Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil

Juan Carlos Cisneros, Nussaïbah B. Raja, Aline M. Ghilardi, Emma M. Dunne, Felipe L. Pinheiro, Omar Rafael Regalado Fernández, Marcos A. F. Sales, Rubén A. Rodríguez-de la Rosa, Adriana Y. Miranda-Martínez, Sergio González-Mora, Renan A. M. Bantim, Flaviana J. de Lima and Jason D. Pardo

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1st revised submission: 11 November 2021
2nd revised submission: 3 February 2022
Final acceptance: 7 February 2022

Note: Reports are unedited and appear as submitted by the referee. The review history appears in chronological order.

Review History

RSOS-210898.R0 (Original submission)

Review form: Reviewer 1 (Michelle A. North)

Is the manuscript scientifically sound in its present form?
Yes

Are the interpretations and conclusions justified by the results?
Yes

Is the language acceptable?
Yes

Do you have any ethical concerns with this paper?
No
Have you any concerns about statistical analyses in this paper?
No

Recommendation?
Accept with minor revision (please list in comments)

Comments to the Author(s)
Please see the attached review report with my comments (Appendix A).

Review form: Reviewer 2 (Jean-Noël Martinez)

Is the manuscript scientifically sound in its present form?
Yes

Are the interpretations and conclusions justified by the results?
Yes

Is the language acceptable?
Yes

Do you have any ethical concerns with this paper?
No

Have you any concerns about statistical analyses in this paper?
No

Recommendation?
Accept with minor revision (please list in comments)

Comments to the Author(s)
A lucid, well written, abundantly documented paper, Very necessary in this moment... Only minor modifications indicated directly in the text (attached pdf (Appendix B)).

Decision letter (RSOS-210898.R0)

We hope you are keeping well at this difficult and unusual time. We continue to value your support of the journal in these challenging circumstances. If Royal Society Open Science can assist you at all, please don't hesitate to let us know at the email address below.

Dear Dr Cisneros

The Editors assigned to your paper RSOS-210898 "Digging deeper into colonial palaeontological practices in modern day Brazil and Mexico" have now received comments from reviewers and would like you to revise the paper in accordance with the reviewer comments and any comments from the Editors. Please note this decision does not guarantee eventual acceptance.
We invite you to respond to the comments supplied below and revise your manuscript. Below the referees’ and Editors’ comments (where applicable) we provide additional requirements. Final acceptance of your manuscript is dependent on these requirements being met. We provide guidance below to help you prepare your revision.

We do not generally allow multiple rounds of revision so we urge you to make every effort to fully address all of the comments at this stage. If deemed necessary by the Editors, your manuscript will be sent back to one or more of the original reviewers for assessment. If the original reviewers are not available, we may invite new reviewers.

Please submit your revised manuscript and required files (see below) no later than 21 days from today’s (ie 14-Oct-2021) date. Note: the ScholarOne system will ‘lock’ if submission of the revision is attempted 21 or more days after the deadline. If you do not think you will be able to meet this deadline please contact the editorial office immediately.

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Thank you for submitting your manuscript to Royal Society Open Science and we look forward to receiving your revision. If you have any questions at all, please do not hesitate to get in touch.

Kind regards,
Royal Society Open Science Editorial Office
Royal Society Open Science
openscience@royalsociety.org
on behalf of Dr Miranda Lowe (Associate Editor) and Nick Pearce (Subject Editor)
openscience@royalsociety.org

Associate Editor Comments to Author (Dr Miranda Lowe):
Thank you for your patience while we sought reviewers for this paper - regrettably, this took a lot longer than usual (and the editors have had to approach a very large number of potential reviewers to receive the two reports we now have). In any case, two reviewers have offered a number of comments that you need to address before we can consider the paper ready for publication - reviewer 1 in particular has a number of concerns regarding, for example, the rigor of your description of your methodologies. This needs to be addressed in any revision. Please ensure that you provide not only a tracked-changes iteration of your paper with the revision but also a clear point-by-point response document that delineates the changes you have made.
Thanks for your support and good luck with the revision.

Reviewer comments to Author:
Reviewer: 1
Comments to the Author(s)
Please see the attached review report with my comments (attached pdf: "RSOS-210898 reviewer report.pdf")
Reviewer: 2
Comments to the Author(s)
A lucid, well written, abundantly documented paper, Very necessary in this moment... Only minor modifications indicated directly in the text (attached pdf: "RSOS-210898_Proof REVIEW JNM.pdf").
===PREPARING YOUR MANUSCRIPT===

Your revised paper should include the changes requested by the referees and Editors of your manuscript. You should provide two versions of this manuscript and both versions must be provided in an editable format:
one version identifying all the changes that have been made (for instance, in coloured highlight, in bold text, or tracked changes);
a 'clean' version of the new manuscript that incorporates the changes made, but does not highlight them. This version will be used for typesetting if your manuscript is accepted.

Please ensure that any equations included in the paper are editable text and not embedded images.

Please ensure that you include an acknowledgements' section before your reference list/bibliography. This should acknowledge anyone who assisted with your work, but does not qualify as an author per the guidelines at https://royalsociety.org/journals/ethics-policies/openness/.

While not essential, it will speed up the preparation of your manuscript proof if accepted if you format your references/bibliography in Vancouver style (please see https://royalsociety.org/journals/authors/author-guidelines/#formatting). You should include DOIs for as many of the references as possible.

If you have been asked to revise the written English in your submission as a condition of publication, you must do so, and you are expected to provide evidence that you have received language editing support. The journal would prefer that you use a professional language editing service and provide a certificate of editing, but a signed letter from a colleague who is a native speaker of English is acceptable. Note the journal has arranged a number of discounts for authors using professional language editing services (https://royalsociety.org/journals/authors/benefits/language-editing/).

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To revise your manuscript, log into https://mc.manuscriptcentral.com/rsos and enter your Author Centre - this may be accessed by clicking on "Author" in the dark toolbar at the top of the page (just below the journal name). You will find your manuscript listed under "Manuscripts with Decisions". Under "Actions", click on "Create a Revision".

Attach your point-by-point response to referees and Editors at Step 1 'View and respond to decision letter'. This document should be uploaded in an editable file type (.doc or .docx are preferred). This is essential.

Please ensure that you include a summary of your paper at Step 2 'Type, Title, & Abstract'. This should be no more than 100 words to explain to a non-scientific audience the key findings of your research. This will be included in a weekly highlights email circulated by the Royal Society press office to national UK, international, and scientific news outlets to promote your work.

At Step 3 'File upload' you should include the following files:
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1) One version identifying all the changes that have been made (for instance, in coloured highlight, in bold text, or tracked changes);
2) A 'clean' version of the new manuscript that incorporates the changes made, but does not highlight them.
-- An individual file of each figure (EPS or print-quality PDF preferred [either format should be produced directly from original creation package], or original software format).
-- An editable file of each table (.doc, .docx, .xls, .xlsx, or .csv).
-- An editable file of all figure and table captions.
Note: you may upload the figure, table, and caption files in a single Zip folder.
-- Any electronic supplementary material (ESM).
-- If you are requesting a discretionary waiver for the article processing charge, the waiver form must be included at this step.
-- If you are providing image files for potential cover images, please upload these at this step, and inform the editorial office you have done so. You must hold the copyright to any image provided.
-- A copy of your point-by-point response to referees and Editors. This will expedite the preparation of your proof.

At Step 6 'Details & comments', you should review and respond to the queries on the electronic submission form. In particular, we would ask that you do the following:
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Author’s Response to Decision Letter for (RSOS-210898.R0)

See Appendix C.

RSOS-210898.R1

Review form: Reviewer 1 (Michelle A. North)

Is the manuscript scientifically sound in its present form?
Yes

Are the interpretations and conclusions justified by the results?
Yes
The authors have made extensive changes to their manuscript based on the first round of reviewer comments, and this hard work has certainly paid off. The Supplementary files are now extremely accessible and useful, and I hope that future researchers wanting to collaborate with locals make use of the list relevant experts and institutions the authors have provided. I sincerely appreciate the translated column headings, and feel that the additional information provided adds a lot of value to these tables. It is a pity the revised figures were not included in the manuscript, but I am sure the font will be more legible (based on the authors’ responses).

I look forward to reading the final, published version of this manuscript, and with the authors well on their future work on this issue. I hope this paper continues to improve awareness of this issue and paves the way to more repatriation of fossils as well as greater collaboration with local researchers.

Review form: Reviewer 2 (Jean-Noël Martinez)

Is the manuscript scientifically sound in its present form?
Yes

Are the interpretations and conclusions justified by the results?
Yes

Is the language acceptable?
Yes

Do you have any ethical concerns with this paper?
No

Have you any concerns about statistical analyses in this paper?
No

Recommendation?
Accept with minor revision (please list in comments)
Comments to the Author(s)
Excellent paper, well documented and very necessary in this moment. I found very few necessary and purely formal corrections that are indicated in the attached file (Appendix D).

Decision letter (RSOS-210898.R1)

We hope you are keeping well at this difficult and unusual time. We continue to value your support of the journal in these challenging circumstances. If Royal Society Open Science can assist you at all, please don’t hesitate to let us know at the email address below.

Dear Dr Cisneros

On behalf of the Editors, we are pleased to inform you that your Manuscript RSOS-210898.R1 "Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil" has been accepted for publication in Royal Society Open Science subject to minor revision in accordance with the referees' reports. Please find the referees' comments along with any feedback from the Editors below my signature.

We invite you to respond to the comments and revise your manuscript. Below the referees’ and Editors’ comments (where applicable) we provide additional requirements. Final acceptance of your manuscript is dependent on these requirements being met. We provide guidance below to help you prepare your revision.

Please submit your revised manuscript and required files (see below) no later than 7 days from today’s (ie 24-Jan-2022) date. Note: the ScholarOne system will ‘lock’ if submission of the revision is attempted 7 or more days after the deadline. If you do not think you will be able to meet this deadline please contact the editorial office immediately.

Please note article processing charges apply to papers accepted for publication in Royal Society Open Science (https://royalsocietypublishing.org/rsos/charges). Charges will also apply to papers transferred to the journal from other Royal Society Publishing journals, as well as papers submitted as part of our collaboration with the Royal Society of Chemistry (https://royalsocietypublishing.org/rsos/chemistry). Fee waivers are available but must be requested when you submit your revision (https://royalsocietypublishing.org/rsos/waivers).

Thank you for submitting your manuscript to Royal Society Open Science and we look forward to receiving your revision. If you have any questions at all, please do not hesitate to get in touch.

Kind regards,
Royal Society Open Science Editorial Office
Royal Society Open Science
openscience@royalsociety.org

on behalf of Dr Miranda Lowe (Associate Editor) and Nick Pearce (Subject Editor)
openscience@royalsociety.org

Subject Editor Comments to Author (Professor Nick Pearce):
Comments to the Author:
We shall be pleased to publish this important paper, subject to the minor final revisions recommended by the second reviewer. Many thanks for choosing to submit to the Science, Policy and Society section of RSOS.
Reviewer comments to Author:
Reviewer: 1
Comments to the Author(s)
Review report for RSOS-210898.R1
Title: Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil

The authors have made extensive changes to their manuscript based on the first round of reviewer comments, and this hard work has certainly paid off. The Supplementary files are now extremely accessible and useful, and I hope that future researchers wanting to collaborate with locals make use of the list relevant experts and institutions the authors have provided. I sincerely appreciate the translated column headings, and feel that the additional information provided adds a lot of value to these tables. It is a pity the revised figures were not included in the manuscript, but I am sure the font will be more legible (based on the authors’ responses).

I look forward to reading the final, published version of this manuscript, and with the authors well on their future work on this issue. I hope this paper continues to improve awareness of this issue and paves the way to more repatriation of fossils as well as greater collaboration with local researchers.

Reviewer: 2
Comments to the Author(s)
Excellent paper, well documented and very necessary in this moment. I found very few necessary and purely formal corrections that are indicated in the attached file.

===PREPARING YOUR MANUSCRIPT===

Your revised paper should include the changes requested by the referees and Editors of your manuscript.

You should provide two versions of this manuscript and both versions must be provided in an editable format:
one version should clearly identify all the changes that have been made (for instance, in coloured highlight, in bold text, or tracked changes);
a 'clean' version of the new manuscript that incorporates the changes made, but does not highlight them. This version will be used for typesetting.

Please ensure that any equations included in the paper are editable text and not embedded images.

Please ensure that you include an acknowledgements' section before your reference list/bibliography. This should acknowledge anyone who assisted with your work, but does not qualify as an author per the guidelines at https://royalsociety.org/journals/ethics-policies/openness/.

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Attach your point-by-point response to referees and Editors at the 'View and respond to decision
letter' step. This document should be uploaded in an editable file type (.doc or .docx are
preferred). This is essential, and your manuscript will be returned to you if you do not provide it.

Please ensure that you include a summary of your paper at the 'Type, Title, & Abstract' step. This
should be no more than 100 words to explain to a non-scientific audience the key findings of your
research. This will be included in a weekly highlights email circulated by the Royal Society press
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effective summary can substantially increase the readership of your paper.

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upload two versions:
   1) One version identifying all the changes that have been made (for instance, in coloured
      highlight, in bold text, or tracked changes);
   2) A 'clean' version of the new manuscript that incorporates the changes made, but does not
      highlight them.
-- An individual file of each figure (EPS or print-quality PDF preferred [either format should be
produced directly from original creation package], or original software format).
-- An editable file of each table (.doc, .docx, .xls, .xlsx, or .csv).
-- An editable file of all figure and table captions.
Note: you may upload the figure, table, and caption files in a single Zip folder.
-- Any electronic supplementary material (ESM).
-- If you are requesting a discretionary waiver for the article processing charge, the waiver form
must be included at this step.
-- If you are providing image files for potential cover images, please upload these at this step, and
inform the editorial office you have done so. You must hold the copyright to any image provided.
-- A copy of your point-by-point response to referees and Editors. This will expedite the
preparation of your proof.

