Evaluation of the MapBiomas Initiative

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EXECUTIVE SUMMARY

The MapBiomas project is a collaborative network of civil society organizations, universities, technology companies, and governmental agencies. These organizations have joined together to produce annual large-scale land-use and land-cover change (LUC/LCC) maps at a 30-metre resolution, from 1985 onwards. The Brazilian continental area is the primary target, but the initiative is gradually expanding to other countries in Latin America and Asia. The core objective of the LUC/LCC maps is to produce more accurate estimations of land-use-related greenhouse gas (GHG) emissions. To this end, MapBiomas makes use of local knowledge related to each biome mapped by the initiative, and the vast imagery database and high-performance computing capacity provided by Google Earth Engine.

This report presents an evaluation of the MapBiomas project for the period of July 2015 to June 2019, the implementation phase of the initiative. The findings, conclusions, and recommendations presented in this report are based on an extensive consultation process involving various stakeholders, in particular, developers and users of MapBiomas products. The evaluation has primarily focused on the governance, financial sustainability, data quality, user experience and utilization, and impacts of MapBiomas products.

Key evaluation findings

- **The MapBiomas project has accomplished the core initial goals and objectives and has reached achievements beyond the initial plan**. MapBiomas delivers annual collections with gradually increased temporal coverage. Despite the methodological constraints faced in initial data collections, subsequent releases of MapBiomas are of acceptable quality, which represents a significant breakthrough in automated LUC/LCC mapping for such a large territory.

- **A network of organizations and a strong and enthusiastic leadership have been essential to the successful implementation of the initiative.** The synergy among institutions has optimized the use of financial and human resources and created a hub of knowledge-sharing among organizations. This was made possible by the strong trust among partners, built through transparency and an active, participatory decision-making process. This has fostered empathy, social support, and collaboration among MapBiomas participants. This relatively intangible asset, which is difficult to objectively measure, was constantly expressed in the interviews and surveys. Sustaining such a collaborative spirit will be essential in consolidating the initiative in the coming years.

- **There is no consensus on the need for MapBiomas to have a more formally institutionalized design.** Opinions diverge among several important partners. On the one hand, developers openly ask for a more formal arrangement. For several stakeholders, converting MapBiomas into a legal entity would facilitate fundraising through long-term partnerships with potential financers, including governmental agencies and private institutions. Moreover, the institutionalization of MapBiomas would provide long-term organizational resilience. On the other hand, leading members of the initiative fear that it could weaken the collaborative culture of the network and potentially lead to competition for funding and human resources. Moreover, respondents argue that there is no empirical evidence or theoretical argument to suggest that the informal arrangement of MapBiomas must be changed to achieve funding sustainability and network continuity.

- **The lack of long-term funding constitutes a challenge for organizations engaged in the MapBiomas project.** MapBiomas is highly dependent on project-based funding and this situation is not likely to change in the near future. Several members of local organizations that participate in MapBiomas in Brazil and other countries report that the lack of long-term funding presents a major challenge in maintaining capable professionals within MapBiomas. Although respondents offer many suggestions for possible pathways to funding sustainability, there is no agreement on which business model MapBiomas should adopt. In the coming years, the primary focus for Biomas should be building new agreements and developing business models to ensure long-term funding.

- **MapBiomas complements existing initiatives by filling important gaps in data availability related to land use.** The MapBiomas project complements other ongoing land-use mapping initiatives by i) producing 30m-resolution LUC/LCC maps covering, for Brazil, the entire territory; ii) providing an unprecedented temporal span with annual LUC/LCC maps from 1985 onwards; iii) developing fully automated land-use classification algorithms; and iv) delivering all products free of cost, including the historical series of LUC/LCC maps, scripts, and unprocessed input data.

- **Users and developers report that the MapBiomas data offer sufficient quality for many applications, yet there are limitations.** The quality of the data has improved considerably from Collection 1 to Collection 3, but there are many inconsistencies that prevent an accurate segregation of human-modified landscapes from natural landscapes. This represents a major limitation for applications intended to measure human impacts in natural ecosystems. This technical limitation is of course not unique to MapBiomas. Other initiatives have faced similar constraints. The legend (LUC/LCC classes) adopted by MapBiomas is approved by most users and developers. Even though it does not address every need, it is the most appropriate solution in light of the existing technical limitations related to fully automated LUC/LCC classification.

- **The accuracy analysis and area change reported by MapBiomas have not been following good research practice, recommended by the international scientific community.** In some cases, the innovative nature of MapBiomas and the need to quickly deliver products have driven the MapBiomas developers toward pragmatic choices rather than scientific-based decisions. Although developing new products in a very short timeframe has made necessary this approach, various stakeholders have pointed out that MapBiomas has not been following good research practice, as recommended by the scientific community, in the validation and accuracy analysis of the LUC/LCC maps produced. This limitation should be solved in the coming collection, as reported by developers.

- **The audience of MapBiomas is increasing exponentially.** MapBiomas users have been increasing exponentially over time, and users return. The number of users jumped from 6 thousand in the first year of the initiative to more than 80 thousand in the period July 2018 to June 2019. The majority of these users are based in Brazil, but this may change in the near future as MapBiomas expands to other countries. Although the success of the initiative does not depend on an ever-expanding number of users, it is an important indicator of the success of the initiative. The larger the audience, the greater the likelihood that new applications of MapBiomas data will be developed.

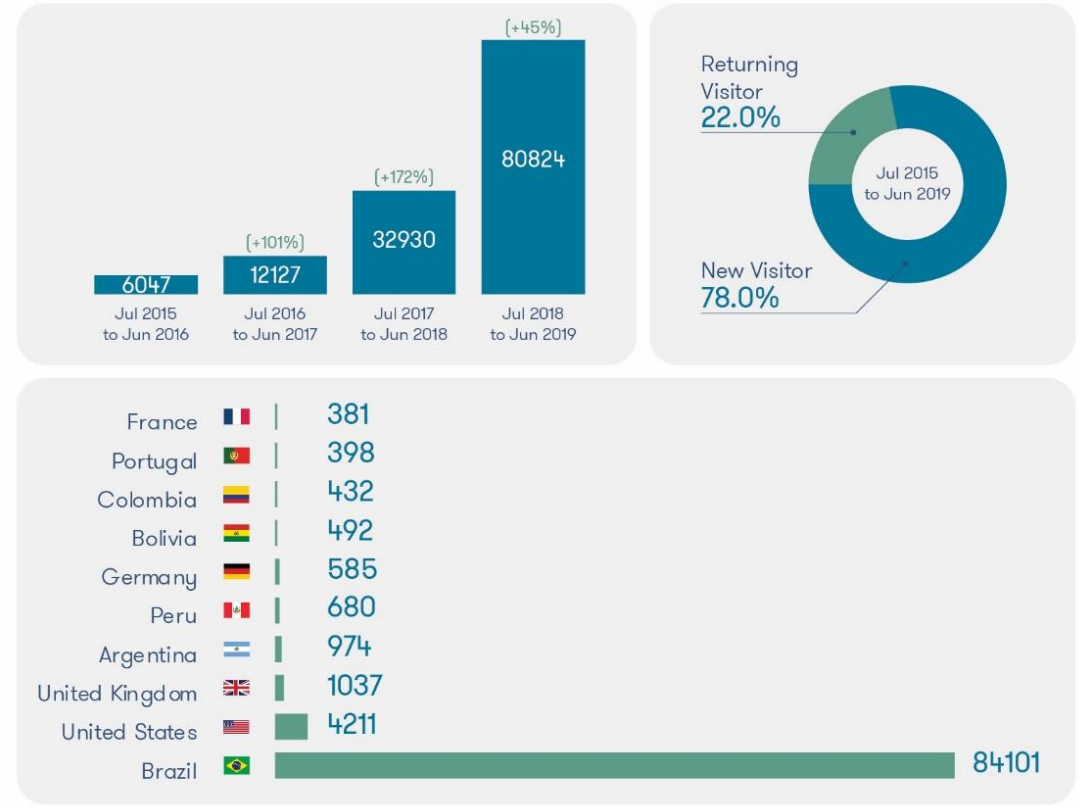

Figure: Metric related to the usage of the MapBiomas platform from its inception in 2015 to June 2019, extracted from Google Analytics.

- **The MapBiomas platform is user-friendly and effective in making data available.** However, many users faced difficulties in handling downloaded files. They found it time-consuming, and, usually, additional processing was required. Moreover, the process of providing feedback to MapBiomas through the forum is very useful. But the initiative could benefit from a systematic collection of user feedback regarding inconsistencies in the LUC/LCC maps.

- **There is strong agreement that MapBiomas is already leading to changes on the ground.** Although no direct link between MapBiomas and improved management of natural resources can be found right now (which in part can be explained by the current political moment in Brazil), there is a general perception that MapBiomas is already leading to changes on the ground. Such an impact should soon become evident with a stronger diffusion of MapBiomas data and consolidation of the MapBiomas Alerts. MapBiomas data are providing a significant contribution to scientific development, which in turn may result in improved land-use governance and more efficient use of natural resources. MapBiomas has also brought light to political debates, fomenting policy dialogues with more accurate annual data on the historical land use occupation in Brazil. Finally, according to our respondents, the MapBiomas Alerts (a branch of the MapBiomas initiative) has the potential to be a game-changer in terms of deforestation control. The Alerts system enables, for the first time, the systematic monitoring of illegal deforestation of native vegetation at a feasible cost. This means that legal action may be taken against deforesters remotely, without on-site inspection. Further, this system may do away with the traditional image deforesters have of themselves as having immunity with regard to environmental crimes. Additionally, the MapBiomas data provide resilience to the supply of deforestation data,

given the recent uncertainty related to the continuity of data monitoring provided by the Brazilian National Institute for Space Research (INPE).

Conclusion

The MapBiomas project has created a collaborative network among experts with inspiring leadership, innovative solutions, pragmatic decision-making, and responsible resource allocation. The successful implementation has achieved and is surpassing the initial core objectives, giving fully free access to LUC/LCC data and, for Brazil (1985 – 2018), expanding the coverage area (Chaco and Amazon regions), and including new products within the MapBiomas network (deforestation alerts analysis system).

In the short to medium term, funding will continue to be sourced from short-term projects, providing part of the personal and institutional needs of the network. Most involved organizations or experts also finance the initiative using their own funding to some extent. Despite having delivered successful results so far, this funding strategy and organizational format presents challenges for some of the organizations. Proper long-term planning and commitments to experts are claimed as burdens in this business model. Network participants point to more centralized and institutionalized alternatives as important steps towards financial sustainability. However, there is no consensus on this topic. Several MapBiomas members consider the current network design to have been—and still be—essential to the success.

MapBiomas is providing large-scale, multi-legend LUC/LCC maps at an unprecedented speed and for an unprecedented time span, in part by boosting the fully automatized classification methodology. Criticism from users, experts, and scientific communities that were at first sceptical to the MapBiomas methodology and the low accuracy of the first released map collections is now diminishing, and the number of users is growing exponentially.

Despite improved data quality and accuracy and reporting in more recent collections, land-use classifications, as in other land-use reporting initiatives, still have many limitations and inconsistencies that limit some applications and users. Because of the extremely innovative methodological approach, it is not clear to what extent accuracy can be improved and how it can be measured reliably along the entire map-collection time span. MapBiomas still needs to improve this understanding and objectively report data accuracy in line with good research practice guidelines.

MapBiomas is already a milestone in LUC/LCC mapping technology and is essential for estimating GHG emissions at the national and state levels in Brazil. Despite these unequivocal impacts, a broader range of impact applications is still unknown and unexplored. MapBiomas Alerts is another great example of the impact of the MapBiomas network, which enable for the first time a systematic identification and punishing of deforesters at a feasible cost.

Recommendations

Recommendation 1: The MapBiomas initiative needs to move gradually from project-based funding to long-term funding to guarantee the financial sustainability of the initiative and ensure long-term commitment with partners developing MapBiomas products. There is no agreement on how to move in this direction, but building agreements with governmental institutions and the private sector in the coming years is recommended.

Recommendation 2: The MapBiomas initiative is in the process of expanding to other countries. The initiative has the potential to contribute in the governance of natural resources in these countries; therefore, such expansion should be encouraged. However, the expansion needs to be governed to ensure that the quality, principles, and vision of MapBiomas are consistent across the various regions. Mechanisms for this governing need to be established. To this end, the creation of a MapBiomas Global Steering Committee would be recommended. The committee would provide overall executive direction, technical advice, and support for national and regional teams to develop fundraising strategies**.**

Recommendation 3: The ultimate goal of MapBiomas is to contribute to sustainable management of natural resources and socio-economic development. The more MapBiomas products are used and the more diverse the user profiles, the greater the likelihood that MapBiomas products will trigger new applications that can lead to significant impacts on the ground. Therefore, it is crucial for MapBiomas to have a well-defined strategy for reaching new users. Such a strategy should continuously search for innovative ways to attract new users from different backgrounds by facilitating access to data and strengthening communication with potential users.

Recommendation 4: The number of MapBiomas users is increasing; moreover, so is the number of supporters, who share the initiative's vision and who are willing to contribute to it. That said, users can make an invaluable contribution toward improving the quality of MapBiomas data. We recommend the creation of simple mechanisms to collect feedback from users of MapBiomas in a systematic and automated manner. This feedback should be validated and used to feed machine learning algorithms to improve coming MapBiomas collections.

Recommendation 5: The core vision of MapBiomas is to provide free access to reliable LUC/LCC information. Although this objective has been accomplished to a large extent, the improvement in quality must be a continuous process. There is much new ground to be broken in enabling the mapping of new features in the landscape and in improving the consistency of land-use classification. To this end, it is of paramount importance that MapBiomas developers maintain their focus and resources aimed at the continuous improvement of the mapping capabilities. The initiative should keep a strong capacity dedicated to innovation, constructing new algorithms and testing new remote sensing products with the goal of improving land-use classification.

Recommendation 6: The primary application of MapBiomas products is related to scientific development. To this end, understanding the uncertainties in the data and controlling them are key to avoiding misleading interpretations of results. Therefore, MapBiomas should develop and follow strict protocols in reporting inconsistencies and uncertainties in the data produced by the initiative. MapBiomas should ensure that the reporting of data inconsistences and accuracy analysis follows good practice guidelines recommended by international scientific communities.

Recommendation 7: In light of the expansion of MapBiomas to other countries and the international community's strong interest in land use and land-use change in Brazil, it is important to establish a clear link between the land-use classes adopted in MapBiomas and other international land-use classification systems. Such a link should be built through a strong consultation process with experts from various regions of the world, to harmonize the definitions of the different land-use classes and set the link between the legend adopted by each system.

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ACKNOWLEDGEMENTS

The evaluation team would like to express our warmest gratitude to the more than 160 enthusiastic respondents in our participatory process, who provided key insights and important information that were crucial in the formulation of this assessment report. The number of participants accepting our invitation was impressive, but most of all, what has been remarkable is the respondents' dedication and good will to provide their best contribution to the evaluation of the MapBiomas initiative, through hours-long voice-call discussions and extensive and detailed descriptions of suggestions and recommendations.

