Natural climate solutions and fire mitigation: early findings on the path to net zero

A mixed methods study on natural climate solutions, fire mitigation, and permanence

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Abstract

Around the globe, governments and multilateral institutions have implemented policies and measures supporting climate change mitigation, which have brought a diversity of actors and approaches together across a wide range of geographic scales, blending governance structures, societies, and cultures. The voluntary carbon market emerged from these efforts to allow unregulated actors to offset emissions that they find difficult to reduce through other means. With vital world forests facing deforestation, degradation, and fragmentation, natural climate solutions (NCS) play an important role the voluntary market in that they provide market participants with an attractive and easily understood mitigation pathway, while generating numerous social and environmental co-benefits. However, NCS activities have been subject to critiques because of risks associated with the permanence (see Glossary) of the offsets that they generate as well as their feasibility and potential impacts on the environment and social justice of climate mitigation efforts that focus on terrestrial carbon storage.

In this working paper, we examine some of the concerns that have been raised about NCS projects by studying permanence with a particular focus on forest fires – a key threat to permanence in NCS projects. We study six REDD+ projects that have been certified under the Verified Carbon Standard (VCS) Program. Our approach uses mixed methods, including analysis of remote sensing data, close study of project documentation and reporting, and surveys of project implementers to understand how projects have performed in the face of fire risk. We also estimate projects' additional fire-mitigation benefits, beyond crediting requirements. We should stress that the fire counts we report should not be used to describe actual fire events or trends within a single area because we have not dropped low-confidence observations. Moreover, we warn against interpreting tree cover and fire counts in absolute terms, without considering matched comparison area(s), because that would misstate projects' true impacts.

Our work contributes preliminary findings and a novel methodology to assess the risk that fires pose to NCS activities and permanence. We find that there have been some loss events and one reversal, but no risk to credit permanence given that an adequately capitalized buffer pool is in place to compensate for reversals.

There is potential for NCS projects to generate fire mitigation beyond the minimum requirement for carbon crediting that could be extended to other projects.

Acronyms

ALM	Agricultural land management
ARR	Afforestation, reforestation, and revegetation
BECCS	Bioenergy with carbon capture and storage
DACCS	Direct air carbon capture and storage
ERRs	GHG emission reductions and/or removals
GHG	Greenhouse gas
IFM	Improved forest management
NBS	Nature-based solutions
NCS	Natural climate solutions
REDD	Reducing Emissions from Deforestation and forest Degradation
REDD+	Reducing Emissions from Deforestation and forest Degradation and the enhancement of forest carbon stocks
VCS	Verified Carbon Standard Program

Glossary

Additionality
A project activity is additional if it can be demonstrated that the activity results in emission reductions or removals that exceed what would be achieved under a "business as usual" scenario and the activity would not have occurred in the absence of the incentive provided by the carbon markets. Additionality is an important characteristic of GHG credits, including Verified Carbon Units (VCUs), because it indicates that they represent a net environmental benefit and a real reduction of GHG emissions, and can thus be used to offset emissions.

Agriculture, Forestry, and Other Land Use (AFOLU)
A category of project activities that includes anthropogenic GHG emissions and emission reductions and/or removals from activities in Agriculture, Forestry, and Other Land Use, and land-use change.

Baseline scenario
The baseline scenario represents the activities and GHG emissions that would occur in the absence of the project activity. GHG crediting programmes require that the baseline scenario be accurately determined so that an accurate comparison can be made between the GHG emissions that would have occurred under the baseline scenario and the ERRs that were achieved by project activities.

Blue carbon
Blue carbon generally refers to wetland ecosystems including mangrove forests, tidal and salt marshes, and seagrasses. Blue carbon project activities commonly include the restoration of these ecosystems through afforestation, reforestation, and revegetation. These activities generate emission reduction and/or removal by storing organic carbon in marine sediments and/or tidal forests such as mangroves.

Emission reduction
A permanent atmospheric benefit, measured in tonnes of carbon dioxide equivalent, quantified as the difference between the emissions of a baseline scenario and the emissions of an activity.

Emission removal
A permanent atmospheric benefit, measured in tonnes of carbon dioxide equivalent, quantified as the net increase in greenhouse gas sinks less greenhouse gas sources, resulting from an activity.

(Non-carbon) co-benefits

Carbon project activities are implemented with the express goal of reducing GHG emissions and/or removing carbon. Many project activities generate non-carbon co-benefits to the local environment and local communities. For example, a mangrove ecosystem restoration (blue carbon) project may improve a community's resilience against flooding and storm surges and restore local fisheries, which are a source of food and livelihoods. A REDD+ project may protect against habitat loss and thereby conserve or promote biodiversity.

Leakage

Net changes of anthropogenic emissions by GHG sources that occur outside the project or programme boundary, but are attributable to the project or programme

Loss event

In an AFOLU project, any event that results in a loss of more than 5% of previously verified emission reductions and removals due to losses in carbon stocks in pools included in the project boundary that is not planned for in the project description.

Natural climate solutions

Specific activities designed to lower GHG emission levels and enhance carbon stocks and sinks in ecosystems like forests, grasslands, and wetlands, through conservation measures, such as halting deforestation, the adoption of sustainable land-use practices and restoration practices.

Nature-based solutions

Activities are those that achieve GHG emission reductions or removals using biological systems (NCS activities), but also generate additional, non-carbon environmental and social co-benefits, for example through restoring native ecosystems, supporting community livelihoods, or conserving biodiversity.

Permanence

This term refers to the expectation that project activities will avoid GHG emissions or sequester carbon over very long time periods; a key requirement among all GHG crediting programs. For many carbon sequestration activities, the resulting ERRs carry a degree of non-permanence risk given that carbon reservoirs can release as well as absorb carbon. For avoided emissions activities, resulting ERRs are assumed to be permanent. GHG crediting programmes commonly require that sequestration activities store carbon over a period of at least 100 years to ensure the permanence of project ERRs and credits issued to projects. Some GHG crediting programs implement other safeguards to ensure permanence, including risk-pooling buffer credit accounts or insurance.

Reduced Emissions from Deforestation and Degradation (REDD)

Activities that reduce GHG emissions by slowing or stopping conversion of forests to non-forest land and/or reduce the degradation of forest land where forest biomass is lost.

REDD+

Activities that reduce GHG emissions from deforestation and/or degradation by slowing or stopping conversion of forests to non-forest land and/or reducing the degradation of forest land where forest biomass is lost; and/or activities that enhance carbon stocks through improved forest management and/or afforestation, reforestation or revegetation.

Reversal

A reversal is defined as a situation where a project's net GHG benefit is negative, accounting for project emissions, ERRs, and leakage, during a given monitoring/verification period.

Verification

Verification is the periodic ex-post independent assessment, by an authorized validation/verification body, of the GHG emission reductions and removals that have occurred as a result of the project during the monitoring period, conducted in accordance with the VCS Program rules.

1. Introduction

1.1 Overview

The world is racing to hold global average temperature rise to well below 2.0 degrees Celsius above pre-industrial levels, the central goal of the Paris Agreement.[1] Governments and non-state actors are supporting a range of activities to reduce greenhouse gas (GHG) emissions and remove carbon from the atmosphere with the goal of meeting the Paris target. In recent years, the voluntary carbon markets have proven effective in delivering climate mitigation at scale while historically other approaches (Kuriyama & Abe, 2018; Stubenrauch et al., 2022) have seen more moderated impacts. Recently, natural climate solution (NCS) activities have contributed a greater share of total mitigation volume.[2]

NCS activities are the subject of increasing attention and scrutiny in scientific journals, media, and industry forums. Some perceive elevated quality risks for NCS activities and associated credits. In parallel, some question the role of NCS in delivering emission reductions and removals (ERRs) on the path to net zero emissions by 2050. In recent years, many actors have shown a distinct preference for carbon removal technologies, such as direct air capture and carbon storage (DACCS) or bioenergy with carbon capture and storage (BECCS) to meet net zero targets (Macfarlane, n.d.). In turn, this trend raises questions about feasibility and the likely environmental and social justice impacts of climate mitigation efforts that focus exclusively on removal technologies (Carton et al., 2021).

This report responds to concerns about NCS projects and quality by studying permanence (see Glossary) with a particular focus on forest fires – a key threat to permanence. We study six REDD+[3] projects certified under the VCS Program, located in Indonesia, Brazil, and Peru. We use mixed methods, including verified project reporting to establish a baseline understanding of projects' performance in maintaining permanence. We also estimate projects' additional fire-mitigation benefits, beyond crediting requirements. For this we use project area shapefiles, fire hotspot data and tree cover data, and calculate differences in trends across project areas and comparison areas. Fire management practices may explain the differences in fire mitigation performance across these two groups. We use a focus group discussion and a questionnaire to collect information on projects' fire risks and management practices.

While fires pose real risks for the six REDD+ projects, we find that project managers sufficiently mitigate these risks through fire prevention, monitoring, and suppression. Among our sample of projects, fire management activities are sufficient to meet GHG crediting requirements without the need to engage programme-level safeguards or tap into resources external to individual projects. Further, we find that some projects generate excess fire-mitigation co-benefits. Looking beyond our sample, we find one case of a reversal, that can easily be compensated for with credits from the VCS Program AFOLU pooled buffer account. We also find that this account is adequately capitalized to guarantee permanence.

This research provides a methodology and early findings on fire risk and permanence as NCS activities scale up in the voluntary carbon markets. We believe these results are a source for cautious optimism though more study is needed. Certainly, all forms of effective climate mitigation will be needed to achieve net zero emissions. We expect that NCS will continue to play an important role in realizing global climate goals.

1 The goal of the Paris Agreement is to limit global warming to well below 2.0 Celsius, and preferably to 1.5 degrees, compared to pre-industrial levels (UNFCCC, n.d.)
2 Based on data from Ecosystem Marketplace (Ecosystem Marketplace, n.d.) and own calculations.
3 REDD refers to activities for Reducing Emissions from Deforestation and forest Degradation, and '+' refers to activities that enhance forest carbon stocks.

1.2 Carbon markets and climate change mitigation

By all accounts, global efforts to reduce GHG emissions to achieve goals articulated in the Paris Agreement have been inadequate (Matthews & Wynes, 2022). Too often, meaningful actions to reduce emissions lag behind stated ambitions of governments, firms, and individuals. The measures necessary to reduce emissions are frequently seen as too expensive or require major changes in behaviour that actors are unwilling to undertake. In the early stages of the global climate regime, policymakers introduced carbon markets as one way to address this lack of individual, corporate, and state action (MacKenzie, 2009). Carbon markets can help reduce emissions in two ways.

First, in a compliance system, such as in a jurisdiction with an emissions trading programme, emitters are compelled either to reduce emissions internally or purchase emission allowances to meet the emissions limit. Second, in a voluntary system, companies that pledge to reduce emissions voluntarily can do so by purchasing carbon credits to offset residual emissions, or those emissions remaining after implementing internal carbon reduction measures. These companies rely in part on a market of carbon credits to meet their climate commitments.

The voluntary carbon markets are served by standards bodies that certify a carbon project's activities and issue credits. Each credit generally represents the achievement of a GHG emission reduction or removal in the amount of one metric ton of CO_2 equivalent (tCO_2e). Some of the world's largest GHG crediting programs, by annual issuance volumes, include those managed by the American Carbon Registry (ACR), the Climate Action Reserve (CAR), the Clean Development Mechanism (CDM), the Gold Standard, and Verra (VCS Program), listed in alphabetical order. Although technical requirements differ somewhat across these programmes, their common, overarching goal is to ensure that carbon credits represent real, additional, measurable, verifiable, and permanent emission reductions or removals. Table 1 shows summary information for these programmes.

Table 1: Representative GHG crediting programmes serving voluntary carbon markets

GHG Programme (administrating organization)	Year established	Geographic coverage	Countries with projects registered	Total projects registered	Total credits issued
American Carbon Registry (ACR)	1996	Global	11	566	197 million
Climate Action Reserve (CAR)	2001	US, Canada, Mexico	2	739	178 million
Clean Development Mechanism (CDM)	1997	Annex 1 countries of the Kyoto Protocol[4]	136	13 164	2270 million
Gold Standard (GS)	2003	Global	81	1788	214 million
Verified Carbon Standard (VCS) Program	2005	Global	86	1834	956 million

Sources (all accessed July 2022)
ACR: https://acr2.apx.com/mymodule/mypage.asp
CAR: https://thereserve2.apx.com/mymodule/mypage.asp
CDM: https://cdm.unfccc.int/Registry/index.html
GS: https://registry.goldstandard.org/
VCS: https://registry.verra.org/app/search/VCS

4 Effectively advanced economies who have ratified the Kyoto Protocol with emissions obligations and are listed in Annex 1 to the Protocol.

1.3 Natural climate solutions

Project proponents implement activities to reduce emissions or remove carbon across economic sectors, ranging from energy to transport, waste, heavy industry, livestock, and Agriculture, Forestry, and Other Land Use (AFOLU), as examples. The terms and categories for organizing GHG inventories and ERR activities vary somewhat. But one widely accepted convention is to distinguish natural climate solutions from technological or industrial activities.

Natural climate solutions (NCS) are the specific interventions designed to lower GHG emissions and enhance carbon stocks and sinks in ecosystems like forests, grasslands, and wetlands, through conservation measures, such as reducing or halting deforestation, the adoption of sustainable land-use practices, and restoration practices (World Economic Forum, 2021). Another common term is nature-based solutions (NBS). Generally, NBS activities are those that achieve GHG emission reductions and/or removals using biological systems (i.e. NCS activities), but also generate additional, non-carbon environmental and social co-benefits (UNEP, 2022), for example by restoring native ecosystems, supporting community livelihoods, or conserving biodiversity.

Some common types of NCS activity include REDD+, Improved Forest Management (IFM), and Agricultural Land Management (ALM). For the most part, these activities lead to emission reductions, or an atmospheric benefit quantified as the difference between the emissions of a baseline scenario and emissions after implementing the activity. Other NCS activities include afforestation, reforestation, and revegetation (ARR) in terrestrial ecosystems like forest or grasslands. These same activities are known as “blue carbon” activities when implemented in aquatic ecosystems such as mangrove forests, tidal and salt marshes, or seagrasses. These latter activities mostly lead to removal of emissions, or an atmospheric benefit, quantified as the net increase in GHG sinks less GHG sources, resulting from an activity. Any given project could implement one or more of these kinds of activities.

Peatlands in Central Kalimantan, Indonesia © PT RIMBA MAKMUR UTAMA

1.4 Natural climate solutions and permanence

Comparing NCS to technological or industrial activities reveals several differences in the permanence of resulting emission reductions and removals. Although not all activities fit neatly into these categories, this dichotomy serves as a useful framework.

ERRs are generally accepted as *permanent* when projects implement activities to store carbon for a period of at least 100 years. This concept applies both to reduction activities, which ensure that carbon remains stored in existing carbon sinks; and to removal activities, which actively sequester carbon.

NCS projects store carbon in forests, soils, oceans, and other ecosystems. The carbon stocks stored in these pools, or reservoirs, are in a continual state of flux due to natural and anthropogenic causes, such as fires, pests, land-use change, and soil disturbance. Although carbon levels are dynamic, for the most part fluxes are nearly balanced and net terrestrial sinks already store about a quarter of historical anthropogenic emissions (Le Quéré et al., 2018). Because of carbon fluxes, NCS-generated ERRs carry a degree of non-permanence risk. To mitigate this risk, some GHG crediting programmes (e.g. VCS) require projects to participate in risk-pooling buffer mechanisms or insurance, in addition to continuous monitoring, GHG quantification, and third-party verification.

Fire mitigation activities in Central Kalimantan, Indonesia. © PT RIMBA MAKMUR UTAMA

Compared to NCS activities, technological and industrial activities generally offer a greater degree of certainty in the assessed permanence of resulting ERRs. For example, an energy efficiency activity leads to a reduction of emissions against a baseline scenario. These emission reductions are assumed to be permanent. Also, consider activities that generate emission removals, such as DACCS and BECCS. While there are some concerns about seismic activity, these activities are expected to generate carbon removals that last 1000 years or longer (Joppa et al., 2021). However, the GHG accounting methodologies for technological and industrial removal activities are still under development and claims of extraordinary permanence, or *durability*, remain to be demonstrated in the field.

1.5 The role of NCS on the path to net zero emissions

The scale of ERRs needed to limit warming to well below 2.0 degrees Celsius is orders of magnitude beyond what is possible today. In its *Sixth Assessment Report*, the Intergovernmental Panel on Climate Change (IPCC) states that mitigation is needed on the scale of about 10 gigatonnes (Gt) CO_2 equivalent annually, with more rapid and deeper near-term GHG reductions through 2030 and higher levels of GHG removals over the long term (IPCC, 2022). In 2021, the global carbon markets delivered about 0.396 Gt of mitigation (Ecosystem Marketplace, n.d.); only about 4% of what is needed on an annual basis. This includes the total volume of ERRs produced; reductions and removals from both NCS and technological/industrial activities.

The world clearly faces a significant undersupply of ERRs today, though IPCC models show that the level of mitigation, particularly through removals, is expected to scale up significantly in the coming decades (IPCC, 2022, p. 6). In the near term, NCS opportunities hold the potential to deliver up to nearly 7 Gt CO_2 equivalent per year by 2030 (World Economic Forum, 2021). Following Cook-Patton et al. (2021), NCS activities offer mitigation that is lower cost, more readily available, and they commonly also offer non-carbon co-benefits such as native ecosystem restoration or support for local communities and livelihoods. Considering these activities' carbon attributes alone, NCS activities are well placed to deliver the mitigation needed at this early stage on the path to 2030 and 2050 net-zero milestones.