At the 'Details & comments' step, you should review and respond to the queries on the electronic
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-- Ensure that your data access statement meets the requirements at
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you cite the dataset in your reference list. If you have deposited data etc in the Dryad repository,
please only include the 'For publication' link at this stage. You should remove the 'For review'
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option (if requesting a discretionary waiver, the form should have been uploaded, see 'File
upload' above).
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At the 'Review & submit' step, you must view the PDF proof of the manuscript before you will be able to submit the revision. Note: if any parts of the electronic submission form have not been completed, these will be noted by red message boxes - you will need to resolve these errors before you can submit the revision.

**Author's Response to Decision Letter for (RSOS-210898.R1)**

See Appendix E.

**Decision letter (RSOS-210898.R2)**

We hope you are keeping well at this difficult and unusual time. We continue to value your support of the journal in these challenging circumstances. If Royal Society Open Science can assist you at all, please don't hesitate to let us know at the email address below.

Dear Professor Dunne,

I am pleased to inform you that your manuscript entitled "Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil" is now accepted for publication in Royal Society Open Science.

If you have not already done so, please ensure that you send to the editorial office an editable version of your accepted manuscript, and individual files for each figure and table included in your manuscript. You can send these in a zip folder if more convenient. Failure to provide these files may delay the processing of your proof.

Please remember to make any data sets or code libraries 'live' prior to publication, and update any links as needed when you receive a proof to check - for instance, from a private 'for review' URL to a publicly accessible 'for publication' URL. It is good practice to also add data sets, code and other digital materials to your reference list.

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The proof of your paper will be available for review using the Royal Society online proofing system and you will receive details of how to access this in the near future from our production office (openscience_proofs@royalsociety.org). We aim to maintain rapid times to publication after acceptance of your manuscript and we would ask you to please contact both the production office and editorial office if you are likely to be away from e-mail contact to minimise delays to publication. If you are going to be away, please nominate a co-author (if available) to manage the proofing process, and ensure they are copied into your email to the journal.
Please see the Royal Society Publishing guidance on how you may share your accepted author manuscript at https://royalsociety.org/journals/ethics-policies/media-embargo/. After publication, some additional ways to effectively promote your article can also be found here https://royalsociety.org/blog/2020/07/promoting-your-latest-paper-and-tracking-your-results/.

On behalf of the Editors of Royal Society Open Science, thank you for your support of the journal and we look forward to your continued contributions to Royal Society Open Science.

Kind regards,
Royal Society Open Science Editorial Office
Royal Society Open Science
openscience@royalsociety.org

on behalf of Dr Miranda Lowe (Associate Editor) and Nick Pearce (Subject Editor)
openscience@royalsociety.org

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Appendix A

Review report for RSOS-210898
Title: Digging deeper into colonial palaeontological practices in modern day Brazil and Mexico

This is a fascinating paper about scientific colonialism in palaeontology, with a specific focus on two fossil rich sites in Brazil and Mexico. The authors clearly describe the problem, the legal frameworks, several cases, as well as providing clear examples of ‘myths’ that they rebut and options for improving the current situation. I think this manuscript is an extremely valuable contribution to the scientific literature and to ‘general’ knowledge on paleontology.

General comments:
Firstly, I would like to say that I really enjoyed reading this manuscript. The ‘story’ is interesting, and the way it has been presented is gripping. It reads like a novel that one does not want to put down – well done. It is also a very important topic, and clearly the authors have extensive experience in this field and with this issue. This comes across in the way it has been presented. However, I do have some relatively minor comments, and a more substantial one.

It is highly irregular to only include a description of the methods in the supplementary information. If a literature review is used, it should be described (even if very briefly) in the main text of the document, so that readers have some idea of the basis of the data used and the conclusions drawn. And even when I access the supplementary material, all it contains are hyperlinks to a web based repository that then autodownloads a zip file of further tables... This is not how one reports methods, but is rather an admirable way of presenting the data used. Somewhere, at least in the Supplementary information but preferably in the main text, there has to be a written description of the methods used to obtain the data upon which part of this study has been based. This should also include a brief description of the Twitter analytics alluded to in the Acknowledgements.

For example, in Table S1, there is no description of how these papers were found (what search terms, what databases or platforms?), or of the content of this table (what does n/a mean for ‘collecting permit’? Does it mean there was not one, it was not mentioned, or that the work described in that paper did not need a permit? Under ‘Issues’, what do the different numbers mean?). All of this information needs to be described somewhere. In addition to a description of the methods in the text, I would also recommend adding a ‘read me’ sheet to each of the supplemental data files, where you explain what the different columns and numbers etc mean.

On another note, regarding Table S1, I would like to see the titles of each of the publications, or a full reference, so that readers can go and find these different papers more easily.

Regarding the other Supplemental tables (I noticed this issue in Table S4 but it may be true for more of them), while I completely acknowledge that English is not the only language of science and is not the primary language of either of these regions or the authors of this paper, I would suggest having the table headings either in English or including their English translations in a ‘read me’ sheet. I realize that translating the data will be a pain, but if you are translating the main manuscript into Spanish and Portuguese anyway, then you might consider having different sheets in each (relevant) table for each of the three languages? Or simply provide an explanation in the first ‘read me’ sheet translating key terms (like “Colecção Científica, exposição, etc.”). As an example, if the content of this specific column in Table S4 (Tipo) is confined to only two or three types of work, it might be easier for all different language readers to interpret if you rather set it up more like I have done in the screenshot below (I had to use Google translate, so I’m sure the headings are not quite correct). I appreciate that the issue of language is a tricky one, but for your paper to have maximum impact, it would be ideal for everything to be multilingual, or at least easy to interpret.
Specific comments:

For these comments, I refer to the page number from the document, and not the PDF page (for example, the abstract/summary is on page 3 which is the 4th page in the PDF. I will report this as Page 3. Also note that the PDF line numbers do not seem to fully correspond with the lines of text, so just estimate which line of text each line number I refer to is indicating.

Page 3 line 16: "Common issues documented in these publications" are these issues truly documented by the publications you found (i.e., do the authors of those publications highlight the issues), or do you mean that they are issues that you found in these publications?

Page 3 line 23: "reposited" is not a commonly used word in English. I would suggest replacing with something like stored, housed, or kept. But I am not of this field, so if the term is commonly used in palaeontology then ignore my comment.

Page 4 line 19-23: I don't entirely understand this statement. I would recommend expanding what you mean by institutionalisation, and why it benefits colonial advancement.

Page 5 line 30: consider rather using the term "while" here, rather than "whereas" (it isn’t really a contrast to the previous phrase)

Page 5 line 40: Rather use the term “scientific reproducibility”

Page 6 line 26: Delete “being” (before “the USA”)

Page 6 line 59: Rather change “previously” to “to notify the council beforehand”

Page 7 line 11-14: Consider making this sentence shorter (e.g., use "theoretically" instead of in theory, remove "in the first place", remove "properly"). This should make it easier to read, but if its still too long, then consider using punctuation or breaking it into two sentences.

Page 7 line 14: Delete “thus” before acknowledge
Page 7 line 19-26: This is a very long sentence. Rephrase to shorten, add punctuation, and consider rewriting as two sentences

Page 7 line 42: Is this not meant to be northEASTERN, rather than northwestern Mexico?

Page 8 line 14: this is the first time the literature review is mentioned. I would strongly suggest that the methods should be mentioned earlier so that the reader understands how you found these papers (refer to my General comments, above)

Page 8 line 18: It is not clear how Box 3 relates to this sentence

Page 8 line 19: Rather than “The majority of this output, I would rather state it something like "Most of this foreign-led research, ..." to make it clear that "this output" isn't referring to the 128 papers

Page 10 line 59: Here again, there needs to be some sort of description of the methods used to find these papers

Page 11 line 4: Does “them” (the 57.14%) refer to the foreign-led papers? Or of all the papers?

Page 12 line 24-26: I am not sure whether the evidence can prove that the foreign researches avoided interaction. I would recommend moderating the language. One could say they neglected to include local scientists, or that this displays a disregard for local laws and expertise.

Page 12 line 37: Rather say that they “likely” represent only a small portion. Because you don’t have the other numbers you cannot say for sure that they do represent only a small portion

Page 14 line 40: do you rather mean "lines of research" or "research practices"?

Page 14 line 42: “metropolis” isn't quite the correct word. I think you mean the colonising countries?

Page 14 line 49: It does not appear to solely be the absence of legislation, seeing as both the case study countries have adequate legislation; it appears to be more about the absence of enforced legislation

Page 20 line 14: How does the sale or purchase of fossils differ from the production of stone products (e.g., for paving or kitchen counters) from quarries that have fossil deposits? I am sure I have seen both the above with little fossil structures in them. And many finds occur in these quarries, which I assume are commercial entities? Without these commercial quarries I assume many fossil deposits would not be revealed. I am not an paleontologist at all, so excuse me if this is a very 'lay' question, but I wonder if this is something you could mention/discuss somewhere

Page 26 line 11: Would it not be possible to develop a framework somewhat akin to PRISMA regarding a checklist of items every paper about fossils should report (e.g., permit information, detailed description of the site, geology etc., current location of the fossils)? And it would be ideal if proposed research protocols were published for peer review before the research is actually undertaken, so that any gaps (e.g., the acquisition of permits) can be highlighted before the study is conducted.

Page 27 line 23-24: What do you propose as a solution for these illegal fossils? Should they therefore not be studied, or if they are to be studied and published, should the specimens be repatriated or at least moved to public collections? My concern is the consequence if highly valuable, unique
specimens fall in this category, then they will not make it to the scientific literature... should the publications simply be open about the fact that they are studying illegal specimens?

Page 51: In the caption of Figure 2, Frey et al 2017 is not referenced as a number the way all other references have been done.

Page 53 Figure 4: I recommend making this figure just a bit larger (fit the width of the page) so that the font is more legible. Also make the currently grey font colour black to improve contrast

Page 58 Figure 9: See whether it is possible to make this figure bigger, to fit the width of the page. I think the font size will be better then, and more legible
Appendix B

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**Digging deeper into colonial palaeontological practices in modern day Brazil and Mexico**

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Digging deeper into colonial palaeontological practices in modern day Brazil and Mexico

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RRH: PALEONTOLOGICAL COLONIALISM IN BRAZIL AND MEXICO

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JCC, NBR, AMG and EMD conceived and designed the project. JCC, AMG, FLP, ORRF, MAFS, AYM, SGM, RAMB, RARR and FJL compiled the data in the tables. NBR, JCC and FLP made the figures. All authors contributed to and approved the manuscript.
Summary

Scientific practices stemming from colonialism, whereby middle- and low-income countries supply data for high-income countries and the contributions of local expertise are devalued, is still prevalent today in the field of palaeontology. In response to these unjust practices, countries such as Brazil and Mexico adopted protective laws and regulations during the 20th century to preserve their palaeontological heritage. However, scientific colonialism is still reflected in many publications describing fossil specimens recovered from these countries. Here, we present examples of ‘palaeontological colonialism’ from publications on Jurassic-Cretaceous fossils from NE Brazil and NE Mexico spanning the last three decades. Common issues documented in these publications are the absence of both fieldwork and export permit declarations and the lack of local experts among authorships. In Mexico, access to many fossil specimens is restricted on account of these specimens being housed in private collections, whereas a high number of studies on Brazilian fossils are based on specimens illegally reposited in foreign collections, particularly in Germany and Japan. Finally, we outline and discuss the wider academic and social impacts of these research practices, and propose exhaustive recommendations to scientists, journals, museums, research institutions, and government and funding agencies in order to overcome these practices.

Keywords: scientific colonialism, parachute science, research ethics, palaeontological heritage, illegal fossil trade, Latin America
1. Introduction

Scientific advances played an important role in the expansion of European powers during colonial times. Scientific curiosity is noted as one of the key motivations behind the expeditions that led to the colonisation and annexation of regions in Asia, Africa, and the Americas [1]. As a result, many “exotic” specimens collected by naturalists or geologists from colonies were sent back to the respective colonial state, to adorn houses of high-ranked members of society or to be reposited in national scientific societies or institutions, with the purpose of scientific inquiry [1,2]. The latter led to the establishment of large museums to house the vast collections of curiosities brought back to Europe from overseas expeditions as well as imperial conquests within Europe. Although colonialism is frequently described in political, social, and military contexts, it is also present in many scientific practices still in use today. The institutionalisation of scientific disciplines, educational programmes, and academic organisations were all products designed to benefit colonial advancement [3].

This structure of colonial science — derived from the practice of science in the colonies — has given rise to ‘scientific colonialism’ in the postcolonial world, some of whose extractive aspects are sometimes referred to as parachute science [4–7], helicopter research [8,9] or even parasitic science [7]. Within scientific colonialism, middle and low income countries are perceived as suppliers of data and specimens for the high income ones, the contributions of local collaborators are devalued or omitted, and the legal frameworks in lower income countries are trivialised or even neglected [6,10–13]. In turn, colonist nations owe their wealth to the extractive colonial practices they have been carrying out for centuries, allowing them to accumulate knowledge, power and financial resources to continue these practices into the present day. These practices are also prevalent in the field of palaeontology [13].

