.

However, one of the questions I raised on the first round of review was related to the proxy used in the manuscript to access land opportunity cost: distance to urban centres. I have argued that this variable could fail to capture some nuances. For instance, different states having very different land opportunity costs as in land value and forgone production at the same distance to an urban centre. While I am convinced by the authors responses and supplementary analysis that using a different variable would probably not change the overall results and is not central to this work, they have also mentioned that the main reason for not using revenues from agriculture or land value was the lack of data. I would like to share some examples of previous works on related fields that have managed to deal with the data limitations and to produce spatial explicitly layers of opportunity cost. For instance, by using land value data:

Strassburg, B. B. N. et al. Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. Nat Ecol Evol 3, 62–70 (2019).

Land value data is currently available for different states and land uses from the federal government: <https://www.gov.br/receitafederal/pt-br/centrais-de-conteudo/publicacoes/documentos-tecnicos/vtn>

Or using expected revenues:

Niemeyer, J., Barros, F. S. M., Silva, D. S., Crouzeilles, R. & Vale, M. M. Planning forest restoration within private land holdings with conservation co-benefits at the landscape scale. Science of The Total Environment 135262 (2019) doi:10.1016/j.scitotenv.2019.135262.

Those methods can guide future analysis or help with sensibility testing for the robustness of using distance to urban centres as a proxy.

Thank you for pointing out these very interesting analyses. We agree that our current measure of distance to urban centers captures one dimension of opportunity cost but that it would be ideal to have parcel-specific measures of land quality or economic returns as additional measures of the opportunity cost of restoration. We also agree that further analyses like the ones you mention could be a compelling extension of our current work. In particular, understanding the correlation between more detailed opportunity cost data and restoration success could help with targeting where restoration programs like PACTO might most cost-effectively work in the future.

We appreciate the additional suggestions for data sources as well. We investigated each of these and there are unfortunately limitations for each one with respect to our study. Crucially, in order for

more detailed data to have power in our analysis, it would need to vary substantially within municipalities. Of the data sets above, only Strassburg et al (2019) fully covers the region that we are analyzing and varies within municipalities. The portion of the website to access this data seems not to be working (<https://www.iis-rio.org/en/projects/plangea/>) at this time. The land value data from the federal government is available but only for an unbalanced municipality panel (and starting in 2019, which means it could already be affected by the treatment). The Niemeyer et al. 2019 analysis has detailed enough data only for São Paulo. IBGE also has some data on yields, but it is also at the municipality level and does not cover our full panel.

We agree that data of this type can help to guide future analysis. We now note in the discussion section that additional analysis of opportunity costs and landowner decisions considering specific land value data is an important area for future inquiry and cite the Strassburg et al. and Niemeyer et al. papers.

In addition, I have some minor additional comments.

First section of Results

First session of results feels more like methods than results. I suggest incorporating to the previous session. For instance, the 1st paragraph of this session could be merged with the 2nd paragraph of the introduction to justify why there is such a coalition. Also, lots of the 2nd paragraph content was already said on the introduction.

Then, I suggest a concise paragraph on the introduction right before the last paragraph with the relevant information from paragraphs 2 and 3 of this section summarising what was done and then starting the results with the next sessions.

Thank you for these suggestions. We have modified the introduction to incorporate the information previously at the start of the results section, according to these recommendations. We believe this improves the exposition as intended by the reviewer. We have also moved some of the detail about enrollment to a different part of the results section because we feel that this detail best fits as part of the data analysis.

Maybe even eliminating the subtitle results and starting with:

*Drivers of restoration success: benefits and costs to landowners and institutional context
(I leave it to the authors whether or not they consider this last suggestion adequate).*

We agree with this suggestion in spirit. Unfortunately, Nature Communications mandates very specific headings within the manuscript and so the overall section must be titled “Results” to comply with their instructions. However, we now start directly with the first subtitle.

Legend Figure 1

You could include the % of area under PACTO in each state in the legend, e.g. Bahia (32% of parcels) and so on.

This information is now in the section “Participation in PACTO induced additional restoration.” We appreciate the suggestion but thought it was too much detail for the legend.