ACRONYMS AND ABBREVIATIONS

CIFF	Children's Investment Fund Foundation
CLUA	Climate and Land Use Alliance
ESALQ	College of Agriculture, University of São Paulo
GEF	Global Environment Facility
GFW	Global Forest Watch
GHG	Greenhouse Gases
GLAD	The Global Land Analysis and Discovery
GPP	Public Policy Group in the College of Agriculture, University of São Paulo
IBAMA	Brazilian Institute of the Environment and Renewable Natural Resources
IBGE	The Brazilian Institute of Geography and Statistics
ICS	Institute for Climate and Society
IDS	Institute for Democracy and Sustainability
IMAZON	Amazon Institute of People and the Environment
INPE	Brazilian National Institute of Space Research
LUC/LCC	Land Use and Land Cover Change
NICFI	Norwegian Climate and Forest Initiative
OC	Climate Observatory
PRODES	Deforestation monitoring system using satellite images
RAISG	Amazonian Geo-referenced Socio-Environmental Information Network
REDD	Reducing emissions from deforestation and forest degradation
SAC	Scientific Advisory Committee
SEEG	System for Estimating Emissions of Greenhouse Gases
TNC	The Nature Conservancy
ToR	Term of Reference
UN	United Nations
USP	University of São Paulo
WRI	World Resources Institute
WWF	World Wildlife Fund

1. INTRODUCTION

This report presents the MapBiomas evaluation's findings, conclusion, and main recommendations. MapBiomas is a multi-institutional project created to develop innovative remote sensing technology to map large-scale land-cover and land-use changes on an annual basis, providing reliable and continuous land-use data. The strategic evaluation of the MapBiomas initiative covered in this report focuses on governance, data production, data distribution, and data utilization.

The evaluation was conducted between March 2019 and July 2019 by the Public Policy Group (GPP) in the College of Agriculture at the University of São Paulo (ESALQ/USP), commissioned by Norway's International Climate and Forest Initiative and the Good Energies Foundation. The assessment of the MapBiomas project was based on a desk review of relevant documents and scientific publications, voice-call interviews with key stakeholders, and an online survey with a wide range of respondents from various sectors. This consultation process attempted to identify how MapBiomas has performed to date, who the users are, how it has been utilized, and, finally, how MapBiomas can develop to meet user needs and have a demonstrable impact on civil society, government, and the private sector.

MapBiomas is an evolving project with several recently added new components. The scope of this evaluation comprised MapBiomas Brazil, MapBiomas Amazonia, MapBiomas Chaco, and MapBiomas Alerts. However, please note that the findings and evidence presented in this report are mostly based on MapBiomas Brazil, which has been operating since 2015. Other initiatives have been launched much more recently, and, therefore, no relevant evidence could be found for many of our evaluation questions.

2. EVALUATION METHODOLOGY APPROACH

2.1 Evaluation questions

Our assessment focused on the data quality, data utilization, and governance of the MapBiomas initiative. The following evaluation questions guided our assessment:

- How is MapBiomas set up and organized as an institution? How appropriate is the established system?
- What size is the team(s) and what experience do teams have? Are there any gaps?
- How does MapBiomas engage with partners and institutions?
- How sustainable is the funding for the project? What are the business models MapBiomas should consider to secure financial sustainability?
- How are strategic decisions about future work made?
- How does MapBiomas compare (pros and cons) with other land-use mapping initiatives, such as, PRODES, GFW/University of Maryland land-cover maps? What is the value of having two initiative cover similar needs?
- Has MapBiomas delivered on objectives and milestones set in agreements with donors?
- Who has used MapBiomas to date? How has the uptake been since its inception?
- How often is MapBiomas being used by users? Are they mainly new or recurring users?

- How have the data of MapBiomas been used to date?
- What impact has MapBiomas had on the ground or within organizations and/or the government?
- What information do users feel is missing?
- Do users feel that the information is easily accessible and that it covers their needs?
- How can MapBiomas reach new users? How to ensure that existing users continue to utilize the platform?
- How can MapBiomas best engage with users?
- How can MapBiomas be used to trigger change on the ground? Does MapBiomas need to take a new direction for the future?

Our assessment of MapBiomas relied on multiple means of data collection, including a desk review of documents and website data traffic analysis, voice-call interviews, and an online survey.

2.2 Desk review

We have conducted a review of the available major documents related to the implementation of the MapBiomas initiative, including documents describing the organizational structure and methodology. Further, relevant scientific and non-scientific publications were scrutinized to identify the main applications of MapBiomas data and potential strengths and limitations discovered by researchers. We identified relevant scientific publications through search engines using the keyword "MapBiomas". Relevant qualitative information in reviewed articles is categorized and discussed later in this report. We have also analysed the MapBiomas website data traffic to identify important information regarding data usage.

2.3 Interviews and online survey

To perform our assessment, we consulted extensively with various stakeholders, focusing primarily on developers and users of MapBiomas products. In this process, we heard the voices and read the words of more than 160 individuals from various institutions in different countries. Voice-call interviews and an online survey were the primary means of consultation, both guided by the evaluation questions. The data collection from the interviews and the online survey followed the ethical principles of confidentiality.

2.3.1 Voice-call interviews

The voice-call interviews enabled a deep understanding of the perceptions of developers and the most relevant users regarding the MapBiomas initiative and products. A questionnaire with open-ended broad questions was shared with the respondents prior to the call. However, the respondents were free and encouraged to touch on topics not included in the questionnaire.

The selection of participants for the voice-call interviews was primarily based on the list of essential respondents suggested by the Norwegian Climate and Forest Initiative (NICFI) and Good Energies Foundation. For the voice-call interviews, we also invited the leading authors of the most relevant scientific publications and the team coordinators of MapBiomas. We invited 43 potential respondents from 36 different institutions, including 11 Biomas developers and 32 users of MapBiomas data. We proceeded with interviews with the 26 potential respondents who accepted

our invitation. The respondents were from 24 different institutions and 4 different countries. The majority were Brazilian (18), but international respondents were also represented (8). These respondents included 11 developers and 15 users.

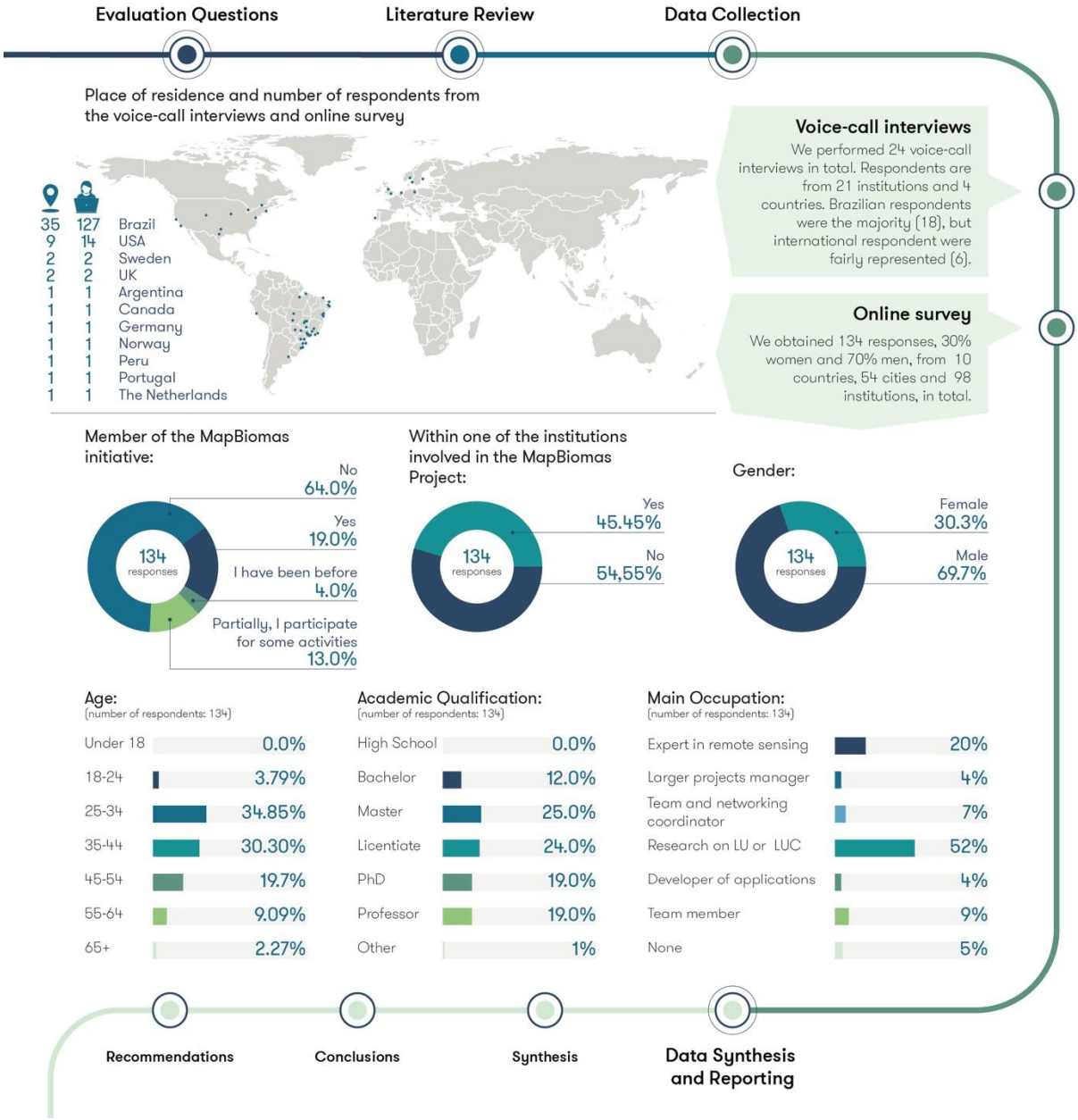

Figure 1. Infographic of the methodological approach we took in our evaluation, including the profiles of voice-call-interview and online-survey respondents.

2.3.2 Online survey

The online survey was designed to capture inputs from a variety of stakeholders, involved and not involved with MapBiomas. The online survey was furnished with many closed-ended questions to allow for developers' and users' perceptions of MapBiomas to be quantified. Open-ended questions were also employed to allow respondents to describe their perceptions, provide feedback, and propose recommendations for the future development of the MapBiomas initiative.

To ensure a representative sample of MapBiomas users, we selected authors of scientific papers identified through search engines using the keywords "MapBiomas" and "land use Brazil" as potential respondents to the online survey. Additionally, we selected the members of major geoprocessing labs in Brazil from various public and private institutions. Journalists authoring recently published news articles about the MapBiomas initiative were also selected as potential respondents of the online survey. The online survey has accepted only one answer per invitation; however, respondents were offered the opportunity to indicate other potential respondents to the questionnaire.

The online survey strategically enabled the consultation of a wider and more diverse group of respondents. We invited more than 600 potential respondents from 171 institutions in 19 different countries. In total, we obtained 134 responses, 30% women and 70% men. The online survey was crucial to ensuring strong participation from younger respondents, who provided important assessment insights. About 40% of the respondents were younger than 35, but almost 90% of the respondents have an advanced degree.

2.4 Synthesis and reporting

The analysis and interpretation of the qualitative data focused on providing answers to the evaluation questions described in the Term of Reference (ToR). Answers and comments from the respondents were sorted into relevant topics derived from the evaluation questions. We evaluated each topic to identify patterns and connections between answers and then synthesized the main findings describing the main agreements, diverging answers, and interesting and relevant viewpoints. Based on these findings, we have drawn several conclusions and provide recommendations.

3. MAPBIOMAS: AN OVERVIEW

MapBiomas is an initiative of the Brazilian Greenhouse Gas Emissions Estimation System (SEEG, Portuguese acronym) and the Climate Observatory (OC, Portuguese acronym). This initiative started in March 2015, officially launching in July 2015. It is driven by the need for annual maps of land-use and land-cover change (LUC/LCC) for the entire Brazilian territory to serve as the basis for more accurate estimations of land-use-related greenhouse gas (GHG) emissions. The primary objective of the initiative has been to produce a historical series of LUC/LCC maps, starting in 1985 and extending to the present time. To reach this goal, methods and procedures were developed to be fully automated and inexpensive, since this would be the only possible way to map such a long series for a continental-scale territory in a relatively short period of time.

3.1 Geographic coverage

MapBiomas was initially created for the Brazilian territory and launched in July 2015 (Figure 3). However, the initiative is currently expanding to other regions. In February 2017, MapBiomas Chaco was launched to provide annual LUC/LCC maps for the Gran Chaco Americano, which covers three new countries, Argentina, Paraguay, and Bolivia. MapBiomas Amazonia was launched in March 2017. Here, MapBiomas partnered with the Amazonian Geo-referenced Socio-Environmental Information Network (RAISG) to produce the LUC/LCC data for the entire Pan-Amazon region, covering an additional seven countries in Latin America, namely Colombia, Ecuador, Peru, Venezuela, Guyana, French Guiana, and Suriname. Currently, MapBiomas is at a very early stage of expansion to all countries in Latin America and Indonesia. Moreover, the

MapBiomas initiative envisions an expansion to other countries in Asia and Africa, in particular to those lacking reliable annual LUC/LCC data and hosting unique natural resources.

3.2 MapBiomas annual LUC/LCC-related products

MapBiomas presents a variety of products intended for different groups. For the general public, a web platform provides images, statistics, and maps for all MapBiomas collections, including satellite image mosaics, land-use and land-cover maps, and reports. Developers and specialists instead share a workspace that allows for customization of image processing and classification parameters and application of spatial and temporal filters as well as a tool for collecting sample data, scripts, and methodological notes for each biome.

3.3 MapBiomas Alerts products

MapBiomas Alert is part of the second phase of MapBiomas products, developed in partnership with governmental agencies and alert providers (INPE, IMAZON, and University of Maryland), bringing into focus the deforested areas in all the Brazilian biomes. Launched in May 2019, MapBiomas Alert consists of a warning system that validates and refines alerts of deforestation, degradation, and regeneration of native vegetation through daily high-resolution images (3 m). To date, MapBiomas Alerts is only under development for Brazil.

By enhancing the effectiveness and usability of existing alert systems, Alerts allows environmental monitoring, evaluation, and management for the purpose of understanding the dynamics of deforestation history, overlapping protected areas, rural settlements, geographical categories, and land-cover and land-use maps provided by MapBiomas Collection 3.1.

Through machine-learning algorithms on Google Earth Engine and Google Cloud Platform, planet images are analysed and classified by teams of software engineers and specialists in remote sensing, land use, and conservation. As a result, the alert polygon is redesigned, followed by a spatial analysis supported by themed maps and the publication of reports on the online platform. This may serve as a verification of zero deforestation commitments and support governance for sustainable environmental development in Brazil.