As a reaction to a long history of colonial science practices, many countries, most notably several Latin American countries, adopted protective laws and regulations during the 20th century in order to preserve their biological, archaeological, and palaeontological heritage. Under these laws, fossils are considered to be property of the nation state, and their sale, purchase, and permanent exportation are prohibited [14–16]. Countries like Brazil [17], Argentina [14], Colombia [18] and Chile [19] also make it compulsory for a foreign party to be associated with a local institution in order to conduct fieldwork in the respective country and collect fossil samples. Brazil and Mexico prohibit the commercial trade of their fossils, require permits for their temporary export and, in the case of Brazil, the permanent export of specimens used for describing new species is not allowed [20,21]. These two countries, despite the presence of laws and regulations, still fall victim to scientific colonialism, including the illicit trafficking of fossil specimens. In fact, the illegal trade of fossils in Brazil has been blamed on the presence of laws; Martin [22,23] states that the very fact
that laws exist for the protection of these fossils could be the reason that officials can be bribed and these fossils can be sold for a considerable price on the black market.

Both Brazil and Mexico are former European colonies with vast territories, large sedimentary basins, and a huge palaeontological potential that remains relatively unexplored. These characteristics, together with the predominance of an overall low income population and a local currency devaluation, make them attractive targets for palaeontological colonialism. In the last decades, the Crato and Romualdo formations of the Araripe Basin in NE Brazil and the Sabinas, Parras and La Popa basins (Mexican Gulf) in NE Mexico have produced an unprecedented wealth of Jurassic to Cretaceous (200–66 million years ago) fossils. These extremely rich fossil and well-preserved deposits, known as Lagerstätten, have enriched our view of evolution revealing a plethora of new vertebrates (figures 1 and 2), invertebrates, plants (figure 3) and fungi [24–27]. These exposures yield tantalizing examples of fossil preservation, including several soft-tissue instances [28–32]. Most of the published research output on fossils from these regions, however, has been led by foreign palaeontologists with few collaborations with local researchers. Many of these studies are based on fossils that have been unethically and/or irregularly acquired and/or exported [33]. Several published fossils lack contextual geographic and geologic information, whereas many important specimens are in private or foreign collections, where they can be difficult to access. Recent papers describing new fossil species such as the snake-like reptile *Tetrapodophis amplexus* [34] (figure 1a) and the dinosaur “*Ubirajara jubatus*” [35] (figure 1c) both from the Crato Formation (Araripe Basin) Brazil, as well as the plesiosaur *Mauriciosaurus fernandezi* [30] (figure 2e) and the shark *Aquilolamna milarcae* [36] (figure 2f) from the Agua Nueva Formation (Sabinas Basin), Mexico have raised a number of questions involving ethics, legal issues, and science reproducibility. In this study, we present and discuss the academic and social impact of the research published during 1990-2021 that likely represent examples of scientific colonialism in Brazil and Mexico (Box 1). We chose this time period as (1) this is when the most research has been carried out in the two basins that we chose as case studies and (2) many of the relevant laws and regulations were established just before or in 1990. We also propose alternatives and recommendations to scientists, journals, research institutions and government agencies in order to overcome these practices.

2. **Legal framework**

2.1. **Brazil**

In Brazil, fossils are protected by Decree 4.146, published in 1942 [37] which states that fossils cannot be privately owned and belong to the Union, and that fossil collecting requires an authorization from Agência Nacional de Mineração, ANM (National Mining Agency, formerly the
National Department of Mineral Production). In 1990, the Brazilian government published Decree 98.830 (Box 1) to regulate foreign scientific expeditions that collect biological or palaeontological material (i.e. fossils) in the country. This law is regulated by Ordinance 55 from Ministério de Ciência Tecnologia e Inovação, MCTI, formerly MCT [38] (see Box 2). According to this legislation [38], any foreign party that wishes to permanently export specimens from Brazil must have a permit from MCTI and a partnership with a Brazilian scientific institution (who will be in charge of applying for the permit). Furthermore, Decree 98.830 explicitly states that fossil holotypes, 30% of any collected taxon, and other specimens “whose permanence in the country is of national interest” cannot be exported. A recent ordinance issued by ANM [39] reinforces the necessity for foreign palaeontologists to comply with requirements stipulated by MCTI’s ordinance of 1990. The original Brazilian laws and their English translations are available in Appendix A.

2.2. Mexico

A law regarding archaeological monuments was established in 1897 [40], as a reaction to the looting of the Mayan site of Chichén Itzá by Edward Thompson, then in charge of being the USA consul in Mérida, Yucatán [41,42]. Currently, the law in force is The Federal Law of Archaeological, Artistic and Historic Monuments and Zones, published in 1972 [43]. The Instituto Nacional de Antropología e Historia, INAH (National Institute of Anthropology and History), was created through an organic law in 1939 [41,44] in order to protect this heritage. A presidential decree issued in 1986 [45], added the article 28bis to the law from 1972, and reformed the Organic Law of INAH, making it responsible for overseeing any activities involving the discovery and treatment of any fossil material, the delimitation of the boundaries of a fossiliferous site, and the safeguarding of the material in a collection [16,46]. The law declares that fossils are property of the Mexican Federation even if they are under custody of a private person (Articles 27, 28 and 28bis [43]. Private collections, i.e. fossil collections owned by private individuals or companies, must be registered by INAH [47]. Fossils in private collections are inalienable and imprescriptible, i.e. once registered, they cannot be transferred to other collections [43]. Since 1986, Mexican law explicitly forbids fossils to be commercially traded in Mexico [45,48]. In 1994, INAH created the National Council of Paleontology to form a multidisciplinary and inter-institutional group with the aim of reaching an agreement on what, how, and why to legislate the research on the palaeontological heritage in Mexico [21,49]. Mexican law does not formally require foreign palaeontologists and institutions to work with a local partner. However, the National Council of Paleontology recently released a series of recommendations for palaeontological studies in the country [50] advising foreign parties that wish to work in the country to previously notify the council (Box 3). The original Mexican laws and their English translations are available in Appendix B.
2.3. UNESCO Convention on Illicit Trafficking

The UNESCO 1970 Convention on the “Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property” [51] was signed in November 1970 and came into effect in April 1972 as a response to the growth in the black market of cultural property since the 1950s. The 1970 Convention is in theory central to preventing the illicit trafficking of cultural property in the first place by promoting international cooperation between countries as a means to protect cultural heritage properly. Signatories of the convention thus acknowledge that the “illicit import, export and transfer of ownership of cultural property is one of the main causes of the impoverishment of the cultural heritage of the countries of origin of such property” and as such, the import, export, and transfer of ownership is prohibited under the convention. Thus, the signatories of the Convention are not only required to set up national laws and services for the protection of the cultural heritage but also to take the appropriate measures so that museums and other institutions within their territories are prevented from acquiring illegally exported cultural property from another country as well as to cooperate with regards to restitution of the object(s). This convention was ratified by several nation states including Brazil (in 1973) and Mexico (in 1972), both of whom consider palaeontological objects or sites as part of the cultural property, as well as Japan (in 2002) which includes geological features among other things and Germany (in 2007), which only considers archaeological objects as such.

3. Case studies

3.1. Case study 1: Palaeontology in the Sabinas, La Popa and Parras basins of Mexico

In northwestern Mexico there are several fossil sites with great palaeontological interest: Parras, La Popa, Rincon Colorado, Múzquiz and Vallecillo (figure 3a, b). They are included within the Sabinas, Parras and La Popa basins, that extend from the center of Coahuila to the southeast of Nuevo León [52]. Most of these sites are popularly known for the presence of dinosaur fossils, but also contain fossils of invertebrates, plants and several aquatic vertebrates (figure 2). The Muzquiz and Vallecillo deposits support the economic activities of the local community, where flagstone material from these deposits is commercially exploited for construction. During the extraction of the slabs, fossils of exceptional preservation can often be found. Some of these may be destroyed in the process of extracting flagstone slabs and others are kept by quarry workers [53]. Unfortunately, some specimens end up on the black market.

One of the most important sites considered in this study is the Vallecillo quarry in Nuevo León, which was first discovered and exploited for its lead, zinc and silver outcrops. Currently,
construction materials are extracted from the quarry. In the 1980s, inhabitants of the Vallecillo village started to find several well-preserved vertebrate and invertebrate fossils from quarries [54]. The palaeontological value of the locality was recognised as early as 1997 [55]. Most of the research on fossils from this locality has been intensively carried out by foreign researchers. Material from the quarry was first exported in 1999-2000 to Germany, to the University of Karlsruhe, where it remained until it was returned to Nuevo León in 2007 and deposited in the Museo La Plomada [56].

We found 128 papers on Jurassic-Cretaceous macrofossils (excluding plants) from Sabinas-La Popa-Parras basins and other sites in Coahuila and Nuevo León states in NE Mexico, published between 1990-2021 (see Box 3, and electronic supplementary material, Table S1). Foreign researchers led 46.88% of the publications (60 papers) (figure 5). The majority of this output, or 51.67% (31 papers), do not include local authors (i.e. an author based at a Mexican scientific/academic institution based on the affiliations of the publications). In four papers [36,57–59], the local authors included within the author list are not affiliated with any scientific institution. Five of these papers are based on fossils stored in private collections (i.e. not in a recognised museum or other official scientific repository), two of which describe new genera and species [30,36]. Finally, two papers mention the purchase of a fossil [29,36] whereas another mentions that a specimen “was obtained by a private collector from a local quarry worker” [60]. We found no record of Mexican fossils being stored in foreign collections, except for a paper published in 1990 [61] that studied a collection of fossils claimed to have been collected in the 1930s.

Some recent studies of fossils from this area warrant a closer look. Frey et al. [30] describe the plesiosaur *Mauriciosaurus fernandezi* (figure 2e) from Vallecillo, in the Sabinas Basin, declaring it will be stored and accessible at Museo del Desierto [30], but only three pages later the authors contradict themselves [30] and state that this plesiosaur specimen is reposited at Museo Papalote Verde in Monterrey (Nuevo León). The latter is a museum aimed at children, exhibiting fossil replicas and does not have an INAH registration nor a permit to store fossils. The specimen was published using the INAH register number CPC RFG 2544 P.F.1 (sic) which in fact refers to a private collection, despite the claims made in the paper. INAH uses a standard protocol for registration numbers, in which the suffix “PF” (=persona fisica) refers to a private individual [62]. The prefix “CPC RFG” is not used by INAH, and probably was confused with a registration code from Museo del Desierto, which actually uses “CPC” (=Colección Paleontológica de Coahuila) in its catalogue, and a misspelling of REG (=registro). According to the INAH standard code, the correct registration number of this fossil should be REG2544PF1, i.e. the collection of Mauricio Fernández (REG2544PF), fossil number 1. As a fossil registered to a private individual by INAH, the only known specimen of the plesiosaur *Mauriciosaurus fernandezi* cannot be transferred to a...
museum as per Federal Law on Archaeological, Artistic and Historical Zones and Monuments [43]. 
This work was published at Boletín de la Sociedad Geológica Mexicana, a journal that, unfortunately, does not formally require fossils to be accessible in a public collection or recognized research institution [63].

The chondrichthyan Aquilolamna milarcae (figure 2f) also found at the Vallecillo quarry and recently described by Vullo et al. [36] in the journal Science - which has general editorial policies with regards to ethics - has already stirred controversy [64] due to a number of issues. The only local person involved in this research is neither affiliated with an institution nor is he a scientist, as he admits in an interview [65] despite being listed as an “independent researcher”.

Vullo et al. [36] openly recognized that the fossil was purchased from a quarry (see original version of Supplementary Materials [66]). The specimen was reported to be registered as INAH 2544 P.F.17 (sic). Again, this is an incorrect catalog number sensu INAH standards. The correct INAH register would be REG2544PF17, i.e., private collection of Mauricio Fernández (REG2544PF) fossil number 17. In a curious statement, Vullo et al. [66] promised that the specimen would be available to researchers in a museum that had in fact not yet been built at the time of publication. As mentioned above, fossils registered in a private collection in Mexico cannot be transferred to other collections [43], as such, this specimen will remain under the custody of the private collector even if it is loaned to a museum. A correction to the Supplementary Materials was published by Vullo et al. on 8 April 2021 [67] and an erratum only one week later [68]. The erratum states that the fossil will be housed at Museo del Desierto in Saltillo, Coahuila, until the new museum opens. In both amended versions of the supplement [67,68], Vullo et al. restated the registration number to incorrectly be INAH 2544 P.F.17 (sic), and did not mention that this is a private collection [62], nor that the fossil was purchased as originally admitted by the authors. Moreover, the owner of the shark holotype recently admitted that he bought the rock that contains the fossil [64].

A general issue, both by foreign and local parties, is the absence of collecting permits being reported in publications, even though researchers require them by law to work in fossil sites [43] (figure 4). To ensure that the law is complied with, when a palaeontological research project is registered through the Council of Palaeontology of INAH, the collecting permit application is included. Permits are generated if the project is approved. Collecting permits may be requested by INAH personnel or local authorities during fieldwork on Federal areas, which rarely occurs. Traditionally, INAH has advised palaeontologists to register their projects when they involve the temporary export of specimens or when they are carried out by foreign researchers only. Recently, the Council of Palaeontology at INAH has published new guidelines encouraging all researchers to register their palaeontological projects [50]. It is worth mentioning that of the journals that publish
palaeontological studies, many only recently began requesting permit information to be disclosed, while the majority do not yet formally request this information at all.

Some of the issues described above represent clear examples of scientific colonialism. It is remarkable that despite the presence of local expertise, which was responsible for the majority of the research output in the same period (68 papers), most studies that were led by foreign palaeontologists do not include local Mexican researchers. It is also questionable that some of these studies include local, independent authors but not local institutions, which may suggest a general aim of non-cooperation with local scientists. In addition, five of these studies were based on fossils from private collections, which casts doubts on access and reproducibility of the results (see below). In contrast, none of the studies led by Mexican authors used fossils from private collections.