Drivers of restoration success: benefits and costs to landowners and institutional context

Lines 121-123: This sentence should be reframed to sound more like a result than methods. For example: The interviews contributed/gave us an understanding of the restoration environment and drivers of impact. And then be placed on the beginning of the next paragraph.

Thank you for this suggestion; we have done this.

Lines 127- 128: The sentence directing the reader to the Supp. Mat. would be better right after when the forest code is mentioned, between brackets. As it is, it breaks the fluidity of the reading.

We have moved this reference to the end of the sentence to which you refer. Due to the formatting requirements of the journal, we have consolidated the sections of the Supplementary Information, so many of the references now refer to the same Supplementary Section (Supplementary Discussion).

Also, the following sentence “Because of these rules” is not very clear. Because of the sanctions imposed by the legislation, which include fines and ..., according to (...)?

We have modified this sentence to:

Because of the risk of financial sanctions due to violations of the 20% forest coverage mandate in the Forest Code (according to at least one restoration consultant and a state prosecutor that were interviewed), the perceived benefits of forest restoration are related to the probability that the law is enforced.

Figure 4:

The legend on the left panel is partially erased.

Thank you for catching this; we have updated this figure.

Heterogeneity in impacts consistent with key drivers of success

Line 243: land or property size rather than landowner size.

We have changed this to “property size.”

Reviewer #3 (Remarks to the Author):

This study, “Scaling forest restoration in the tropics: evidence from Brazil’s Atlantic Forest Restoration Pact” presents compelling evidence that assistance to landholders to restore forests on their lands can indeed have influence on landscape-level regeneration. The large dataset is impressive and covers a critical area both for conservation and human livelihoods. I commend the authors on this work and believe it will make a valuable contribution to Nature Communications.

Thank you for reviewing the paper and for your constructive comments.

My only substantial concerns are that the post-intervention time-scale is short for classification of actual “Forest restoration” and the 2019 cutoff date seems arbitrary at this point. I would normally want to see more interrogation of the map products to determine that they are indeed capturing reforestation satisfactorily. Here I find that the robust statistical approach provides a convincing case that there is indeed a significant treatment effect in growth captured by the maps regardless of any measurement error. Nonetheless, I would suggest the authors exercise a little more caution in labeling this growth as “forest restoration”.

It would also be beneficial to extend the analysis a few years beyond 2019. I assume that this was the last year available when the analysis was first conducted. However, MapBiomas seems to now have maps available through 2022 if not 2024 at the link cited. Extending the analysis a few years would help contextualize the 2019 results – is this year indeed an outlier or is it part of a longer trend extending through Bolsonaro’s term? (if so, the impact would indeed largely be reversed). A few additional years of analysis would also help to allay concerns that the regrowth is not actually forest or cannot yet be perceived in the satellite images if the actual treatment started later. If it is too difficult to rerun the full analysis with the more recent MapBiomas product, I suggest at least running a sub-analysis (included in the appendix) to show that 2019 is indeed an outlier.

We agree that there can be issues of measurement error in classification of forest recovery and have sought to be clear about which data sources we have used for our dependent variable. We reviewed the MapBiomas methodology and our data processing. As we now write in the data description: “MapBiomas applies a ‘per pixel classification trajectory analysis’ that explicitly validates forest regrowth and deforestation events. The analysis utilizes a 5-year moving leads/lags window to verify change persistence. For example, a pixel classified as forest regrowth in 2015 must have an anthropic land use classification in 2013 and 2014, followed by three years of native vegetation from 2015 to 2017, among other persistence criteria.” This methodology within MapBiomas is intended to ensure that classifications of “forest regrowth” are genuine. For this reason, we feel our description of the results as indicating forest restoration is reasonable.

Our analysis originally ended in 2019 because of data availability at the time we wrote it. However, we agree that an analysis of the robustness of the results using recently released data is warranted. In order to address this new request to use an extended series of data, we spent considerable time and downloaded Collection 9, which is the most recent version. Collection 9 adjusts the classification algorithm considerably, adding two land use classes and using somewhat different rules for forest transition classifications.