1.6 Motivation for this study

Forest fire is a key permanence risk for NCS projects and quality, and yet there is a dearth of rigorous evidence on the linkage between forest fires, GHG crediting programmes, individual projects, and permanence. A growing body of scientific literature (Cames et al., 2016; Schneider & Wissner, 2022; West et al., 2020) seeks to understand project quality by investigating projects' additionality, leakage, and permanence. Academic studies of GHG crediting programmes focus more on issues of additionality, GHG emission reduction and removal quantification, and to a lesser extent on permanence. To our knowledge, there are no rigorous studies that investigate the link between forest fires, GHG crediting programmes, projects, and permanence.

In the media, compelling narratives make a variety of critiques about carbon crediting programmes and specific projects, particularly NCS projects. Journalists commonly call into question the validity of methods for GHG accounting and their application with individual projects (Song, 2019; World Rainforest Movement, n.d.). On permanence, authors (Calma, 2019; Titiyoga, 2019) commonly call into question the permanence of projects that experience fire, and many rely on problematic data and methods or lack due consideration for programme-wide safeguards designed specifically to ensure credit permanence. More extreme pieces (e.g. Dupont-Nivet, 2019) approach and nearly cross a line to claim that forest fires lead to the reversal of ERRs. Many authors do not disclose their analysis or any substantive discussion of the research underlying published findings on this topic.

NCS projects, forest fires, and permanence risks are especially salient topics, and we find there is little rigorous evidence on projects' performance against fires. With this research, we set out to contribute a methodology and early findings. Without reliable evidence, market participants, policymakers, and the public are sometimes left uninformed about NCS projects and their role in ensuring permanence. The world must make great gains in scaling up climate mitigation in the coming years and decades to meet key climate goals. This will require major investment in high-quality projects to generate the gigatonne scale of climate mitigation needed. We aim to contribute to this broader discussion about quality.

2. Research approach

This study is prompted by the policy question: do forest fires pose a material risk to the permanence of NCS projects and issued credits? To make the research for this study feasible, we configure our policy question into the three research questions listed below. Each of these research questions aligns to one of the three parts that together form our methods. The remainder of this section gives an overview of our research methods.

1. Do projects experience loss events and reversals?
2. How well do projects perform against fire compared to other protected areas?
3. What fire management practices do high performing projects implement?

For all parts of this research, we focus on a subset of six NCS projects registered under Verra's VCS Program. For part 1, we complement deeper project-level investigation with programme-wide analysis covering all projects registered with the VCS Program that carry a risk of non-permanence. These include AFOLU projects. For parts 2 and 3, we focus on our sample of six NCS projects, given the level of effort required to collect and process data for each project.

We selected six projects implementing REDD+ activities, which are a subset of NCS activities within the wider category of AFOLU. As of July 2022, there were 106 REDD+ projects, 254 AFOLU projects, and 1840 total projects registered under the VCS Program, globally. We focused on REDD+ projects given the relevance of forest fires to conservation activities, which form the core of REDD+ project activities. We make use of project documents and other information, such as publicly available geographic data. Table 2 provides summary information about these projects. We selected these projects based on project data availability on the Verra Registry, sufficient fire activity in the project areas, sufficient time since each project's start date, and geographic diversity. Additionally, we deliberately dropped from our sample candidate projects in regions with a higher propensity for naturally occurring forest fires. By choosing projects in regions with humid tropical forests, we expect that any fire-induced forest cover loss that we identify is likely anthropogenic.

Table 2: Projects, summary information, and assessed risk of non-permanence

Project ID	Project name	Country	Project activity	Project start date	Verification periods, to date
674	Rimba Raya Biodiversity Reserve Project	Indonesia	APDD (REDD)	1 July 2009	1 Jul 2009 – 22 Jun 2017
944	Alto Mayo Conservation Initiative	Peru	AUDD (REDD)	15 June 2008	15 Jun 2008 – 14 Jun 2018
1115	Jari/Amapá REDD+ Project	Brazil	AUDD (REDD)	14 Feb. 2011	14 Feb 2011 – 15 Oct 2019
1360	Forest Management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo Indigenous communities of Ucayali region	Peru	AUDD (REDD)	1 July 2010	1 Jul 2010 – 30 Jun 2018
1477	Katingan Peatland Restoration Project	Indonesia	APDD (REDD) + WRC, ARR	1 Nov. 2010	1 Nov 2010 – 31 Dec 2020
1503	RESEX Rio Preto-Jacundá REDD+ Project	Brazil	AUDD (REDD)	1 Oct. 2012	1 Oct 2012 – 30 Sep 2015

Project activity acronyms
ARR: Afforestation, reforestation, and revegetation
APDD: Avoided planned deforestation and forest degradation
AUDD: Avoided unplanned deforestation and forest degradation
WRC: Wetland restoration and conservation

2.1 Do projects experience loss events and reversals?

As a first step, we reviewed verified project reporting and programme-wide data to determine whether projects have experienced carbon stock loss events and reversals, and whether the VCS Program sufficiently compensates for any such reversals.

A loss event describes the situation where a project experiences a loss in carbon stocks equivalent to more than 5% of previously verified ERRs. A loss event alone does not immediately indicate the potential for non-permanence because a project could still replace lost carbon stocks through project activities during the same verification period. A reversal describes the situation where a project's net GHG benefit is negative during a project's given verification period, indicating the potential for non-permanence. However, even if a project experiences a reversal, Verra taps a programme-wide mechanism to ensure permanence.

Should a project experience a reversal, Verra would cancel credits deposited into the AFOLU pooled buffer account[5] (also called the buffer pool) to compensate for 100% of ERRs impacted by the reversal. Following a loss, as a first measure, Verra places buffer credits on hold in an amount equivalent to the estimated loss stated in the loss event report. And should the loss lead to a verified reversal, Verra will cancel these on-hold buffer credits as well as any additional volume of buffer credits required to compensate for the full impact of the reversal. We reviewed project reporting and activity on the VCS Program buffer pool to assess for non-permanence. This first step provides a baseline understanding about measures taken to ensure permanence.

2.2 How well do projects perform against fire compared to other areas?

We used geospatial methods to test projects against comparison areas for potential to generate additional fire-mitigation benefits. We describe fire mitigation as a non-carbon co-benefit where a project generates sufficient fire mitigation during a given monitoring/verification period to increase or maintain carbon storage, resulting in a positive net GHG benefit without any reversals and without relying on the AFOLU pooled buffer account. Estimating this co-benefit proved challenging.

To approximate fire-mitigation co-benefits, we quantify and compare changes in fire incidence and tree cover between a project area and its matched comparison area or areas. Under ideal circumstances, we would be able to use other methods and/or more data to estimate projects' impacts more precisely. Given constraints, we used protected areas rather than control areas. And given that protected areas also implement conservation measures, our results do not show the impact of implementing an intervention compared with a counterfactual. In fact, using protected areas for comparison sets a very high standard to estimate project's impacts given protected areas' express purpose is to conserve nature, often by legal mandate. Still, we hope the unique combination of research questions and methods might be useful. Scaling up this research with a greater number of observations would lend additional confidence to these findings.

5 The VCS Program requires the conservative deduction of AFOLU projects' ERRs from crediting. Instead of being issued as carbon credits, these buffer credits are deposited into the Verra AFOLU pooled buffer account for future use in case of reversals. Under the VCS Program, these deductions from projects and deposits to the AFOLU pooled buffer account are made upon each project's initial credit issuance.

2.3 What fire management practices do high performing projects implement?

Finally, we used qualitative methods primarily to better understand the fire management practices that higher-achieving projects implement. We used a questionnaire and a focus group discussion (FGD) with representatives of our sample projects. With the questionnaire, our aim was to collect more granular and uniform data about sample projects and their respective levels of fire threat as well as resources, or resource gaps, and specific fire management activities. Through the FGD, our secondary goal was to ground the theory and assumptions underlying our quantitative methods.

3. Research methods, materials, and data

3.1 Assessing projects for losses and reversals

We use two steps to establish a baseline understanding about projects, the VCS Program, and permanence. First, we assess projects' performance by summing the volume of losses and reversals across each project's full verification periods, to date. And second, we assess the VCS Program's performance by summing the volume of credits within the buffer pool that have been cancelled to compensate for any reversals (due to fire or any other cause).

For this first part of the study, we reviewed project reporting and a Verra data set. Project reporting includes project description documents, monitoring reports, and loss reports, all authored by the respective project proponent and reviewed by Verra. We reviewed verification reports, which are authored by third-party validation/verification bodies, and also reviewed by Verra. These kinds of project reports are publicly accessible for all projects registered under the VCS Program or indeed any of the most used GHG crediting programmes. We also accessed Verra's publicly accessible data set showing activity on the AFOLU pooled buffer account. All of these materials and data were gathered from the Verra Registry in July 2022.

3.2 Assessing projects for excess fire mitigation

This second part of the methods are meant to estimate projects' performance in generating excess fire-mitigation benefits beyond the minimum needed for crediting and without tapping the VCS Program buffer pool. We compare projects' performance against that of matched comparison areas and the following specifies our procedure.

Step 1: Selecting and matching project areas to comparison areas

In environmental conservation research, and impact evaluation more broadly, designing a counterfactual is a perennial challenge, especially without the benefit of random assignment and with relatively few observations (NCS projects in this study). Other researchers have used a range of methods from difference-in-differences with control areas and before-after to synthetic matching (Bos et al., 2017; Roopsind et al., 2019).

We use protected areas for comparison. We initially generated control areas, following Bos and colleagues (Bos et al., 2017). For each project area, our approach was to generate a control area based on a composite of administrative units intersecting the boundaries of the project area and excluding the project area itself. However, in the context of our study, we believe this approach likely introduces bias rather than controls for it. For example, a project area may intersect with up to five administrative units that span more than 100 kilometres across, with ecosystems and a propensity for forest fire and tree cover loss potentially very different compared to that of the project area. Instead, we chose protected areas such as national parks, national forests, and conservation areas.

We expect that protected areas serve as useful comparators, but these are not counterfactual or control areas. Protected areas, contrasted against our initial approach to generating control areas, likely better fit the contours of natural ecosystems as do NCS project areas. We expect that project areas have more similar drivers of fire and tree cover loss when compared with protected areas, rather than compared with our initial counterfactual areas.

We matched protected areas to project areas to enable meaningful comparisons. We used a K-means clustering approach, performed in GEODA, to match each project area to one or more similar protected areas. Some projects were matched to just one protected area while others were matched to as many as four. The areas were matched by natural and anthropogenic drivers of forest fire (World Economic Forum, 2021; Soares-Filho et al., 2012; Gralewicz et al., 2012). These include mean elevation, mean tree cover percentage, mean urban cover, mean cropland percentage, mean road density, and individual terrestrial ecosystems. This matching activity helps reduce bias when comparing fire and tree cover loss across project and comparison areas. Future studies might also use forest fragmentation as an additional matching attribute. We note that fragmentation indicates a higher fire risk (Armenteras et al., 2013b). Fragmentation is an important aspect of some selected project and comparison areas and controlling for this should add to the confidence of project and comparison area matches.

We note that there is a possibility of error in the K-means clustering results because means may not be the best summary measure for the statistical distribution of the variables used to identify similar attributes among the protected areas. Let us take the elevation data set as an example where a project could feature a tall mountain surrounded by valleys at low elevation. Using K-means clustering would not capture the elevation change within this project. Instead, the approach would cluster this project with others based solely on mean elevation.

Step 2: Counting fires and calculating tree cover loss

Next, we quantified annual trends in fire incidence and tree cover loss across all project areas and matched comparison areas. For fire incidence we used archived NASA MODIS fire hotspot data. For the tree cover data, we use the University of Maryland's Global Forest Change 2000-2020 data set. We processed these data sets by year and analysed trends across all project areas and matched comparison areas.

In selecting MODIS fire points, we chose to include all available data points without dropping observations with low confidence scores or ratings. The MODIS Collection 6 Active Fire Product User's Guide notes that some observations can have low confidence because the data use a contextual algorithm that exploits the strong emission of mid-infrared radiation, distinctive but not unique to fires, and assigns each pixel of the MODIS swath a *fire* or other designation (Giglio et al., 2020). The data should not be relied upon for 100% accurate fire detection. We chose not to drop low-confidence observations because we are interested in fire densities and the spatial relations that these densities illustrate, rather than identifying any particular fire. We apply the same processing across both project and comparison areas.

For the data on loss of tree cover, we note that the data documentation clearly states that the data does not show regeneration. Thus, raw tree cover loss percentages do not accurately represent actual loss events that occurred from 2000 to 2020. This is a major area for future studies to improve upon, especially in REDD+ projects, because forest regeneration is vastly important for preserving or regenerating carbon after deforestation events.

We use several indicators to describe the impacts of fire and tree cover loss. For each area, we sum the fire counts over a given period of time (Equation. 1). However, to compare areas that vary in size, we normalize fire counts by dividing Eqn. 1 by the area of interest, which gives the density of fires per unit area of forest (Eqn. 2). We take a similar approach with tree loss and divide the area of tree cover loss by total forest area (Eqn. 3). These indicators are calculated as follows:

$$Fire\ counts\ between\ years\ Y_1 \&\ Y_2\ =\ \sum_{Y_1}^{Y_2} f_Y\ \ (with\ units\ of\ no.of\ fires) \tag{1}$$

$$Fire\ density\ between\ years\ Y_1 \&\ Y_2 = \frac{\sum_{Y_1}^{Y_2} f_Y}{A}\ (with\ units\ of\ no.of\ fires\ per\ ha) \tag{2}$$

$$Tree\ cover\ loss\ between\ years\ Y_1 \&\ Y_2 = \frac{\sum_{Y_1}^{Y_2} l_Y}{A}\ (with\ units\ of\ ha\ lost\ per\ ha\ forest) \tag{3}$$

Where

Y_1 and Y_2	years of interest,
f_Y	fire count in year-Y,
A	area of interest, and
l_Y	tree cover loss in year-Y.

For this part of the research, the period starts one year after each project's start date and ends on 31 December 2020. By aligning the study period start date to one year after project start dates, we can be sure that we measure projects' performance. We note that 1 November 2000 is the earliest date for which archived MODIS fire data is available and we dropped years that precede the six projects' start dates.

This study focused on tree cover loss attributed to fire alone, and thus does not investigate tree cover loss attributed to other drivers, such as natural resource extraction, pests, drought, etc. Future studies with more expansive scopes benefit by studying tree cover loss attributed to a wholistic set of drivers.

Step 3: Robustness checks

We exported yearly fire data and tree cover loss data to spreadsheets to compare trends for robustness checks. We used Pearson's correlation coefficient to determine if there was a linear correlation between tree cover loss and fires and to test for statistical significance. We tested for correlation using two models. We first tested using fire and tree cover loss data of the same year. We also tested for correlation with a one-year lag between the two data. For example, we correlated 2010 fire data with 2011 tree cover loss data. By contrast, the same-year correlation is meant to capture 2010 fires in 2010 tree cover loss data. The results of the robustness check for each project and their respective comparison area(s) are shown in the far-right two columns of Table 4 through Table 9.

To ensure we estimated projects' fire-mitigation performance accurately, we set the study period start date to each project's start date. Project start dates are given in Table 1. For each project, we use the same start date for the project's matched comparison area(s) and we used data one year after the implementation date. For example, the Katingan Peatland Restoration Project (ID 1477) was implemented in 2010 and was matched to three comparison areas. We assessed, beginning in 2011, the fire and tree cover data for changes in both the project area and its comparison areas. We chose 31 December 2020 as the end-date for study periods to allow the longest time period possible. We note that this research was started during 2021.

Last, we used yearly fire data to create a kernel density map of each project area and comparison area to visually detect areas with dense fires and to show their spatial relation to tree cover loss. We layered the tree cover loss data and fire data, derived from the kernel density maps, to check for spatial alignment. These graphics provide useful visual representations of the correlation. Where fire and tree cover align and correlate with statistical significance, we believe that fire is among the leading drivers of tree cover loss. An example diagram is shown in Figure 2 in the following pages. And a full set of diagrams are shown in Figures A1 to A18, in Annex 3.

Overview of data

We used a variety of data for this second part of the research. We accessed project specific KML files from the Verra Registry. These delineate project area boundaries. For comparison areas, we accessed protected lands for each relevant country from the World Database on Protected Areas, managed by Protected Planet. We matched protected areas to NCS project areas using six data sets including: 2017 Built up and Cropland data sets from the Copernicus Land Monitoring Service, elevation GTOPO30 from the US Geographical Survey, World Terrestrial Ecosystems Pro Package from ArcGIS Pro, Road systems from the World Food Programme, and 2010 Tree Cover from Global Land Analysis and Discovery. To assess the performance of both projects and their matched comparison areas, we used the NASA MODIS Archive active fire data and Global Forest Change 2000–2020: Year of gross forest cover loss event (loss year). For additional details, see Annex 2.

3.3. Investigating effective fire management practices

This part of our study used qualitative methods, primarily to benchmark projects' respective fire threat levels and to identify higher-achieving projects' fire management practices.

We designed and implemented a questionnaire using a web-based survey tool covering the topics listed below. Annex 4 includes a copy of the questionnaire.

1. The level of threat posed by fires near or within the project area.
2. The rank of fire management among competing project operational priorities.
3. The level of knowledge or training possessed by the project.
4. The specific fire prevention, monitoring, and suppression activities implemented by the project.
5. The level of equipment and other physical assets available to the project.
6. The specific equipment and tools used by the project.
7. The level of financial resources available to the project for fire management.
8. The percentage of the project's annual operational budget allocated to fire management.

A secondary goal of our qualitative research was to cross-check our geospatial methods with people who have on-the-ground perspectives of projects and fires. We led a FGD in August 2022 with representatives of sample projects in attendance. All project teams were invited, and all sent representatives except for Alto Mayo Conservation Initiative (ID 944). We presented methods and initial results from parts 1 and 2 of this study and sought verbal feedback through targeted and open-ended questions. We sought to elicit responses on major drivers of forest loss, the behaviour of actors of deforestation, and the bounds of fire seasons across these diverse geographies. We asked about government programmes designed to mitigate fire or other confounding factors that may influence part 2 of this study. Following the FGD, we invited written feedback on these same topics via email. Annex 4 includes a copy of the FGD questions. We analyse quantitative results In Section 5 and participant feedback and a literature review add valuable perspective to this analysis.