3.4 The collaborative network and the operationalization of MapBiomas

MapBiomas is made possible through a collaborative network of different organizations, including civil society, universities, governmental agencies, and private companies. These are local organizations mapping LUC/LCC, software engineering companies, and Google Earth Engine.

3.4.1 Local organizations mapping LUC/LCC

In a collaborative manner, MapBiomas has put together interdisciplinary teams with strong local knowledge related to LUC/LCC mapping. These teams are formed by professionals from various fields, remote sensing experts, in particular, but also forest, environmental and social scientists, geologists, and others. Due to the continental extension of Brazil, MapBiomas has one team for each biome (Amazon, Cerrado, Atlantic Forest, Caatinga, Pampa and Pantanal), but also specialized teams responsible for mapping cross-cutting themes (Pasture, Agriculture, Forest Plantation, Coastal Zone, Mining, Urban Infrastructure). In other countries, the MapBiomas initiative has one team for each country, but new teams will be included in the future. The process of identifying

new organizations in other countries that meet the requirements of MapBiomas is challenging. These organizations should have a strong technical capacity in remote sensing as well as the required financial capacity.

Table 1: Local organizations mapping LUC/LCC in the various countries working with the MapBiomas initiative

Country	MapBiomas Branch	Biome/Theme*	Responsible Organization
Brazil	MapBiomas Brazil	Atlantic Forest	Fundação SOS Mata Atlântica and ArcPlan
		Caatinga	Universidade Estadual de Feira de Santana (UEFS) and Associação Plantas do Nordeste (APNE)
		Cerrado	Instituto de Pesquisa Ambiental da Amazônia (IPAM)
		Pampa	Universidade Federal do Rio Grande do Sul (UFRGS)
		Pantanal	Instituto SOS Pantanal and ArcPlan
		Pasture*	Universidade Federal de Goiás (LAPIG/UFG)
		Agriculture*	Agrosatélite
		Coastal Zone*	Instituto Tecnológico Vale / Solved
		Urban Areas*	Terras App
	MapBiomas Brazil-Amazonia	Amazon	Instituto do Homem e do Meio Ambiente da Amazônia (IMAZON) and Instituto Socioambiental (ISA)
Colombia	MapBiomas Amazonia		Fundación Gaia Amazonas (Gaia)
Ecuador			EcoCiencia
Peru			Instituto del Bien Común (IBC)
Venezuela			Provita
Guyana			IPAM and Solved
French Guiana			IPAM and Solved
Suriname			IPAM and Solved
Bolivia			Fundación Amigos de la Naturaleza (FAN)
Paraguay	MapBiomas Chaco	Chaco	Asociación Guyra Paraguay
Argentina			Instituto Nacional de Tecnología Agropecuaria

3.4.2 Google Earth Engine

MapBiomas would not be possible without the powerful computing capacity offered by Google. MapBiomas has signed a technical cooperation agreement with Google Earth Engine[1] to develop the MapBiomas products. Google Earth Engine provides high-capacity and high-performance cloud computing for the initiative and provides an immense catalogue of satellite imagery and geospatial datasets that are the basis for generating MapBiomas products.

[1] https://earthengine.google.com/

3.4.3 Software engineering companies

Currently, MapBiomas partners with two software engineering companies, Terras[2] and EcoStage[3]. These companies support the MapBiomas initiative by building scripts and applications capable of translating the local organizations' LUC/LCC knowledge into image processing and classification within Google Earth Engine. Moreover, the software companies produce the web platform of MapBiomas, the interface for consultation and distribution of the MapBiomas products.

3.4.4 Scientific Advisory Committee (SAC)

An independent advisory committee (SAC) provides technical and scientific advice for developing the MapBiomas initiative. The SAC has the major role of verifying and providing recommendations for the methodologies adopted by MapBiomas teams. This committee consists of nationally and internationally recognized experts in remote sensing.

3.4.5 Financial support

The initiative is financed by several donors, namely the NICFI, Gordon & Betty Moore Foundation[4], Good Energies Foundation[5], Arapiaú Institute[6], Climate and Land Use Alliance (CLUA)[7], Institute for Climate and Society (iCS)[8], Humanize Institute, Children's Investment Fund Foundation (CIFF)[9], and Rainforest Foundation Norway[10]. In addition, several local organizations use their own resources for MapBiomas activities.

3.4.6 Institutional support

The MapBiomas initiative is not an institution or a legal entity with legal rights and obligations. Therefore, MapBiomas partners with several organizations that facilitate fund administration and distribution among partners. Currently, the following organizations provide institutional support to MapBiomas: i) Avina Foundation11, ii) World Resources Institute (WRI)12, iii) The Nature Conservancy (TNC)13, iv) the Institute for Democracy and Sustainability (IDS, Portuguese acronym)[14], v) Climate, Forest and Agriculture Coalition[15], vi) Fundacion Vida Silvestre[16], and vii) World Wildlife Fund (WWF)[17].

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[2] https://www.terras.agr.br/2019/index-w
[3] http://www.ecostage.com.br/en/index.html
[4] https://www.moore.org/
[5] https://www.goodenergies.org/
[6] http://arapyau.org.br/
[7] http://www.climateandlandusealliance.org/
[8] https://www.english.climaesociedade.org/
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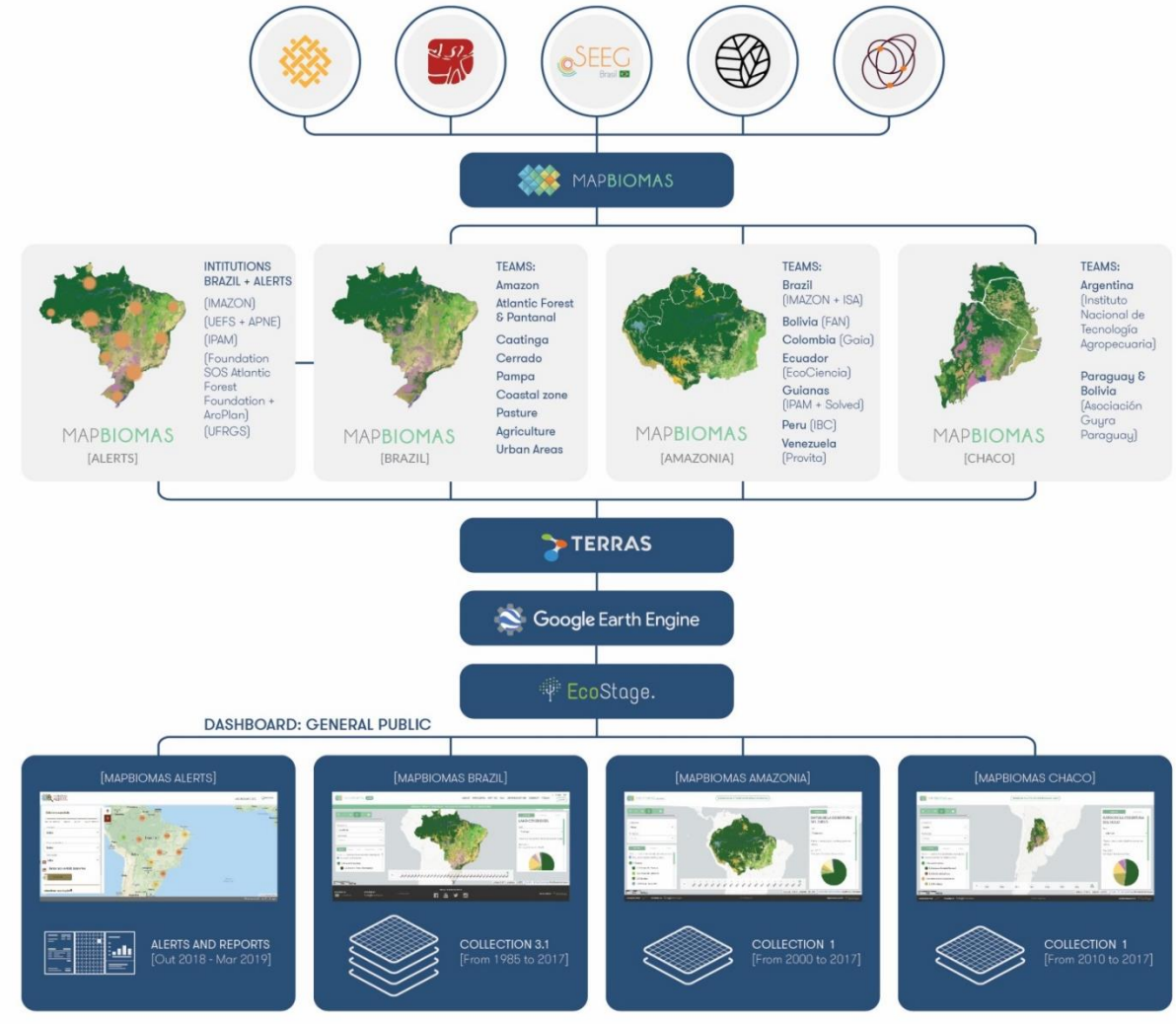


Figure 2: MapBiomas workflow

3.5 Key outputs of MapBiomas to date

Since its inception, MapBiomas has released four collections for Brazil, one collection for the Pan-Amazonia region, and one collection for the Chaco region. In addition, MapBiomas has released the MapBiomas Alerts. LUC/LCC Collection 1.0 in Brazil was launched in April 2016, covering 2008 to 2015. In April 2017, Collection 2.0 was released, covering 2000 to 2016, followed by an improved collection 2.3, in December 2017. Collection 3.0, released in August 2018, was the first collection to cover a historical series of 33 years, from 1985 to 2017. This was followed by Collection 3.1, the latest MapBiomas collection available for Brazil.

Launched in 2017, MapBiomas Amazonia-RAISG had its Collection 1.0 of LUC/LCC maps released in March 2019, covering the entire Pan-Amazonia region. This was the first MapBiomas product outside Brazil. In May 2019, MapBiomas Chaco released its Collection 1.0, covering the Gran-Chaco biome in Argentina, Bolivia, and Paraguay. And finally, MapBiomas Alerts launched, in June 2019.

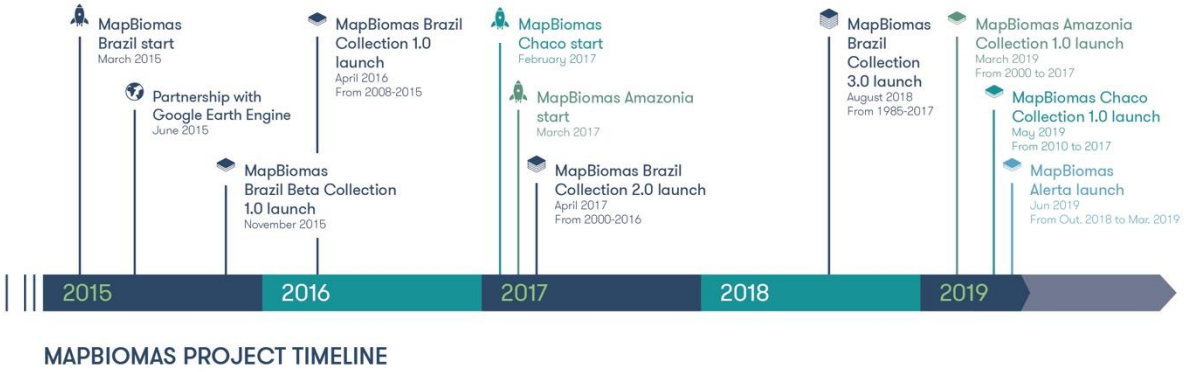


Figure 3: Timeline of the implementation of the MapBiomas initiative.

4. MAIN FINDINGS FROM THIS EVALUATION

4.1 Implementation and governance of MapBiomas

Finding 1: The objective and milestones set out in the initial agreement with donors have been accomplished to a large extent with many additional achievements beyond the initial plan.

The MapBiomas initiative was created for the primary purpose of producing reliable annual land-use change information for more accurate estimates on annual GHG emissions in Brazil. In the initial agreement with donors, MapBiomas committed to delivering three collections of land-use data covering the entire Brazilian territory. The first collection, published in April 2016, would cover the period of 2008 to 2015. The second collection, published in April 2017, would cover 2000 to 2016. And finally, Collection 3, published in 2018, would cover the period of 1985 to 2017. These goals have been accomplished. Given the innovative nature of the project, the initial agreement did not specify data-quality requirements. As a matter of fact, at the beginning of the initiative the outcome was highly uncertain and discredited by many experts who were sceptical about the quality of LUC/LCC maps produced through fully automated tools. However, MapBiomas products in the subsequent collections have been used in several academic and non-academic research projects, demonstrating sufficiently high data quality and exceeding expectations.

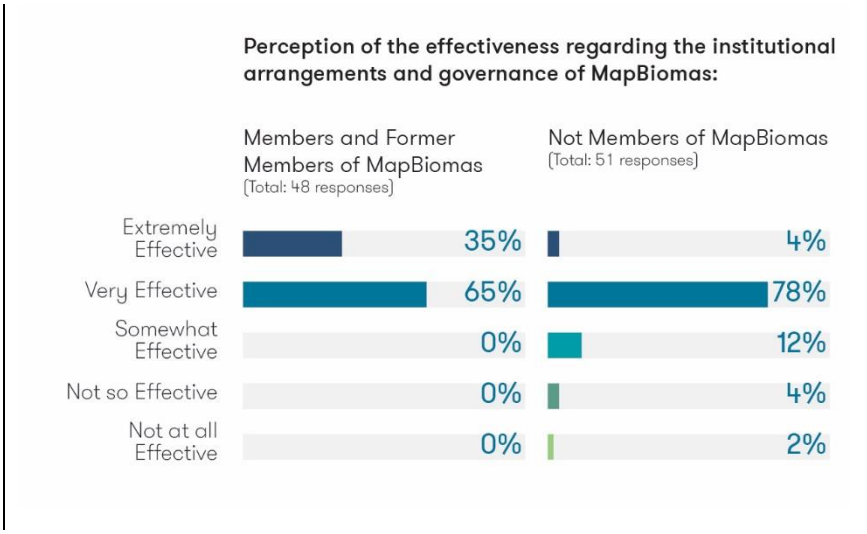
MapBiomas has broken new ground by producing large-scale mapping of land use and land-use change at a feasible cost using the latest available technology. With the lessons learned from MapBiomas in Brazil, the initiative is expanding to other regions where land-use information is scarce or inexistent.

Moreover, the large sets of data produced by MapBiomas and the capacities developed within the initiative are triggering a number of new applications and new studies that go beyond the initial purpose, as further discussed in Finding 19. The lessons learned from the development of MapBiomas, and the human capacity and intelligence developed within the project, enabled the creation of MapBiomas Alerts, a game-changing initiative that promises to provide the first-ever systematic monitoring and surveillance of legal and illegal deforestation in Brazil and potentially in other countries, as further discussed in Finding 23.

Finding 2: The system established to govern the MapBiomas initiative has been effective in setting the direction, and controlling the implementation, of the initiative in a time-efficient manner.