3.2. Case study 2: Palaeontology in the Araripe Basin of Brazil

The Araripe Basin is located in the Northeast of Brazil (figure 4), a region with the highest concentration of poverty in the country (47.9% of the population in the region) [69]. Fossiliferous outcrops occur in the south of the Ceará State, northwest of the Pernambuco State and east of Piauí State, encompassing several municipalities with low Human Development Index (HDI; a statistic composite index of life expectancy, education, and per capita income indicators) [70].

The Araripe Basin in north-eastern Brazil has been a source for the black market of fossil specimens for a long time [33,71,72]. The export of Araripe fossils is as old as the first scientific reports on their existence. The earliest recognition of palaeontological specimens from the Araripe Basin was in an 1800 letter from the Brazilian naturalist João da Silva Feijó, and the reported fossils were promptly sent to the Portuguese Academy of Sciences, where they still reside to this day [73]. The first formal account of an Araripe fossil was an illustration in the famous book series Reise im Brasilien (1823-1831) by two German naturalists who were members of the entourage of Maria Leopoldina of Austria, shortly before she became Empress consort of Brazil [74]. After the Brazilian expedition of George Gardner (1836-1841), who sent abundant Brazilian fossil fishes to the ichthyologist and proponent of scientific racism Louis Agassiz [75] in the USA, the importance of Araripe specimens became clear overseas, stimulating the exploitation, trade and assembly of huge collections. Some of these collections were fortunately destined to publicly accessible institutions, such as the Axelrod Fossil Fish Collection (donated to the American Museum of Natural History, New York) and the Desirée Collection (donated to the Museu Nacional, Rio de Janeiro). It is, however, impossible to estimate the number of private collections containing Brazilian fossils, and the (illegal) trade persists to this day [76–79].

We found 71 papers on Cretaceous macrofossils (excluding invertebrates and non-holotype material) from the Araripe Basin, published between 1990-2021 (see Box 3 and electronic
supplementary material, Table S2 for list of papers and methods used). The majority of these publications (59.15%), were led by foreign researchers, and over half of them (57.14%) excluded local Brazilian researchers (figure 5). A large proportion (88%) of the fossils described in these publications (all holotype specimens) were taken from Brazil to be housed in foreign museum collections and have not been returned. Of the publications describing fossils that were permanently taken to foreign collections, not a single one reported exportation permits. Only one of these [80] reported that the specimens were collected during fieldwork conducted by the authors, yet did not mention a collecting permit, which would have been required by law. Several papers provide only vague statements of provenance (e.g. “Araripe Basin, Brazil” [81], “Araripe Plateau, Brazil” [82]), and do not mention fieldwork nor explain how the fossils ended in foreign collections. This fact, together with the absence of reported exportation permits, leads us to consider that these fossils may have been purchased (figure 5). Some publications inform that the fossils were “obtained from a quarry workman” [83] or “from a fossil digger” [84] and in eight papers [85–92], the fossil purchase is admitted by the authors.

Brazilian researchers, on the other hand, are responsible for 40.85% of the published research (29 papers) on new species of Araripe vertebrates and plants during the same period (figure 5). Three of these papers are based on fossils deposited in foreign collections and did not mention exportation permits; one of these fossils is mentioned to have been collected in the 1960s [93] whereas the two others [94,95] lack any data on provenance and probably were purchased by the museums.

Two recent studies on particularly high-profile fossils, deserve our attention here due to the questionable practices exposed therein. The 2015 publication of the putative legged-snake Tetrapodophis amplectus from Araripe in the journal Science by Martill et al. [34] (figure 1a) caused quite some controversy [96]. To start with, the publication did not involve any Brazilian researchers or institutions. The authors also claimed that the specimen was permanently available in a museum. The fossil, however, belongs to a private collector in Germany [96–98] and access to this specimen has reportedly been made difficult for other researchers who wish to study it [96,97]. Finally, the authors did not provide any evidence that the fossil was legally collected and exported from Brazil.

More recently in 2020, the collection, study, and publication describing a new dinosaur species “Ubirajara jubatus” (figure 1c), also from the Araripe Basin, similarly did not include Brazilian researchers or institutions. This paper was published in the journal Cretaceous Research but has been temporarily retracted at the time of our study while an investigation is carried out [35]. The now-retracted publication mentioned that the fossil material was collected and removed from Brazil after 1990, which attracted much attention from the media. Through a journalistic report
[99], the authors presented a signed document from 1996 by an agent at the regional office of the National Department of Mineral Production named José Betimar Melo Filgueira. The document in question is surprisingly vague, without specifying how many or which kind of fossils were exported, mentioning only "two boxes with limestone samples containing fossils". The document also does not identify the applicant, nor the destination of the material. There was also no information on whether this was a temporary or permanent exportation, and no mention of any collaborating Brazilian institution. The aforementioned agent has previously collaborated with one of the authors [100] of the “Ubirajara jubatus” paper around the same time that the specimen was exported from Brazil, which may represent a conflict of interest. Furthermore, no mention is made by the authors of the study about having the necessary export authorization from MCTI as per Decree 98.830 [17]. The journal Cretaceous Research has become a popular venue for hosting many studies on ethically questionable fossils (see section 9.2 below).

Several of the above mentioned studies led by foreign researchers represent clear cases of scientific colonialism. As seen in the previous case study in Mexico, the examples here also show a general aim to avoid interaction with local scientists, but to an even greater extent than seen in Mexico. To make matters worse, the overwhelming majority of these studies are based on fossils likely to be both illegally purchased and exported. Our survey shows that the primary destinations of most of the illicitly exported fossils are the Museum für Naturkunde Berlin (13 plant holotypes) and Staatliches Museum für Naturkunde Karlsruhe (10 vertebrate holotypes) (see electronic supplementary material, Table S2). Because our study was limited to fossil holotypes, and we did not include arthropods and other invertebrates, the above numbers represent only a small portion of the fossils that have been irregularly taken from Brazil to foreign institutions. A preliminary search for Araripe arthropod papers on Google Scholar (see electronic supplementary material, Table S3), however, indicates that at least 47 holotypes of insects, arachnids and chilopods were illegally transferred to Staatliches Museum für Naturkunde Stuttgart, at least seven to Senckenberg Museum in Frankfurt am Main, four to Museum für Naturkunde Berlin, four to Staatliches Museum für Naturkunde Karlsruhe, and several others to various institutions and private collections, totaling a minimum of 90 Araripe holotypes in German collections. In addition, our survey of papers located at least four vertebrate holotype fossils housed in Japanese collections, along with seven more arthropod holotypes identified through a preliminary search on Google Scholar.

4. Beyond the Araripe and Sabinas basins

Colonial palaeontology practices in Brazil and Mexico are not limited to Sabinas-La Popa-Parras and Araripe basins. In México, important Pleistocene mammal specimens from the Yucatán Peninsula have been targeted as well [101–106]. A 2012 study found that foreign-led research has
extensively been done in several northern Mexican states (Baja California Sur, Coahuila and Nuevo León) [107]. Furthermore, it identified research carried out exclusively by US-based researchers in three States: Guanajuato, Jalisco, and Sonora [107]. The petrified wood from the Permian Pedra de Fogo Formation in Brazil has also been the subject of these same practices [108–111] with a number of holotypes being irregularly stored at the Chemnitz Museum in Germany. Other fossil deposits from Brazil should be included in the list, such as the Miocene strata of the Acre Basin [112,113].

Likewise, Latin America is not the only region hit by such practices. Other countries such as Morocco, Mongolia, and Myanmar (Burma) have also been on the receiving end of palaeontological colonialism. Moroccan palaeontology has been largely fed by commercial fossil exports to mainly Europe and North America despite the fact that Morocco is a signatory of the UNESCO 1970 Convention and a 1994 ministerial order explicitly prohibits the export of fossils [114,115]. While exporters usually obtain a large income from fossil exports (estimated at US$100,000 per year), these fossils are originally excavated or found by local people living in marginalised areas who derive very limited income from these fossils [115]. As a result, Morocco has been the source of a great number of exceptional specimens without any contextual information on the geography or geology, a large number of them being described and published by a commercial collector lacking a scientific background, and/or without any participation from Moroccan research institutions [116]. In 2019, the Moroccan government drafted a decree with specific recommendations regarding authorised exports and loans — a step forward regarding the protection of palaeontological heritage as well as the livelihoods of those dependent on it [115]. Similarly, palaeontological research in the Mongolian Gobi desert had been occurring for almost a century, but until recently, this palaeontological heritage was largely unknown to the general public in Mongolia [117]. This has changed in recent years due to efforts by the Mongolian government assisted by other parties in other countries to arrange the repatriation of fossils (See Section 9 below) as well as an international initiative for scientific outreach largely driven by the non-profit Institute for the Study of Mongolian Dinosaurs [118]. Lastly, the realisation by the palaeontological community of the controversial provenance of Myanmar (Burmese) amber and its link to smuggling and human rights violations has sparked reforms across the palaeontological community [119]. The reaction of some professional societies and journals was to declare a moratorium on amber material from Myanmar [120–122]. This set a precedent for both professional societies and journals to adapt their guidelines and codes of conduct to address and curtail unjust and unethical research practices although some journals and societies have resisted adopting these standards.
5. **In defense of scientific colonialism in palaeontology and beyond**

There are several arguments commonly used by researchers and fossil collectors to defend unethical scientific practices which result in scientific colonialism, not only in Mexico and Brazil but also in other countries:

5.1. **Fossils should be considered global heritage, not national heritage [22,23,123].**

This is one of the most popular justifications for colonial practices in palaeontology. The argument is that unlike archaeological artifacts, fossils are not related to any geopolitical boundaries, history or culture of a specific people, region, or country [22,23,123]. This is an incorrect assumption as fossils have been known to humankind since ancient times and, in several documented cases, have become part of the local folklore and myth [124–127]. Furthermore, even with archaeological artifacts and heritage sites, connection between the people who produced the monuments or artifacts and modern nation states is often tenuous. For example, the claim related to geopolitics could also be applied to other sites or objects such as the Stonehenge and Sutton Hoo in England, Lascaux in France, or the Colosseum in Italy. These sites existed long before modern nation states were established and in several cases were produced by people without a clear connection to modern residents of the nation-state, but saying that these are not to be considered national heritage of those countries respectively would be broadly rejected as ridiculous. Furthermore, the 1970 UNESCO Convention, the basis for both national and international legislations, states that the definition of such objects belongs to the nation state in which they are located [128]. We argue that fossils add to local heritage in the form of scientific and even historic and cultural importance or value. The idea that natural history should be considered “global heritage” stems from the systems that aided the construction of the colonies as "living laboratories", where research lines and experiments that would not have been feasible in the metropolis would have been carried out without limitations [3]. In the modern world, this line of thinking would lead to a form of neocolonial pillage of the palaeontological resources in countries that are unable to protect them [128] - an archetype of scientific colonialism. This would be not only destructive to the local scientific community but also to individuals that make use of these fossils for cultural purposes [3,129]. The absence of legislation aimed at protecting palaeontological resources allows nations with considerably greater access to funding to exploit these resources, hindering scientific development in the country of origin, which has led to the skewed knowledge production in palaeontology we witness today [13]. It is also important to note that nations with greater access to funding owe this wealth, in great part, to the extractive colonial practices they have been carrying out for centuries. Furthermore, this argument is often, tellingly, not applied to resource-rich Global North countries like the USA, Canada, and Italy where local legislation requires compliance with a permitting system in order to make
collections (see below), whether this system applies to a subset of public lands (as in the USA) or any lands (Canada and Italy).

5.2. **Host countries do not have adequate facilities or personnel to store fossil objects so they are safer in “western” museums [130–132].**

The case of the National Museum in Rio de Janeiro burning down in 2018 [133] is now often used as an example to show that fossils are not safe in Brazil. Targeting museums only in the Global South using this argument is fundamentally wrong. Western museums and historical sites are similarly at risk of being damaged or destroyed, e.g. through fire [134–137], substandard conditions of museums [138,139], high risk to extreme weather conditions [140–143]. The holotype of the dinosaur *Spinosaurus aegyptiacus* collected in Egypt and stored in Munich [144], and that of crocodilian *Gryposuchus jessei* collected in Brazil and stored in Hamburg [145], were both destroyed in Allied bombing campaigns during WWII, together with several other important fossils in museums across Germany [146].

There are several natural history museums in both Brazil and Mexico, some of which are located in the states where the fossils that we mention in this study were collected (figure 6). The Palaeontology Museum “Plácido Cidade Nuvens” at Santana do Cariri, which contains thousands of fossils from the Araripe Basin, was founded in 1985 - presumably before most of the Araripe Basin fossils included in this study were collected. Currently, local researchers associated with this museum coordinate controlled excavations in the region [147–149], and several scientific publications have been produced based on these materials [150–156] (see more publications in electronic supplementary material, Table S2). This museum would be the logical place to store a number of holotypes and other important fossils that are now in foreign collections. Furthermore, even if ex-colonies did have insufficient repositories or personnel, this argument ignores the rank hypocrisy that a long history of colonial extraction is the most obvious reason why museum facilities are absent, insufficient, or underfunded to begin with.