4. Results

4.1 Projects experience some loss events

This first part of our research set out to establish a baseline understanding about permanence by assessing for losses and reversals.

We checked our sample of six NCS projects for loss events and found that one of these experienced one loss event. This loss event did not lead to a reversal. We also checked for reversals among all 190 AFOLU projects that have achieved initial credit issuance and thus made contributions to the buffer pool. We found that buffer credits were cancelled for one project outside of our sample. Still, the scale of cancelled buffer credits is so small that it does not pose a material risk to permanence at the levels of project or GHG crediting programme due to the volume of credits held in the pooled buffer account.

Our review of project reporting showed that, to date, one of the six NCS projects studied experienced a loss event during their verification periods. The Rimba Raya Biodiversity Reserve Project (ID 674) experienced a loss of 278 886 tCO_2e as a result of forest fires and activity-shifting leakage within the project boundary between 1 July 2011 and 30 June 2012. This loss was reported in October 2013 with an initial estimate of 211 902 tCO_2e lost. Upon receipt of the loss event report, Verra placed an equivalent volume of buffer credits on hold, pending verification. This volume was within range of the project's individual contribution to the buffer pool, at 242 373 buffer credits. At the project's next verification, the verified loss of 278 886 tCO_2e was deducted from project crediting for the period. With net emission reductions of 11 163 715 tCO_2e, the loss represents about 2.5% of crediting during the period. Given that the project compensated for the loss in this period, the buffer credits were released from their on-hold status back to the buffer pool. That is, the project replaced the full volume of verified losses and generated additional emission reductions, representing a net positive GHG benefit during the verification period. Thus, there was no reversal and no risk to permanence in this case.

We analysed the Verra Registry buffer pool report and found that one of the 190 contributing projects had experienced a reversal. The International Small Group and Tree Planting Program (TIST) Program in Kenya, VCS 001 project (ID 594) is one of 17 registered ARR projects that together operate as a carbon programme under the VCS Program. The TIST Program collectively includes over 23 000 small community groups of agriculturalists who have planted over 23 million trees across Kenya, Uganda, and India. In the project's loss event report, from 2020, the proponent states a family of landowners chose to leave the TIST Program to harvest their trees for timber. The project achieved gross removals of 24 291 tCO_2e during its third verification period. To account for lost carbon stocks, the proponent also reported a negative volume of removals equivalent to the volume of carbon that the leaving landowners sequestered in past periods. Across the project's first and second verification periods, lost carbon stocks sum to 73 127 tCO_2e. Gross removals less lost stocks resulted in a reversal of 48 838 tCO_2e for the verification period. Verra cancelled 48 838 buffer credits from the buffer pool, consistent with the rules governing buffer pool management. While this project experienced a reversal, we find there was no risk to the permanence of any issued credits given the cancellation of buffer credits.

We consider the overall robustness of the VCS buffer pool. In July 2022, the account included about 63 million buffer credits. About 1 million of these were on hold for 25 different projects, either for reported loss events or given that more than five years have passed since a project's last verification, per VCS Program requirements. We note that credits on hold represent 1.65% of total buffer credits. And cancelled credits represent 0.08% of total buffer credits. Only one reversal has occurred since the buffer pool mechanism was introduced in 2008. Should any other project experience a reversal due to forest fire or any other cause, the scale of buffer credits available, coupled with loss and reversal trends to date, suggest that the buffer pool is sufficiently robust to compensate for potential reversals and guarantee permanence.

4.2 Some projects generate fire mitigation co-benefits

This second part compares projects' performance in generating excess fire-mitigation against that of matched comparison areas to estimate potential for co-benefits. We present our findings in stepwise fashion.

Project area and comparison area matches

In all, we matched the six NCS project areas to 12 comparison areas. The Indonesia projects happened to be in relatively close proximity to each other and share common drivers of fire and tree cover loss. As such, both project areas matched to a common set of three comparison areas. Each of the other project areas matched to one or more distinct comparison areas. Table 3 provides summary information on projects' matched comparison areas and each comparison area's designation. Figure 1 provides a visual overview of the spatial relations of all six project areas and their matched comparison areas.

Figure 1: Overview of all project areas matched comparison areas

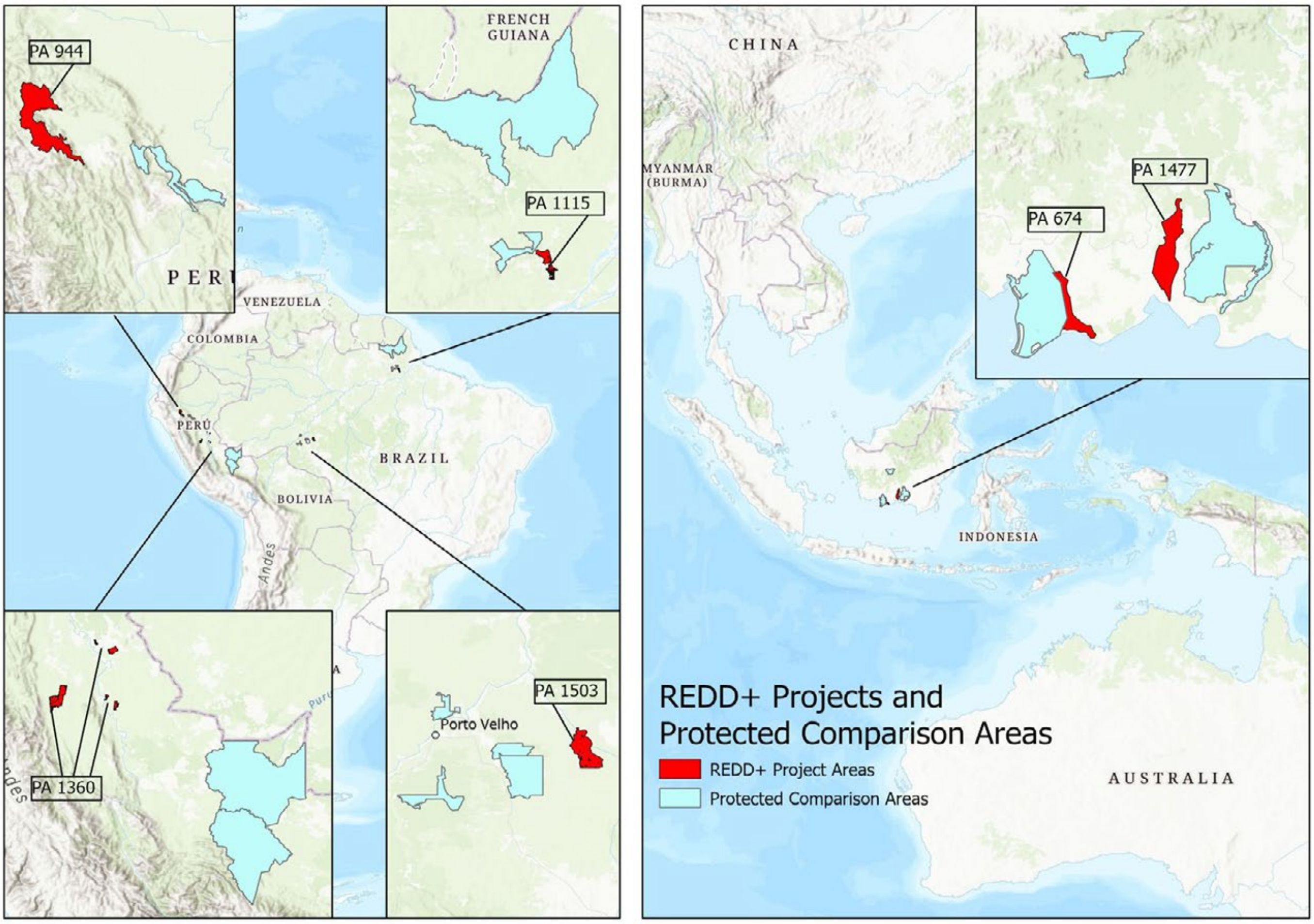


Table 3: Protected lands matched to REDD+ projects

Project ID, by country	Name of comparison area	Designation of comparison area
	Indonesia	
674 and 1477	Tanjung Puting National Park	National park/Ramsar site, wetland of international importance
674 and 1477	Sebangau National Park	National park
674 and 1477	Bukit Baka Bukit Raya National Park	National Park
	Brazil	
1503	Jamari National Forest	National forest
1503	Samuel Ecological Station	Ecological station
1503	Bom Futuro National Forest	National forest
1503	Forest Conservation Unit of Sustainable Yield Rio Madeira B	National forest
1115	Tumucumaque Mountains National Park	National park
1115	Jari Ecological Station	Ecological station
	Peru	
944	Cordillera Escalera Regional Conservation Area	Regional conservation area
1360	Alto Purus National Park	National park
1360	Manu National Park	National park

Fire count and tree cover loss results

We compare each project's performance in mitigating fire incidence and tree cover loss against that of its matched comparison area(s). Where a project outperforms its comparison area(s), we determine that the project has generated fire-mitigation co-benefits.

For each project, Table 4 through Table 9 show the variables of interest: tree cover loss, fire counts, and fire counts normalized per square kilometre. These tables also show correlation results using two models: a same-year model, and a one-year lag model (e.g. 2010 fire data correlated with 2011 tree cover loss data). Each table shows the project's results in the top row followed by results for matched comparison area(s) below. Where a project matched to more than one comparison area, we include an additional row at the bottom with averaged comparison area results.

Note that for each project and its comparison area(s), we chose to use the tree cover loss and fire count results generated using the one-year lag model, except for RESEX Rio Preto-Jacundá REDD+ Project (ID 1503). Looking at differences in correlation results across regions, we note that differing forest fire seasons may be a contributing factor. In Brazil and Peru, forest fire seasons occur from May through October (Bradley & Millington, 2006; Voiland, 2020). Results from the RESEX Rio Preto-Jacundá REDD+ Project (ID 1503) in Brazil do not use the one-year lag model because we suspect that, in this project, forest cover loss precedes fire. The data support this, given lower p-values for correlation results using the same-year model. In Indonesian Borneo, the main forest fire season is August through October, though forest fires have occurred in February and March in some years (Van Der Werf, 2015). We used the one-year lag model for both

Indonesia projects because there, fire precedes forest cover loss, and the one-year lag model better captures this relationship.

RESEX Rio Preto-Jacundá REDD+ Project (ID 1503) and its comparison areas showed stronger correlation using the same-year model. Another study found that forest loss and corresponding fire incidence could be found either in the same year or one year apart (Adrianto et al., 2019, p. 13). These researchers focused on Indonesia's Riau province, from 2001 through 2012. They note that, "there are two possible reasons for this observed relationship between fire and forest loss. Either the fire causes the forest loss, or forest loss makes the landscape more susceptible to fire" (Adrianto et al., 2019, p. 13). It is possible that people clear forest litter before harvesting timber in and around this project, which could increase susceptibility to fire through "forest edging" (Armenteras et al., 2013b). This leads to a stronger association in the same-year model because deforestation precedes forest fire events.

Indonesia results

We begin by reviewing the Indonesia results. The two Indonesia projects and most of their matched comparison areas returned high, positive correlation coefficients with strong statistical significance (see Table 4 and Table 5). We interpret these results as evidence that variation in tree cover loss is not explained by random chance. Further, we infer that fire is among the leading drivers of tree cover loss in all Indonesia observations except in the Bukit Baka Bukit Raya National Park comparison area, where correlation was low and lacking statistical significance.

We cross-check these findings by reviewing the fire incidence and tree cover loss diagrams in Figures A1 through A5. For all but the Bukit Baka Bukit Raya National Park comparison area, we find significant spatial overlap between fire and tree cover loss. In the national park, the diagram in Figure A5 shows fires along the park's boundary line in the northwest, northeast, and south. Although fire and tree cover loss coincide here, the tree cover loss is concentrated along rivers which enable access to this remote park. These tree cover outcomes are consistent more with natural resource extraction, such as logging, rather than forest fire (Elias, 2013).

We find that the Katingan Peatland Restoration Project (ID 1477) outperformed the two comparison areas in which forest fire is a leading driver of tree cover loss. The project lost a lower percentage of its tree cover, and it experienced significantly fewer fires, both in total count and normalized per square kilometre. We deduce that the project has generated excess fire mitigation.

The Rimba Raya Biodiversity Reserve Project (ID 674) outperformed the same two comparison areas in terms of total fire counts, but it experienced a higher normalized fire count per square kilometre. These outcomes may be explained by the project's relatively smaller total area compared to the parks' vast total areas, with forest fires concentrated closer to the project area. The results also show that the comparison areas outperformed this project, with a lower percentage of tree cover lost. Again, should forest fires be concentrated closer to the project area, this may be a contributing factor. Overall, we deduce that the project has not generated excess fire mitigation.

Brazil and Peru results

Unlike the Indonesia results, the majority of project and matched comparison areas across Brazil and Peru returned only moderate correlation coefficients, and most of these lacked statistical significance. Of the four sets of projects and matched comparison areas, there was not even one complete set with a project area and at least one comparison area with statistically significant correlations. Thus, we are not able to comment on whether projects in these countries generated excess fire mitigation.

However, it may be useful to interpret some of the standalone results. The Brazil project named Forest Management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo

Indigenous communities of Ucayali Region (ID 1360) returned a high, positive correlation coefficient with strong statistical significance (see Table 9). These results show that forest fire is among the leading drivers of tree cover loss in the area. We cross-check these with the fire incidence and tree cover loss diagram in Figures A9 and find significant overlap between fire and tree cover loss. But without statistically significant results for its comparators, the project's tree cover loss and fire count results tell us little about the project's performance.

The Peru project entitled Alto Mayo Conservation Initiative (ID 944) makes an interesting example. Recall the Bukit Baka Bukit Raya National Park, in Indonesia, where tree cover loss appears to be aligned more with logging than with forest fire. We review the diagram for this Peru project (ID 944) in Figure A14 and find a similar pattern. Here, forest fire and tree cover loss share almost no overlap. Forest fire is heavily concentrated on the project area boundary towards the southwest. The vast majority of tree cover loss is found in the north, with some activity in the southeast corner. Where there is tree cover loss, it coincides with rivers, roads, settlements and other correlates of natural resources extraction (Armenteras et al., 2013b). Other drivers could include climate change, forest fragmentation, and forest edging due to roads, agricultural expansion, and forest clearing. We believe that here, logging for timber is a more likely driver of tree cover loss than forest fire.

An orangutan in Central Kalimantan, Indonesia © PT RIMBA MAKMUR UTAMA

Fire count and tree-cover loss tables

Table 4: Rimba Raya Biodiversity Reserve Project (ID 674) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (one-year lag)	Fire count, from start date (one-year lag)	Fire count per KM^2 (one-year lag)	Correlation (one-year lag)	Correlation (same year)
Rimba Raya Biodiversity Reserve Project (ID 674) (1 Jan 2009 – 31 Dec 2020)	19.67%	1003	1.55	0.79***	-0.19
Sebangau National Park (1 Jan 2009 – 31 Dec 2020)	14.22%	4531	1.15	0.95***	0.01
Tanjung Puting National Park (1 Jan 2009 – 31 Dec 2020)	9.5%	4505	0.75	0.91***	-0.15
Bukit Baka Bukit Raya National Park (1 Jan 2009 – 31 Dec 2020)	2.8%	29	0.01	0.09	0.18
Comparison area / Correlation (1 Jan 2009 – 31 Dec 2020)	6.65% (mean)	9,065 (sum)	0.65 (mean)	0.95*** (mean)	-0.68 (mean)

*** $p < 0.01$; ** $p < 0.05$; * $P < 0.1$

Table 5: Katingan Peatland Restoration Project (ID 1477) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (one-year lag)	Fire count, from start date (one-year lag)	Fire count per KM^2 (one-year lag)	Correlation (one-year lag)	Correlation (same year)
Katingan Peatland Restoration Project (ID 1477) (1 Jan 2011 – 31 Dec 2020)	6.6%	291	0.19	0.98***	-0.12
Sebangau National Park (1 Jan 2011 – 31 Dec 2020)	9.1%	4315	0.66	0.95***	-0.01
Tanjung Puting National Park (1 Jan 2011 – 31 Dec 2020)	14.1%	3688	0.9	0.96***	-0.15
Bukit Baka Bukit Raya National Park (1 Jan 2011 – 31 Dec 2020)	2.58%	25	0.01	0.36	0.01
Comparator average / Correlation (1 Jan 2011 – 31 Dec 2020)	8.63% (mean)	8,028 (sum)	0.57 (mean)	0.96*** (mean)	-0.09 (mean)

*** $p < 0.01$; ** $p < 0.05$; * $P < 0.1$

Table 6: RESEX Rio Preto-Jacundá REDD+ Project (ID 1503) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (same year)	Fire count, from start date (same year)	Fire count per KM^2 (same year)	Correlation (same year)	Correlation (one-year lag)
RESEX Rio Preto-Jacundá REDD+ Project (ID 1503) (1 Jan 2013 – 31 Dec 2020)	9.46%	1071	1.06	0.59	0.45
Jamari National Forest (1 Jan 2013 – 31 Dec 2020)	0.45%	33	0.02	0.70*	0.40
Samuel Ecological Station (1 Jan 2013 – 31 Dec 2020)	0.19%	47	0.07	0.09	-0.45
Bom Futuro National Forest (1 Jan 2013 – 31 Dec 2020)	5.0%	1035	1.02	0.68*	-0.32
Forest Conservation Unit of Sustainable Yield Rio Madeira "B" (1 Jan 2013 – 31 Dec 2020)	4.93%	389	0.81	0.17	0.38
Comparison area / Correlation (1 Jan 2013 – 31 Dec 2020)	1.92% (mean)	1504 (sum)	0.34 (mean)	0.50 (mean)	-0.20 (mean)