In a new section of the appendix, we briefly describe these changes in the MapBiomas Collection 9 data and provide a comparison analysis. In particular, we show the figure that delineates the year by year forest recovery variable after matching, as well as the main difference in difference specification. Overall, comparison of the Collection 6 and Collection 9 figures demonstrates that Collection 9 classifies considerably less restored forest in general because of the changes in classification algorithms. However, our program impact results are robust to using the new collection and the longer time series. The difference in difference specification including years through 2021 produces point estimates that are smaller but statistically indistinguishable from the ones that we estimate using Collection 6. These exercises can be found in Supplementary Figure 7

and Supplementary Table 15. This indicates that positive program impacts were not reversed by the inclusion of data from more recent years.

We have added a brief description of this robustness check to the Materials and Methods section and we point readers to the additional analysis in the Supplemental Information.

We also note that in working to review our first set of data and create an extended data series, we discovered a processing error on our part that affected the year 2019 data only. For MapBiomass Collection 6 (downloaded 2022), while there were observations on deforestation for 2019, there were no observations for restoration due to the 5-year moving window methodology. Because our outcome included the sum of restoration and deforestation (net recovery), this processing error for 2019 went undetected. Given this data gap, we should not have included the year 2019 in the original series.

We have now corrected the original dataset and the paper results to exclude 2019. We have also corrected the relevant tables and text in the paper. Excluding this final year does not meaningfully change the results of the prior analysis (except that the main results are slightly larger and there is no longer the apparent outlier in 2019). Given that the original methodology, data series and results have already been through two rounds of review and incorporated comments according to the other two reviewers, we retain the use of Collection 6 in the main paper.

Minor issues:

Line 96: “the total area is roughly twice the land area of the District of Columbia in the United States” – I am not sure this is the most helpful illustration of the size for most readers and can perhaps be dropped altogether.

We have dropped this.

Figure 3: Note says “treated (red line) and untreated (blue line)” but legend and story have it the other way around.

Thank you for pointing this out! We have changed the figure note.

Figure 4: “dots indicate this treatment effect evaluated at 25, 50, 75, and 100% coverage of the analysis units in a restoration parcel”. Clarify what is meant by “coverage” here. I assumed it meant vegetative coverage until reading the methods much later.

Thank you for this suggestion. We modified the text here to: “The treatment variable in this case is continuous, and the dots indicate the treatment effect evaluated at 25, 50, 75, and 100 % of the cell under restoration.”

Line 347: Change “coverage categories” to “land cover categories” for clarity

Done.

Figure 6: It seems that this could be presented in a single figure, with the fine value as the X axis (and state labels inserted where they fit along that axis). The only reason for not doing so that I can see is that the clean gradient shown in the top figure would be muddled, but then this gradient is misleading.

We have modified this figure and hope that you find it improved. The two subfigures always had the same order, but we have now brought the two pieces closer together and harmonized the distances.

Line 370 – 375: The temperature and precipitation data are discussed here with the matching variables but are not used in the matching analysis. I believe they are used as covariates in the regression analysis. This should be clarified here.

We have now clarified this in the data description section.

Table B5: Post-Matching Means: Maybe specify here that Net forest recovery (ha), 2010-2019 is the dependent variable and thus not matched here.

Thank you for this suggestion. We have separated the table into “post treatment variables” and “pre treatment variables and included subheadings within them.

Overall, this is a very nice piece and I thoroughly enjoyed reading it.

Thank you!

Reviewer #3 (Remarks on code availability):

The code is not yet available at the link provided. I understand that it will be uploaded there upon publication.

We are uncertain why the link was not live when you looked at it. We have republished it and hope that this corrects the issue.

REVIEWERS' COMMENTS and responses

Reviewer #1 (Remarks to the Author):

Dear authors,

Thank you for your thoughtful revisions in response to the previous round of peer review. I have the updated version of your manuscript, and I appreciate the effort you have put into addressing the comments and improving the clarity and rigour of your work.

I find the study to be well-conducted and the conclusions well-supported by the evidence provided.

At this stage, I do not have any further concerns, and I am pleased to recommend your manuscript for publication. I believe it will make a valuable contribution.

Thank you for your additional review of the paper. We are glad you found the revisions to be in keeping with your suggestions and that you found the study to be well-conducted.