5.3. **There is a lack of local scientific expertise, research education and investment in science [157,158].**

The number of researchers in high income countries is generally higher than that in middle and low income countries [159]. However, the assumption that no infrastructure for research training nor “appropriately-qualified” local researchers exist in lower income countries (e.g. Brazil or Mexico) is fundamentally flawed. There are many natural history museums and several institutions that offer postgraduate palaeontological courses in both Brazil and Mexico (figure 6). Raja et al. [13] also show that South American countries contribute significantly to palaeontological research in the
region, with Brazil and Mexico being the leading countries in the region after Argentina. At the time of publication, the Brazilian Palaeontological Society (SBP) has 376 associates and the Mexican Palaeontological Society (SOMEXPAL) has 142 members. These numbers should be considered conservative as they may only reflect the population of researchers who choose to have a formal association with these scientific societies. Despite the acknowledged need for even more investment in science in both Brazil and Mexico, the research output from these countries has increased notably in recent years and grows at a faster rate than most Global North counterparts. According to data from the National Science Foundation from the USA, Brazil and Mexico had a growth of 9.13% and 6.8%, respectively, in science publications between 2000 and 2018 (see figure 8), with Brazil ranked 11th in world research output. Germany and the UK, on other hand, only increased 2.37% and 1.34%, during the same interval (figure 7). As mentioned above, Mexican researchers were responsible for the majority of publications (51.12%) on Sabinas, La Popa and Parras fossils in the last three decades, whereas Brazilian palaeontologists produced 40.85% of the research on the Araripe Basin in the same period. It is also worth mentioning that lower income countries tend to have the highest percentages of open access publications, thus making their research more widely available [160].

5.4. There is a disinterest in fossils among the local community [161,162].

The local community can only express interest in the local heritage when they have adequate access to that heritage. Science outreach activities, including those produced by local museums, not only inform people but help to generate links between society and the object of dissemination. In addition, they provide information for the public to make sound social, economic, and political choices about their own surroundings and resources. Removing fossils from their place of origin results in the deprivation of opportunities to develop the community's appreciation and cultural connection with their palaeontological heritage. Furthermore, publishing any knowledge about fossils from a particular locality in a language other than the local language and without appropriate scientific outreach or public engagement also contributes to depriving the local people of access to that information and leads to further alienation. Several outreach activities that connect palaeontologists, schools, NGOs and the general public currently occur in both Brazil and Mexico (see some examples in figure 8). Social media has also played a big role in promoting palaeontology in Brazil and Mexico. These activities have had tremendous impacts on the popularisation of palaeontology in these countries as well as education, geoconservation and geotourism.

It is important to mention here that this public engagement by Brazilian palaeontologists is precisely the reason that the hashtag #UbirajaraBelongstoBR gained popularity on multiple social
media platforms following the controversial publication of the study describing "Ubirajara jubatus" in December 2020 [163]. The hashtag has been associated with hundreds of thousands of posts on Twitter (figure 9), hundreds of posts on Instagram and Facebook, and at least 150 YouTube videos across 115 different channels. Distinct types of audiences participated in the #UbirajaraBelongstoBR movement: scientific and non-scientific as well as Brazilian and non-Brazilian. Following the movement, dozens of articles in both Portuguese and English were published in Brazilian media [99,164,165], as well as in international news articles [163,166].

5.5. Specimens are lost to science if they cannot be not collected and studied [119,167]

This argument is frequently used by palaeontologists to justify poor research practices, even beyond examples of colonial science. Those who use this argument wrongly assume that legislations and guidelines for ethical conduct act as barriers to science. In truth, legislation and guidelines for ethical conduct seek to increase participation in science, particularly from local researchers, and create a more equitable environment for all. Providing that the work complies with the legislation of the country of origin (see below), fossil material can be collected or studied by any researcher with the desire and means to do so. Researchers who use this argument are therefore wrongly implying that fossil specimens cannot be adequately collected or studied by local researchers, or that local expertise is absent entirely. This is almost always not the case, as exemplified by the research output by locals in Brazil and Mexico (see section 5.3 and figure 7).

Fossils are lost everyday due to natural and human processes, such as weathering and erosion, natural disasters, quarrying, and construction; there is no conceivable way that palaeontologists can collect and document all fossils that were ever formed. Even when fossils are collected, important contextual data (e.g. stratigraphy, location information, etc.) and even the specimen itself, can become lost through poor collecting procedures, inadequate preservation, disasters or accidents (see section 5.2). This loss of fossil data is not restricted to low income countries - it occurs worldwide. Arguing that specimens will be lost to science because they have not been collected and studied by ‘Western’ researchers is deeply rooted in colonialism and is easily exposed by turning to look at fossil specimens from countries in the Global North.

5.6. Laws are too complicated or difficult to access [10,11,168]

Although fossil laws in Brazil and Mexico are typically compared with the permissive laws of Germany and the United Kingdom, comparisons are seldom made with countries like Canada or Italy, which strictly regulate collection and export of fossils, the USA, which regulates fossil collection on public lands, or even Australia, which restricts exportation of fossils found in any part
of its territory. In Canada, export of fossil resources is strictly and explicitly regulated at both the
federal level by the Canadian Cultural Property Export Control List (C.R.C., c. 448) [169], with
further restrictions at the level of individual provinces. Furthermore, Canada protects several
localities of world importance through UNESCO and the national park system. These include the
classic Joggins Fossil Cliffs [170] and Dinosaur Provincial Park [171], both UNESCO World
Heritage sites, and the Burgess Shale, which is protected as part of the Yoho and Kootenay National
Parks [172], and the Devonian Escuminac Formation, protected within Parc National de Miguasha
[173]. Italy, a high-income European country, also protects its fossil resources under a series of
cultural heritage laws, the same legislation which applies to archaeology [174]. Fossil commerce and
permanent exportation is illegal, and collecting requires an authorization by Soprintendenza
Archeologia, Belle Arti e Paesaggio (Superintendence of Archeology, Fine Arts and Landscape)
[174]. Italian fossils can be temporarily exported only for study and/or exhibition with the
permission of the Soprintendenza. The USA, also, explicitly protects fossils in the public trust so
long as those specimens are collected on public lands [175], and requires that these fossils remain
property of the federal government. As public lands represent approximately 25% of the landmass
of the USA (including the majority of the fossiliferous mountain west), this represents a substantial
restriction on fossil collections and export from the USA. Furthermore, a number of national parks
and monuments in the USA have been established in areas of significant palaeontological resources,
sometimes explicitly with the intention of preserving those resources. Fossil collecting laws within
Australia are variable among its provinces and territories. In Queensland, the Northern Territory
and Tasmania, collection of fossils is partly restricted, requiring a licence [176]. The export of
fossils from Australia (as well as meteorites) is restricted by the Protection of Movable Cultural
Heritage Act 1986 and the associated Regulations 1987, requiring the issue of a permit by an
accredited examiner [176]. We are not aware of criticism of these heritage laws as unnecessarily
nationalists, and we are not aware of major engagement by foreign research communities with
groups attempting to circumvent these protections. We therefore must conclude that the existence of
heritage laws is not an obstacle to good palaeontological research [177].

However, it can be difficult for foreign researchers to navigate local legislation and
bureaucracy, and cooperation with local institutions in Brazil and Mexico is essential in this regard
(and required in the case of the former). In addition to assisting with legal procedures, the institution
can properly guide foreign researchers on specific legislation regarding the collection, study, and/or
temporary export of fossils. The relevant laws that apply to palaeontological work in Brazil and
Mexico have been provided in full and translated to English herein (see Appendix 1 and 2). The
bureaucracy that may annoy and frustrate some helps to regularise and supervise, so that the local
legislation is complied with and the local heritage is protected.
5.7. Commercial exploitation of fossils helps science [178,179].

This assumption suggests that through commercial exploitation of fossil deposits (e.g. mining, quarrying) and the trading of extracted fossils may result in more fossils ultimately being uncovered. However, a greater number of fossils does not necessarily imply a benefit for science. When fossils are openly traded, the exploitation of fossil deposits can become uncontrolled, likely resulting in a loss of important provenance information about that material. The removal of fossils without any documentation of geological information reduces the scientific value of these specimens; new fossil material may lead to the discovery of new species but, without context, these specimens cannot inform on the ecology or evolution of these organisms. In the case of permissible trade (i.e. allowing only the sale of certain types of fossils and/or fossils from certain locations), as in Morocco, the law of “supply and demand” must be considered. The commercialization of this type of rare object (1) leads to an increase in inequality in science, by concentrating this type of material in institutions and countries with the financial means to acquire them, (2) encourages the existence of private collections, which can be an obstacle to the reproducibility of science, and (3) stimulates the artificial modification of fossils [180,181] to obtain a better market price. The latter can be exemplified by a case from the Araripe Basin itself. Martill et al. [85] studied an illicitly acquired, artificially “enhanced” specimen from Brazil and only discovered these heavy modifications during the course of their work. The case left the authors so "irritated" that they decided to express this frustration in the name of the new taxon: *Irritator challengeri*.

Commercial exploitation can be an ally in specific cases when it involves controlled, regulated, and documented collection of material. Nonetheless, this discussion should be led by the local community, together with effective communication initiatives from palaeontologists and local experts to highlight the scientific and cultural importance of fossils.

6. Implications for science and the local community

6.1. Private collections can interfere with the reproducibility of science and prevent access to information to the scientists and the general public.

Fossil specimens and the data obtained from them need to be accessible by scientists, not only for reproducibility and replicability, but also for verification and comparison purposes. A private collection is usually one that is in the ownership of a personal or corporate entity and any access to the material is at the discretion of the owner [182]. However unless the appropriate arrangements are made, there is a risk of losing these fossil materials due to changing circumstances, e.g. death or illness, or changes in personal finances that necessitate selling off parts of a collection. Current and future research relies on the permanent accessibility and stable storage of these materials, which
unless placed in a public trust, is rarely the case for privately owned collections [120,183]. Private
collections also hinder access of information to the general public. Science is a public endeavour,
often funded by tax money and as such, scientists have a responsibility to relay the findings and
provide access to materials - through museums - to the public. When fossils are stored in private
collections, this negates the public’s ability to not only enjoy but also scrutinise scientific research
arising from public funds.

6.2. The purchase of fossils, besides being currently illegal in these countries, does
not benefit the local community in the long term.

Fossil deposits are finite. With the depletion of the resource, the living wage earned from any trade
quickly becomes inaccessible to people financially dependent on it. In addition, the impacts of
mining activity, including environmental damages and tailing monitoring in many cases, will be
borne by the community long after the resource is exhausted. It is a trade-off whose cost generally
falls on the most vulnerable citizens in the long run.

The areas discussed in this study are of economic vulnerability, mid-low human
development index (HDI), inequality and low level of education that contrast with European
standards [70,184]. The local communities are thus vulnerable to the exploitation of third parties,
and the economic benefit most of the time does not reach the segment of the society that really
needs it [69] (e.g. see a survey of Araripe fossil prices by Martill [185]). The permanence of the
material in regional institutions, on the other hand, such as museums and universities, has the
potential to generate a more sustainable and lasting economy, with a greater and more equal
distribution of income. Museums and geo- or palaeontological parks attract tourists, which help to
support a network of establishments and people of the service sector, such as restaurants, hotels, gas
stations, tourist guides, handicraft makers and retail outlets. In addition, they provide support for
educational institutions, helping to train personnel and generate scientific and technological
products (fourth sector of the economy). The simple withdrawal and trade of fossils does not
effectively contribute to the economic development of the region. Purchasing important fossils,
either by private collectors or foreign researchers/museums, is depriving local museums from
attractions that could potentially boost visitors and contribute to the local economy. The support of
this type of activity keeps “the colonised country” as an eternal exporter of commodities dependent
on its "coloniser" to provide specialised services and products.

6.3. Lack of interaction with local scientists can generate poor-quality research.

Although the inclusion of local researchers is not required by law in Mexico, this is not the case in
Brazil where it is compulsory (see section 2.1). Local researchers have more specific knowledge
about the geological context of the region, the co-occurrence of fossils, relevant studies that have been published in local or regional magazines, and other useful information, for example on security/safety or socio-political issues. International collaboration can contribute significantly to their training, which is one way to give back to the country of origin of the fossil material. In addition, local researchers who regularly interact with, or have even grown up and lived in, communities close to fossil sites are best placed to understand the economic and cultural needs of these communities as well as to conduct outreach activities focused on the significance of the local fossils. Outreach activities, as mentioned above, are necessary to raise awareness and protect the heritage, they can also result in new fossil discoveries by local people.

An example of a problem produced by non-cooperation with local researchers is the confusion that perpetuates around *Irritator* (figure 1) and the strikingly similar form *Angaturama*, two spinosaurid dinosaurs from the Araripe Basin, Brazil. Both species were published in the same month, with only a few days difference. One, described exclusively by non-Brazilian researchers, based on the posterior portion of a skull, which was acquired from fossil traders [85]; and the other, described by Brazilian researchers, based on the anterior portion of a skull, acquired through a donation from a private collection to the Universidade de São Paulo [186]. The situation caused some authors to speculate that the fossils belonged to the same individual [187,188], which was, much later, discarded [189]. Communication with local researchers could have avoided this problem and resulted in a much more comprehensive work from the beginning. Moreover, this is another example of how illegal collections of fossils can harm science. If the appropriate field data had been recorded during a legal and controlled collection, there would be no uncertainty about whether both holotypes belonged to the same individual.

6.4. It affects ethical partnerships between local and foreign parties

The *modus operandi* of scientific colonialism, in palaeontology and beyond, generally negatively affects the local image of foreign researchers that wish to cooperate with local palaeontologists through an equitable partnership. Parachute science practices generate distrust towards foreign parties as a whole, regardless of which researcher is the leader of a group or which institution the researcher(s) represents. Conversely, local researchers who wish to partner with foreign colleagues are often looked upon with suspicion by other local researchers due to the bad image generated by third party colonial practices. Overall this situation prevents the progress of international scientific cooperation and hampers the development of local science and local researchers.
6.5. **Negative impact on local science development by making it difficult to access specimens.**

Allowing fossil materials to be reposited in foreign institutions restricts the advancement of the palaeontological discipline in their countries of origin. When fossils are taken away to foreign institutions, they may become unavailable to local researchers and students. Visa-related issues [190] and reduced funding [13] are some of the major obstacles to international travel that are more likely to be faced by researchers in the Global South. Abysmal currency exchange rate differences routinely prevent Latin American researchers from traveling to access fossils in foreign collections. This is an especially serious problem with regard to access to holotypes. While access to digital specimen data is becoming increasingly more available certain types of research still require many fossils to be examined in person. Moreover, the difficulty of accessing the fossil material also implies that the research cannot be reproduced by peers who might be interested in replicating the study and/or further testing it. As such, removing fossils from their country of origin deepens the inequality between science produced in "colonised" and "colonising" countries.