*** $p < 0.01$; ** $p < 0.05$; * $P < 0.1$

Table 7: Jari/Amapá REDD+ Project (ID 1115) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (one-year lag)	Fire count, from start date (one-year lag)	Fire count per KM^2 (one-year lag)	Correlation (one-year lag)	Correlation (same year)
Jari/Amapá REDD+ Project (ID 1115) (1 Jan 2012 – 31 Dec 2020)	3.81%	183	0.28	0.53	0.14
Tumucumaque Mountains National Park (1 Jan 2012 – 31 Dec 2020)	0.07%	17	0.01	-0.30	0.09
Jari Ecological Station (1 Jan 2012 – 31 Dec 2020)	0.03%	0.00	0.00	N/A	N/A
Comparator average / Correlation (1 Jan 2012 – 31 Dec 2020)	0.06% (mean)	17 (sum)	0.01 (mean)	-0.30 (mean)	0.30 (mean)

*** $p < 0.01$; ** $p < 0.05$; * $P < 0.1$

Table 8: Alto Mayo Conservation Initiative (ID 944) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (one-year lag)	Fire count, from start date (one-year lag)	Fire count per KM^2 (one-year lag)	Correlation (one-year lag)	Correlation (same year)
Alto Mayo Conservation Initiative (ID 944) (1 Jan 2009 – 31 Dec 2020)	1.92%	22	0.01	0.48	0.35
Cordillera Escalera Regional Conservation Area (1 Jan 2009 – 31 Dec 2020)	0.01%	39	0.01	-0.19	0.24

*** p < 0.01; ** p < 0.05; * P < 0.1

Table 9: Forest Management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo Indigenous communities of Ucayali Region (ID 1360) and comparison area results

Project name and ID / name of comparison area (time period of study)	Tree cover loss, from start date (one-year lag)	Fire count, from start date (one-year lag)	Fire count per KM^2 (one-year lag)	Correlation (one-year lag)	Correlation (same year)
Forest Management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo Indigenous communities of Ucayali Region (ID 1360) (1 Jan 2011 – 31 Dec 2020)	8.8%	678	0.02	0.80***	0.79***
Alto Purus National Park (1 Jan 2011 – 31 Dec 2020)	0.06%	4	0.01	0.33	-0.11
Del Manu National Park (1 Jan 2011 – 31 Dec 2020)	0.25%	108	0.01	-0.28	-0.23
Comparator average / Correlation (1 Jan 2011 – 31 Dec 2020)	0.14% (mean)	112 (sum)	0.01 (mean)	-0.23 (mean)	-0.26 (mean)

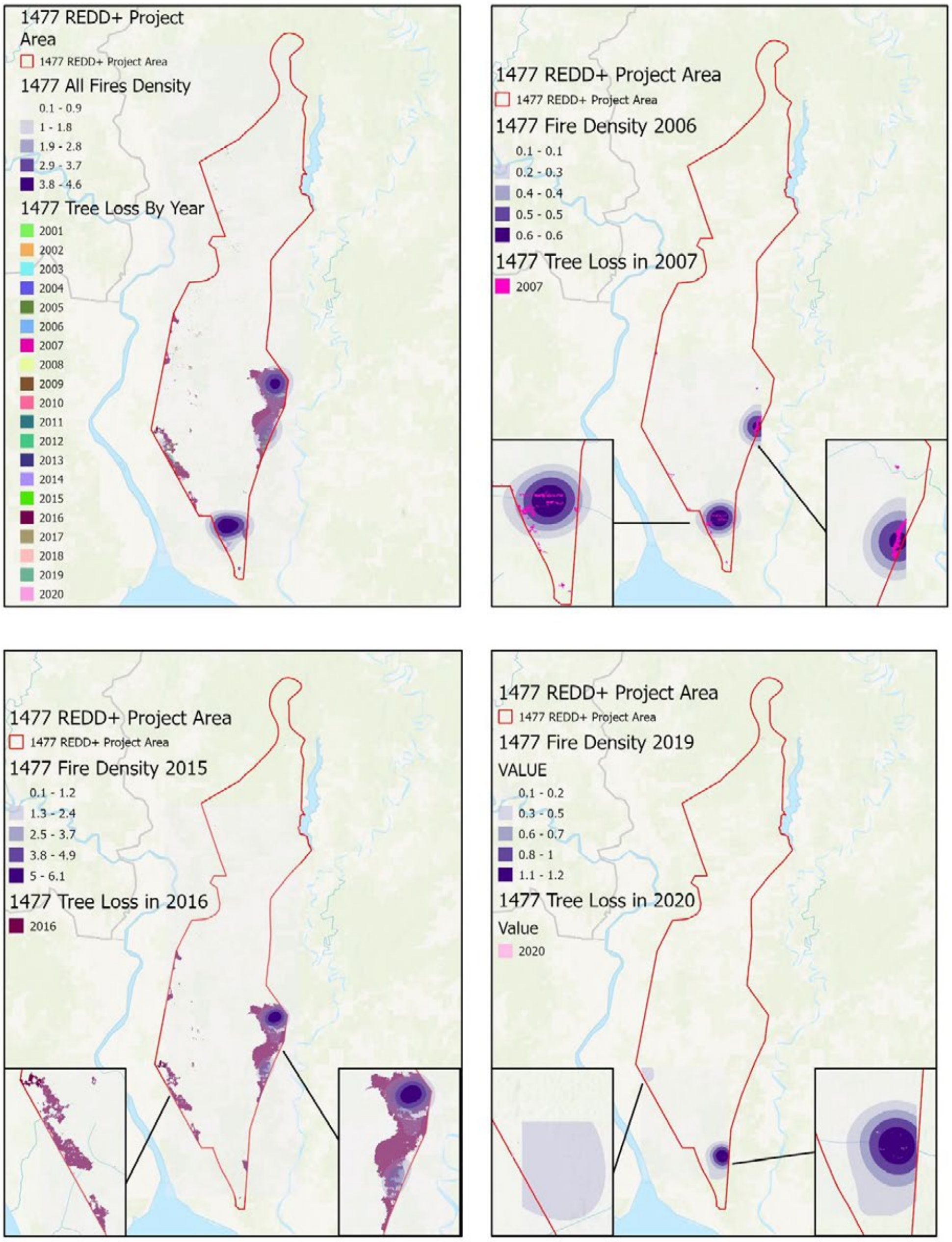
*** p < 0.01; ** p < 0.05; * P < 0.1

Kernel density and tree cover loss Layouts

As described in section 3.2., we generated diagrams to show the spatial correlation between fire incidence and tree cover loss. As an example, Figure 2 shows correlation for the Katingan Peatland Restoration Project (ID 1477). Annex 3 includes a comprehensive set of these diagrams for all project areas and comparison areas.

In Figure 2, the top left panel shows all fire incidence and tree cover loss. The top right panel shows 2006 fire incidence with 2007 tree cover loss. The bottom left panel shows 2015 fire incidence with 2016 tree cover loss. And the bottom right panel shows 2019 fire incidence with 2020 tree cover loss.

Figure 2: Katingan Peatland Restoration Project (ID 1477) fire incidence and tree cover loss diagrams



4.3 Effective fire management practices

For projects that have achieved fire-mitigation co-benefits, this third part presents the relative fire threat level and practices and resources for fire prevention, monitoring, and suppression. Among our six sample projects, only the Katingan Peatland Restoration Project (ID 1477) was found to have statistically significant results and demonstrable co-benefits. This section draws from the project's questionnaire response.

Fire threat assessment: the project reported that the project's carbon stocks face a significant threat due to forest fire. Fires commonly occur near or within the project area. And when fires occur, they are often widespread or intense. This lends confidence that fire is among the leading drivers of tree cover loss for this project.

Prioritizing fire management: the project ranked operational priorities by the amount of budget and time allocated and described fire management as an essential management practice, placed at or near the top of their management priorities.

Fire management knowledge and training: the project describes its level of knowledge and training as advanced. The project includes expert team members tasked with fire-mitigation planning and implementation. The team develops and uses best practices for the project.

Specific fire management activities include use of fire-break plantations; revegetation activities; rewetting peatland; awareness-building programmes with local communities; use of patrols to scout the project area; use of drones to observe the project area; use of early warning systems including weather forecasting and satellite-based fire alerts; local community fire monitor groups; and local community fire fighters.

Fire management equipment and other assets: the project expressed possessing a moderate level. It has most of the equipment and other assets needed to effectively prevent, monitor, and suppress fires, and more equipment or other assets would help the project improve fire mitigation only marginally.

Specific fire management equipment and other assets include the following: computer systems for weather forecasting and fire alerts; communication tools, including radios, mobile phones, satellite phones; monitoring posts and watchtowers; drones; hand tools, including axes, shovels, hooks, etc.; power tools, including generators, chainsaws, flame throwers, etc.; watercraft, including patrol boats, fireboats, etc.

Financial resources for fire management: the project describes this level as fully sufficient. The project has all of the financial resources needed to effectively prevent, monitor, and suppress fires to the extent possible. Further, the project reported allocating more than 40% of its annual operational budget to fire management activities including: peat rewetting, awareness campaigns, and suppression activities.

5. Discussion

5.1 NCS projects, fire mitigation, and permanence

The VCS Program appears to be performing as designed, ensuring permanence through its requirements, GHG accounting methodologies, and tools and buffer pool mechanism.

We find that although fires are common in some project areas, actual loss events are uncommon. Our review of all projects with any loss events found that one reversal has occurred in the 17 years since the VCS Program was launched, and in the 14 years since the buffer pool mechanism was introduced. In light of recent study of other GHG crediting programmes, we find that the VCS Program buffer pool is adequately capitalized to compensate for reversals (Badgley et al., 2022). The permanence of credits issued to all 190 registered projects with any degree of non-permanence risk are guaranteed through the pooled buffer account. With about 63 million buffer credits deposited in the buffer pool as of July 2022, total historic cancellations made to compensate reversals sum to 0.08% of current buffer pool reserves.

5.2 NCS projects and additional fire-mitigation co-benefits

We determined that there is potential for NCS projects to generate fire-mitigation co-benefits, based on the geospatial results from the two Indonesia cases we studied. Our results showed that one project (ID 1477) outperformed its comparison areas, while the other (ID 674) did not. Here we offer additional context about the projects for a richer interpretation of our geospatial results.

Methodological considerations

Reflecting on our methods, we reiterate the technical challenge of evaluating environmental conservation activities without the benefit of random assignment and with relatively few observations. We do not use counterfactuals for comparison, and we expect that our methods underestimate the true performance of NCS projects in generating excess fire mitigation. Given our use of protected areas for comparison, we emphasize that our estimates of projects' fire-mitigation performance are particularly conservative.

Further, on methods, we reiterate that our tree cover loss data do not account for regeneration. As such, raw tree cover loss percentages should be used only for comparing performance between a project area and its matched comparison area or areas. These data should not be used to describe actual loss events or trends within a single area. Similarly, fire counts should not be used to describe actual fire events or trends within a single area because we have not dropped low-confidence observations. Any attempt to interpret these tree cover and fire results in absolute terms, ignoring performance against matched comparison area(s), would be misguided and would misstate projects' true impacts.

Correlation results

Recall that this second part of the study generated statistically significant correlation results for the two Indonesia projects and their matched comparison areas. Our analysis did not return significant results for any other set of project and comparison areas. In the Brazil and Peru study areas, fire's contribution to tree cover loss is probably weaker than other drivers. For example, in section 4.2 we describe the tree cover loss patterns in Alto Mayo Conservation Initiative (ID 944) as consistent with natural resource extraction. During the FGD, project representatives from the region expressed that logging, rather than forest fire, is a more common deforestation driver.

Among the areas we studied, RESEX Rio Preto-Jacundá REDD+ Project (ID 1503), and one of its comparison areas, returned statistically significant results using the same-year model rather than the one-year lag model. During the FGD, project representatives from the region concurred with this choice of model. They expressed that in this region it is common practice for unauthorized loggers to first clear some proportion of trees to access a forest stand before setting controlled burns to clear litter, enabling the felling of trees and extraction of logs. We find this description consistent with the same-year model results.

The phenomenon of forest edging, which we believe is occurring in RESEX Rio Preto-Jacundá REDD+ Project (ID 1503), is explained by Armenteras and colleagues (Armenteras et al., 2013b). The authors used FIRMS active fire data and calculated the distance that fire occurred from the forest edge in NW Amazonia. Their study noted that the number of fires increased when there were higher rates of forest fragmentation. They noted that areas with low percentages of tree cover were at higher risk for burning. Their research found that it was important to “maintain a high forest connectivity and a low forest fragmentation in NW Amazonia to buffer the reserves from large-scale edge effects and even to reconnect the forest fragments,” (Armenteras et al., 2013a, p. 73). This is important in this case because deforestation events are occurring before the fire events which point to the edging effect and a decline in the integrity of the forest.

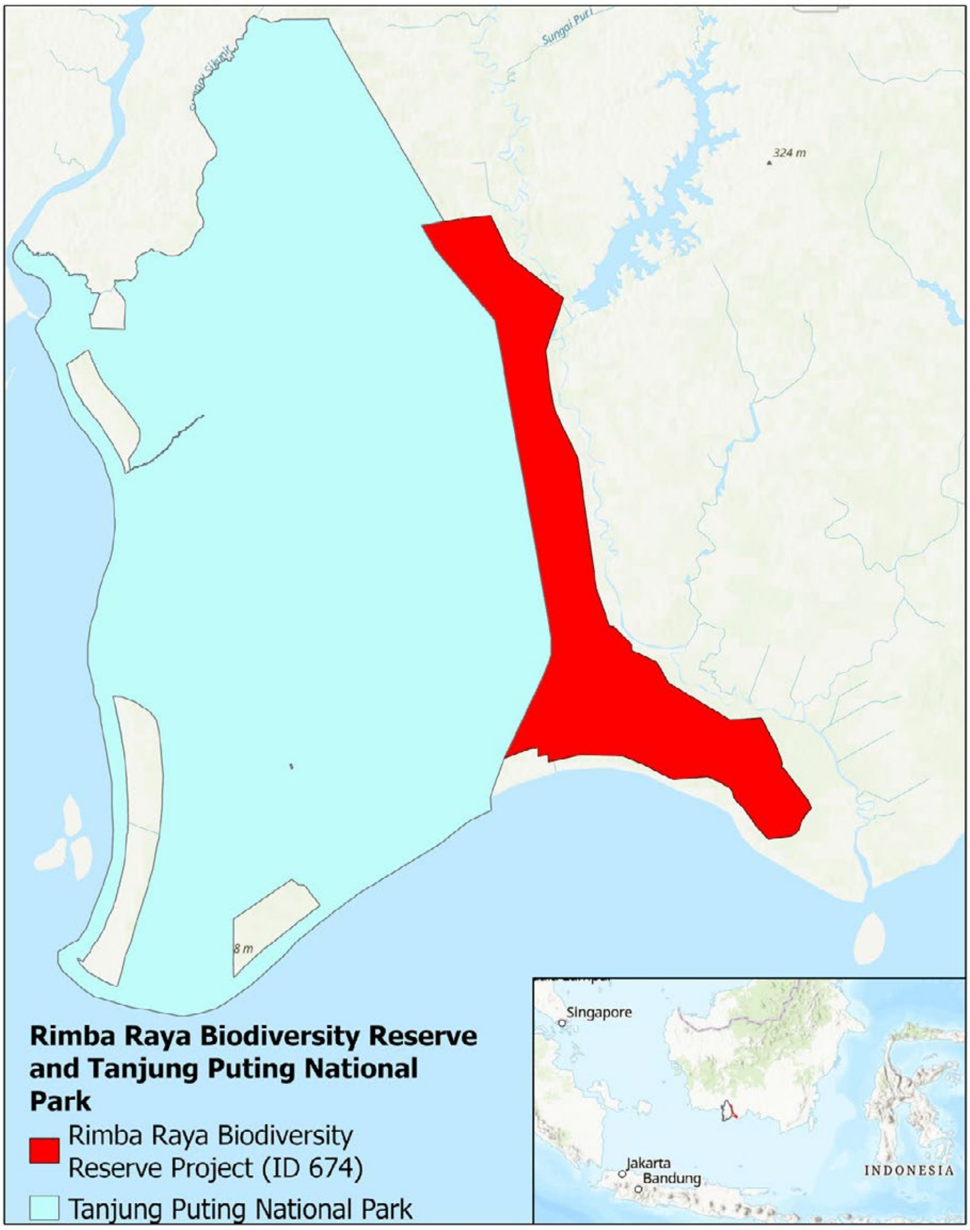
Project performance in Indonesia

Results from the Katingan Peatland Restoration Project (ID 1477) demonstrate fire-mitigation co-benefits. During the FGD, project representatives expressed that forest fire in the region is a highly plausible driver of tree cover loss. This is well-documented in the literature (Nikonovas et al., 2020). Focus group participants added that fires are mostly human induced, for agricultural expansion, though there is a high underlying fire risk given the peatlands in the region. We consider possible confounding factors to explain the project’s performance and note the 2020 Indonesia Presidential Instruction on Forest and Land Fires Mitigation, which directed the administration to coordinate and finance efforts to mitigate forest fires (Cabinet Secretariat of the Republic of Indonesia, 2020). We do not think that this expansive policy package influences our estimates of project performance because it targeted all Indonesian land vulnerable to forest fire, including project and comparison areas. By comparing performance across these kinds of areas, our methods account for external influence like this one while estimating project performance.

Results from the Rimba Raya Biodiversity Reserve Project (ID 674) suggest that this specific project did not lead to fire-mitigation co-benefits. However, we consider that the project was designed to protect the adjacent Tanjung Putting National Park from agricultural expansion. The two areas share a border of about 90 kilometres, with the park located to the west of the project. This is shown in Figure 3. Noting that this park serves as one of the comparison areas for the Indonesia projects in this study, this unique interaction between project and comparison area may render comparison between these two areas less meaningful. Even so, we compare performance between the project and Sebangau National Park, also showing better performance in the park compared to the project area.