We find that, in practice, the governance of the MapBiomas initiative is formed by vigorous central control and monitoring of the initiative that makes use of an active participatory decision-making process. Product development is decentralized and performed in partnership with recognized institutions in each biome and cross-cutting theme, in the case of Brazil. There is a strong perception among respondents in voice-call interviews and the online survey that the established institutional arrangement to govern MapBiomas has been effective in delivering results within the timeframe of the project. Such effectiveness can, to a large extent, be attributed to the focus on deliverables given by the coordination of the initiative. This approach has made the initiative extremely time efficient, but developers and users have reported a caveat regarding this approach, as further discussed in Finding 13.

Figure 4: Perceptions of the institutional arrangement and governance of MapBiomas



Finding 3: The network of organizations has been a core element in the success of the initiative in delivering products and promoting synergism among institutions.

The collaborative network of organizations is one of the major strengths of the MapBiomas initiative. MapBiomas brought together several institutions that are at the forefront of remote sensing technologies applied to LUC/LCC mapping. Organizations with distinct or even competing goals have joined forces under the same vision. This collaboration has enabled MapBiomas to put together the most qualified and experienced professionals, while making use of the existing local knowledge in the organizations related to the territory being mapped by MapBiomas. Respondents share a common understanding that the collaborative network has promoted synergism among these organizations and increased trust, optimizing the use of available resources and human capacities. Moreover, this network facilitates knowledge-sharing and capacity building within the network.

Finding 4: A strong leadership promoting integration and building trust among partners has been crucial for the establishment of the initiative, and for creating a collaborative spirit among members.

Interestingly, most respondents involved in the initiative praised the role of the MapBiomas coordinator in conducting the initiative and in engaging partners. The coordination of MapBiomas has been effective in building trust among partners and promoting synergism in the actions of involved organizations. Respondents report that the leadership's enthusiasm and transparent decision-making have served to inspire MapBiomas members, contributing to the successful establishment of the initiative and strong engagement among partner institutions.

On the other hand, since MapBiomas is not an institution, the survival of the initiative appears to be highly dependent on one or a few leaders, who bear the main responsibility for fundraising, fund redistribution and for maintaining the link with and between involved organizations. Such dependency may represent a risk in the long run. However, this risk could be mitigated through an institutionalization of MapBiomas by converting the multiple roles currently played by the coordinator into formal positions in a strong core management structure in which individual people can be replaced but responsibilities persist.

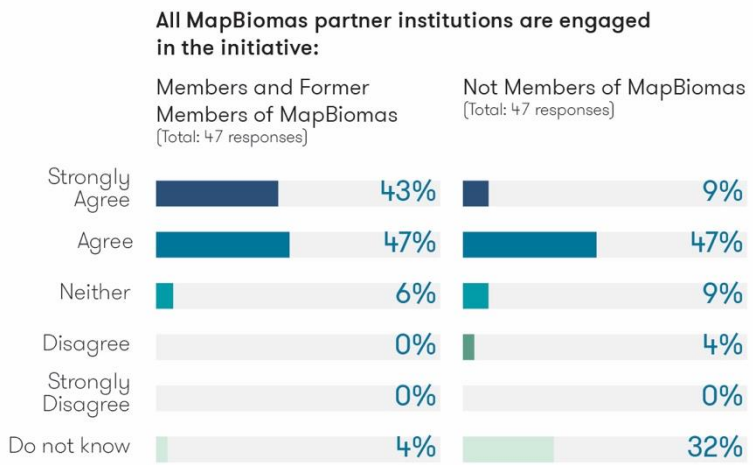


Figure 5: Perceptions on the engagement among MapBiomas partners

Finding 5: Institutionalizing MapBiomas could facilitate fundraising, reduce dependency, and increase transparency. However, concerns regarding a potential weakening of partner engagement in conjunction with institutionalization have been expressed.

There is no consensus among respondents about the need for and importance of institutionalizing the MapBiomas initiative. To various respondents, the institutionalization of MapBiomas would be of crucial importance and lead to multiple benefits. Since MapBiomas does not have a legal status, funds are received in many different ways, usually through other institutions that receive the funds and redistribute them among MapBiomas partners. In several cases, this arrangement leads to increased administrative costs and overcomplicates the flow of resources, which in turn complicates accountability and transparency. Institutionalization could reduce administrative costs and facilitate the flow of resources, increasing transparency and simplifying accountability. Moreover, the institutionalization of MapBiomas could facilitate the establishment of new

partnerships, in particular with governmental institutions, which could be an important step towards the initiative's financial sustainability.

However, several respondents expressed concerns that an institutionalization of MapBiomas could weaken the collaborative culture that the network of organizations has created, and potentially lead to competition with partner institutions for funding and human resources. Were MapBiomas to become an institution, such concerns should be properly addressed beforehand. The balance between providing legal status and maintaining the strengths of a broad collaborative network could be achieved by restricting institution attributes to just those aspects in which improvements are expected, such as fundraising, fund redistribution, public relations, and overall network management.

Finding 6: The members of the teams of each biome and cross-cutting theme are among the most prominent experts in remote sensing in their regions, yet most teams do not have enough qualified developers.

It is well recognized that MapBiomas integrates the most prominent organizations in remote sensing from each region being mapped. These organizations host the most qualified experts in mapping and land-use change. The teams of each region and theme consist of experienced experts as well as young and highly capable professionals. However, experience and capacity are unequally distributed among the various MapBiomas network organizations. While some teams have a large staff and a long history in remote sensing technology, other teams are relatively new, with much less qualified developers. The collaborative network of MapBiomas has permitted more qualified teams to transfer technology and capacity to less qualified ones. This collaborative approach permits an improvement in the consistency and quality of MapBiomas products in different regions.

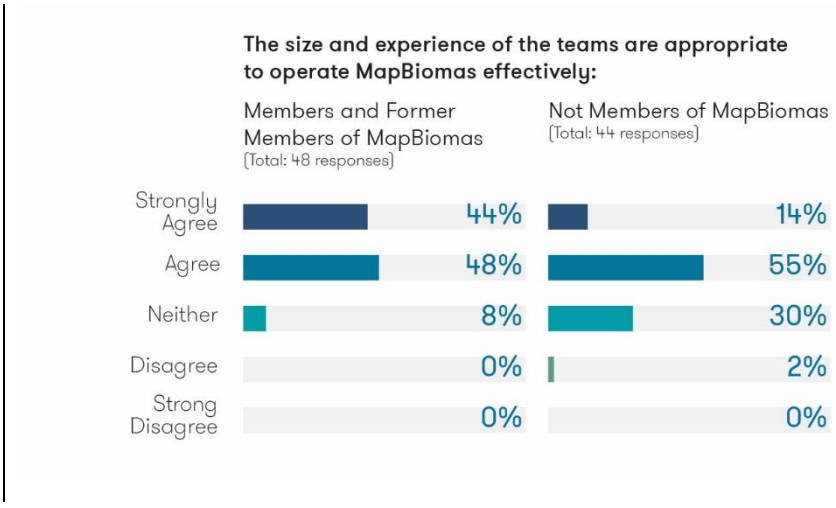


Figure 6: Perceptions on team development in MapBiomas

MapBiomas has a strong focus on creating automated tools, which in turn demands strong programming skills from all partners. On the one hand, running automated tools and delivering products where they are used are tasks that do not require long training and are very suitable for engaging universities and teams with a high turnover of people. On the other hand, most of the teams involved in MapBiomas, even those most qualified, struggle with the lack of programmers. Programming requires long training and is not easily found. This limits the capacity of most partners to further develop potential applications of MapBiomas products.

Finding 7: Strategic decision-making regarding the development of the initiative is done through frequent communication among MapBiomas members to ensure a strong participatory process

The decision-making process within MapBiomas is based on the active participation of all members. Decisions are made through semesterly technical workshops, monthly coordination calls, and weekly follow-up calls. The semesterly workshops are face-to-face meetings in which all members can present their work and discuss the major challenges in the development of MapBiomas products. These workshops are essential to solving major technical problems and sharing knowledge among the various teams. Major strategic decisions and directions of the initiative are agreed on at these events. Coordination meetings, which are usually online interactions involving only the coordinators of each team, serve to discuss topics related to the strategy and governance of the initiative. Additionally, weekly online calls are carried out involving all members of the MapBiomas initiative. These are follow-up calls to discuss the progress of each team's activities, where all members are free to provide inputs and suggest adjustments in the development of MapBiomas products. This arrangement and the intense communication among members of MapBiomas enable a quick and transparent decision-making process.

Each organization is responsible for making technical decisions regarding the methodological approach used to map each region. These organizations are also internally free to test new methodologies and take new directions in the development of MapBiomas products. Lessons learned internally in each organization are then shared and discussed with other teams.

The participatory decision-making on technical issues contrasts with the centralized decision-making on fundraising and major agreements with donors. So far, this pattern has reportedly been very effective but could push the limits of the initiative or diverge to embark on new developments before addressing basic data quality problems.

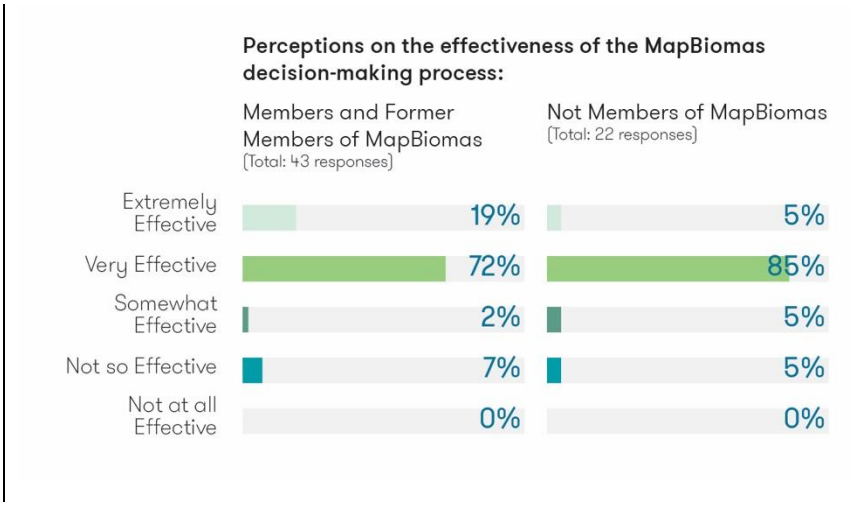


Figure 7: Perceptions on the decision-making process within MapBiomas

4.2 Funding sustainability

Finding 8: The lack of long-term funding constitutes one of the major challenges for MapBiomas teams in Brazil and in other countries where MapBiomas is expanding. The lack of long-term funding prevents team expansion and impedes maintenance of capable human resources.

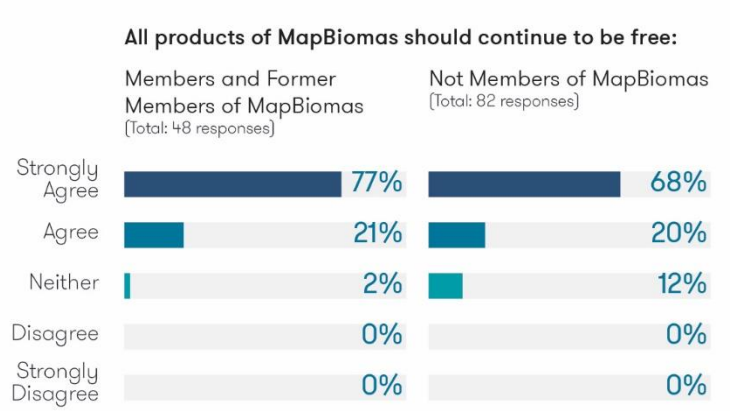
The additional funds MapBiomas has brought to the network organizations has permitted the hiring of new staff, increasing and improving the MapBiomas teams. However, maintaining capable professionals within the initiative has been difficult due to a lack of long-term funding, as reported by several MapBiomas team leaders in Brazil and other countries. In some cases, the project-based funding of MapBiomas prevents team coordinators from properly dimensioning their teams. As a result, team members are often under pressure and overloaded. Further, staff trained during the project are often hard to maintain within the initiative due to short-term commitments and the risk of budget shortages.

Many participants see the initiative as an investment and an opportunity to build their network and stay updated on new remote sensing technologies. However, long-term engagement depends on long-term funding, especially for partners from the private sector and from NGOs. For universities, the current funding model is more likely to be sustainable due to lower labour costs and a naturally high turnover.

Finding 9: Let's keep the MapBiomas products free! There is strong agreement among stakeholders that the MapBiomas products should remain open access.

One of the core visions of MapBiomas is to provide free access to data on land use and land cover. The MapBiomas initiative is made possible by the free use of Google Earth Engine technology, where the licensing agreement prevents any commercial use. Therefore, any product produced by MapBiomas using Google Earth Engine cannot be sold. MapBiomas could purchase a commercial Google Earth Engine license, which would then permit MapBiomas products to be sold. However, there is a consensus among all stakeholders that MapBiomas products should remain open access, and all products should be free of charge. It is commonly understood that the data produced by MapBiomas have a substantial value for scientific development and innovation. Restricting access to such valuable information could prevent or slow down the development of innovative services and new applications of MapBiomas for effective management of natural resources.

Figure 8: Perceptions on keeping MapBiomas products open-access



Finding 10: The MapBiomas initiative is still highly dependent on project-based funding and is likely to continue to be so in the near future.

The funding available for MapBiomas is mostly project-based funding from external donors. These resources have been crucial in setting up the initiative and developing the core products. Today, the initiative is in the process of consolidation, proving its societal value as the applications of the products come to light (See **Finding 19**.) Some of the applications under development hold the potential to trigger the interest of financers from the private sector and governmental agencies, capable of providing long-term and unrestricted funding. However, testimonials from different stakeholders suggest that these applications are at a very early stage of development, and agreements with potential long-term financers are yet to be reached. Therefore, the initiative is still in consolidation phase and appears to remain dependent on project-based funding in the near future.

Finding 11: There is no agreement on the business model MapBiomas could adopt to secure financial sustainability; however, several possibilities can be explored.

Shifting from project-based and short-term funding to long-term funding is necessary; this is a common understanding among most developers of MapBiomas. However, there is no agreement about what business model could potentially provide long-term funding for the initiative. A sustainable business model for MapBiomas is likely to be based on multiple sources of funding, including, for example, funding from private companies, international development agencies, and governmental agencies. The establishment of a pooled fund, for which many potential financers could be explored, is pointed out as a potential option to provide sustainable funding for MapBiomas.

MapBiomas is recognized as offering valuable products for many potential financers in the public and private sectors. The historic series of land-use maps produced by MapBiomas bring forth crucial data for understanding historic land-use occupations, which can facilitate the implementation of legislation related to irregular land-use occupations and tenure regularizations. Likewise, this information can support environmental ministries and agencies in the monitoring and management of natural resources. MapBiomas data can also support ministries of finance as well as agriculture, offering annual data on agricultural land expansion, essential for more accurate taxation. Such information can also support the monitoring and prediction of agricultural

production and revenue. Further, this data would be essential for monitoring the compliance of farmers with environmental legislation.