6.6. **The creation of a large amount of dubious data**

Sometimes, fossils can be collected from outcrops without any taphonomic or stratigraphic control, especially when the collection is coordinated by commercial collectors. As a result, relevant information, or even crucial information to the understanding of that material, is permanently lost. Some publications on Brazilian specimens only vaguely state when the fossil was collected, instead of providing comprehensive geographical and geological context (see section 3.2). We cannot discount that this might be intentional, as admitting that a Brazilian fossil was found after 1942 implies that a collection permit from ANM would have been necessary to collect it. The absence of permit information from a publication does not necessarily indicate that a particular team did not obtain the necessary permits to perform a palaeontological expedition. In fact, several local palaeontologists have also not reported the required collecting permits in their publications. In situations where fossil trading is permitted or fossil trafficking develops, fossils can even be artificially modified by fossil collectors or sellers to value them, as was the case with *Irritator challengerii* (Martill et al. 1996). This results in poor quality or non-reproducible research, and correcting these errors can require years of research, greatly delaying the advancement of science.

6.7. **“Fossil laundering”**

In some cases, it seems apparent that irregularly collected/acquired fossils have been made to appear more ethically palatable to journals and the wider research community by adding a local researcher as a secondary author. In many instances of this, the local author is not affiliated to any
research institution (e.g. [36,59,92,191,192]) (figures 4 and 5, electronic supplementary material, tables S1 and S2). While we advocate for giving credit where it is due, this “token authorship” represents the power dynamics at play and is a clear attempt at “fossil laundering”. Amateur palaeontologists produce very valuable contributions to science while often working with their own resources [193,194]. For example, in Coahuila, Mexico, the Paleontólogos Aficionados de Sabinas A.C. (Civil Association of Amateur Palaeontologists of Sabinas, see figure 8c) established the Múzquiz Palaeontology Museum in 2005 [53]. Working with local dedicated amateurs and students is immensely important for reasons outlined in Section 6.4, and we do not criticise their deserved inclusion as co-authors in studies in which they took part, particularly as they are the group most likely to be excluded from publications more generally. Our criticism is instead directed towards the absence of true partnerships between foreign researchers and local scientific institutions. In many instances, this practice frequently creates ethical and, in some cases, legal problems and promotes the exploitation of local communities.

7. Historic examples of foreign collaborations in Brazil and Mexico

We are not advocating for a nationalistic approach to palaeontological research. International collaboration is an inherent part of the scientific endeavour and aids the development of local science. International collaborations are not a new phenomenon in Brazil or Mexico. Llewellyn I. Price, a Brazilian-born palaeontologist who worked with Alfred. S. Romer in the USA, teamed with a number of foreign researchers after returning to Brazil [195–198] and eventually became known as the “founder of vertebrate palaeontology in Brazil”. Brazilian palaeontologist Carlos de Paula Couto, formerly Price’s student, later on partnered with George Gaylord Simpson [199,200] and became the main specialist on fossil mammals in Brazil, further training generations of new local researchers. Both Llewellyn I. Price and Carlos de Paula Couto were prolific authors [201] and contributed greatly to the development of Brazilian science.

In 1950, the Department of Palaeontology of Petróleos Mexicanos (PEMEX) was established, where Manuel Maldonado-Koerdell (Mexican) and Federico Bonet (Spanish) began the training of Mexican palaeontologists. Maldonado-Koerdell is considered the founder of the modern Mexican palaeontology community [202]. He promoted international cooperation as noted in his work “Correlation of the Triassic formations of Central America, México, and the United States” [203]. He had a great interest in Pan-Americanism and collaborated with Central American government agencies on projects related to mining (Nicaragua) and palaeontology [202]. The palaeontologists trained by Maldonado-Koerdell, were, in turn, pioneers in the study of other organisms. Agustín Ayala-Castañares was a pioneer of micropalaeontology in Mexico and had successful collaborations with several foreign researchers from Switzerland, USA and Cuba [204–
His collaborations are also highlighted in the work “Opportunities and challenges for Mexico-US cooperation in ocean sciences” [208].

8. Small steps in the right direction and the repatriation challenge

Some research groups involved in scientific colonialism practices seem to be reviewing their approaches. Extended research on the Brazilian petrified wood stored at the Chemnitz Museum, Germany has been developed by Brazilian scientists in collaboration with German researchers [209–213] with funding provided by Brazil’s Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq (National Council for Development of Research and Technology). Despite this valuable collaboration, the irregularly acquired and exported specimens of fossil wood, including several holotypes, remain in Germany. Repatriation and restitution of fossils, especially ones that were acquired illegally, constitutes a key process towards the decolonisation of palaeontology by addressing the injustices under colonial or neocolonial contexts, as well as shifting the power of protecting heritage resources to the country of origin [214–216].

Several museums in the Global North are facing repatriation demands for fossils, and indeed other cultural and anthropological objects, and some countries making those demands have been successful [217,218]. One high-profile case that set a precedence for the application of national fossil laws to another country was that of the repatriation of two *Tarbosaurus bataar* specimens along with 16 other fossil specimens from the United States to Mongolia following a successful legal case in 2013 [219]. This success is due to the efforts of Bolortsetseg Minjin, a Mongolian palaeontologist who alerted the Mongolian authorities after seeing an advertisement for the auction of a *Tarbosaurus* specimen in New York. Neil Kelley, a palaeontologist based in the USA, started a petition on change.org to stop the auction [220], which attracted the attention of an American lawyer, Robert Painter, and Phillip Currie, a Canadian palaeontologist, who along with Minjin and Kelley provided expertise to show that these fossil specimens originated in Mongolia [221]. This paved the way for the repatriation of more than 30 Mongolian fossil specimens from the United States [222], as well as from France and South Korea [223].

In 2019, a French court ruled in Brazil’s favour for the repatriation of 45 fossil specimens originating from the Araripe region [224]. The circumstances of this case draws parallels with the *Tarbosaurus* one. After being alerted by palaeontologists on Facebook to the online auction of one of the biggest and almost complete *Anhanguera santanae* specimens, Brazilian palaeontologists alerted the Brazilian Public Prosecutor’s Office which immediately launched an investigation with the help of French authorities [78,224]. Another case of successful repatriation is that of Chinese fossils from Australia in 2008 thanks to the efforts of Australian palaeontologist John Long with the help of his Chinese collaborators who worked together with the Australian Federal Police following
a request from China in 2004 [225]. These cases highlight the importance of local expertise, collaborative networks and social media in uncovering and fighting the illicit trafficking of fossils.

An irregularly large number of Brazilian fossils have illegally ended up in foreign collections in Germany and Japan. At least 12 holotypes of Araripe fossil vertebrates and invertebrates are illegally housed in museums and private collections in Japan (e.g. Collection Masayuki Murata) (see Table S2). At least 90 Araripe holotypes were smuggled to German museums (see section 3.2 and electronic supplementary material, tables S2 and S3), mostly to Stuttgart, Karlsruhe and Berlin. Brazil faces great difficulty in repatriating these fossils. Historically, these countries have been the least in favour of the 1970 UNESCO Convention [226] and only ratified the Convention in the 2000s. Guidelines for the restitution of objects under “colonial contexts” in Germany were only developed in 2019 but are not legally binding and do not provide any reliable legal framework within which legal claims can be made [227]. That said, Chile has successfully retrieved fossils stored in Germany in the past, with the assistance of a German museum [217]. However, the repatriation of the *Psittacosaurus mongoliensis* specimen, smuggled out of China and purchased by the same German museum after changing “owners” several times, has been largely unsuccessful [228,229] and as of 2020, still has not been restituted [230]. German museums recently agreed to the repatriation of several archaeological artifacts acquired during the colonial times [227], including the Benin bronzes to Nigeria [231]. We expect that this will in the future be extended to palaeontological specimens as well.

9. Ways forward

9.1. Advances in technology and information sharing

Technology can be an ally in the process of decolonising palaeontology. Museums can share replicas, CT-scans, photogrammetry data and 3D prints of important fossils, allowing information to be exchanged more equitably [232]. An international party working on Permian fossils in NE Brazil is already using this approach. New vertebrate fossils are repositioned at Universidade Federal do Piauí, in Teresina, Brazil, while casts, photogrammetric models and CT-scans of the fossils are shared among various partner institutions overseas [233–236]. Researchers should also consider making their CT-scan data available in an online repository such as MorphoBank or MorphoSource, which would facilitate equitable data sharing and reproducibility. Ideally, fossil materials, especially holotypes, should be repatriated to their country of origin. Fossil repatriation is generally perceived negatively by the museums that face these demands, which foresee large costs associated with the shipment of the material, as well as the loss of prominent specimens that can attract the public or provide valuable research data. However, the process of repatriation has enormous
potential to establish new partnerships in the countries of origin, especially when new technologies, such as those mentioned above, are embraced.

9.2. Recommendations to journal editors and reviewers

Palaeontology-oriented journals, and those that routinely publish palaeontological studies, should adopt more rigorous guidelines regarding research ethics and the legal status of the fossils featured in their articles. Ideally, journals should require authors to report both collecting and exportation permits where applicable, i.e., when a study is based on fieldwork and when fossils are not reposited in their countries of origin. Some journals with a history of publishing questionably-acquired fossils (see electronic supplementary material tables S2 and S3) seem to be moving in the right direction. Palaeontology and Papers in Palaeontology have both recently updated their guidance to authors, which now states that all manuscripts should include “clear provenance information” and that “samples should always be collected and exported in accordance with relevant permits and local laws, and in a responsible manner” [237]. Both journals also now require specimens to be “deposited in a recognised museum or collection to permit free access by other researchers in perpetuity” [237]. Though this guidance does not include any specific examples of where permits would be required, or where authors might go to find more information, it is certainly a step in the right direction. Current Biology and other Cell Press journals, which frequently publish palaeontological studies, advocate for transparency and accessible reporting [238] and as of January 2021 allow authors to include an inclusion and diversity statement in an attempt, among others, to curb the amount of scientific colonialism present in academia [239]. A recent study describing a new Chinese pterosaur fossil published in Current Biology used this opportunity to highlight that the author list of this paper included “contributors from the location where the research was conducted who participated in the data collection, design, analysis, and/or interpretation of the work” [240].

Other palaeontological journals apparently have strict policies regarding ethics and legality but unfortunately do not put them into practice. Cretaceous Research, for example, states in its guide for authors that “Fossil material of uncertain or dubious provenance will not be accepted for publication in Cretaceous Research. This includes material currently housed in museum collections which lack detailed field collecting records, and/or which provenance cannot be definitively ascertained with certainty” [241]. This journal, however, notoriously publishes to this day numerous fossils of highly questionable origin from Araripe [242–245] (including “Ubirajara jubatus”[35], temporarily retracted after complaints from other researchers and social media pressure) and even amber from Myanmar (19 papers in 2021 so far), the latter already being formally banned by a
number of palaeontology journals for ethical and legal reasons [120–122] (see discussion in Section 4).

Both in Brazil and in Mexico, fossil trade or export without a permit is illegal. Manuscripts involving fossils from these countries that only include vague statements involving the acquisition of a specimen or that cannot provide full information regarding how the fossil was obtained, should not be considered for publication. Brazilian fossils collected after 1942 and stored in foreign collections should be regarded with high suspicion. Authors that claim that a Brazilian fossil in a foreign collection was obtained before 1942 should be able to produce evidence of this. We are aware that Brazil’s ANM authorized the legal exportation of some Brazilian fossils after this date (e.g. *Prionosuchus plummeri* specimens stored at the Natural History Museum in London, UK, [246], but these are very rare cases that involve non-type specimens, and authors that study this kind of material should demonstrate the pertinent documentation from the keeper institutions. Any Brazilian holotype collected after 1990 that is stored in a foreign collection represents a violation of Brazilian laws as demonstrated above. Authors must obtain and provide proper documentation from ANM and MCTI that demonstrates that these fossils were collected and exported legally. Fossils that are kept in private collections and not in research institutions, should also not be considered for publication, especially when involving new taxa. Mexican fossils having an INAH registration number are not necessarily reposed in museums or universities because this government agency also registers private collections. Moreover, in order to encourage registration, INAH does not ask questions regarding provenance or authenticity of the fossils. Authors that wish to publish Mexican fossils registered by INAH should provide documentation by this organ proving that the fossil in question is available to scientists in a research institution and not part of a private collection. As mentioned above, some of the foreign researchers that usually work on these fossils openly advocate breaking local laws and regulations [10,11,168]. The burden of proof is on the side of the authors of the manuscripts. We strongly recommend that editors refuse to publish studies on these fossils unless their legal status has been clearly proven with supporting documentation by the authors. We also recommend that reviewers go beyond the requirements of the journal to ask these questions and demand documentation proactively, in the cases where journal editorial policies are lagging or inadequate. While it is imperative that research complies with the national legislature, there is no legal requirement to engage in work that is ethical or abstain from parachute science. We therefore must also recommend that editors, reviewers, and authors be mindful of the implications of research that is not equitable.
9.3. Recommendations to local governments and authorities

Governments should review laws regularly to avoid creating legal loopholes by consulting experts, ensuring that no conflict of interest exists, and enforce current laws and regulations. In August 2020, a bill was passed in the Nuevo León Congress that redefined the material from Vallecillo (in the Sabinas Basin), collected for over two decades, as “unusual engravings in carbonate limestone”. One of the main concerns, as reported by journalists at the time [247] and voiced by the Council of Palaeontology of INAH [248], is that the new law opens the possibility to openly trade fossils extracted from the Vallecillo quarry thus bypassing fossil protection legislations [247,248]. In order to make our study more accessible to local authorities and policy makers, we have made translations to Spanish and Portuguese available (see supplementary electronic material Translation S1 and S2).