Another way to interpret comparative performance between the Rimba Raya Biodiversity Reserve Project (ID 674) and its comparators is that the project is fulfilling its design as a buffer zone, shielding Tanjung Putting National Park from oil palm and other industrial agricultural expansion from the east. We note that the park is designated as a wetland of international importance under the Ramsar Convention and home to notable wildlife, including one of the largest remaining populations of the endangered Bornean orangutan.

Figure 3: Proximity of Rimba Raya Biodiversity Reserve to Tanjung Puting National Park



6. Conclusions

Around the globe, governments and multilateral institutions have implemented varied regulatory and economic instruments to support climate mitigation. The evolving international landscape has brought a diversity of actors and approaches to mitigation, from sub-national actors, non-state actors, and cities to businesses, Indigenous Peoples, and private citizens. The international community is rallying to scale up mitigation while recognizing that global GHG emissions have yet to peak, and that the scale of the climate change problem continues to grow (IPCC, 2022).

Against this backdrop, both public and private investment are expanding to meet the moment. But overall investment has not yet met the level needed to fund mitigation at a scale consistent with the Paris target. Through the Inflation Reduction Act of 2022, the United States government made the largest financial commitment supporting climate mitigation, at USD 370 billion. Even so, global financial flows remain three to six times lower than levels needed by 2030 to meet the Paris target of limiting warming to below 2 degrees Celsius, and capital and liquidity are not the binding constraints. One key barrier to the deployment of commercial finance is inadequate assessment of climate-related risks and investment opportunities (IPCC, 2022).

All forms of effective climate mitigation are needed to achieve net zero emissions and to deliver on the Paris target. The voluntary carbon markets in general, and NCS activities in particular, play an important role in realizing these goals while also generating unique social and environmental co-benefits. With key world forests facing deforestation, degradation, and fragmentation, it is vital to fund the NCS activities that conserve nature, equally for the preservation and enhancement of existing carbon stocks and for the promotion of non-carbon benefits like native ecosystem restoration and support for community livelihoods (Chen et al., 1999; Noon et al., 2022).

As offsetting becomes mainstream, credit quality has become a popular subject of media attention and scientific inquiry. Businesses are ramping up commitments to reduce emissions internally and to offset residual emissions using carbon credits. Natural climate solutions, especially, have garnered attention given the link between projects, forest fires, and permanence. While standards bodies ensure the permanence of activities through the certification process, there remains little rigorous study on this linkage.

We contribute early findings and a novel methodology for assessing the risk that forest fires pose to NCS activities and permanence under the VCS Program. We find that there have been some loss events and one reversal, but no risk to credit permanence given an adequately capitalized buffer pool to compensate for reversals. We find that there is potential for some NCS projects to generate excess fire mitigation beyond the minimum required for crediting without tapping the buffer pool. And we describe management practices that have proven effective in the field for fire prevention, monitoring, and suppression. As discussed in section 4.3, these include: prioritizing budget and time for fire management, investing in knowledge, training, equipment, and other assets, and implementing specific measures such as firebreaks, awareness-building programmes with local communities, use of patrols and early warning systems, and local community fire monitor groups and firefighters.

We expect that this evidence resolves many of the questions raised by journalists about NCS activities and issued credits where forest fires may appear to threaten permanence, at least for those activities certified under the VCS Program. We find that the VCS Program has fulfilled its role in ensuring permanence, to date. We conclude that forest fires have not posed a material risk to the permanence of NCS projects and credits.

NCS activities hold the potential to deliver mitigation at a scale consistent with key climate goals. Market participants, policymakers, and the public are actively shaping the role that NCS activities will have on the path to net zero emissions as they consider permanence and other quality attributes through carbon project finance, development, and credit procurement. We aim to contribute to this broader discussion on quality through this study.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Declarations

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Conflict of interest
The authors declare no conflict of interest.

Authors' contributions
MB outlined the general research approach and designed and led the first and third parts of the research. LF and RB designed and led the second part of the research. MB led the writing of the introductory sections and results for the first and third parts. LF and RB led the writing of results for the second part. All authors helped write the discussion and conclusions sections. And all authors edited and commented on drafts of this research and approved the vinal version.

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Annexes

Annex 1: Data sources

Dataset name	Source	Data link	Data description
Project KML files	Verra Registry	registry.verra.org	For all VCS-certified projects, the Verra Registry hosts publicly available documents, including files delineating project areas. A KML was downloaded as a polygon boundary for each selected project.
MODIS Fire Data	NASA	Archive Download - NASA | LANCE | FIRMS	This country-by-country point data layer indicates the presence of fire from 2000 to 2020 in each of the project areas and their respective comparison areas.
World Database on Protected Areas	Protected Planet	Explore the World's Protected Areas (protectedplanet.net)	This dataset was downloaded country-by-country and includes polygons of all protected lands within a country.
2017 Global Land Cover: Built Up	Copernicus & Land Monitoring Service	Land Cover Viewer (vito.be)	This is a worldwide raster dataset that was downloaded in tiles. It shows the percentage of urban space, using an integer 1–100% scale.
Tree Cover: 2010	Global Land Analysis & Discovery (GLAD)	Global 2010 Tree Cover (30 m) | GLAD (umd.edu)	This is a worldwide raster dataset that was downloaded in tiles. It shows the percentage of tree cover with an integer 1-100% scale.
Elevation: GTOPO30	U.S. Geographical Survey (USGS)	USGS EROS Archive - Digital Elevation - Global 30 Arc-Second Elevation (GTOPO30) | U.S. Geological Survey	This dataset is a worldwide raster dataset that was downloaded in tiles. It has a horizontal grid spacing of approximately 1 kilometre.
2017 Global Land Cover: Cropland	Copernicus & Land Monitoring Service	Land Cover Viewer (vito.be)	This is a worldwide dataset raster dataset that was downloaded in tiles. It shows the percentage of crop land using an integer 1–100% scale.
World Terrestrial Ecosystems Pro Package	Esri, USGS, TNC	World Terrestrial Ecosystems Pro Package - Overview (arcgis.com)	This dataset is a polygon layer that shows worldwide climate regions, world landforms, and world vegetation and landcover.
Roads	World Food Program	Explore Layers - WFP GeoNode	This dataset is a country-by-country line layer that features roads from highways down to track/trail.
Administration Units	The Humanitarian Data Exchange	Welcome - Humanitarian Data Exchange (humdata.org)	This dataset was downloaded country-by-country and includes polygons of each administrative boundary.
Global Forest Change 2000–2020: Year of gross forest cover loss event (lossyear)	University of Maryland Department of Geographical Sciences	Global Forest Change (storage.googleapis.com)	This worldwide raster dataset shows areas where there has been forest change from a forested to a non-forested state. It is a yearly dataset that was downloaded in tiles.

Annex 2: Fire hotspot data and kernel density processing

Kernel densities were calculated for fire hotspot data in each of the years for which data was available. We then mapped resulting fire densities with tree cover loss to show spatial correlation between fire density and tree cover loss.

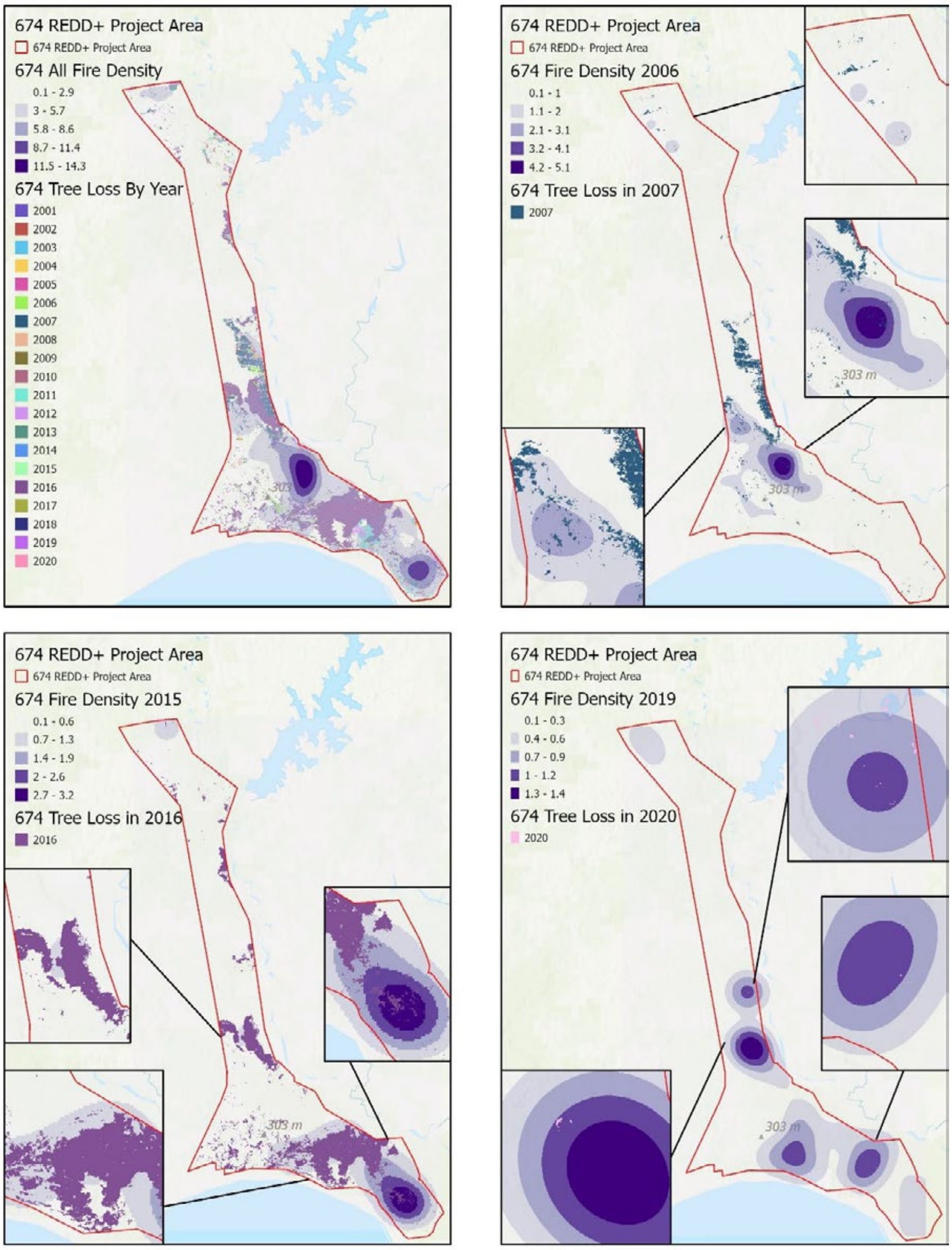
In Indonesia, the two projects were matched to three nearby national parks. Figures A1 through A5 show the Indonesia project areas and the comparison areas to which they were matched. For each set of diagrams, there is a fire density and tree cover map for all years. The other three show the three years with the greatest fires in each project or comparison area. For all of the Indonesia project and comparison areas, there is a one-year lag between the fire data and the tree cover loss data.

In Brazil, each of the two projects was matched to a separate set of comparison areas. The Jari/Amapá REDD+ Project (ID 1115), shown in Figure A6, was matched to a national park and an ecological station. These are shown in Figures A7 and A8. The RESEX Rio Preto-Jacundá REDD+ Project (ID 1503), shown in Figure A9, was matched to three national forests and one ecological station. These comparison areas are shown in Figures A10 through A13. As with the Indonesia areas, each set of Brazil diagrams depicts fire density and tree cover for all years in one map and other diagrams show the three years with the greatest fires in project and comparison areas. In the Jari/Amapá REDD+ Project (ID 1115) there is a one-year lag between the fire data and the tree cover loss data. However, for the RESEX Rio Preto-Jacundá REDD+ Project (ID 1503) we do not use a time lag. Instead, we use fire data and tree loss data of the same year for this project.

In Peru, we matched the two projects to separate sets of protected comparison areas. Alto Mayo Conservation Initiative (ID 944), shown in Figure A14 was matched to a regional conservation area, shown in Figure A15. The Forest Management to Reduce Deforestation and Degradation in Shipibo Conibo and Cacataibo Indigenous Communities of Ucayali Region project (ID 1360), shown in Figure A16, was matched to two national parks. These comparison areas can be found in Figures A17 and A18. Similarly, the set of Peru diagrams includes a fire density and tree cover loss map for all years. Other diagrams show the three years with greatest fire for the project and comparison areas. In both Peru projects we used a one-year lag between the fire data and the tree cover loss data.

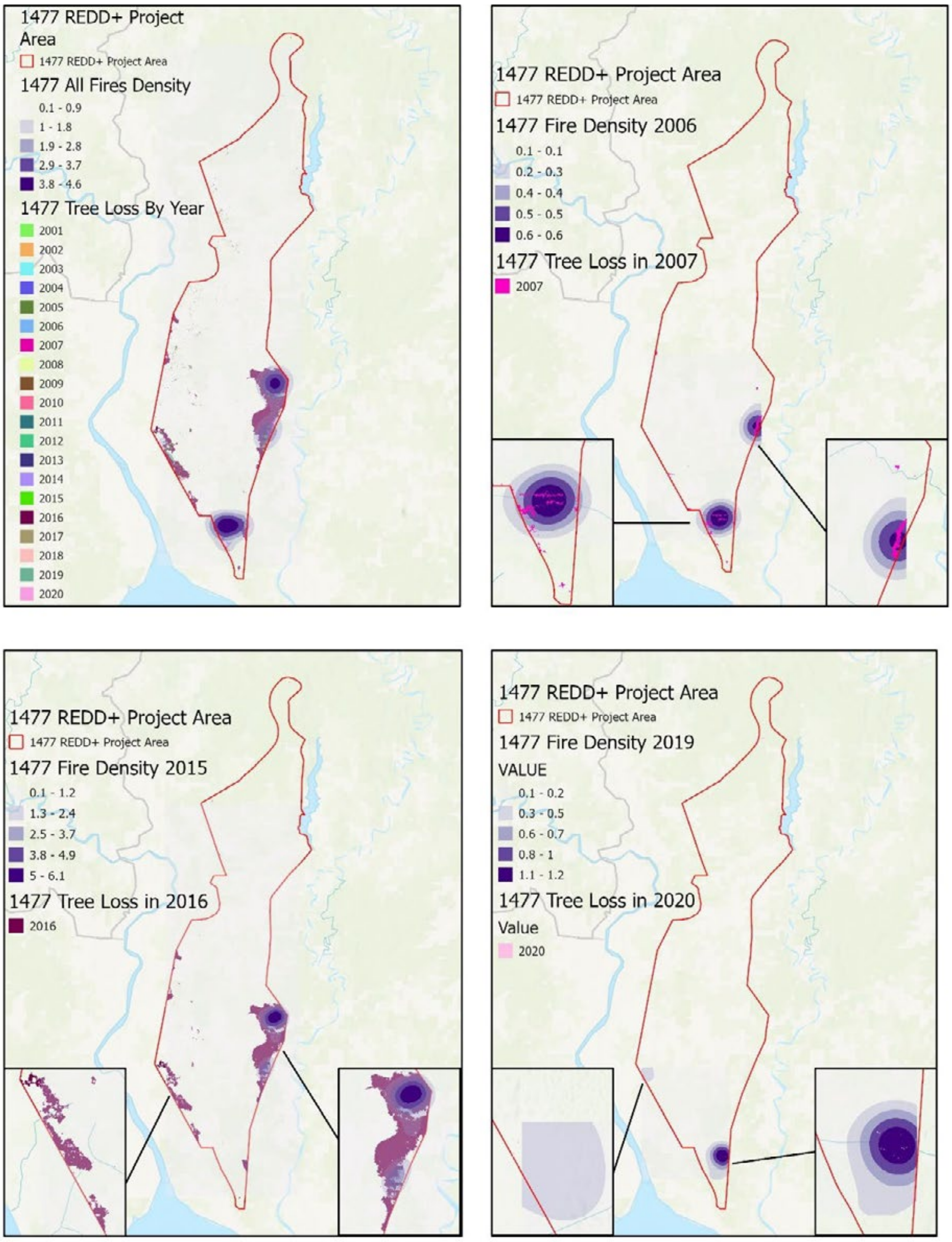
Annex 3: Fire incidence and tree cover loss diagrams

Figure A1: Rimba Raya Biodiversity Reserve Project (ID 674)



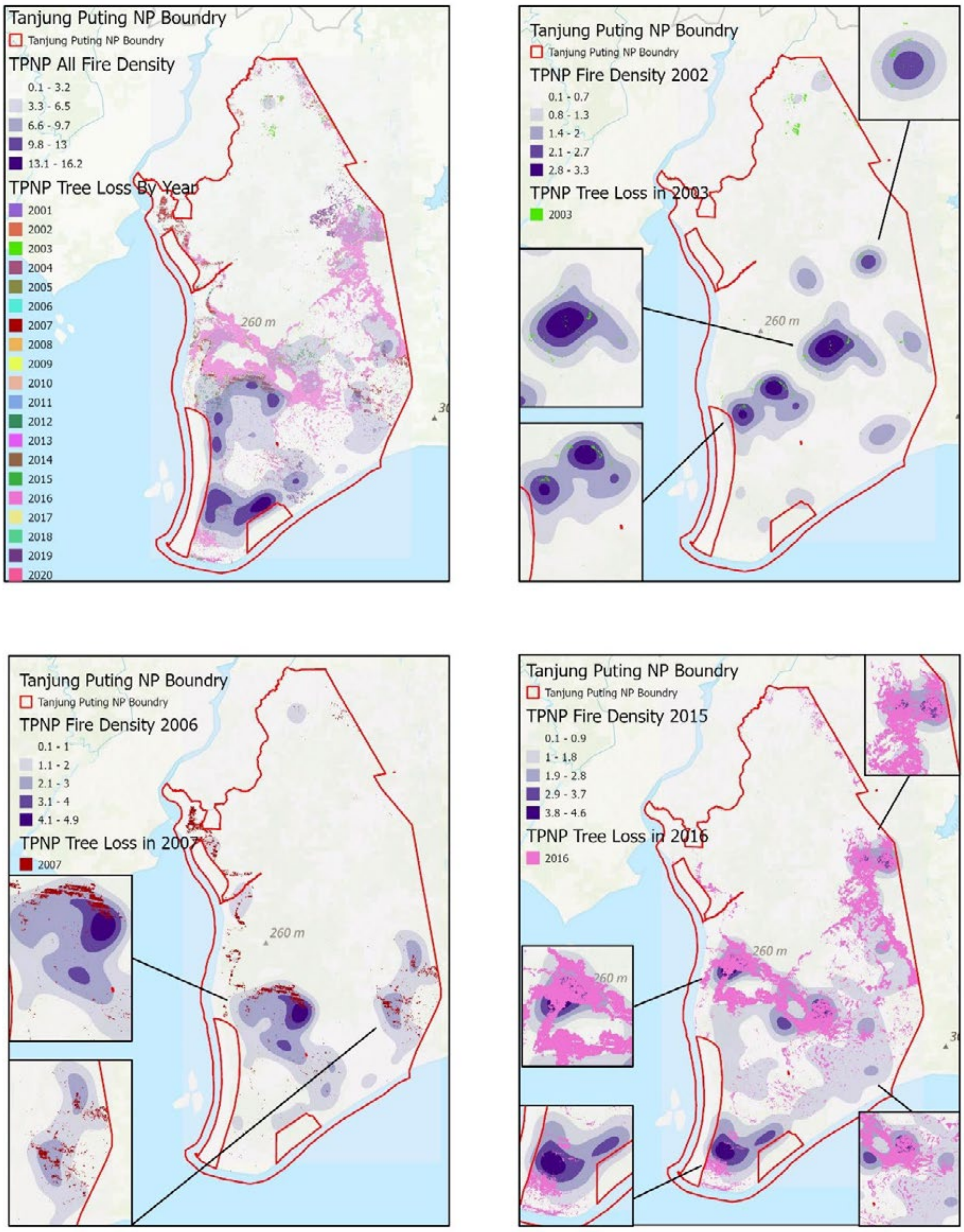
The top left panel shows all fires and all tree cover loss. The top right panel shows 2006 fire density with 2007 tree cover loss. The bottom left panel shows 2015 fire density with 2016 tree cover loss. The bottom right panel shows 2019 fire density with 2020 tree cover loss.