Reviewer #3 (Remarks to the Author):

I have read the revised version of “Scaling forest restoration in the tropics: evidence from Brazil’s Atlantic Forest Restoration Pact” and agree that the authors have addressed all of the concerns I expressed in my previous comments except for one (regarding Fig 6).

I appreciate the extra work taken to evaluate the more recent MapBiomass data and think that showing this updated analysis adds to the value of this analysis. While I am not as optimistic as the authors about how the new trend line will extrapolate to subsequent years, I understand that this is beyond the scope of this research.

Thank you for reviewing the paper and we are glad you found that we addressed all of your concerns except one.

My only pending concern is that Fig 6A still does not have a quantitative x axis (as seems implied by the point sequence). I do not understand why the x axis cannot be the fine amount -- essentially moving Sao Paulo and Minas Gerais before Espirito Santo and Rio de Janeiro. Not doing so seems misleading (even if B provides the data for the correct interpretation -- why require the reader to do this task mentally?)

We agree with the reviewer that there might be other ways to present this figure. Currently, the order of states is determined by part a of the figure. In part a, we show the state specific estimates of PACTO impact. The left-right order is determined by the magnitude of these point estimates. In part b,

we show the value of the related fines per forest hectare for each state. The states are shown using the same order as in part a, which allows for an easy visual comparison between the rank orders in part a vs. part b. We believe it is most clear to maintain this way of showing the results, but we have sought to better explain the ordering by adding notes to the caption. The caption now specifically says that in part a, states are ordered by the magnitude of the point estimates, and in part b, that states are shown in the same left-right order as part a. There is no way of displaying magnitudes on the x-axis, since these are associated with states, not values. The magnitudes for each state are measured on the y-axes. We hope this added text addresses the reviewer's concern.

Also, I was able to access the code at the link now and don't see the code related to the MapBiomass analysis. Can that code be included?

We had started the code available from the already processed data. We have now included the code that includes this first basic step of processing to the same Dataverse repository.

Outside these small requests, I think this manuscript is ready for publication and will make a great contribution to Nature Communications.

Thank you.

Reviewer #3 (Remarks on code availability):

I do not have Stata, so did not review the code specifics. However, it looks to me that the code related to the MapBiomass data extraction/prep is not included at the link provided. It would be ideal if this code could be included.

Thank you, yes, we have now included this code.

The study entitled “*Scaling forest restoration in the tropics: evidence from Brazil’s Atlantic Forest Restoration Pact*” has performed a robust analysis of the effects of a program of incentives to promote restoration within private land in Brazil. To do that, they have worked with post-matching differences-in-differences estimation to compare the trajectories of parcels of land adhered to the program (treatment) with similar parcels non-adherent (control).

I believe the work is original and highly relevant to the interface between Conservation Science and Policy, by evaluating and discussing the effectiveness and pathways to upscale ecological restoration, with obvious applications in the real world.

One of the key features of this work is having a large dataset of areas undergoing restoration and a clear intervention. They were also careful enough to support their choices of co-variables for matching by interviewing relevant stakeholders.

Overall, the data and methodology are adequate and give support to the main conclusions and the quality of the study is satisfactory.

I have, however, some issues that need to be addressed by the authors if this manuscript is to be published.

The manuscript lacks definitions of key terms that are important for a broader audience, both terms from the restoration science and from the Brazilian legislations regulating restoration within private land.

I also think that in some cases there is a disconnection between the main text and the supplementary material. Some information from the supplementary material needs to be brought to the main text but mostly, the Supp. Mat. deserves to be more emphasized in the main text, directing the reader interested in more details.

I did not find any data or code, so I was not able to evaluate this aspect of the work.

My specific comments to the text are as follows:

Main text

Introduction

1st. paragraph

It would be useful to have references of how much land is privately owned to support the claim that forest restoration needs to include it (line 4).

The study has not been introduced yet nor the restoration program. This phrase needs to be reformulated. Perhaps: restoration programs can offer assistance(...)(line 9)and add some reference, for instance:

<https://www.sciencedirect.com/science/article/pii/S0169534722001719>

Similar to what? To the referred program, similar among themselves in general? I also think there is something missing here, like: While restoration initiatives are expanding rapidly due to....complete (ref!), there is little evidence regarding their effectiveness to ...deliver what? this need to be cleared said (line 10).