The Brazilian Institute of Geography and Statistics (IBGE, Portuguese acronym), could also contribute to financing MapBiomas, since much of the data published by IBGE on agricultural and livestock production and occupation could be substantially improved in quality and precision through a partnership with MapBiomas.

Large commodities traders interested in keeping their products detached from unsustainable forms of agricultural production could benefit greatly from the annual data produced by MapBiomas, and, therefore, potentially contribute to financing the initiative. Moreover, several private companies and civil society organizations may require MapBiomas data to monitor sustainability and the results of their interventions. REDD-related investments can use MapBiomas data to monitor avoided deforestation or restoration. Likewise, institutions providing credit services can use MapBiomas data to detach their investments from landholders owning rural properties where illegal deforestation has taken place.

For sustainable funding of MapBiomas, international funds for sustainable land use (GEF, UN) should also be explored in view of MapBiomas expansions to other countries in Latin America and Indonesia and, soon, to other countries in Africa and Asia, where the lack of land-use data challenges interventions to promote sustainable land use.

MapBiomas Alerts is providing a tremendous service for the Brazilian public prosecution in the monitoring and identification of irregular deforestation. The Alerts system can facilitate and reduce the cost of issuing fees related to illegal conversion of native vegetation. This provides a strong case for linking governmental funding related to environmental protection and law enforcement with the MapBiomas initiative.

These suggestions are collected from stakeholder testimonials. Obviously, constructing these partnerships and building such agreements with potential financers are not trivial tasks. As a matter of fact, such agreements may not be viable or may take several years. Likewise, some of these funding opportunities may have unwanted strings attached, which could potentially compromise the values of the initiative. Nevertheless, the MapBiomas initiative can potentially benefit from long-term funding from many of these sources.

Finding 12: MapBiomas complements other land use initiatives by filling important gaps in land-use data.

There are several ongoing initiatives similar to MapBiomas that continuously map land-use change. For example, IBGE provides data of land cover and land-cover change in Brazil every other year, using satellite image interpretation together with field visits. The PRODES project monitors deforestation in the Brazilian Amazon since 1988, offering annual deforestation maps through satellite image interpretation since 2004. Global Land Analysis and Discovery (GLAD) provides an annual global map of tree-cover change (Hansen *et al.*, 2013), where the tree cover is defined as vegetation taller than 5 metres.

Although these initiatives' products overlap to some extent, MapBiomas is commonly understood to meet very different needs, complementing other initiatives by filling important gaps in the availability of data related to land use and land-use changes (

Table 2). MapBiomas is the first initiative to produce a historical annual series of LUC/LCC data from 1985 using a common methodology across all the years. Moreover, MapBiomas was the first initiative to produce LUC/LCC maps considering a wide number of land-use features in comparison to most existing initiatives. These added values represent an important development in the public availability of LUC/LCC information.

Figure 9: Perceptions on the extent to which MapBiomas complements other ongoing initiatives

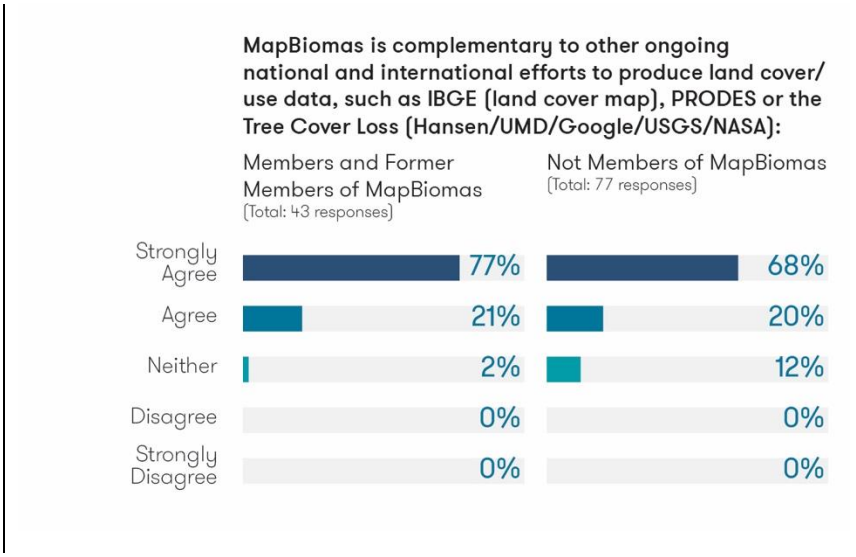


Table 2: Comparison between the most relevant initiatives providing continuous land-use data in Brazil.

	IBGE	PRODES	GLAD	MapBiomas
Coverage	Brazil	Amazon and Cerrado Biomes	Global	Brazil, Amazonia and Chaco regions
Mapped Features	Land use and land use change	Deforestation	Tree-cover change	Land use and land use change
Frequency	two-years	Yearly	Yearly	Yearly
Mapped Period	2000 - ongoing	2004 - ongoing	2013 - ongoing	1985 - ongoing
Format	Vector	Raster	Raster	Raster
Resolution	1000m	30m	30m	30m

4.3 Data Quality and validation of the land-use and land-cover change maps

Finding 13: The quality of the MapBiomas data has improved considerably from Collection 1 to Collection 3. Users and developers report that the MapBiomas data offer sufficient quality for many applications, but there are limitations.

MapBiomas Collection 1.0 (Beta) for the Brazilian territory, which launched in 2016, has been heavily criticized by users, who reported low quality with many inconsistencies in the land-cover classifications. Despite the limitations, releasing this first collection was an important step for the development of the MapBiomas products and was used as a means of collecting feedback from users and learning lessons that could be incorporated in subsequent collections. The consistency in the quality of MapBiomas LUC/LCC maps has improved considerably from Collection 1.0 to Collection 3.0. Much of this improvement has been attributed to the shift in the method used to classify satellite images. New algorithms were based on modern machine learning techniques, such as the Random Forest Algorithm. The change in methodology had singular relevance for improving the quality of the classification of vegetation types other than forest, such as the Caatinga and Cerrado vegetation. Most developers and users of MapBiomas considered the quality of the latest MapBiomas products to be acceptable (*Figure 10*).

Despite the substantial improvement in the data consistency of the MapBiomas land-cover and land-cover change maps, there are many limitations and inconsistencies to be found in MapBiomas products. Among the most common limitations reported by users and developers, we highlight the following:

- Confusion between the classifications of cultivated pastureland and native grassland vegetation.
- Confusion between the classifications of cropland and pastureland. Despite improvements from Collection 1 to Collection 3, the class mosaic of agriculture and pasture still represents a fairly large portion of the Brazilian territory.
- Confusion between the classifications of planted forest and native forest.
- Despite the high resolution of 30m, applications of MapBiomas data at the small scale can be misleading, considering that some regions might have a stronger concentration of misclassified land uses. Accordingly, MapBiomas can be extremely consistent in other regions.

Please note that most of these reported limitations are not exclusive to MapBiomas products. Classification of grassland and pastureland or planted and natural forest is typically difficult for initiatives using supervised classification, too. Yet, failures in separating anthropogenic from natural landscapes constitute a relevant limitation for applications of this data aiming at identifying human-induced changes and impacts. Therefore, research and development towards improved algorithms capable of overcoming these limitations should continue and be intensified in the next phase of MapBiomas.

Each local organization produces a LUC/LCC map for each land-use class, which is then integrated into a single final map for each year. This process of integration is based on a number of assumptions and prevalence rules, which can be different for each biome. Arguably, the prevalence

rules have a weak technical foundation, and layers of high accuracy may overlap with layers of poor accuracy. Several users reported that it would be valuable to report the layers that have been overlapped in this integration process. Such information could be valuable in identifying regions of conflicting land uses or to feed uncertainty and sensitivity analysis.

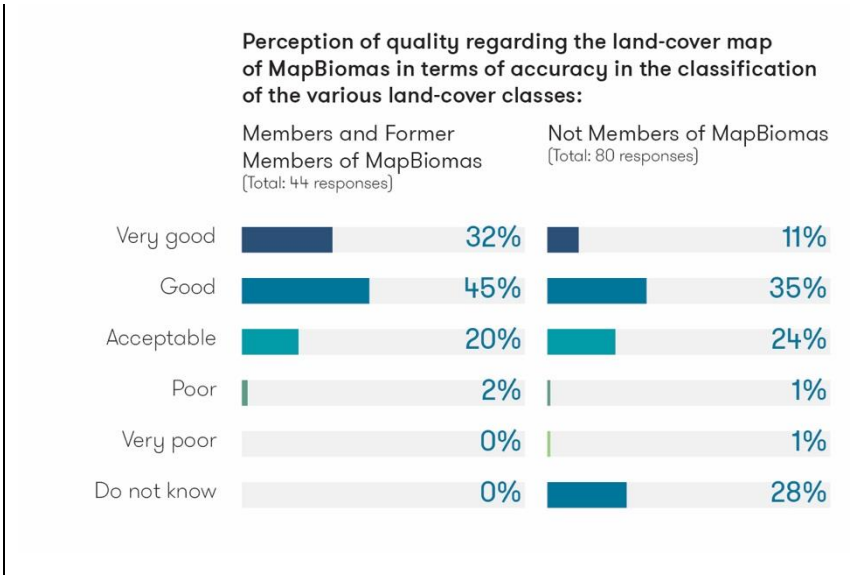


Figure 10: Perceptions on the quality of MapBiomas products

Finding 14: Area-change reported by MapBiomas has not been following the good research practice recommended by the international scientific community. The limitations of MapBiomas data need to be more clearly and accurately reported to avoid being discredited, and to ensure that the use of MapBiomas data does not lead to misleading studies and conclusions.

The innovative nature of MapBiomas and the need to quickly deliver products have in some cases driven developers toward pragmatic choices rather than scientific-based decisions. Although this approach has been necessary to enable the development of new products in a very short time frame, various stakeholders pointed out that MapBiomas has not been following good research practice, recommended by scientific communities, in the validation and accuracy analysis of the land-cover and land-use maps produced. This criticism is also supported by scientific literature (Zalles *et al.*, 2019).

To date, data accuracy and validation have not followed proper sampling design to ensure unbiased results. Moreover, the area reported by MapBiomas is based on pixel-counting, which is not in line with good practices (Olofsson *et al.*, 2014). The scientific community recommends that reported land-use change area not be exclusively based on pixel-counting, but rather based on the error matrix, which enables estimating the error in the classification for each class and measures the uncertainty (Olofsson *et al.*, 2014). Developers have faced difficulties in agreeing on a methodological approach that is suitable for validating and estimating the accuracy of MapBiomas products, as reported by several developers. Considering the continental extension being mapped by MapBiomas, the long-time series, and the large number of mapped features, validation and accuracy analysis is not a trivial task. This is a slow process that requires substantial human capacity. To overcome this problem, MapBiomas is currently inspecting the LUC/LCC using 100,000 points for the validation, accuracy analysis, and adjustment in the reported area for each year of the time series. These points have been chosen randomly, ensuring that areas with different slopes are

properly represented in the sample. The results of this validation process should be available in MapBiomas Brazil Collection 4.0.

To ensure that the MapBiomas collections used by planners and academic scientists lead to effective development, limitations in the data need to be clearly communicated to avoid misleading applications. It was pointed out by several respondents that the failures and inconsistencies in the data have been poorly systematized and reported, since this has not been a priority. Therefore, it is recommended that MapBiomas makes it clear for what purposes the products can be used and for what purposes there are restrictions, in order to prevent any kind of misuse. In addition, some partners stated the preference for a communication strategy emphasizing the work in progress rather than the future potential uses for which the products are not already suitable. In the long term, a more cautious approach would further improve the reputation of the initiative.

4.4 Users and utilization of MapBiomas products

Finding 15: The number of users of the MapBiomas platform has increased exponentially over time, and users are returning. The majority of the users are based in Brazil, but this may change in the near future as MapBiomas expands to other countries.

The audience for the MapBiomas platform has increased exponentially over the initial four years. In the first year (July 2015 to June 2016), about 6,000 users accessed the platform. This figure doubled in the second year. In the third year, the number of users increased at an impressive rate of 170%, almost tripling the number of users. In the most recent year, the MapBiomas platform has reached over 80,000 users (July 2018 to June 2019). From its inception in July 2015 until June 2019, the MapBiomas platform has received a total of about 113,000 visits. This number is likely to keep on increasing exponentially with the recent launch of the new branches, namely:

- http://alertas.mapbiomas.org/
- https://amazonia.mapbiomas.org/
- http://chaco.mapbiomas.org/
- Other initiatives in the early stages of development (MapBiomas Indonesia, MapBiomas Semi-Arida, etc.)

These results are also borne out by the online survey, which shows that later collections are used more frequently by users (***Figure 13***). Our findings suggest that users of the MapBiomas platform are returning frequently. Website analytics indicate that 22% of the total visits in the four years of the initiative are returning visitors. Visitors returning to the website is a positive indicator of users' satisfaction with the platform and products. Web analysts also consider this metric a powerful indicator of the initiative's reputation. Considering that these are still the early days of the MapBiomas platform and that the number of new users is increasing every day, the 22% figure is an extremely high rate of returning visitors. As the platform matures, this figure would be expected to increase. This conclusion is also confirmed by users of the MapBiomas products responding to the online survey. Over 90% of users indicate that they would be using MapBiomas data in the future (***Figure 12***). Most users of MapBiomas to date are based in Brazil (Figure 11); however, this may change in the future considering the recent expansion of MapBiomas to other countries.