Figure A2: Katingan Peatland Restoration Project (ID 1477)



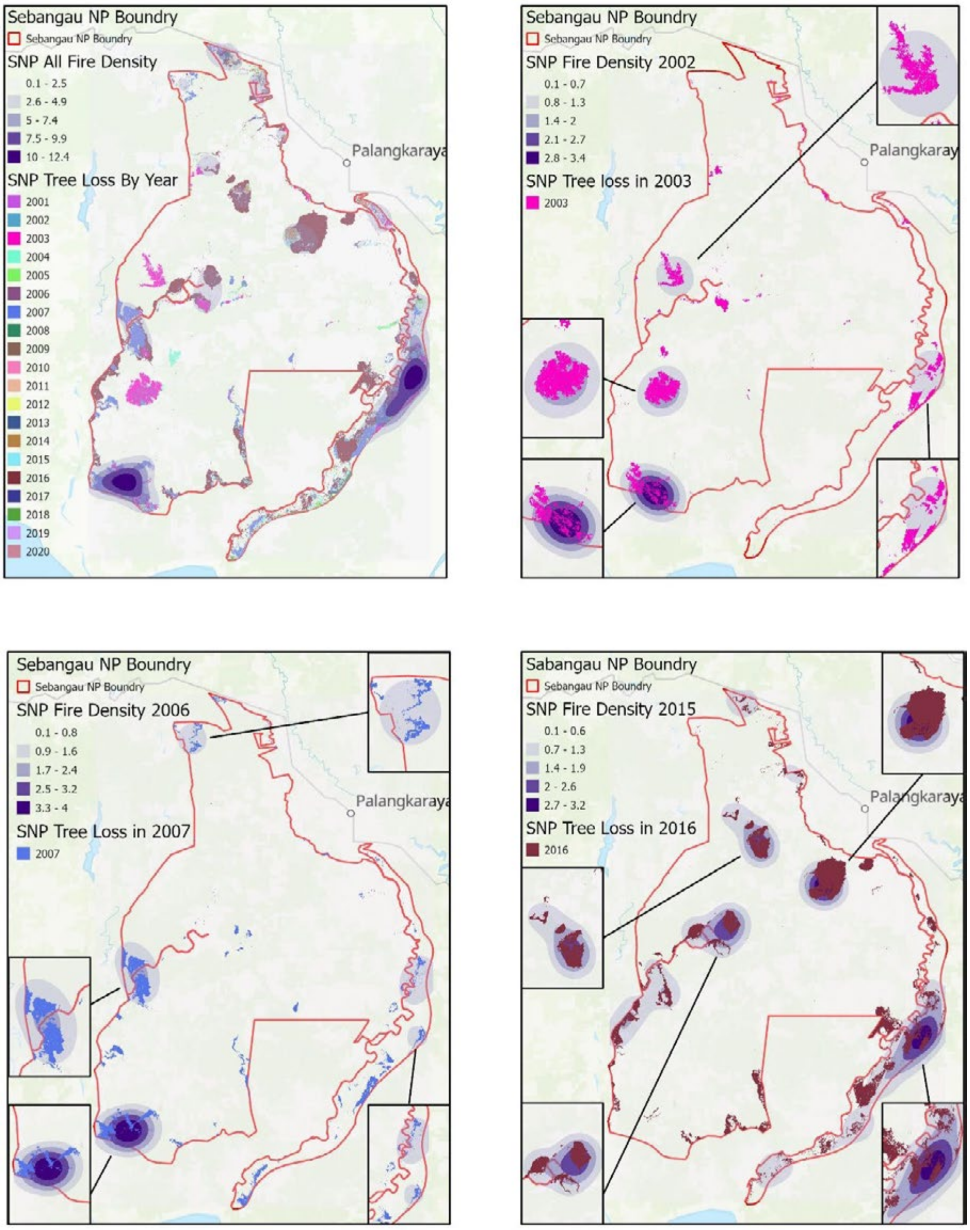
The top left panel shows all fires and all tree cover loss. The top right panel shows 2006 fire density with 2007 tree cover loss. The bottom left panel shows 2015 fire density with 2016 tree cover loss. The bottom right panel shows 2019 fire density with 2020 tree cover loss.

Figure A3: Tanjung Puting National Park



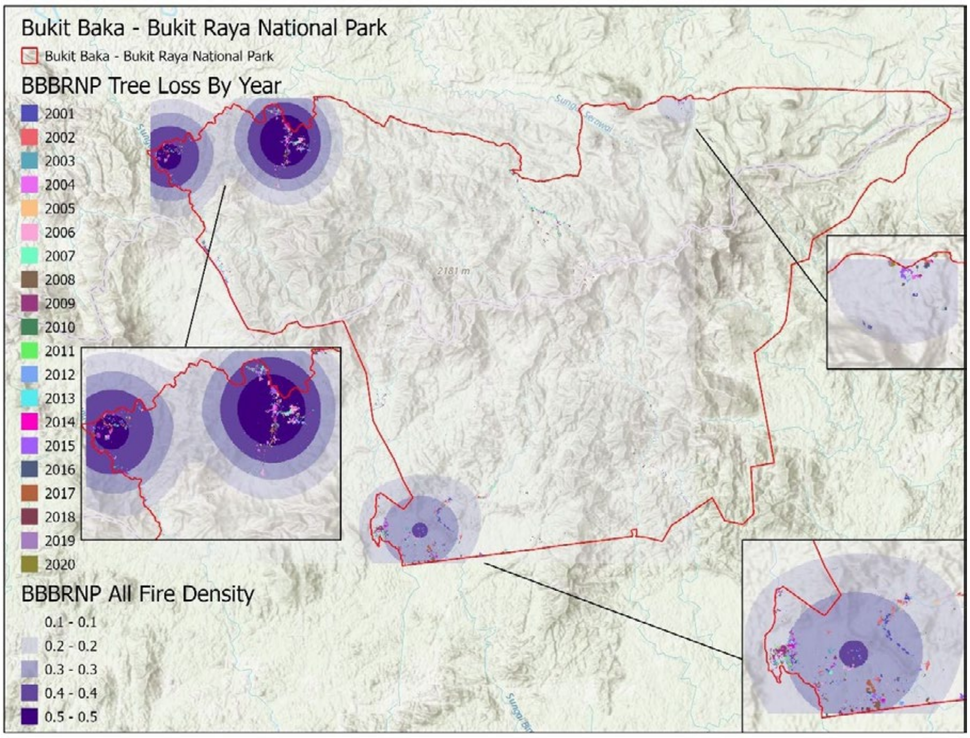
The top left panel shows all fires and all tree cover loss. The top right panel shows 2002 fire density with 2003 tree cover loss. The bottom left panel shows 2006 fire density with 2007 tree cover loss. The bottom right panel shows 2015 fire density with 2016 tree cover loss.

Figure A4: Sebangau National Park



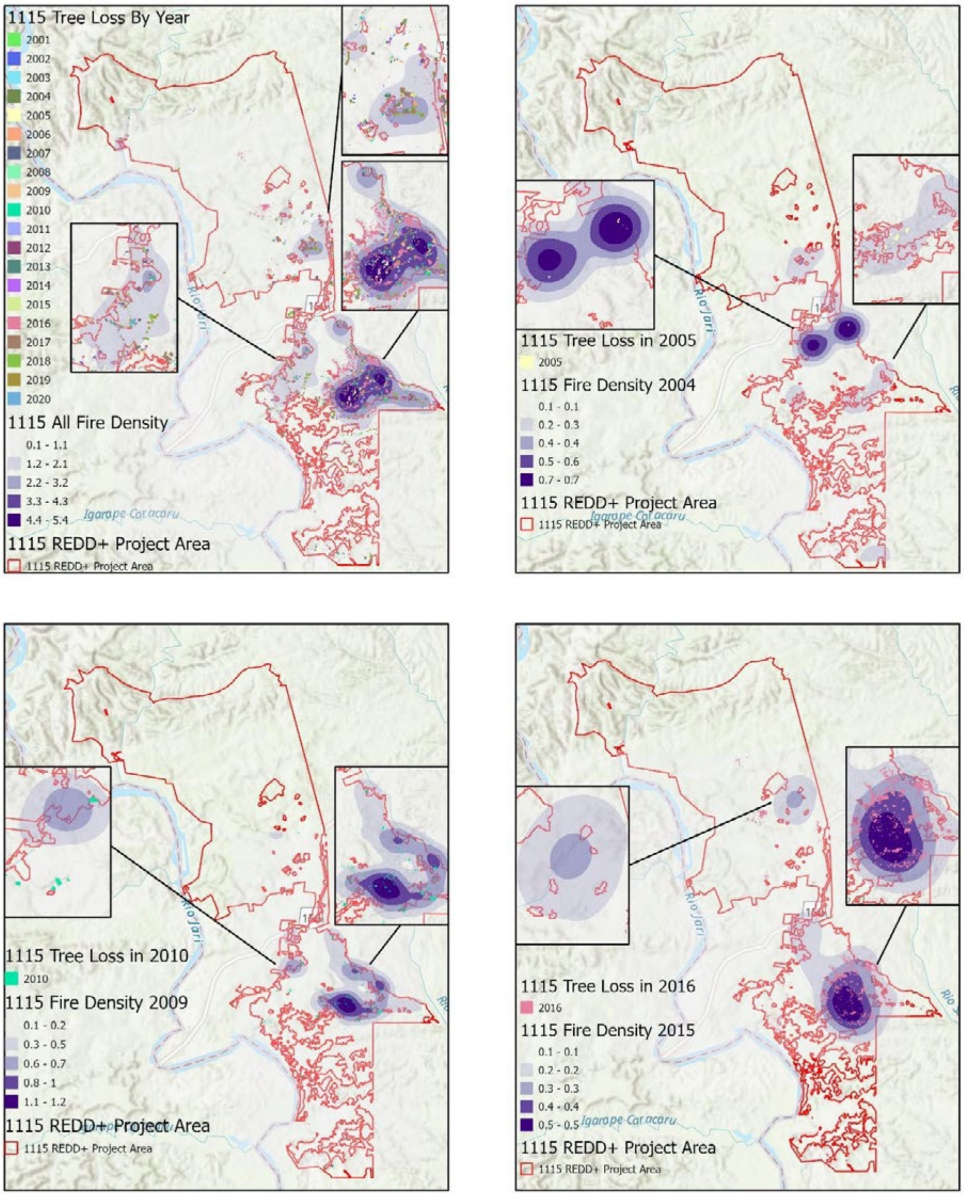
The top left panel shows all fires and all tree cover loss. The top right panel shows 2002 fire density with 2003 tree cover loss. The bottom left panel shows 2006 fire density with 2007 tree cover loss. The bottom right panel shows 2015 fire density with 2016 tree cover loss.

Figure A5: Bukit Baka - Bukit Raya National Park



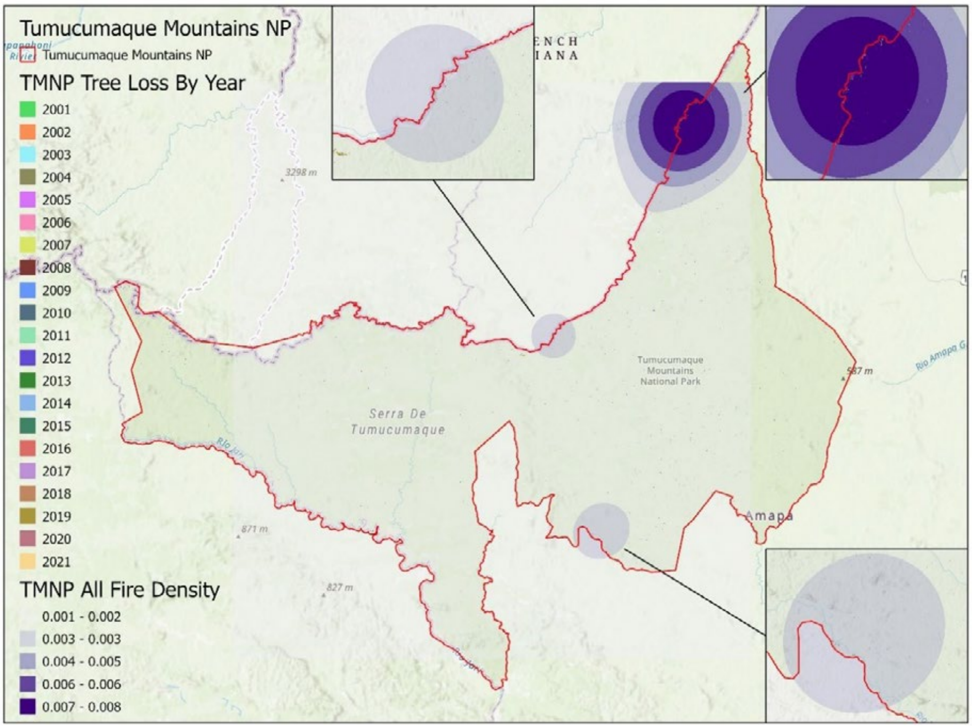
This map shows fires and tree cover loss across all years.

Figure A6: Jari/Amapá REDD+ Project (ID 1115)



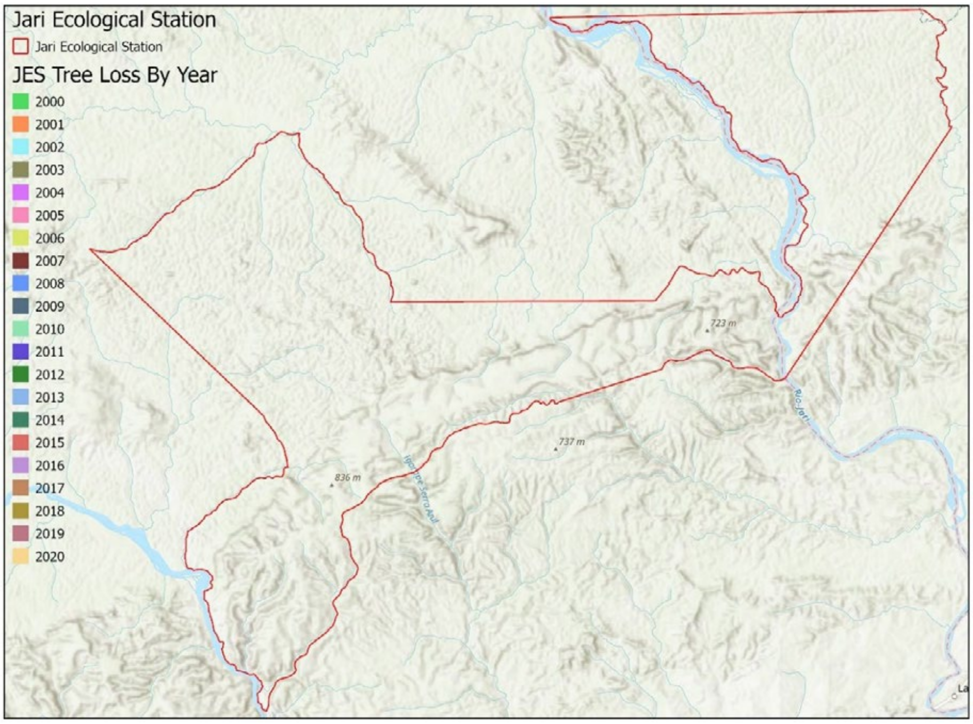
The top left panel shows all fires and all tree cover loss. The top right panel shows 2004 fire density with 2005 tree cover loss. The bottom left panel shows 2010 fire density with 2011 tree cover loss. The bottom right panel shows 2015 fire density with 2016 tree cover loss.