2nd. paragraph

Because the article aims for a broad audience, I suggest some short definition of terms such as natural regeneration and assisted Regeneration. And why this depends on locality.

“(...)requires private landowners to preserve natural vegetation(...)”: to preserve and restore if this required preserved area is not present. This need to be explained.

I also suggest mentioning the more up-to-date name: Brazil's Native Vegetation Protection Law, also known as the Forest Code. And refer to the supplementary material for more details.

Also include a range. Just substantial is too vague.

3rd. paragraph

I think you can be clearer on what do you mean by opportunity costs. Land opportunity cost?

Enforcement probabilities is also too vague. Legislation enforcement concerning mandatory forests within property...

4rd. paragraph

“(...) depending on the proportion of area (...)”. of which area? property? some other domain? not clear?

I realized later this is explained in the results. But it needs clarification here to, or a reformulation to a more general statement.

Results

1st. paragraph

“(...)By contrast, in the Amazon region much more land is public or in indigenous territories. (...)”. I think this is not very relevant.

“(...)Nearly 90% (roughly 1.1 million km²) of the BAF (...) over the last 500 years(...)”. Reference?

I think you should add something about the relevance of reversing this trends for ecosystem services, since so many people live on the BAF, and also to reduce species extinction on this biodiversity hotspot.

3rd. paragraph

“(…)A complication for our analysis is that land area units (grid cells) may be partially or fully supported by PACTO (Figure B2) (…).” It would be easier why this happens with a bit more context. Something like: Because our units of analysis were 2ha in size, a complication of our analysis is...

Legend Figure 3.

Estimated is redundant.

proportion of our units of analysis treated

4th. paragraph

Excluding control cells withing 500m of the treatment makes the effect relevant. Could it be also due to some neighbour effect where landowners not enrolled with pacto also decide to undergo restoration when they see benefits from their neighbours?

Legend Figure 4.

I would not use the word “plots”. It would also be interesting to explain what the time-varying controls are. Also, instead of mentioning the cell, I would say something like our unit of analysis and explicitly say its size. I would also avoid et cetera.

5th. paragraph

If I understood correctly, 5000 ha is the restoration that can be attributed exclusively to the treatment effect, but there could be more areas restored than that, right? Otherwise, it's not very clear to me why not computing the total restored areas from the images.

Drivers of restoration success: benefits and costs to landowners and institutional context

2nd. Paragraph

The benefits are perhaps not obvious so it would be good to give some examples here, like you did for the costs.

“(…)Brazil's economic powerhouses (agriculture, cattle, and logging)”. Is it logging or forestry?

“(…)Since the opportunity cost of land is high (e.g., cattle farming earns an average of \$100/ha/year [12]), restoration (…).” This seems like a low opportunity cost, compared to other agricultural activities. Alo, one could claim that most restoration should for that reason target pasturelands.

Active restoration also needs to be defined.

3rd. Paragraph

I think this paragraph needs further development. What is the role of each of those stakeholders? Why having all of them is important? For ex. why NGOS are necessary?

Since this is explained further down, maybe a brief explanation on the necessity of all those actors, which will be further developed on the paragraph to come. I also think that part of the reason of having diverse stakeholders is explained in the next paragraph.

5th. paragraph

I suggest briefly explaining what a Legal Reserve is and referring to the supplementary material for further details.

I also I think there is something missing which is the effect of both the FC and the "Lei da Mata Atlantica", which makes deforestation illegal. This can be seeing as an additional risk to restoration, since the landowner will not be able to clear the land back again.

6th. paragraph

The CAR requires some context for non-Brazilians and readers unfamiliar with the details of the legislation in general. Same comment as for the Legal Reserve.

What kind of credit? bank loans for agricultural activities? How does this work? be more specific.

I am not sure what you mean by water restoration.

Heterogeneity in impacts consistent with key drivers of success

"(1/km to city)". I did not understand why you have considered distance as a ratio.

2nd. Paragraph

This effect seems also connected with land opportunity cost. was that included in the model? By isolating the effect of o.c., the effect of the state itself would be more clear.

3rd. Paragraph

I wonder if fines per capita is the best way of considering the importance of fines. The number of fines probably depend more on the number of properties -- or the area of the state - than on its population, especially because most of the population is located in cities.