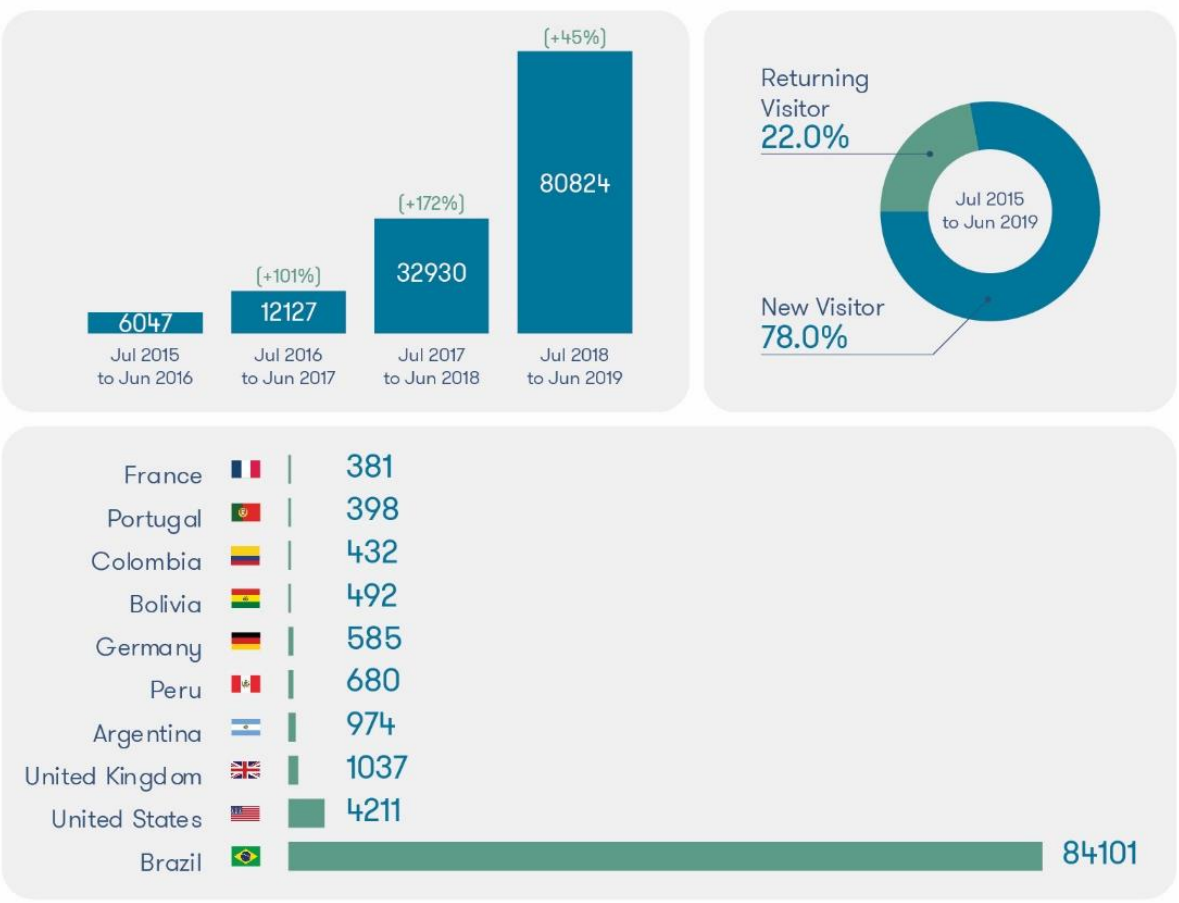


Figure 11. Metric related to the usage of the MapBiomas platform since its inception in 2015 until June 2019, extracted from Google Analytics.

Figure 12: Attitudes towards future MapBiomas products

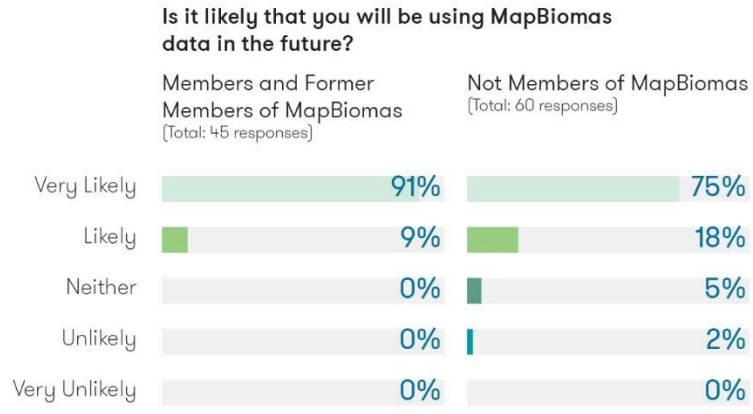
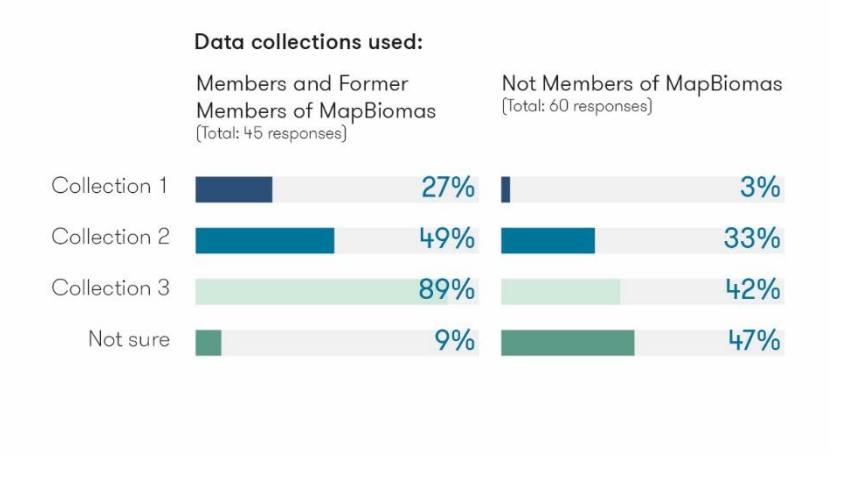


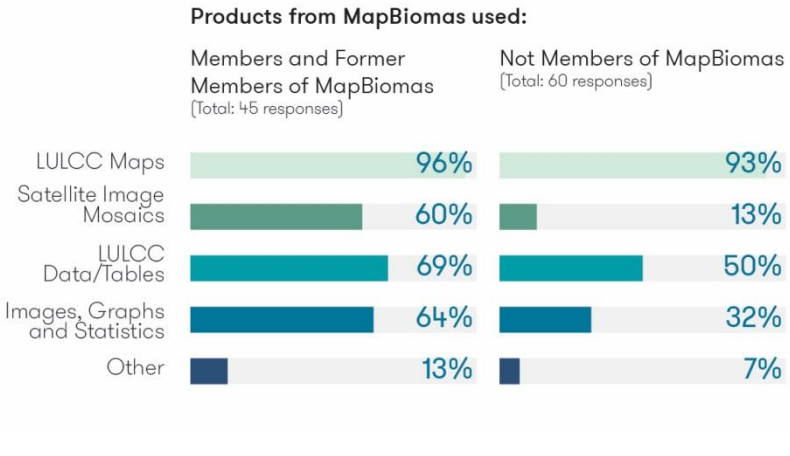
Figure 13: Usage of the three initial releases of MapBiomas Brazil data



Finding 16: Although land-use and land-cover maps are the most popular products, other products such as satellite-image mosaics and predefined tables and graphs are in frequent use.

The LUC/LCC maps are the initiative's most used and popular products. However, other outputs are also frequently accessed. Mosaics of satellite images are extremely useful to remote sensing experts producing analyses other than land-use maps or producing land-use maps with different methodologies and scales. Likewise, less specialized users find tabular data and graphical materials provided by MapBiomas extremely useful for their applications. Several respondents highlight the need and desire to see MapBiomas developing additional products customized for those users who are not specialized, as a strategy for reaching new users. Several respondents believe that the MapBiomas platform and products can provide a substantial contribution to educators, by providing educational material not only at the university level but also for basic education, to increase students' landscape-management knowledge and skills in their territories. Moreover, MapBiomas data can contribute to students' understanding of the importance of these data in planning and decision- and policymaking to solve the major sustainability problems society faces.

Figure 14: MapBiomas products used by members and non-members of MapBiomas



Finding 17: The MapBiomas platform is user-friendly and effective in making data available. However, many users faced difficulties in handling downloaded files. They found it time-consuming and, usually, requiring additional processing.

In general, users of the MapBiomas platform consider MapBiomas data to be easily accessible (Figure 15). The MapBiomas website presents a beautiful and engaging graphic design. The architecture and content of the website are logical and well-planned, making navigating the different pages rather easy. All pages load quickly, but some of the pages, such as 'web collector' and 'workspace', were offline when our assessment took place.

Most of the criticism regarding access to MapBiomas is related to the options for downloading MapBiomas collections. The platform is designed to only offer the option to download the collection by pre-defined geographic regions, such as biome, state, or municipality. Direct download is only available by biome, where the downloaded annual maps are consolidated into a single file with several bands representing each year of the historical series. This data downloading process is as simple as possible. In a couple of clicks, users can get entire MapBiomas collections on their hard disk, in a fast and simple process. However, most users are not necessarily experts and not very familiar with GIS tools. They are usually not interested in an entire collection, including all the years. Moreover, they would prefer to download data for a customized region. Therefore, downloading the historical series for a predefined region makes the user experience more challenging. Future development of the platform could improve the user experience by adding the option of downloading customized packages of MapBiomas data.

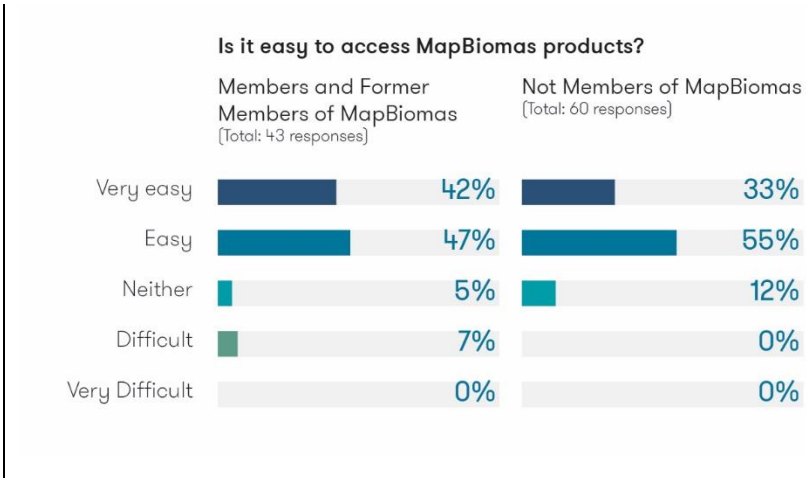


Figure 15: Perception regarding MapBiomas data accessibility

Finding 18: The process of providing feedback to MapBiomas through the forum is very useful, but MapBiomas could benefit from a systematic effort to collect feedback from users regarding data inconsistences.

MapBiomas provides a forum where users can provide feedback, ask questions, and find solutions to major challenges they may face when using MapBiomas products. Developers are very responsive and helpful in solving problems. However, a couple of users highlight that there is no straightforward way to provide feedback regarding inconsistencies in the land-use classifications provided by MapBiomas. To provide feedback, users must contact the developers directly to report inconsistences and hope that the feedback will be incorporated in the next collection. This is an inefficient process, especially considering the growing number of users and, therefore, the likely

increase in feedback. Collecting feedback from users in a systematic and automated manner can represent an important opportunity to construct a wide database of inconsistences that can later feed a process of continuous improvement in product quality.

4.5 Impact of the MapBiomas project

Finding 19: MapBiomas provides a significant contribution to scientific development. The MapBiomas data are paving the way for original and ground-breaking studies.

MapBiomas provides a significant contribution to scientific development. We identified almost 40 scientific publications explicitly citing MapBiomas, in many different scientific journals, including the most prestigious ones. Moreover, many unpublished studies were reported during our consultation process. The applications of MapBiomas data are extremely diverse. A great number of studies in various subjects have been performed in conjunction with developing MapBiomas or employing MapBiomas data, including:

- Remote sensing (Costa *et al.*, 2018, Diniz *et al.*, 2019, Mariano *et al.*, 2018, Mas *et al.*, 2019, Parente & Ferreira, 2018, Parente *et al.*, 2019, Rosa, 2016, Saraiva *et al.*, 2019, Taquary *et al.*, 2019, Wagner *et al.*, 2019)
- Land-use occupation and environmental impact assessment (Almeida *et al.*, 2018, Freitas *et al.*, 2019, Mariano *et al.*, 2018, Pendrill & Persson, 2017, Tyukavina *et al.*, 2017, Wagner *et al.*, 2019, Wang *et al.*, 2019);
- Ecosystem services and biodiversity assessments (Bonanomi *et al.*, 2019, Jaffé *et al.*, 2019, Mendes-Oliveira *et al.*, 2017, Rosa *et al.*, 2017, Ruggiero *et al.*, 2019),
- Climate change (Anderson *et al.*, 2018, de Azevedo *et al.*, 2018, De Oliveira Silva *et al.*, 2018, Junger *et al.*, 2019);
- Land-use governance, planning, and management (Albuquerque Sant'Anna, 2018, Alves *et al.*, 2019, Cortner *et al.*, 2019, De Oliveira Silva *et al.*, 2018, Freitas *et al.*, 2019, Garrett *et al.*, 2018, Oliveira *et al.*, 2018, Parente & Ferreira, 2018, Vieira *et al.*, 2019, Zalles *et al.*, 2019);
- Disease spreading and human health (Rosa *et al.*, 2017, Santos *et al.*, 2018);
- Water management (Souza *et al.*, 2019); and
- Supply chain sustainability (McCord *et al.*, 2018).

The MapBiomas contributions to these various studies vary. For example, Mendes-Oliveira *et al.* (2017) employed MapBiomas data to evaluate the sustainability of oil palm monoculture regarding Amazonian forest mammal diversity. Albuquerque Sant'Anna (2018) used MapBiomas data to assess the effect of existing public policies in the occurrence of natural disasters. Pendrill and Persson (2017) combined MapBiomas data with other land-use datasets to quantify the conversion of native vegetation in Latin America. Some studies only used MapBiomas data to compare and validate other land-use classification products (Tyukavina *et al.*, 2017, Zalles *et al.*, 2019). These studies will certainly provide information for policy development and decision-making, which can promote development towards more sustainable land-use systems, and more intelligent natural resource management.

Finding 20: There is strong agreement that MapBiomas is already leading to changes on the ground. No concrete evidence can be brought at the moment, but evidence of impact should soon be available with greater diffusion of MapBiomas data and consolidation of MapBiomas Alerts.

There is a strong perception among developers and users of MapBiomas data that the initiative is leading to changes on the ground (Figure 16). There is no science-based linkage between the launch of MapBiomas and any significant changes towards more efficient or sustainable land-use management. Further, we cannot find any concrete evidence that relates the MapBiomas initiative to any meaningful improvement in land-use governance. However, the MapBiomas products will indubitably, directly or indirectly, lead to changes towards improved land-use governance and preservation of ecosystem services in the medium to long term. The MapBiomas data enable an understanding of the history of land-use occupation for each part of the Brazilian territory, which is key information in understanding how and when the occupation has taken place. Such data will be strategic in establishing a link between land-use occupation and social and environmental changes at the local level, important information for planners and decision-makers. Moreover, expectations are high for MapBiomas Alerts to be a viable tool for promoting quick and significant changes on the ground by reducing or potentially halting illegal deforestation (see more in **Finding 23**). However, MapBiomas Alerts has just been launched, and its potential impact should become noticeable in the coming years.