However, due to the asymmetry of power between the governments of formerly colonized countries and major colonial powers of the Global North, the burden to prevent smuggling of fossils poached in countries with robust heritage laws must also be taken up by the countries where these fossils are ultimately purchased. Efforts to counter smuggling of cultural and national heritage objects as well as fossils and protected wildlife have been undertaken in some countries of the Global North, notably Canada and the US [219,249], but this effort has largely focused on high profile items (e.g. dinosaur skeletons) rather than general trade in contraband heritage objects. Other countries, such as Germany, have previously been referred to as being one of the centers of international trade of illicit antiquities [250]. More robust adherence to international conventions on smuggling of heritage objects by destination countries is a critical piece of any effort to bolster local fossil protection legislation.

9.4. Recommendations to research institutions, funding agencies, and reviewers

Palaeontology is a science that captures wide public interest [251,252]. Colonial science practices repeatedly carried out by some palaeontologists can evolve into a negative public perception towards an academic institution that tolerates them. Complying with local regulations is not only a logical step before undertaking an expedition or research on internationally-sourced specimens, but should also be an expected ethical practice for palaeontologists and scientists in general. Some professional palaeontological societies currently have a Code of Conduct addressing this specific point that their members must comply with [253,254]. Museums and universities should advise and support their palaeontologists that perform research in low-income or resource-poor countries in order to avoid conducting colonial science practices. Universities should also consider including science history and ethics courses as part of their undergraduate and graduate programmes to ensure that the future generation of palaeontologists receive adequate training on ethical issues within palaeontology. Funding agencies should make it compulsory for applicants to demonstrate that they
will comply with the laws of the countries they wish to carry out research in. Failure to so this
should result in the funding being terminated. Funders should also have a requirement that
equitative, institutionalized cooperation with local counterparts be facilitated in a way that can
benefit both parties involved in the collaboration. As with manuscript reviews, grant reviewers
should consider preemptively scrutinising proposed partnerships and international fieldwork
irrespective of whether the funder currently requires this oversight. Reviewers should also be
mindful of the ethical implications of proposed partnerships and outcomes, outside of legal
requirements.

Museums share a burden of responsibility for colonial practices that is difficult to ignore
[255]. It is hard to imagine that nearly a hundred Araripe holotype fossils (and presumably an even
larger number of non-type fossils) made it illegally to museums in Germany without the knowledge
or even support from their respective curators. As seen above, there are several cases in which
authors openly admit that fossils were purchased. Details of purchases are even recorded on
museum labels within collections (figure 10a) and there are even cases in which Araripe fossils are
being sold by the museum gift shops (figure 10b). Museums should adopt strict policies regarding
the reception of specimens in their collections. Banning the admission of fossils with dubious
provenance data or from countries that prohibit their exportation, as is the case of Brazil and
Mexico, should be embraced as a formal policy.

10. Conclusions

We recommend that museums, universities, and funding agencies avoid facilitating research or
researchers that are involved in colonial scientific practices, especially when there are signs of
violation of local laws and regulations, such as the illegal purchase and export of fossils. It is
equally important that journals make it mandatory for authors to provide applicable research and
exportation permits, and refuse to publish research that is produced through unethical and irregular
activities, such as the cases enumerated herein. Foreign researchers must respect local laws and
regulations and engage in constructive, ethical, and equitable partnerships. The extractive history of
colonialist palaeontology cannot be rewritten, but we can forge a new path based on respectful
cooperation that mutually benefits both foreign and local institutions, as well as the local
communities that remain the custodians of their palaeontological heritage. Colonialist science must
end, not only because it is a destructive, pervasive practice that has deep, negative ethical and social
implications, but also because it often produces dubious, non-reproducible research.
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Figure captions

**Figure 1.** Holotype vertebrate fossils from Araripe Basin, Brazil, stored in foreign collections. (a) SMNK PAL 29241, proposed holotype skeleton of the feathered dinosaur “Ubirajara jubatus” [35], paper temporarily retracted by publisher at the time of preparing this study), (b) SMNK PAL 3828, holotype of the pterosaur Ludodactylus sibbicki [88]. (c) SMNK 2344 PAL holotype of the pterosaur Tupandactylus navigans [256], (d) SMNS 58022 holotype of Irritator challengeri [85] (e) SMNK PAL 3804, holotype of the crocodyliform Susisuchus anatoceps [257], (f) Private collection BMMS BK 2-2, holotype of the putative legged-snake Tetrapodophis amplectus [34], photograph by Michael Caldwell.

**Figure 2.** Fossils from the Sabinas Basin stored in a private collection. (a) cf. Tselfatia formosa, ~750mm body length. (b) cf. Belenostomus longirostris, ~700mm body length. (c) pachyrhizodontid fish ~750mm body length. (d) chelonia cf. Terlinguachelys sp., ~300mm body length. (e) Holotype of plesiosaur Mauriciosaurus fernandezi (Frey et al. 2017). (f) Holotype of Aquilolamna milarcae [36]. All fossils are deposited in the collection registered by INAH as REG2544PF, which is housed by Mauricio Fernández (seen in the photograph) in Monterrey, Nuevo León, Mexico. (e, f) Image captures from video by Grupo Reforma Youtube Channel (El Norte - Grupo REFORMA 2021).

**Figure 3.** Fossil sites at the Sabinas, La Popa and Parras basins (NE Mexico) and Araripe Basin NE Brazil). (a) La Mula Quarry, North of Múzquiz, Coahuila. (b) Vallecillo Quarry in Nuevo León State, with quarry worker Ramón Ramírez. (c) Nova Olinda Quarry in Ceará State. Photographs (a) courtesy of Alberto Blanco-Piñón, and (b) by Selene Velázquez.

**Figure 4.** Publications on Jurassic and Cretaceous fossils from Sabinas, La Popa and Parras basins, and other sites in Coahuila and Nuevo León states between 1990-2021 (Plants and microfossils
excluded). (a) Issues detected in the publications. (b) Current location of the fossils. See electronic supplementary material, Table S1, for list of publications and description of methods used.

**Figure 5.** Publications on Cretaceous fossils from Araripe Basins, Brazil, between 1990-2021 (only holotypes, invertebrates excluded). See electronic supplementary material, table S2, for list of publications and description of methods used. (a, c) Current location of the fossils. (b) Issues detected in the publications.

**Figure 6.** Museums, natural monuments, and institutions providing postgraduate courses related to palaeontology in Mexico and Brazil. See detailed list in electronic supplementary material, tables S4 and S5.

**Figure 7.** Comparison of papers published by country during 2000–2018. Data from National Science Foundation from USA available through The World Bank at: https://data.worldbank.org/indicator/IP.JRN.ARTC.SC

**Figure 8.** Outreach activities and public interest in palaeontology in Mexico and Brazil. (a) The cross of Picos de Pato (duck-bill dinosaurs) and Tiranosaurios streets at Rincón Colorado, Coahuila, México (with palaeontologist Giuseppe Leonard). (b) School students learn how to find fossils in the Jovens Paleontólogos (Young Palaeontologists) Project in Nova Olinda, Ceará, Brazil, by Universidade Regional do Cariri (URCA). (c) Meeting of Paleontólogos Aficionados de Sabinas A.C. (Civil Association of Amateur Palaeontologists of Sabinas) in Coahuila (René Hernández Rivera and Jim Kirkland seen in the photograph). This association created the Museo Paleontológico de Múzquiz in 2005 [53]. (d) Fan art with #UbirajaraBelongstoBR hashtag posted on Twitter in December 2020 (credit: Saulo Daniel Ferreira Pontes, @saulodfp).
Figure 9. Posts on Twitter.com using the hashtag #UbirajaraBelongstoBR between 13 December 2020 and 31 March 2021.

Figure 10. (a) acquisition of Araripe fossils by Staatliche Museum für Naturkunde Stuttgart. SMNS 58022 holotype of the dinosaur Irritator challengeri, (label says “purchased from M. Kandler 1991”); SMNS 55414 pterosaur (indeterminate genus), (label says “purchased from K. H. Frickhinger, Planegg in Munich, 5.6.187” [sic]); 82001 pterosaur (indeterminate genus), (label says “purchased from K. H. Frickhinger Planegg in Munich, 5.6.1987, together with 55404-55415 for the price”); 56994 pterosaur Tropeognathus robustus, (label reads “acquired from C. Novaes Ferreira, São Paulo, Brazil (7.11.1990)”. (b) Araripe fishes (Dastilbe sp.) being sold at a souvenir shop in Staatliche Museum für Naturkunde Karlsruhe in 2011. Commerce and exportation of fossils has been forbidden in Brazil since 1942 (see section 2).
Box 1. Clarification

All views expressed in this paper rely solely on information, or lack thereof, provided in the publications discussed herein. We do not assume that the authors of the papers here discussed have violated or intended to violate any local laws or regulations. Neither do we assume that all of the co-authors of a particular paper concur with irregular or unethical practices eventually made by another co-author or by an institution.

Box 2. Portions of Decree 98.830 from 1990 and Ordinance 55 from 14/03/1990 of the Minister of Science and Technology that are relevant to foreign palaeontologists.

Decree 98.830 from 1990

Article 3 The activities referred to in Article 1 will only be authorized as long as there are co-participation and co-responsibility of a Brazilian institution with a recognized technical-scientific concept in the research field correlated with the work to be developed, according to the assessment of the National Council for Scientific and Technological Development (CNPq).

Ordinance 55 from 14/03/1990 of the Minister of Science and Technology: "Regulates the collection of scientific material by foreigners, according to Decree 98.830 / 1990"

42 - The MCT, through the co-participant and co-responsible Brazilian institution, will retain, from the collected material, for the destination to Brazilian scientific institutions, the following items:

(...) e) all fossil type-specimens;

f) At least 30% of the specimens of each taxon identified at any time;

Box 3. Recommendations for palaeontological studies in the country by National Council of Paleontology (INAH) [50]:

In the event of the intervention of an academic partnership from foreign institutions as co-responsible for the project, the Paleontology Council must be notified in a timely manner of their participation and the work they will carry out within the research project. The co-manager of the foreign institution must deliver in writing and with a handwritten signature an official letter in
which they undertake to send INAH a report of the results obtained from their participation, as well as the products generated, once the project is concluded.
Electronic supplementary material:

Table S1. Sabinas, La Popa and Parras basins fossil publications by foreign authors
DOI: 10.5061/dryad.8sf7m0cnd. Available at:
https://datadryad.org/stash/share/ebBibeh8gnm2lvrXMvZq07eB_5zzhA5JQ2OQnN500ts

Table S2. Araripe fossil publications by foreign authors (vertebrates and plants)
DOI: 10.5061/dryad.g79cnp5q1. Available at:
https://datadryad.org/stash/share/KJvxFGJNSjlf7rtGlzIR3CEeDzp4-pLEEKrRnez1798

Table S3. Preliminary list of Araripe fossil arthropod publications
DOI: 10.5061/dryad.mw6m905wv. Available at:
https://datadryad.org/stash/share/PNYVwUjM8vFasi6jeLNl2T6bxlGYdCH0LxUAnEBsWH0

Table S4. List of palaeontology museums and postgraduate courses in Brazil with palaeontology advisors
DOI: 10.5061/dryad.pc8661nz. Available at:
https://datadryad.org/stash/share/g16fg3iQgQoC5dNCCGON6HM0uUL6dt7LOARhBTz7Z4I

Table S5. List of palaeontology museums and postgraduate courses in Mexico with palaeontology advisors
DOI: 10.5061/dryad.n8pk0p2vp. Available at:
https://datadryad.org/stash/share/sGadbKQ2aQflF8VEC5QDSvMI9Bv2J7eeILL-VT-h47E

Translation S1. Complete article in Portuguese
Will be made available if approved by the journal.

Translation S2. Complete article in Spanish
Will be made available if approved by the journal.

Appendix A. Laws in Brazil (includes English translations)
DOI: 10.5061/dryad.cc2fqz664. Available at:
https://datadryad.org/stash/share/neDIPnhuj0WJc-4YyIm0gH--gO_uiKiaUjQwpCjHkbY

Appendix B. Laws in Mexico (includes English translations)
DOI: 10.5061/dryad.d2547d82x. Available at:
https://datadryad.org/stash/share/eYJbLx9wNnQ6vCEvDgMKHv5dB9Yn_BAsXrzDHTFksQM
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934x983mm (72 x 72 DPI)
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Response letter

On behalf of my co-authors, I am pleased to submit the revised version of manuscript RSOS-210898, “Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil”. All authors listed on the title page have read the revised manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission for Royal Society Open Science.

We are sincerely grateful for the constructive critiques and positive responses from both reviewers. We have considered all of them, and have made revisions to the manuscript in accordance.

We all believe that the revised version is a substantial improvement. Please find our direct responses (demarcated with plain text) to each of the reviewers comments (in bold italicised text) below. We have modified the manuscript according to all the recommendations requested by the referees and we have added several minor corrections in order to improve clarity, grammar, and style.

Two major updates have been included to the manuscript:

1. The first one being the revelation that the “Ubirajara jubatus” fossil was bought by the Karlsruhe museum in 2009 and the permanent retraction of its publication by the journal Cretaceous Research.

2. The second update concerns the repatriation of 36 fossil spiders from the Araripe Basin that had been exported illegally to the USA.