Figure 6.

This figure made me think if the total area under restoration, as part of the PACTO or not, would also follow this pattern. Because a smaller effect could also mean that

both treatment and control are more similar .e.g. are restoring areas. Can you test for that?

Also review the legend. The text could be improved.

Discussion

1st. paragraph

“There are two exceptions to this (...).” This is a very strong statement, consider attenuating it.

Also, not clear if the second exception is the Chinese program.

2nd. paragraph

Be specific about the resolution:

via 30m resolution satellite imagery, such as the ones we used for this study...

“Restoration in later-enrolled cells will (...).” Review tense.

“(...) due to concerns about that the measurement error in the outcome is likely to exceed the useful information for these very small parcels.” This sentence is not very clear. It needs rephrasing.

3rd. paragraph

Our dataset sounds better.

4th. paragraph

But how about land opportunity cost as in land value? This could be estimated spatially explicitly and probably has very different patterns in different states.

5th. Paragraph

There is a very long and useful discussion in the supplementary material that deserves to be mentioned in here to direct the reader.

Materials

1st. paragraph

The fact that multiple parcels can be managed by a single landholder needs to be added to the limitation discussion as landowner's behaviour can affect the effectiveness.

Methods

In the supplementary material, the authors mentioned that the importance for water provision is also used to choose areas for the PACTO. If this is the case, and also considering that according to the landowners water is associated with forests – what

could motivate restoration -- shouldn't a variable capturing this be included as covariable for matching?

2nd. paragraph

"(...) higher(...)" in altitude

"(...) farther from cities (...)"

If the matching was done by municipality, how come the controls could have different municipalities ID than the treatment?

3rd. Paragraph

How about the other co-variables described in 4.4? were they included in the matching or not?

Post-matching regression

2nd. And 3rd paragraphs

Most of those paragraphs would be better placed in Results and Discussion sections.

Supplementary material

Table A. My perception is that is more usual to add the notes information together with the table title. In addition, the Note is not very clear, I suggest some rewriting: e.g. it is no clear what (1), (2) and (3) represent.

Extended methods

1st. paragraph

I would say additional methods.

Be more specific of what you mean by spatial issues.

Matching and difference in difference estimation

1st. paragraph

Add some reference on the goal of matching.

"Clearly, the treated group has a much higher propensity for restoration going into the treatment period (...)" I suggest something like: Even before the treatment event.

2nd. Paragraph

Is protected area a binary category? or some proportion? Clarify how this variable was accessed.

3rd. Paragraph

“(...) in the denominator of the outcome (...)”

4th. Paragraph

“(...) consistent with our main findings (...)”

5th. Paragraph

“Cell fixed effects eliminate the influence of observable fixed confounders like slope, elevation, and bioclimate is eliminated as well as that of all unobserved fixed confounders”. This sentence is confusing, consider rewriting.

6th. Paragraph

“Clustering also alleviates spatial autocorrelation to the extent that landscapes are vary over larger, rather than finer, areas, like municipalities such that within municipality variation of landscape features is low”. This sentence also needs rewriting.

Figure B1

The classes seem more a reclassification of Mapbiomas than original classes from the database.

Table B4.

The 0.25 threshold is based on what? This threshold seems very important as in the next table, both variables reflecting restoration are the ones that have the largest normalized differences between control and treatment.

Table B8

Not clear what are land surface categories, nor geology and bioclimate.

Table B9

There is one column missing.

Supporting policies: the Forest Code and the CAR

Some of this information needs to be in the main text and then you can refer to this section for further info.

Here you need to define what are Legal Reserves and APPs.

Role of PACTO

Why restoration in the tropics is complex needs reference.

Role of Local NGOs

I think the case of the rural settlement was never mentioned before so this needs a bit more context.

Legal Compliance and Enforcement

Small landowners are also dismissed of restoring LR, what can help explain their lack of awareness of restoration obligations.

2nd. Paragraph

BAF was not defined before in the supp. Mat.

5th. Paragraph

I was not aware that there was a size threshold for landowners in the CAR. Is that a fact?

Figure F5

Is that restoration or the treatment -- adherence to pacto – that is less effective?