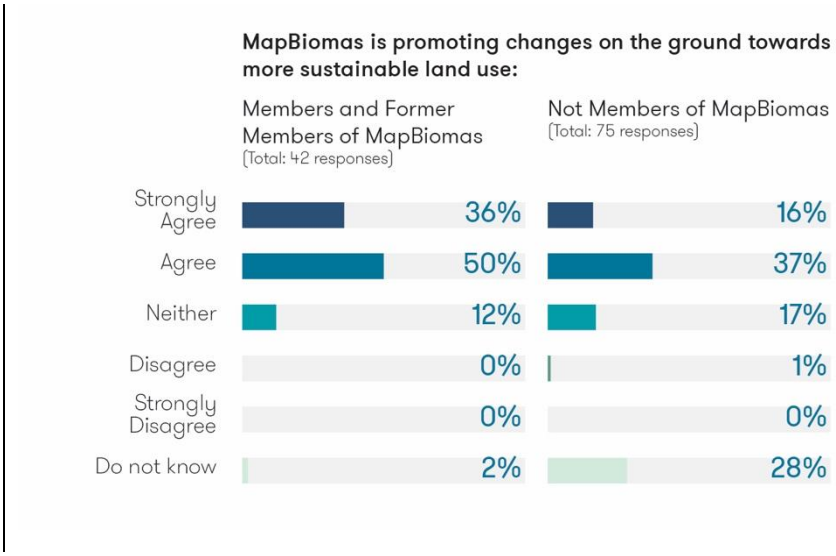


Figure 16: Perception regarding the impact of MapBiomas

Finding 21: MapBiomas is being noticed! So are the concerns about land-use change and the need for protection of nature and ecosystem services.

Thanks to a very competent and efficient communication strategy, the MapBiomas initiative has been featured in the most prestigious and popular news agencies in Brazil and other countries, such as The Guardian, BBC, Mongabay, G1, O Globo, UOL, Folha de São Paulo, o Estadão, and many others. Driven by the enlightening information provided by the MapBiomas platform, many reputable journalists have produced news articles based on the information from MapBiomas. This intensive exposure of MapBiomas data is to our understanding one of the most important contributions of MapBiomas to date. Providing the general public with reliable data regarding land

use is crucial for raising popular awareness of social and environmental problems related to land use. Enabling this understanding of the historic and current land-use occupation is crucial to building the critical public opinion on this subject and is the most effective manner of promoting long-term changes toward more sustainable land-use systems.

Finding 22: The MapBiomas data brought light to political debates related to land-use policies and land occupation in Brazil, providing important information for policy formulation and orienting interventions from civil society and governments.

To several respondents, the MapBiomas information is used in political debates related to land-use policies, governance, and land occupation in Brazil. The initiative is providing basic and applied information for policy formulation and is guiding actions by civil society, business, and governments. However, there is a wider scope of practical applications regarding private and public land-use governance, policy design, and compliance to which MapBiomas can provide a substantial contribution as the initiative becomes more widely known and adopted by various organizations. Here are two examples of ongoing political debates to which the MapBiomas data may provide a substantial contribution:

a) Implementation of the Brazilian Forest Act: The Forest Act (Law 12.651/2012) is the major Brazilian regulation protecting native vegetation on private land. Half of the Brazilian native vegetation is on private land. The implementation phase of the Forest Act is done at the state level, where systems to support decisions are still under development. During the implementation of the Forest Act, the past land use and land cover affects legal requirements for protection of the native vegetation. The most important periods for a complete technical analysis of each farm's situation are: the current date, 2008, 2000 (in the Amazon), 1989, 1965, and 1934. MapBiomas covers four of the six time periods needed, geographically covering the entire Brazilian territory, and no other land-use database is as comprehensive.

b) Soy and beef moratorium: Private commitments of some traders require land to be deforested before certain deadlines. Although more detailed information is needed, MapBiomas can provide important indicators useful for strategic planning and decision-making within companies and support banks' risk assessments to guide market expansion in moratorium regions. Likewise, MapBiomas may offer valuable indicators to feed models verifying companies' compliance with zero-deforestation agreements.

c) Agricultural credits: Several private credit institutions have commitments to zero deforestation. MapBiomas is one of the tools available for addressing land-use changes and identifying deforestation patterns in a consistent way, covering large agricultural production regions in Brazil and elsewhere.

Finding 23: MapBiomas Alerts holds the potential to totally change the game. This system enables, for the first time, the systematic monitoring of illegal deforestation of native vegetation at a feasible cost.

MapBiomas Alerts started from the need to refine existing deforestation alerts from other organizations to produce strategic information that allows validation and interpretation for these low-resolution deforestation alerts. The initiative was implemented in a very short timeframe, thanks to the existing capacities and collaborative network established to produce MapBiomas

annual LUC/LCC products. MapBiomas Alerts was constructed in collaboration with governmental agencies on the front-line of deforestation surveillance in Brazil as well as those agencies responsible for environmental law enforcement, namely i) the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), ii) the Public Prosecutors' Office, and iii) the Environmental Police.

There is a strong belief among the various stakeholders we consulted that MapBiomas Alerts holds the potential to absolutely change the game when it comes to stopping deforestation. This initiative enables, for the first time, a systematic and remote surveillance of illegal conversion of native vegetation. Using state-of-the-art satellite images, MapBiomas Alerts can identify native vegetation conversion and cross-reference this information with tenure data and data on environmental permits for conversion. MapBiomas Alerts then provides a detailed and customized report using high-resolution (Planet[18]) satellite images ready to support authority decisions about the suitable administrative or legal procedure, enabling environmental law enforcement to levy fees and bring legal action against deforesters remotely. The operational advantage is in avoiding, in many cases, having surveillance agents visit deforested sites to prove the illegal activity, which is a much slower and costlier process.

In the eyes of many of our respondents, this technological development absolutely changes the game, not only for enabling the identification and punishing of deforesters, but also for phasing out the traditional view of deforestation as a crime that largely goes unpunished.

Finding 24: MapBiomas holds the potential to contribute to land-use governance, not only in Brazil but in many other countries as well. The methodology is fully replicable in other regions around the globe at a low cost. However, identifying suitable local organizations can be challenging.

In any country, land-use governance includes a range of dimensions, such as legal and institutional framework, technical procedures, data collection, data registration, and control and monitoring systems. There is a clear perception among developers and MapBiomas users that the initiative can contribute to improvements in land-use governance in Brazil and other countries (Figure 17) where LUC/LCC data is scarce or non-existent. MapBiomas can strengthen governance and incentivize responsible land use in two complementary ways. First, the developed methodology generates large-scale LUC/LCC maps in a very time-efficient way using open-source technology, which empowers civil society to plan, monitor, and control its own environment transparently. Second, the organizational network built around MapBiomas can function not only as a technical forum, but also as an opportunity to organize the participation of civil society in policy discussions by prioritizing agendas, territories, and strategies.

A fundamental premise for MapBiomas to become a reference for civil society and for the government is the engagement of local partners already recognized for their excellence in remote sensing techniques and environmental science, so that the product can be properly validated and not perceived as competition. Without local capacity and knowledge, it is very difficult to create the basic conditions for successful MapBiomas implementation. In addition, it would be worthwhile to always adapt MapBiomas to local demands. However, the possibility for civil society

[18] https://www.planet.com

to enhance land-use governance could also trigger political resistance or face legal restrictions, making MapBiomas networks impossible to consolidate in some places.

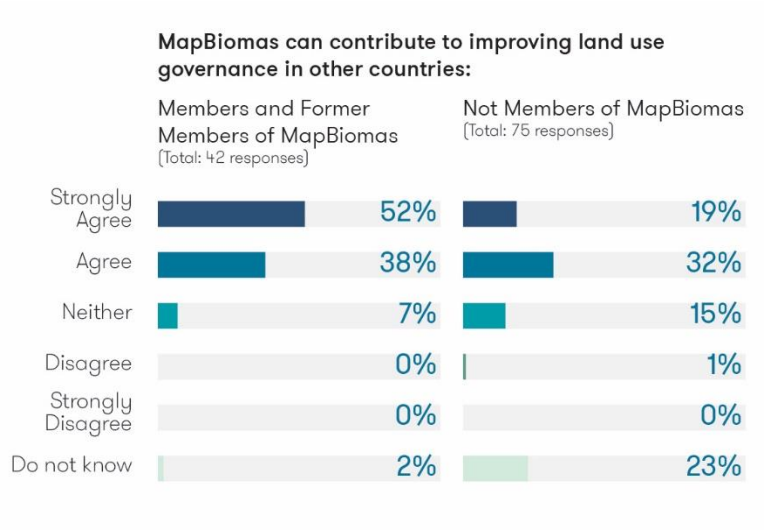


Figure 17: Perception related to potential impacts of MapBiomas in land-use governance

5. CONCLUSIONS

Implementation and governance

The MapBiomas network has had a successful implementation phase, reaching the initial core objectives, which was no small feat. To reach these objectives, developers of MapBiomas had to break new ground and develop innovative solutions and new algorithms to enable the fully automated production of LUC/LCC mapping for a continental territory. The timely and successful implementation of the initiative to date can to a large extent be attributed to the vibrant collaborative network of organizations and a strong and inspiring leadership, which made good use of a quick and pragmatic decision-making approach based on an intensive participatory process. MapBiomas integrated leading experts in remote sensing and highly motivated young professionals from different backgrounds. The collaborative nature of the initiative permitted knowledge-sharing and capacity building among organizations.

Funding sustainability

MapBiomas has evolved based on short-term funding, and it is likely to maintain this strategy in the coming years. However, short-term or project-based funding challenges some of the involved organizations in Brazil and other countries. Short-term funding prevents proper planning, and it is difficult to make long-term commitments and secure capable professionals to run the initiative.

Many alternative business models could potentially ensure financial sustainability for the initiative, and there is no consensus on a specific version. But there is strong agreement that any business model to be adopted in the future should preserve the core vision of the initiative of providing reliable and quality data free of cost, because restricting access to such valuable information could prevent or slow down development of innovative services and new applications towards effective management of natural resources.

Users and data utilization

The MapBiomas platform audience has increased exponentially in the first four years of the initiative, and the same goes for the use of MapBiomas products. Users are mostly Brazilian to date, with a fair amount of users from Europe and the United States. However, the share of users from other countries should increase rapidly in the near future with the launch of MapBiomas products for other countries in Latin America and Indonesia.

The MapBiomas platform is extremely engaging and user-friendly, strongly approved by its audience. Downloading MapBiomas products is simple and straightforward, but the lack of a customized downloading system makes the user experience more difficult and may undermine the use of MapBiomas data for less specialized users. Moreover, there is a need for a systematic way of collecting user feedback regarding inconsistences in the data provided by MapBiomas.

Data quality

In recent collections, MapBiomas data are of adequate quality for many applications, and users approve of the data to a large extent. However, the land-use classifications have many limitations and inconsistences, which, while not particular to the MapBiomas project, may prevent several important data applications. A notable example is the limited capacity of the methodology adopted to separate human-modified landscapes from natural landscapes, such as natural grassland from pastureland or planted forest from native forest.

In some cases, the need to quickly deliver products has driven the developers toward pragmatic choices rather than scientific-based decisions. Uncertainty and accuracy analysis of output has been inconsistent. Although this pathway has been necessary to enable the development of new products in a very short timeframe, in the long run such an approach may undermine the credibility of the initiative among scientific communities. Moreover, the need for accurate and objective measurement of errors is necessary to avoid misinterpretations of the results.

Impacts

The LUC/LCC products of MapBiomas complement ongoing land-use mapping initiatives by producing 30m-resolution LUC/LCC maps covering the entire territory, in the case of Brazil, and, soon, other countries in Latin America and Asia. Further, the MapBiomas products bring an unprecedented temporal span by providing annual LUC/LCC maps from 1985 onwards. These data are currently triggering important scientific developments and innovation that hold the potential to contribute to more efficient and sustainable land-use systems.

The scientific developments provided by MapBiomas are unquestionable. Automatic large-scale, multi-legend, long-term, and fast LUC/LCC mapping already has a history before, and will continue after, MapBiomas. The initial core objective, to provide input data for SEEG— GHG emission calculations at the national and state level for Brazil—is fully addressed and has measurable impacts. But despite, intuitively, a novel map and data collection like MapBiomas having a much greater scope of impact-related use, empirical examples of these are not yet evident. MapBiomas has directly led to MapBiomas Alerts—a platform designed to help deforestation alert analysis—but MapBiomas Alerts relies on the MapBiomas network, and only marginally MapBiomas mapping.

MapBiomas still faces the challenge of strengthening and fostering collaboration with end-users of LUC/LCC information by actively searching them out and engaging with them. Users' development of meaningful applications is essential to sustain MapBiomas network in many ways, ranging from fundraising to the motivation of such a large net of experts and institutions. Customized applications, such as MapBiomas Alerts, which uses the network per se as an asset, instead of the LUC/LCC map series, has proven effective in impact applications and may serve as a model for other ones.

6. RECOMMENDATIONS

Recommendation 1: MapBiomas needs to gradually move from project-based funding to long-term funding to guarantee the financial sustainability of the initiative and ensure long-term commitment with partners. In the coming years, MapBiomas should find agreement on which business models to adopt to increase the share of long-term and unrestricted funding. Developing agreements with governmental institutions and the private sector would be recommended.

- **Suggestion 1: Institutionalize MapBiomas.** Institutionalizing MapBiomas would be encouraged to ensure long-term resilience. Institutionalizing could facilitate the establishment of partnerships and fundraising with governmental and private entities. To ensure a balance between providing legal status and maintaining the strengths of a broad collaborative network, we recommend restricting the institutional attributes to those aspects in which improvements are expected, such as fundraising, fund redistribution, public relations, and overall network management.

Recommendation 2: MapBiomas is in the process of expansion to other countries. Given the potential contribution of MapBiomas to the governance of natural resources in these countries, such expansion should be encouraged. However, mechanisms should be established to govern expansion and ensure that the quality, principles, and vision of MapBiomas are consistent across the various regions.

- **Suggestion 2: Create a MapBiomas Global Steering Committee.** A global steering committee could provide the overall executive direction and support national and regional teams in developing fundraising strategies**.**

Recommendation 3: The ultimate goal of MapBiomas is to contribute towards the sustainable management of natural resources and socio-economic development. The more MapBiomas products are used and the more diverse the profile of users, the greater the likelihood that the products will trigger new applications that can lead to significant impacts. Therefore, it is crucial that MapBiomas have a well-defined strategy for reaching new users. Such a strategy should continuously search for innovative ways to attract new users from different backgrounds by facilitating access to data and strengthening communication with potential users.

- **Suggestion 3: Inspire the next generation of professionals**. We recommend that MapBiomas strengthens communication with educators, providing inspiring material that can support education on subjects related to land-use planning and natural resource management.

- **Suggestion 4: Facilitate integration with other platforms:** Development and maintenance of a functional application programming interface (API) to facilitate

integration with other initiatives and speed up development of automated applications using MapBiomas data.

- **Suggestion 5: Implement a custom download interface**. We would suggest the implementation of a custom download system that follows a three-step user interface for downloading MapBiomas data. In the first step, users choose the geographic regions by i) selecting predefined regions, such as biome, special regions, state, and municipality, ii) uploading a polygon in shapefile or kml format, or iii) drawing a polygon. In the second step, users should be given the option to choose which dataset they need. Finally, in the last step, users will check and confirm the order and insert an email address to which the link for downloading the datasets will be sent. The order will be queued and processed within the MapBiomas server or Google Cloud, and made available for download for a short period of time.