Figure A7: Tumucumaque Mountains National Park



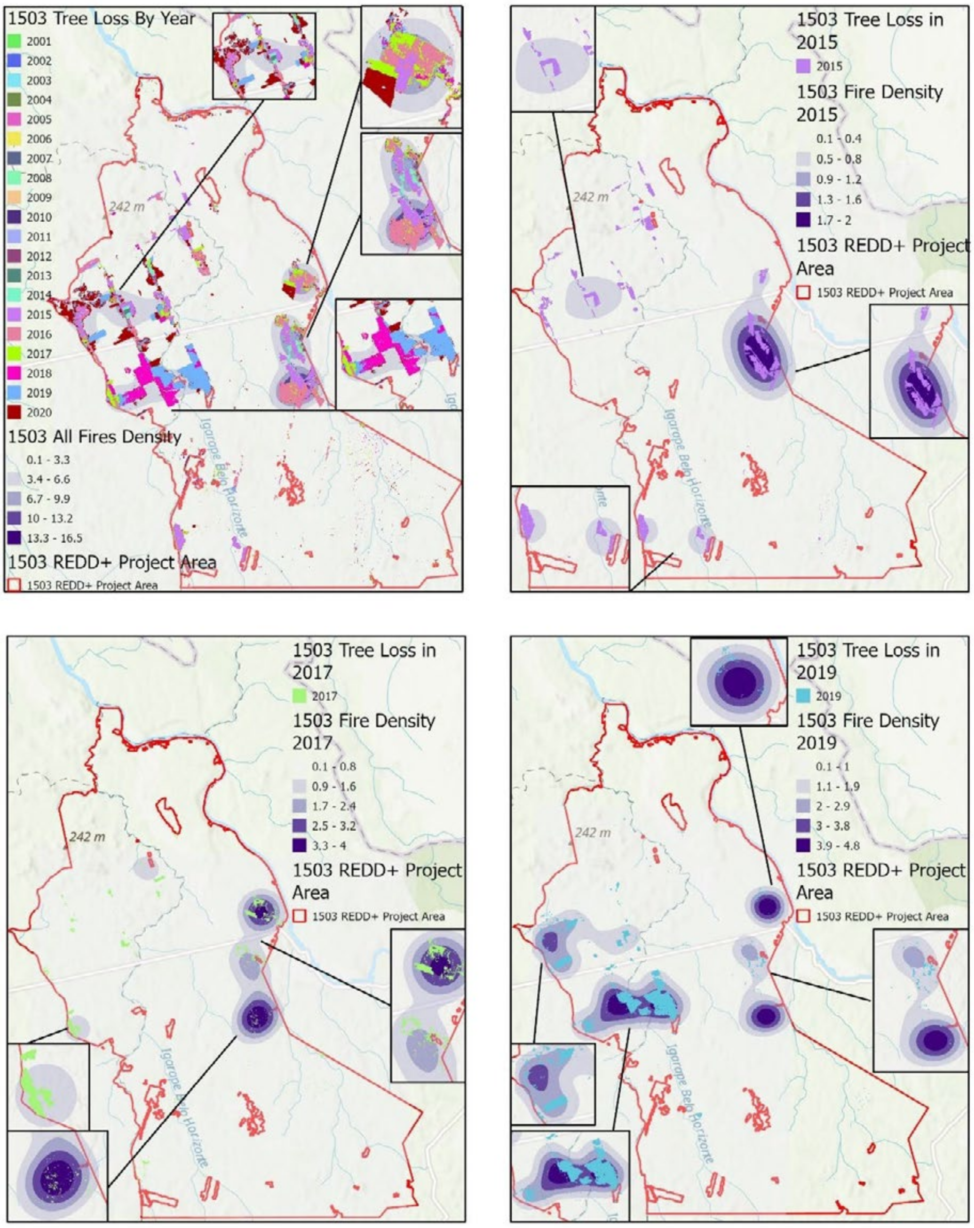
This map shows fires and tree cover loss across all years.

Figure A8: Jari Ecological Station



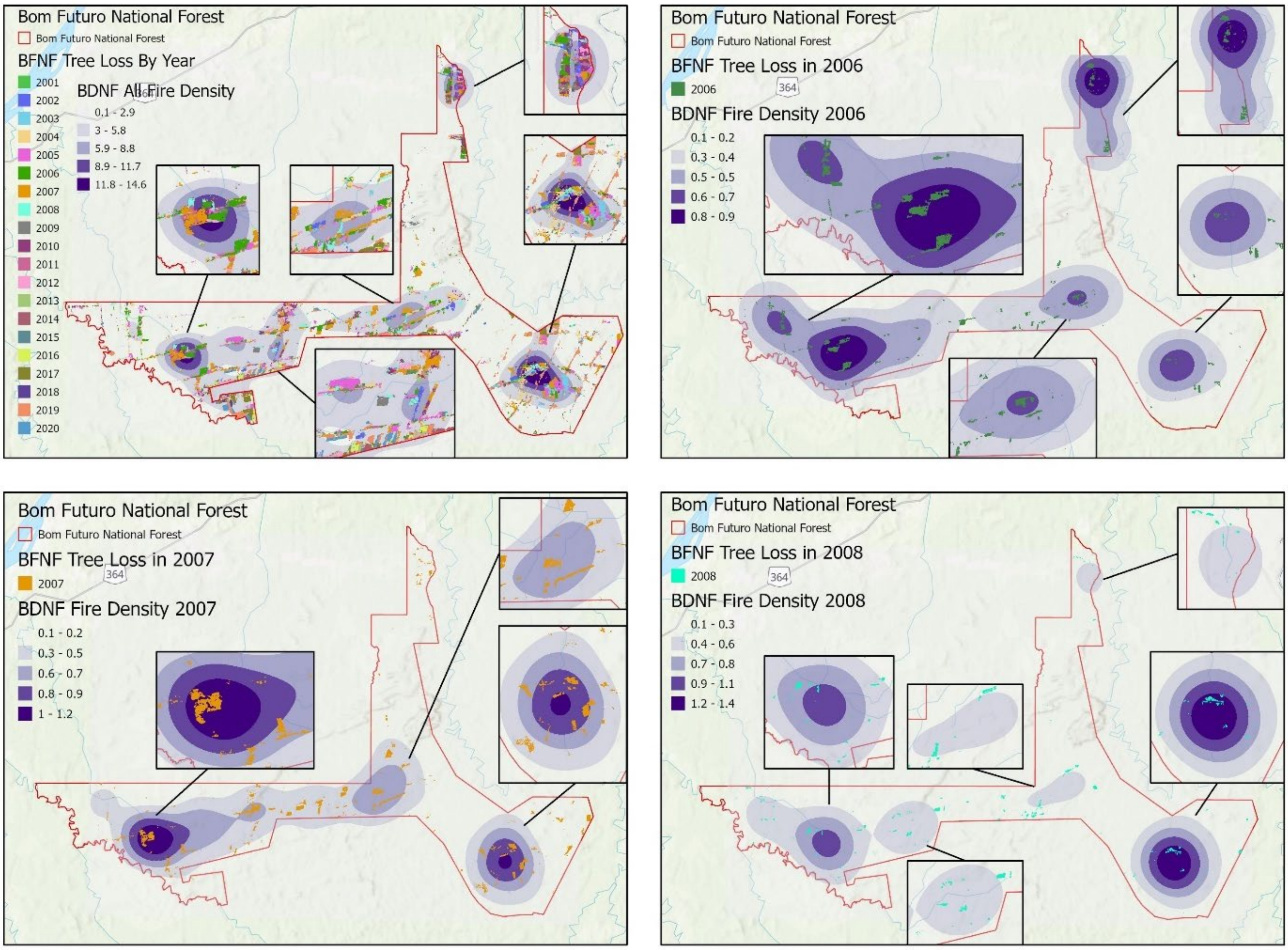
This map shows tree cover loss across all years. There were no fires within the boundaries of the ecological station during the study period.

Figure A9: RESEX Rio Preto-Jacundá REDD+ Project (ID 1503)



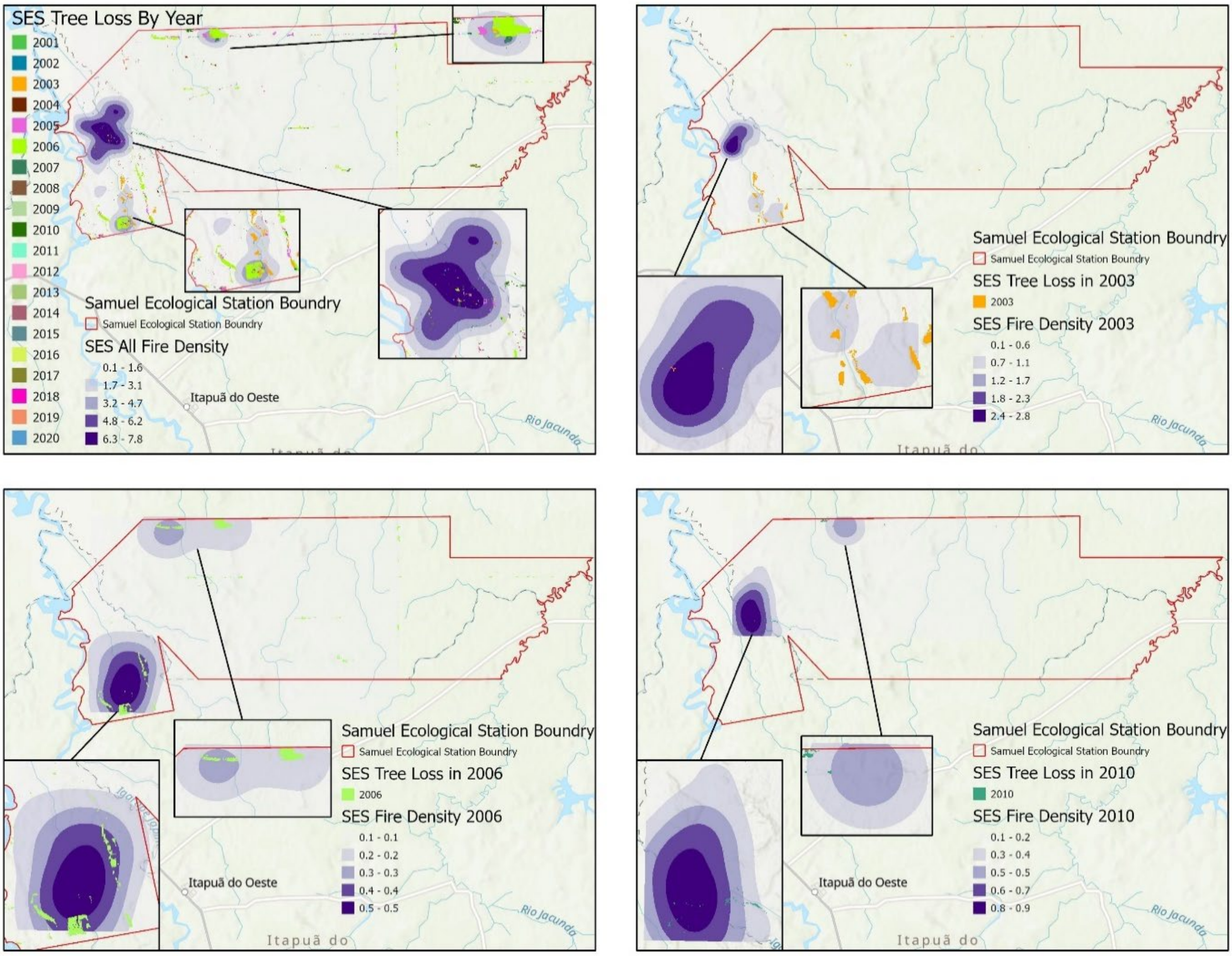
The top left panel shows all fires and all tree cover loss. The top right panel shows 2015 fire density with 2015 tree cover loss. The bottom left panel shows 2017 fire density with 2017 tree cover loss. The bottom right panel shows 2019 fire density with 2019 tree cover loss.

Figure A10: Bom Futuro National Forest



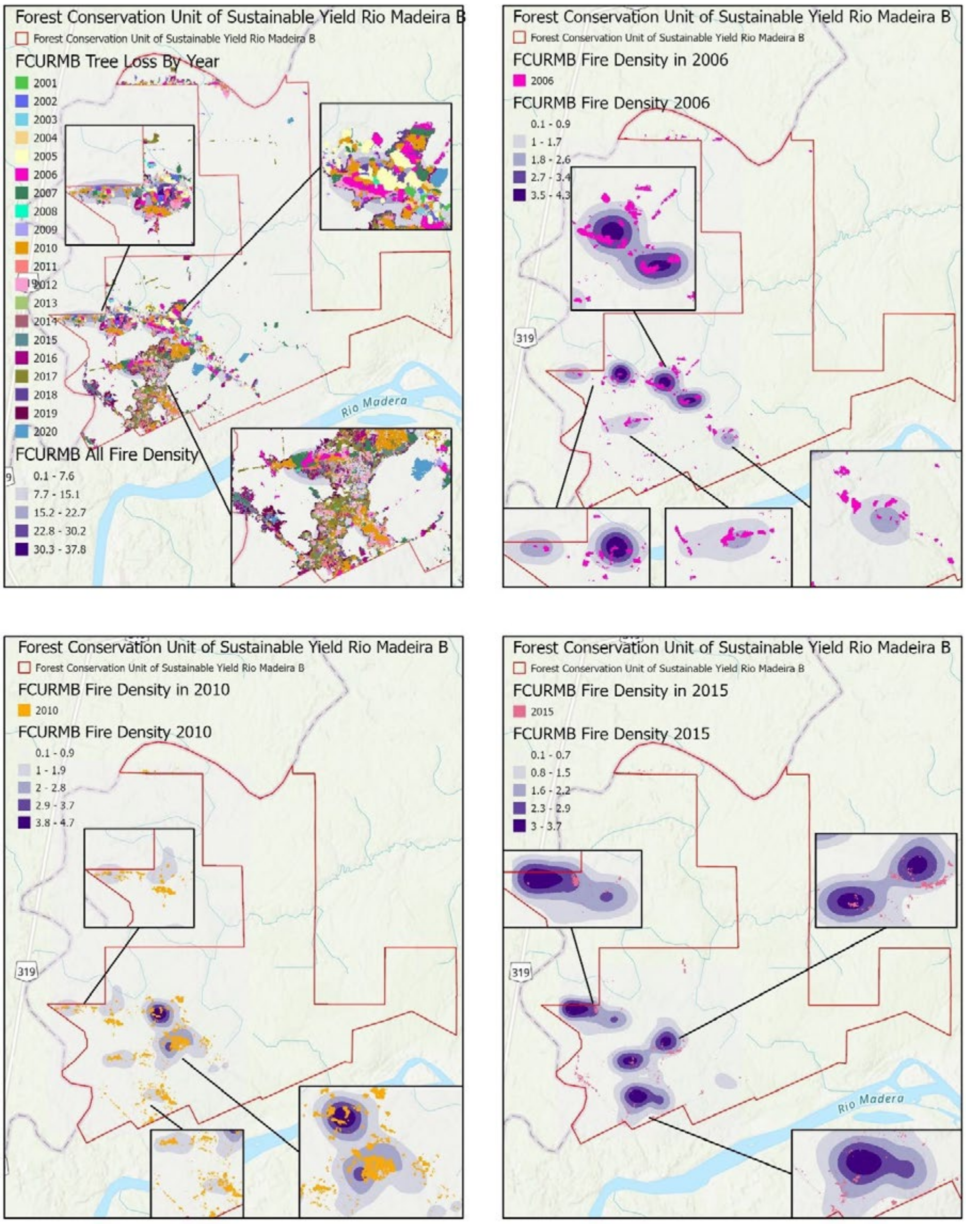
The top left panel shows all fires and all tree cover loss. The top right panel shows 2006 fire density with 2006 tree cover loss. The bottom left panel shows 2007 fire density with 2007 tree cover loss. The bottom right panel shows 2008 fire density with 2008 tree cover loss.