Scaling forest restoration in the tropics: evidence from Brazil's Atlantic Forest Restoration Pact

General Comments

This is an interesting and relevant research that focus on a well know and large-scale restoration programme and network that takes place in the Brazilian Atlantic Forest and that aims at promoting forest restoration by supporting private landowners in different ways. The work is novel and important as it brings to light i) the role of a large-scale restoration programme that could be used as model around the globe and ii) the opportunities and obstacles for these types of initiatives to have positive impacts on restoration. The work shows that the PACTO was responsible to promote net forest restoration inside its partner areas, when compared to control areas. The manuscript also includes an interview component, complementing the results and discussions around obstacles related to conservation in private lands.

The research methods are sound, being considered among the most robust methods for impact evaluation, and the work presents interesting results and discussion that are relevant to a wide community. Yet, there are some improvements in text flow, clarity of methods and connection of quantitative and qualitative analysis that should be made.

I detail below some problems and suggestions for improvement.

1. The text is somehow repetitive. For example, the research objectives were presented in more than one place, written in different ways. Some parts of methods (maybe due to methods subsections) are also repetitive and sometimes confusing. More will be mentioned about this below.
2. Interviews: It is great that the authors included a qualitative analysis based on interviews to complement quantitative ones, and I find it a great opportunity to make the article more robust and interesting. However, there are several improvements that need to be made, such as:
 - a. There is no description of the questions asked in the interviews. These should be stated in the SM so the soundness of this part of the analysis can be evaluated. More details about questions, and how these were applied are important for the type of information that needs to be collected.
 - b. In the article, authors mention that the interviews are for understanding the drivers and mechanisms of PACTO for restoration. But it is not very clear how the quantitative analysis and these will be integrated. Important to make it clear.
 - c. There is no information about the interviews in the Methods part of the main article.
 - d. Throughout the results, it is hard to know what information comes from the respondents, other articles, or authors opinions/perceptions. These need to be referenced.

e. Results from interviews are mainly described in the SM, and are extremely interesting, adding a soul to the manuscript, and allowing the reader to understand the perception of actors in the field. Of course, there is a balance regarding the amount of information you include in the main manuscript, but I think the main text would benefit immensely by including some more findings from the interviews.

f. Based on the above, I suggest the authors have a section where they can provide more details about what interviewees said and relate it to the quantitative results and relate to the context (very well presented in the SM) in the results and maybe discussion. The amount of information that should be included can be balanced with the removal of repetitive text.

3. Introduction:

a. 1st Paragraph talks about “private benefits”. Can authors explain what it means?

b. 2nd paragraph has a description about PACTO, but it is still unclear how it works (it will only become clear later in the text). So the next paragraphs can be better understood, it would be important to include more detailed information about PACTO here.

c. 3rd paragraph. At the end of it, the authors mention opportunity costs and enforcement probabilities, but this only gets clear later in the text (and maybe in the SM). Needs some more explanation.

4. Results

a. 2nd paragraph could use some information that is currently in the SM to be clearer, such as more details on the choice of studying the period before 2009.

b. Figure 2: can you include in this figure the subset of the areas that were evaluated? It would be interesting to see if they are concentrated in one state or region.

c. I would also suggest the design sampling method with the grid cells presented in SM should also be placed in the main text.

d. The results for 2019 are quite drastic, particularly as we are seeing data from inside the treated parcels. The authors haven't discussed anything about that, and although it might be related to the deforestation in the Bolsonaro period, it would be interesting to know how this has affected the areas inside PACTO partners. It might elucidate something about how the context or current policies can influence a program's action.

5. Section on drivers of restoration success (Results)

a. It is not clear where the framework comes from and what it states. I suggest moving some information from the SM.

b. As mentioned earlier, it is hard to know where the information comes from: interviews, context or literature. I suggest including more information about the interviews, if necessary, explaining some of the context as done in the SM. Otherwise, it is hard to make a connection to the main goal of the article and with the factors that might influence restoration.