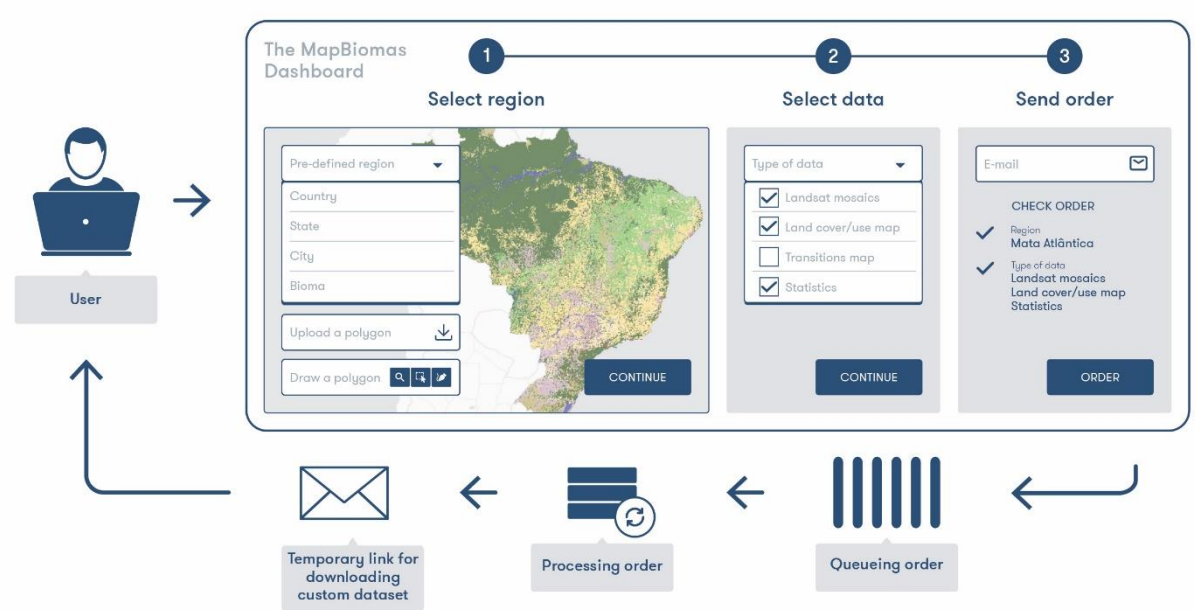


Figure 18: Suggestion for a three-step download interface to improve the user experience in accessing MapBiomas data.

Recommendation 4: MapBiomas has a growing number of users, but more than that, the initiative has a growing number of supporters, who share the vision of the initiative and who are willing to contribute in the best way they can. That said, users make an invaluable contribution to improving the quality of MapBiomas data. We recommend the creation of innovative and simple mechanisms to collect feedback from MapBiomas users in a systematic and automated manner. This feedback should be validated and used to feed machine learning algorithms to improve coming MapBiomas collections.

- **Suggestion 6: Bring user feedback collection to the next level:** Development of applications that enables user feedback regarding inconsistencies in land-use and land-cover classification to be collected. Such a system should enable users to identify inconsistencies and report errors for the various years in the time series. Such information should then be validated by developers from regions in which the inconsistencies have been identified, and then feed machine leaning algorithms to prevent repetition.

Figure 19: Suggestion for an automated user feedback system to facilitate conversion of user feedback into a more consistent land-use classification.

Recommendation 5: The core vision of MapBiomas is to provide free access to reliable LUC/LCC information. Although this objective has been accomplished to a large extent, the improvement in quality must be a continuous process. There is much new ground to be broken in enabling the mapping of new features in the landscape and in improving the consistency in the land-use classification. To this end, it is of paramount importance that MapBiomas developers maintain their focus and resources aimed at the continuous improvement of the MapBiomas mapping capabilities. The initiative should keep a strong capacity dedicated to innovation, constructing new algorithms, and testing new remote sensing products with the goal of improving land-use classification.

- **Suggestion 7: Invest in research and innovation to separate human-modified from natural landscapes:** Development of algorithms capable of differentiating: i) pastureland from natural grassland; ii) natural forest from planted forest; iii) depredated pastureland and degraded forestland; iv) different types of crop land from pastureland; v) intensified use from extensive use.

- **Suggestion 8: Test new open-access sensors:** Exploring Sentinel satellites and other upcoming sensors that have the potential to enable better-quality products than those derived from Landsat satellites.

Recommendation 6: MapBiomas products' primary applications are related to scientific development, in which both understanding uncertainties in the data and controlling them are fundamental to avoid misleading interpretations of results. Therefore, MapBiomas should develop and follow strict protocols for reporting inconsistencies and uncertainties in the data produced by the initiative.

- **Suggestion 9: Follow recommendations by the scientific community for accuracy analysis:** The process of validation and accuracy assessment of MapBiomas should follow recommendations from the scientific community. Such accuracy analysis should be calculated not only for the entire country, but regionalized indicators of accuracy should be considered, as a means of identifying the regions where land-use classification is least consistent.

- **Suggestion 10: Publish peer-reviewed scientific papers:** MapBiomas methods and procedures for producing land-use/land-cover maps as well as measuring uncertainties should be documented in scientific publications to ensure the peer-review process and scientific validity of MapBiomas products.

- **Suggestion 11: Report layers overlapped in the integration phase:** In the process of integration between each class to produce the final land-use map, the prevalence rules are applied and overlapping zones of low priority are disregarded for the final map. We would encourage MapBiomas developers to produce one more product from this integration process, namely the overlapping layers disregarded in this integration, for transparency and to enable users to identify potential geographic patterns in data inconsistency. This information could potentially be useful for users who want to control uncertainties from MapBiomas products through sensitivity analysis.

Recommendation 7: In light of the expansion of MapBiomas to other countries and the international community's strong interest in LUC/LCC in Brazil, it is important to establish a clear link between the land-use classes adopted in MapBiomas and other international land-use classification systems. Such a link should be built through a consultation process with experts from various regions of the world to harmonize the definitions of the different land-use classes and set the link between the legends adopted by each system.

- **Suggestion 12: Define the relation to other land-use classification systems:** The dataset specifying the relation between each MapBiomas class and those of other land-use classification systems should be attached to the metadata file accompanying each downloaded MapBiomas dataset.

7. REFERENCES

Albuquerque Sant'anna A (2018) Not So Natural: Unequal Effects of Public Policies on the Occurrence of Disasters. Ecological Economics, **152**, 273-281.

Almeida DNOD, Oliveira LMMD, Candeias ALB, Bezerra UA, Leite ACDS (2018) Uso e cobertura do solo utilizando geoprocessamento em municípios do Agreste de Pernambuco. Revista Brasileira de Meio Ambiente, **4**.

Alves GHZ, Santos RDS, Figueiredo BRS *et al.* (2019) Misguided policy may jeopardize a diverse South brazilian environmental protection area. Biota Neotropica, **19**.

Anderson LO, Neto GR, Cunha AP *et al.* (2018) Vulnerability of Amazonian forests to repeated droughts. Philosophical Transactions of the Royal Society B: Biological Sciences, **373**, 20170411.

Bonanomi J, Tortato FR, Gomes RDSR, Penha JM, Bueno AS, Peres CA (2019) Protecting forests at the expense of native grasslands: Land-use policy encourages open-habitat loss in the Brazilian cerrado biome. Perspectives in Ecology and Conservation, **17**, 26-31.

Cortner O, Garrett RD, Valentim JF, Ferreira J, Niles MT, Reis J, Gil J (2019) Perceptions of integrated crop-livestock systems for sustainable intensification in the Brazilian Amazon. Land Use Policy, **82**, 841-853.

Costa DP, Santos JJD, Chaves JM, Franca WDJSaD, Vasconcelos RND (2018) Novas tecnologias e sensoriamento remoto: aplicação de uma oficina didática para a disseminação das potencialidades dos produtos e ferramentas do mapbiomas. Sustainability, Agri, Food and Environmental Research, **6**, 36-46.

Cunha DGF, Magri RaF, Tromboni F *et al.* (2019) Landscape patterns influence nutrient concentrations in aquatic systems: citizen science data from Brazil and Mexico. Freshwater Science, **0**, 000-000.

De Azevedo TR, Costa Junior C, Brandão Junior A *et al.* (2018) SEEG initiative estimates of Brazilian greenhouse gas emissions from 1970 to 2015. Scientific Data, **5**, 180045.

De Oliveira Santos F, Teixeira BR, Passos Cordeiro JL *et al.* (2018) Expansion of the range of Necromys lasiurus (Lund, 1841) into open areas of the Atlantic Forest biome in Rio de Janeiro state, Brazil, and the role of the species as a host of the hantavirus. Acta Trop, **188**, 195-205.

De Oliveira Silva R, Barioni LG, Queiroz Pellegrino G, Moran D (2018) The role of agricultural intensification in Brazil's Nationally Determined Contribution on emissions mitigation. Agricultural Systems, **161**, 102-112.

Diniz C, Cortinhas L, Nerino G, Rodrigues J, Sadeck L, Adami M, Souza-Filho PWM (2019) Brazilian Mangrove Status: Three Decades of Satellite Data Analysis. Remote Sensing, **11**, 808.

Freitas MG, Rodrigues SB, Campos-Filho EM, Do Carmo GHP, Da Veiga JM, Junqueira RGP, Vieira DLM (2019) Evaluating the success of direct seeding for tropical forest restoration over ten years. Forest Ecology and Management, **438**, 224-232.

Garrett RD, Koh I, Lambin EF, Le Polain De Waroux Y, Kastens JH, Brown JC (2018) Intensification in agriculture-forest frontiers: Land use responses to development and conservation policies in Brazil. Global Environmental Change, **53**, 233-243.

Hansen MC, Potapov PV, Moore R *et al.* (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. Science, **342**, 850-853.

Jaffé R, Veiga JC, Pope NS *et al.* (2019) Landscape genomics to the rescue of a tropical bee threatened by habitat loss and climate change. Evolutionary Applications, **0**.

Junger PC, Dantas FDCC, Nobre RLG *et al.* (2019) Effects of seasonality, trophic state and landscape properties on CO2 saturation in low-latitude lakes and reservoirs. Science of The Total Environment, **664**, 283-295.

Mariano DA, Santos CaCD, Wardlow BD, Anderson MC, Schiltmeyer AV, Tadesse T, Svoboda MD (2018) Use of remote sensing indicators to assess effects of drought and human-induced land degradation on ecosystem health in Northeastern Brazil. Remote Sensing of Environment, **213**, 129-143.

Mas J-F, Nogueira De Vasconcelos R, Franca-Rocha W (2019) Analysis of High Temporal Resolution Land Use/Land Cover Trajectories. Land, **8**, 30.

Mccord P, Tonini F, Liu J (2018) The Telecoupling GeoApp: A Web-GIS application to systematically analyze telecouplings and sustainable development. Applied Geography, **96**, 16-28.

Mendes-Oliveira AC, Peres CA, Maués PCRDA, Oliveira GL, Mineiro IGB, De Maria SLS, Lima RCS (2017) Oil palm monoculture induces drastic erosion of an Amazonian forest mammal fauna. PLOS ONE, **12**, e0187650.

Oliveira PPA, Corte RRS, Silva SL *et al.* (2018) The effect of grazing system intensification on the growth and meat quality of beef cattle in the Brazilian Atlantic Forest biome. Meat Science, **139**, 157-161.

Olofsson P, Foody GM, Herold M, Stehman SV, Woodcock CE, Wulder MA (2014) Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, **148**, 42-57.

Parente L, Ferreira L (2018) Assessing the Spatial and Occupation Dynamics of the Brazilian Pasturelands Based on the Automated Classification of MODIS Images from 2000 to 2016. Remote Sensing, **10**, 606.

Parente L, Silva APME, Taquary E, Júnior LGF (2019) DEEP LEARNING APPLIED TO REMOTE SENSING: AN APPROACH FOR THE DETECTION OF CATTLE DRINKING FOUNTAINS USING PLANET IMAGES. In: *Anais do XIX Simpósio Brasileiro de Sensoriamento Remoto*. pp Page, Santos.SP.Brasil. Campinas : GALOÁ.

Pendrill F, Persson UM (2017) Combining global land cover datasets to quantify agricultural expansion into forests in Latin America: Limitations and challenges. PLOS ONE, **12**, e0181202-e0181202.

Rosa JD, Weber GG, Cardoso R, Górski F, Da-Silva PR (2017) Variability and population genetic structure in Achyrocline flaccida (Weinm.) DC., a species with high value in folk medicine in South America. PLOS ONE, **12**, e0183533.

Rosa MR (2016) Comparação e análise de diferentes metodologias de mapeamento da cobertura florestal da Mata Atlântica. (ed Boletim Paulista De Geografia V, 2016, P.25-34) pp Page.

Ruggiero PGC, Metzger JP, Reverberi Tambosi L, Nichols E (2019) Payment for ecosystem services programs in the Brazilian Atlantic Forest: Effective but not enough. Land Use Policy, **82**, 283-291.

Saraiva M, Silva D, Cortinhas L, Duverger SG, Siqueira JV, Junior CS (2019) CONSTRUÇÃO DE MOSAICOS TEMPORAIS NORMALIZADOS DE IMAGENS PLANET. In: *Anais do XIX Simpósio Brasileiro de Sensoriamento Remoto*. pp Page, Santos.

Souza CM, Kirchhoff FT, Oliveira BC, Ribeiro JG, Sales MH (2019) Long-Term Annual Surface Water Change in the Brazilian Amazon Biome: Potential Links with Deforestation, Infrastructure Development and Climate Change. Water, **11**, 566.

Taquary E, Parente LL, Silva APME, Júnior LGF (2019) A NOVEL APPROACH TO RECOGNIZING PATTERNS IN REMOTE SENSING TIME-SERIES USING DEEP LEARNING. In: *Anais do XIX Simpósio Brasileiro de Sensoriamento Remoto*. pp Page, Santos.SP.Brasil. Campinas : GALOÁ.

Tyukavina A, Hansen MC, Potapov PV, Stehman SV, Smith-Rodriguez K, Okpa C, Aguilar R (2017) Types and rates of forest disturbance in Brazilian Legal Amazon, 2000–2013. Science Advances, **3**, e1601047.

Wagner FH, Sanchez A, Tarabalka Y *et al.* (2019) Using the U-net convolutional network to map forest types and disturbance in the Atlantic rainforest with very high resolution images. Remote Sensing in Ecology and Conservation, **0**.

Wang Y, Ziv G, Adami M *et al.* (2019) Mapping tropical disturbed forests using multi-decadal 30 m optical satellite imagery. Remote Sensing of Environment, **221**, 474-488.

Vieira RRS, Pressey RL, Loyola R (2019) The residual nature of protected areas in Brazil. Biological Conservation, **233**, 152-161.

Zalles V, Hansen MC, Potapov PV *et al.* (2019) Near doubling of Brazil's intensive row crop area since 2000. Proceedings of the National Academy of Sciences of the United States of America, **116**, 428-435.