Both are relevant to the topic of our contribution and are addressed in the discussion, and a new figure (Fig. 10) was also included. A number of new references have been incorporated to the manuscript as well. We have also reorganized the manuscript discussing Mexico before Brazil and the title has been slightly changed to reflect this.

Sincerely,

Dr Juan Carlos Cisneros on behalf of all co-authors
Email: juan.cisneros@ufpi.edu.br

Reviewer #1:

General comments
Firstly, I would like to say that I really enjoyed reading this manuscript. The ‘story’ is interesting, and the way it has been presented is gripping. It reads like a novel that one does not want to put down – well done. It is also a very important topic, and clearly the authors have extensive experience in this field and with this issue. This comes across in the way it has been presented. However, I do have some relatively minor comments, and a more substantial one.

Many thanks for your appreciation.

It is highly irregular to only include a description of the methods in the supplementary information. If a literature review is used, it should be described (even if very briefly) in the main text of the document, so that readers have some idea of the basis of the data used and the conclusions drawn.

The original formatting of the manuscript was made in accordance with the guidelines for the new subject focus of the journal “Science, Society and Policy” that provided example manuscripts/articles with the methods sections in the supplementary. We are aware of the importance of the methods for this particular study and hence have moved the methods section to the main text.

And even when I access the supplementary material, all it contains are hyperlinks to a web based repository that then autodownloads a zip file of further tables... This is not how one reports methods, but is rather an admirable way of presenting the data used. Somewhere, at least in the Supplementary information but preferably in the main text, there has to be a written description of the methods used to obtain the data upon which part of this study has been based. This should also include a brief description of the Twitter analytics alluded to in the Acknowledgements.

For example, in Table S1, there is no description of how these papers were found (what search terms, what databases or platforms?), or of the content of this table (what does n/a mean for ‘collecting permit’? Does it mean there was not one, it was not mentioned, or that the work described in that paper did not need a permit? Under ‘Issues’, what do the different numbers mean?). All of this information needs to be described somewhere. In addition to a description of the methods in the text, I would also recommend adding a ‘read me’ sheet to each of the supplemental data files, where you explain what the different columns and numbers etc mean.

All the relevant information regarding how the publications used in this study were selected (including the sources, platforms and databases used) can be found in the methods section, now found in the main text. We include a list of all issues that we looked at along with the corresponding values as provided in Tables S1 and S2. We also address the issue of no permits being reported in the study. The methods used for the Twitter analytics are now described in this section.

On another note, regarding Table S1, I would like to see the titles of each of the publications, or a full reference, so that readers can go and find these different papers more easily.
The edits have been made for all three tables (S1-S3) that list fossils from Mexico and Brazil.

Regarding the other Supplemental tables (I noticed this issue in Table S4 but it may be true for more of them), while I completely acknowledge that English is not the only language of science and is not the primary language of either of these regions or the authors of this paper, I would suggest having the table headings either in English or including their English translations in a ‘read me’ sheet. I realize that translating the data will be a pain, but if you are translating the main manuscript into Spanish and Portuguese anyway, then you might consider having different sheets in each (relevant) table for each of the three languages? Or simply provide an explanation in the first ‘read me’ sheet translating key terms (like “Colecção Científica, exposição, etc.”). As an example, if the content of this specific column in Table S4 (Tipo) is confined to only two or three types of work, it might be easier for all different language readers to interpret if you rather set it up more like I have done in the screenshot below (I had to use Google translate, so I’m sure the headings are not quite correct). I appreciate that the issue of language is a tricky one, but for your paper to have maximum impact, it would be ideal for everything to be multilingual, or at least easy to interpret.

We have translated the requested terms inside tables S4 and S5 and made the suggested set up with additional columns.

Specific comments:

For these comments, I refer to the page number from the document, and not the PDF page (for example, the abstract/summary is on page 3 which is the 4th page in the PDF. I will report this as Page 3. Also note that the PDF line numbers do not seem to fully correspond with the lines of text, so just estimate which line of text each line number I refer to is indicating.

Page 3 line16: “Common issues documented in these publications” are these issues truly documented by the publications you found (i.e., do the authors of those publications highlight the issues), or do you mean that they are issues that you found in these publications?

These are issues that we identified in these publications. We have rephrased the sentence to highlight this.

Page 3 line 23: “reposited” is not a commonly used word in English. I would suggest replacing with something like stored, housed, or kept. But I am not of this field, so if the term is commonly used in palaentology then ignore my comment.

This is a common term in palaeontology.

Page 4 line 19-23: I don’t entirely understand this statement. I would recommend expanding what you mean by institutionalisation, and why it benefits colonial advancement

We have now rephrased the sentence to provide more information:
“The development of scientific disciplines, educational programmes, and academic organisations were all products designed to benefit colonial advancement [3] e.g. advancements in geological tools allowed colonial powers to uncover and exploit several natural resources in colonies. “

Page 5 line 30: consider rather using the term "while" here, rather than “whereas” (it isn’t really a contrast to the previous phrase)

The suggested edits were made.

Page 5 line 40: Rather use the term “scientific reproducibility”

The suggested edits were made.

Page 6 line 26: Delete “being” (before “the USA”)

The suggested edits were made.

Page 6 line 59: Rather change “previously” to “to notify the council beforehand”

The suggested edits were made.

Page 7 line 11-14: Consider making this sentence shorter (e.g., use “theoretically” instead of in theory, remove "in the first place", remove "properly"). This should make it easier to read, but if its still too long, then consider using punctuation or breaking it into two sentences.

The suggested edits were made. We have also rephrased the sentence as below:

“The 1970 Convention promotes international cooperation between countries as a means to protect cultural heritage and is theoretically central to preventing the illicit trafficking of cultural property.”

Page 7 line 14: Delete “thus” before acknowledge

The suggested edits were made.

Page 7 line 19-26: This is a very long sentence. Rephrase to shorten, add punctuation, and consider rewriting as two sentences.

The sentence was rephrased as below:

“Thus, the signatories of the Convention are required to enact national laws and services for the protection of the cultural heritage. They are also expected to take the appropriate measures so that museums and other institutions within their territories are prevented from acquiring illegally exported cultural property from another country, as well as to cooperate with restitution of the object(s). ”

Page 7 line 42: Is this not meant to be northEASTERN, rather than northwestern Mexico?

That 's correct. We corrected our mistake.
Page 8 line 14: this is the first time the literature review is mentioned. I would strongly suggest that the methods should be mentioned earlier so that the reader understands how you found these papers (refer to my General comments, above)

The methods section has now been moved to the main text and includes information regarding the literature review.

Page 8 line 18: It is not clear how Box 3 relates to this sentence

We removed the citation of Box 3 here. Thanks for pointing this out.

Page 8 line 19: Rather than “The majority of this output, I would rather state it something like ”Most of this foreign-led research, ...“ to make it clear that ”this output“ isn't referring to the 128 papers

The suggested edits were made.

Page 10 line 59: Here again, there needs to be some sort of description of the methods used to find these papers

The methods have been moved to the main text.

Page 11 line 4: Does “them” (the 57.14%) refer to the foreign-led papers? Or of all the papers?

That’s correct. We have made edits so that this is now more clear:

“....and over half of foreign-led publications (57.14%) showed no evidence....”

Page 12 line 24-26: I am not sure whether the evidence can prove that the foreign researches avoided interaction. I would recommend moderating the language. One could say they neglected to include local scientists, or that this displays a disregard for local laws and expertise.

We edited the text as requested:

“They also display a disregard for local expertise to an even greater extent than observed in the examples from Mexico.”

Page 12 line 37: Rather say that they “likely” represent only a small portion. Because you don’t have the other numbers you cannot say for sure that they do represent only a small portion

The suggested edits were made.

Page 14 line 40: do you rather mean "lines of research" or "research practices"?

We mean “research practices”. The suggested edits were made.

Page 14 line 42: “metropolis” isn't quite the correct word. I think you mean the colonising countries?
The suggested edits were made.

**Page 14 line 49:** It does not appear to solely be the absence of legislation, seeing as both the case study countries have adequate legislation; it appears to be more about the absence of enforced legislation

We have edited the text to make this more clear:

“The inadequate, or complete absence of, law enforcement aimed at protecting palaeontological resources...”

**Page 20 line 14:** How does the sale or purchase of fossils differ from the production of stone products (e.g., for paving or kitchen counters) from quarries that have fossil deposits? I am sure I have seen both the above with little fossil structures in them. And many finds occur in these quarries, which I assume are commercial entities? Without these commercial quarries I assume many fossil deposits would not be revealed. I am not a palaeontologist at all, so excuse me if this is a very 'lay' question, but I wonder if this is something you could mention/discuss somewhere

We have now added this to our discussion:

“Nevertheless, we do not criticise the commerce of fossil-bearing limestone nor the mining operations per se, as long as they comply with legal requirements and their environmental impact is addressed. Limestone mining is an important source of employment in many areas. Furthermore, many important fossils would not have been uncovered if it wasn’t for commercial mining. Local institutions in both Brazil and Mexico regularly visit them in order to prevent significant fossils from being destroyed or accidentally sold as construction material. In Araripe, outreach activities are carried out involving quarry workers in order to raise awareness and encourage them to report these fossils.”

**Page 26 line 11:** Would it not be possible to develop a framework somewhat akin to PRISMA regarding a checklist of items every paper about fossils should report (e.g., permit information, detailed description of the site, geology etc., current location of the fossils)? And it would be ideal if proposed research protocols were published for peer review before the research is actually undertaken, so that any gaps (e.g., the acquisition of permits) can be highlighted before the study is conducted.

This is an interesting idea, and in fact some journals are actually now requesting permit information in the submission system. The recommendations we provide in our manuscript could be implemented in different ways by the journals.

**Page 27 line 23-24:** What do you propose as a solution for these illegal fossils? Should they therefore not be studied, or if they are to be studied and published, should the specimens be repatriated or at least moved to public collections? My concern is the consequence if highly valuable, unique specimens fall in this category, then they will not make it to the scientific literature... should the publications simply be open about the fact that they are studying illegal specimens?

We recognize that some illegal fossils are unique and scientifically valuable and their non-study represents a loss to science. One of our points through the manuscript
though, is that science should not be done at the expense of ethics (and laws should 
not be broken in the way too). An illegal fossil that has been published (and because 
of this, became public and “discovered” by its source country that previously was not 
aware of its existence) should be repatriated. This is a moral obligation and a way to 
legalize it and repair the damage caused to a country’s heritage. But not all the 
negative effects are fixed with this, because the expertise, techniques, etc. that were 
developed through its study mostly helped the country in the Global North that 
illegally acquired the specimen, perpetuating the scientific dependency by a country 
in the Global South. The issue of dubious data that is inherent to these fossils is not 
fixed with repatriation either, some valuable information on taphonomy, 
sedimentology, stratigraphy, geographical provenance, etc. will be permanently lost 
due to the practices inherent to illicit traffic. Ideally journals should not accept 
manuscripts based on these specimens, this is necessary to reduce the demand of 
fossils from the illicit market by museums and collectors and thus break the chain of 
events that damage the source country and its heritage in several ways (scientifically, 
economically, culturally, etc.). Thus, we consider that it is preferable that illicit fossils 
are not studied.

Page 51: In the caption of Figure 2, Frey et al 2017 is not referenced as a number the 
way all other references have been done.

We corrected this.

Page 53 Figure 4: I recommend making this figure just a bit larger (fit the width of the 
page) so that the font is more legible. Also make the currently grey font colour black 
to improve contrast

We have improved the size of the fonts and the figure is slightly larger.

Page 58 Figure 9: See whether it is possible to make this figure bigger, to fit the width 
of the page. I think the font size will be better then, and more legible

We have improved the size of the fonts and the figure is slightly larger.

Reviewer #2:

A lucid, well written, abundantly documented paper, Very necessary in this moment... 
Only minor modifications indicated directly in the text.

We thank the reviewer for their kind comments. All the suggestions made by the 
reviewer in the provided PDF file have been addressed.
Appendix D

Juanuary 7th 2022

Second review of the manuscript:

“Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil”  
(Cisneros et al.)

Excellent paper, well documented and very necessary in this moment.
Please consider the following purely formal corrections (pages of the manuscript, not the complete proof file in pdf; for example, I consider as page 1, the page 1 of the manuscript which is the page 9 of the complete proof file in pdf):

Page 6, fourth and fifth lines - There are confusions in the references of the figures: Tetrapodophis amplectus corresponds to figure 2f and “Ubirajara jubatus” corresponds to figure 2a.

Page 11 - Erase 3.1.

Page 12, seventh line (“line16”) - There is an error in the figure reference which is not figure 5 but figure 4. In the phrase “We found no record of Mexican fossils being stored in foreign collections, except for a study published in 1990 [66] that studied a collection of fossils claimed to have been collected in the 1930s”, replace “that studied” by “on” so avoiding the redundancy of “study” and “studied”.

Page 16, “line 46” - Error on the reference of Tetrapodophis amplectus which is not 2a but 2f.

Page 17, second line - Error on the reference of “Ubirajara jubatus” which is not 1c but 2a.

Page 57 - Change order considering Box 2 for Mexico and Box 3 for Brazil, to be coherent with the main text.

Captions of figures 1, 2, and 11 – Genera and species names should go in italics.

Jean-Noël Martinez
Instituto de Paleontología
Universidad Nacional de Piura
Perú
Response letter

On behalf of my co-authors, I am pleased to submit the revised version of manuscript RSOS-210898, “Digging deeper into colonial palaeontological practices in modern day Mexico and Brazil”. All authors listed on the title page agree to its submission for Royal Society Open Science.

We have incorporated the minor modifications required by reviewer 2. In addition, we updated some references that were in press at the moment of writing and added a new one.

Sincerely,

Dr Juan Carlos Cisneros on behalf of all co-authors
Email: juan.cisneros@ufpi.edu.br