- c. Figure 6. Are the environmental fines used in Figure 6 related to forest code compliance only? Or general state applied fines for any environmental aspects?
- 6. Discussion: I think it can be improved by connecting better to the findings from the interviews and context.
- 7. Materials and methods
 - a. I suggest restructuring the methods subtopics, as they are quite repetitive and confusing. Do you need an overview section? I would replace it with a figure. My suggestion for the sections is: i) data and study area, ii) forest cover data, iii) matching (including covariates for matching). It is important to differentiate what was covariates for matching and for regression, why you chose each of them for both analyses, and why they are different (this is something that gets confused throughout the text and in the SM), iv) difference in differences with details; v) interviews! There is no information about the interview part, from which state they were, questions asked, etc.
 - b. 1st paragraph (item 4.2) it is still not clear who own the land and who restores. It is important it is stated earlier, and why the importance of explaining well roles in the PACTO network.
 - c. 2nd paragraph (Methods). You could estimate the number of parcels in the same property using the CAR. It would be interesting to see if the analysis was made with a great number of the parcels belonging to the same owner. Could this somehow impact the analysis, and how?
 - d. Why have you used PA coverage as a covariate? Why not exclude the PA areas from the analysis? Also, why haven't you used SNUC data as it is in some cases more reliable than WCMC one? The WCMC one might include also IL, for example. Would it be appropriate to include them?
 - e. Why buffer of 500m? Is it enough for spillover effect?

I have carefully read the new revised version of the manuscript and the authors responses to my previous comments. I believe the manuscript has been substantially improved and the authors have satisfactorily addressed my concerns.

However, one of the questions I raised on the first round of review was related to the proxy used in the manuscript to access land opportunity cost: distance to urban centres. I have argued that this variable could fail to capture some nuances. For instance, different states having very different land opportunity costs as in land value and forgone production at the same distance to an urban centre. While I am convinced by the authors responses and supplementary analysis that using a different variable would probably not change the overall results and is not central to this work, they have also mentioned that the main reason for not using revenues from agriculture or land value was the lack of data. I would like to share some examples of previous works on related fields that have managed to deal with the data limitations and to produce spatial explicitly layers of opportunity cost. For instance, by using land value data:

Strassburg, B. B. N. *et al.* Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nat Ecol Evol* **3**, 62–70 (2019).

Land value data is currently available for different states and land uses from the federal government: <https://www.gov.br/receitafederal/pt-br/centrais-de-conteudo/publicacoes/documentos-tecnicos/vtn>

Or using expected revenues:

Niemeyer, J., Barros, F. S. M., Silva, D. S., Crouzeilles, R. & Vale, M. M. Planning forest restoration within private land holdings with conservation co-benefits at the landscape scale. *Science of The Total Environment* 135262 (2019)
doi:10.1016/j.scitotenv.2019.135262.

Those methods can guide future analysis or help with sensibility testing for the robustness of using distance to urban centres as a proxy.

In addition, I have some minor additional comments.

Firs section of Results

First session of results feels more like methods than results. I suggest incorporating to the previous session. For instance, the 1st paragraph of this session could be merged with the 2nd paragraph of the introduction to justify why there is such a coalition. Also, lots of the 2nd paragraph content was already said on the introduction.

Then, I suggest a concise paragraph on the introduction right before the last paragraph with the relevant information from paragraphs 2 and 3 of this section summarising what was done and then starting the results with the next sessions.

Maybe even eliminating the subtitle results and starting with:

Drivers of restoration success: benefits and costs to landowners and institutional context

(I leave it to the authors whether or not they consider this last suggestion adequate).

Legend Figure 1

You could include the % of area under PACTO in each state in the legend, e.g. Bahia (32% of parcels) and so on.

Drivers of restoration success: benefits and costs to landowners and institutional context

Lines 121-123: This sentence should be reframed to sound more like a result than methods. For example: The interviews contributed/gave us an understanding of the restoration environment and drivers of impact. And then be placed on the beginning of the next paragraph.

Lines 127- 128: The sentence directing the reader to the Supp. Mat. would be better right after when the forest code is mentioned, between brackets. As it is, it breaks the fluidity of the reading. Also, the following sentence “Because of these rules” is not very clear. Because of the sanctions imposed by the legislation, which include fines and ..., according to (...)?

Figure 4:

The legend on the left panel is partially erased.

Heterogeneity in impacts consistent with key drivers of success

Line 243: land or property size rather than landowner size.