Figure A11: Samuel Ecological Station



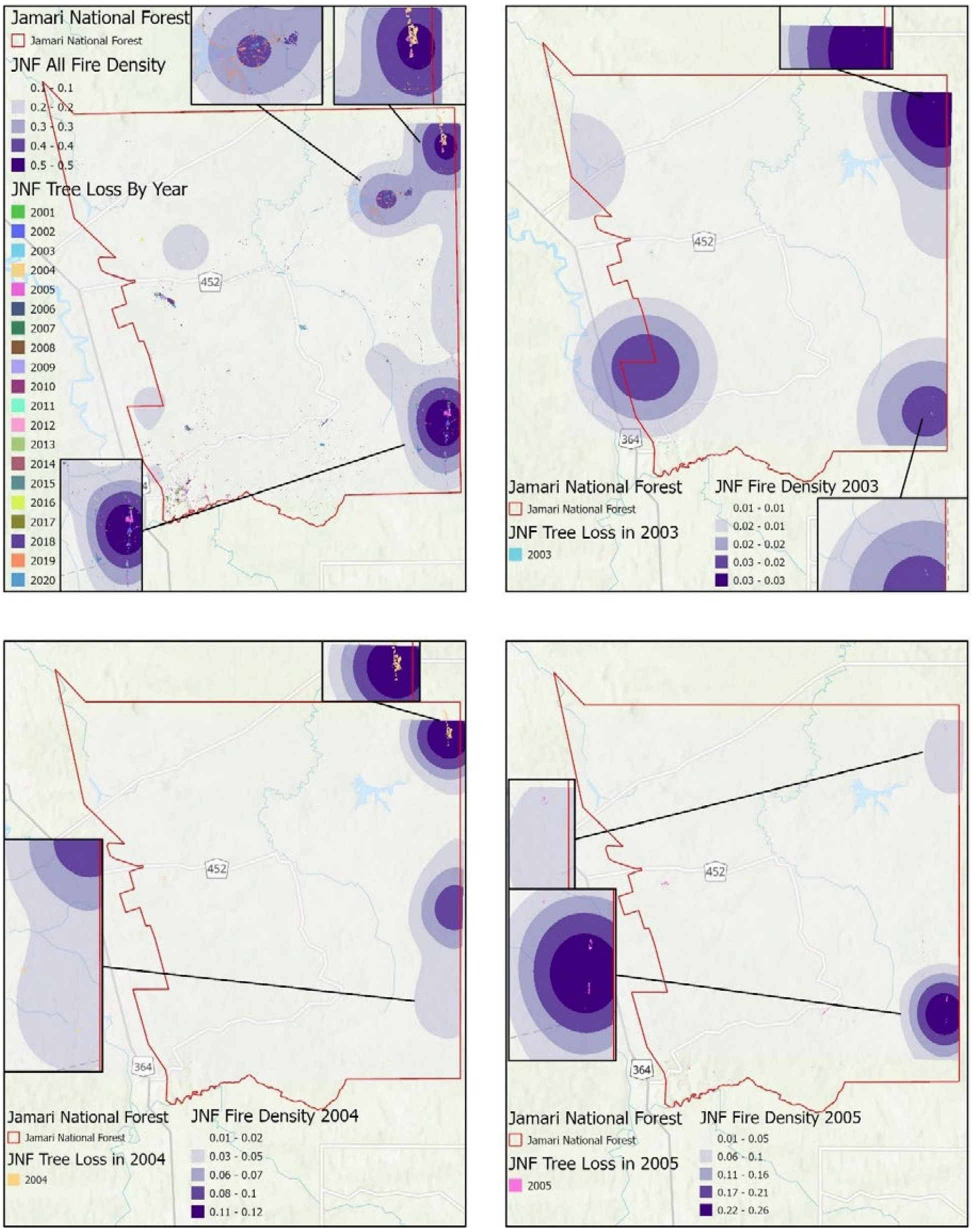
The top left panel shows all fires and all tree cover loss. The top right panel shows 2003 fire density with 2003 tree cover loss. The bottom left panel shows 2006 fire density with 2006 tree cover loss. The bottom right panel shows 2010 fire density with 2010 tree cover loss.

Figure A12: Forest Conservation Unit of Sustainable Yield Rio Madeira “B”



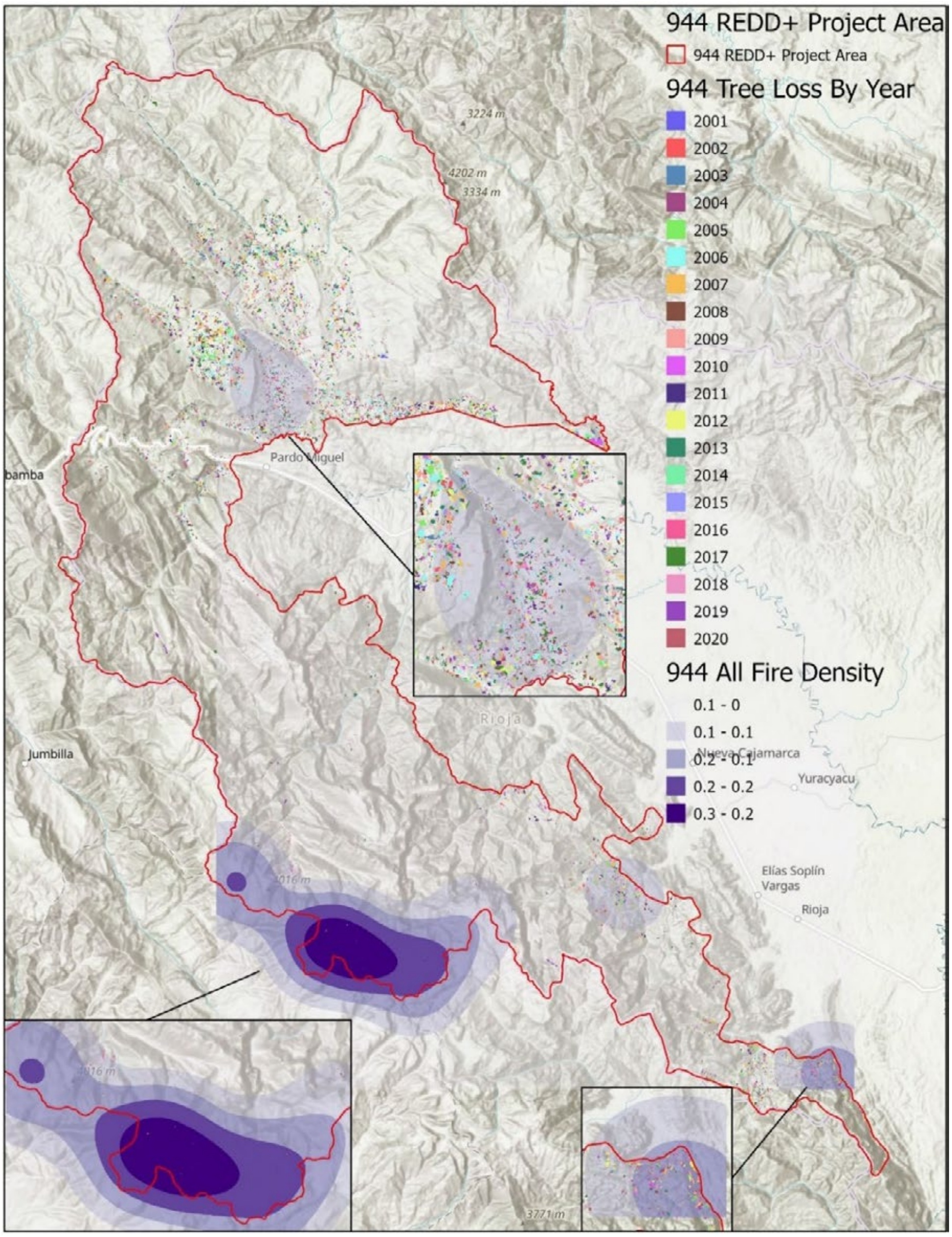
The top left panel shows all fires and all tree cover loss. The top right panel shows 2006 fire density with 2006 tree cover loss. The bottom left panel shows 2010 fire density with 2010 tree cover loss. The bottom right panel shows 2015 fire density with 2015 tree cover loss.

Figure A13: Jamari National Forest



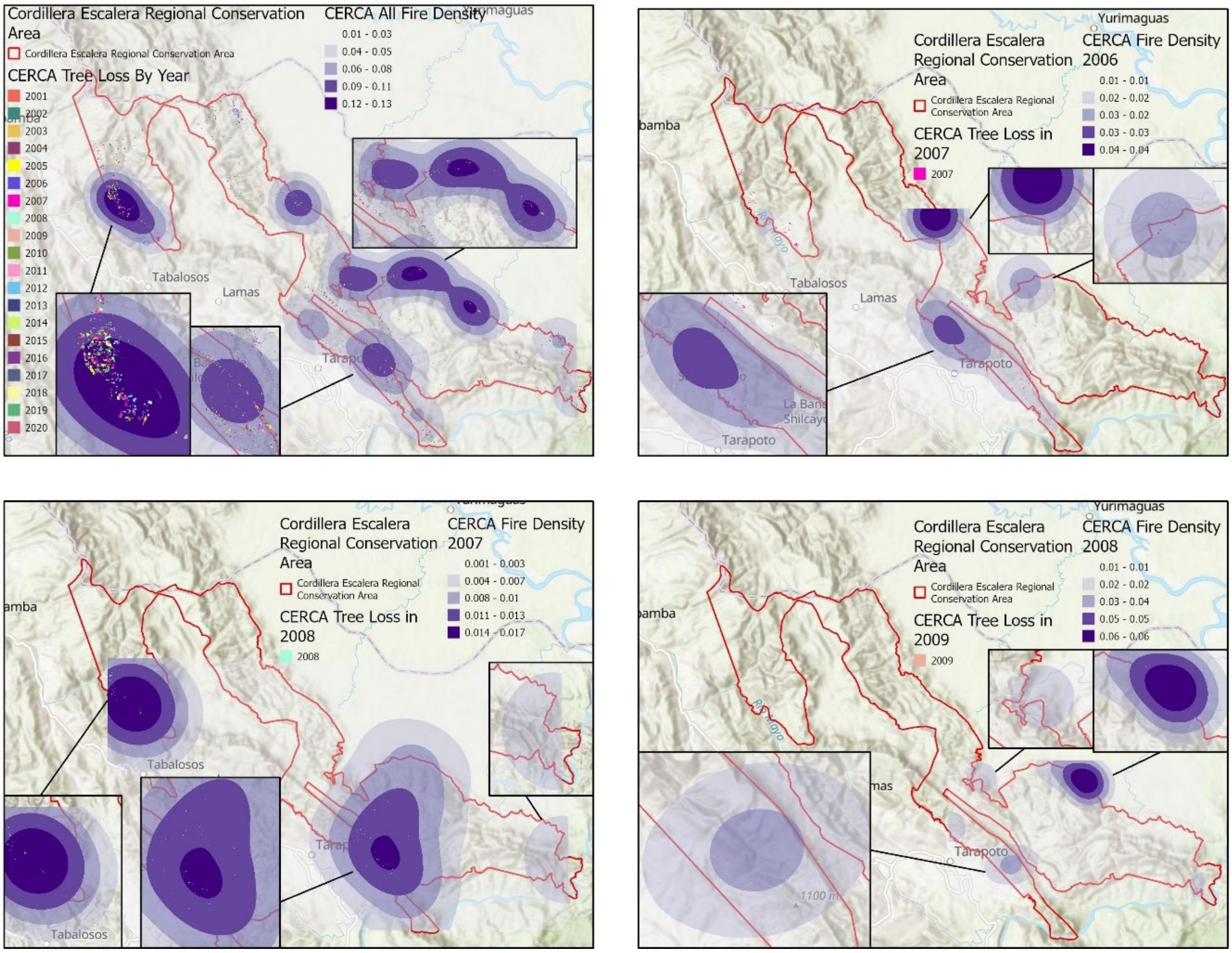
The top left panel shows all fires and all tree cover loss. The top right panel shows 2003 fire density with 2003 tree cover loss. The bottom left panel shows 2004 fire density with 2004 tree cover loss. The bottom right panel shows 2005 fire density with 2005 tree cover loss.

Figure A14: Alto Mayo Conservation Initiative (ID 944)



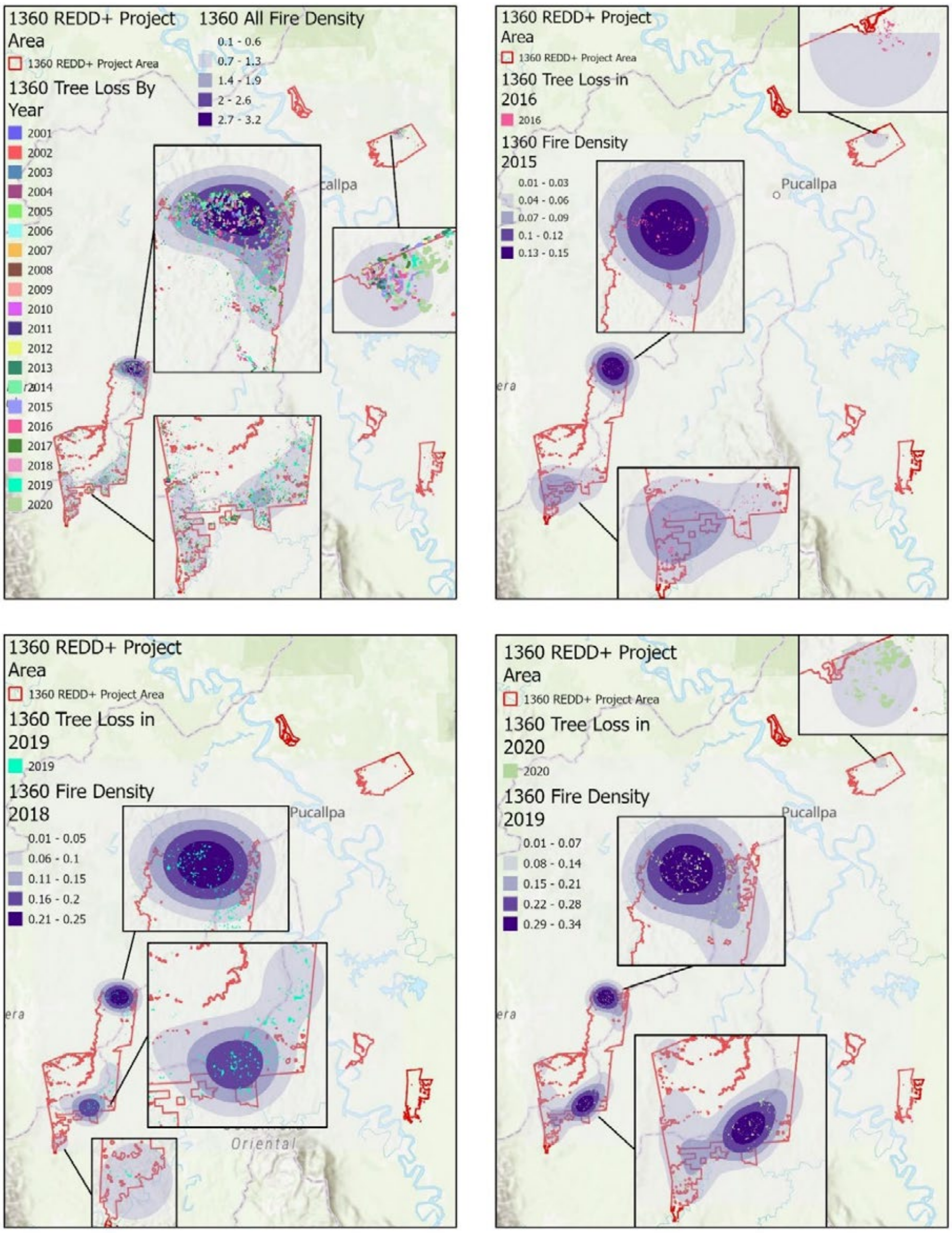
This map shows fires and tree cover loss across all years.

Figure A15: Cordillera Escalera Regional Conservation Area



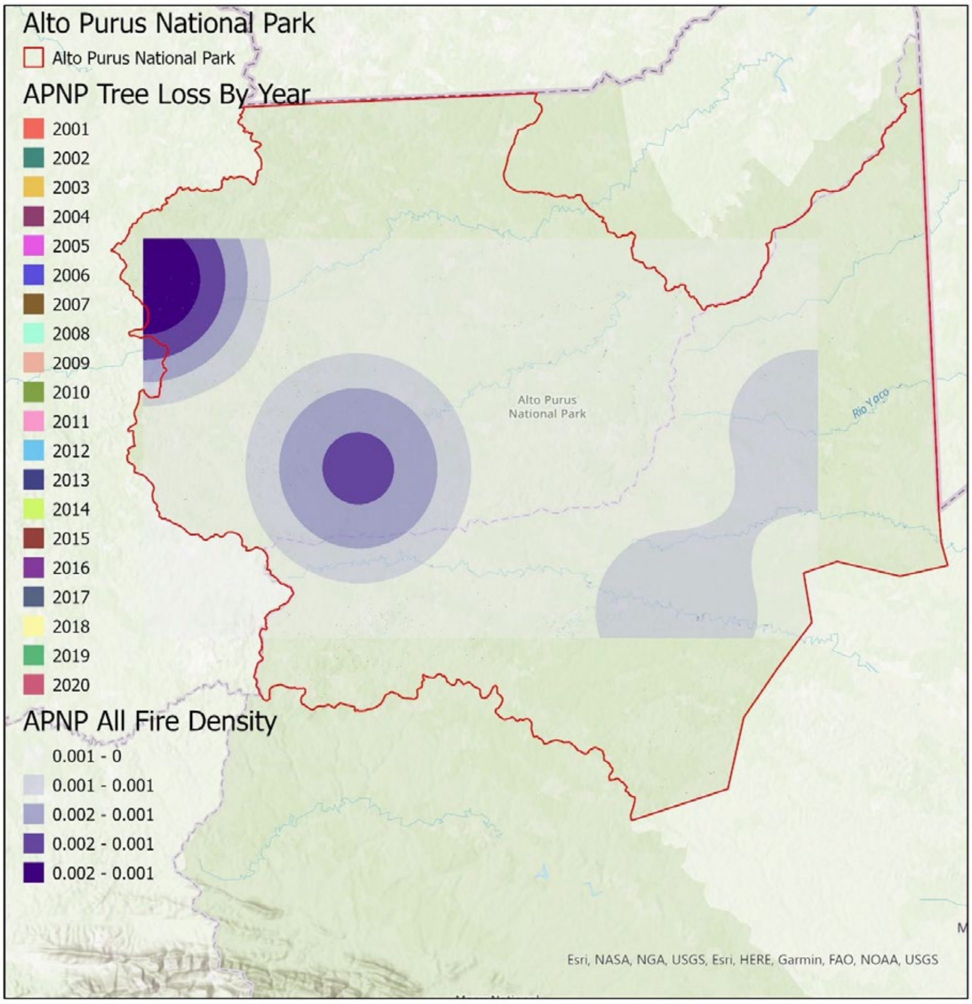
The top left panel shows all fires and all tree cover loss. The top right panel shows 2006 fire density with 2007 tree cover loss. The bottom left panel shows 2007 fire density with 2008 tree cover loss. The bottom right panel shows 2008 fire density with 2009 tree cover loss.

Figure A16: Forest management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo Indigenous communities of Ucayali region (ID 1360)



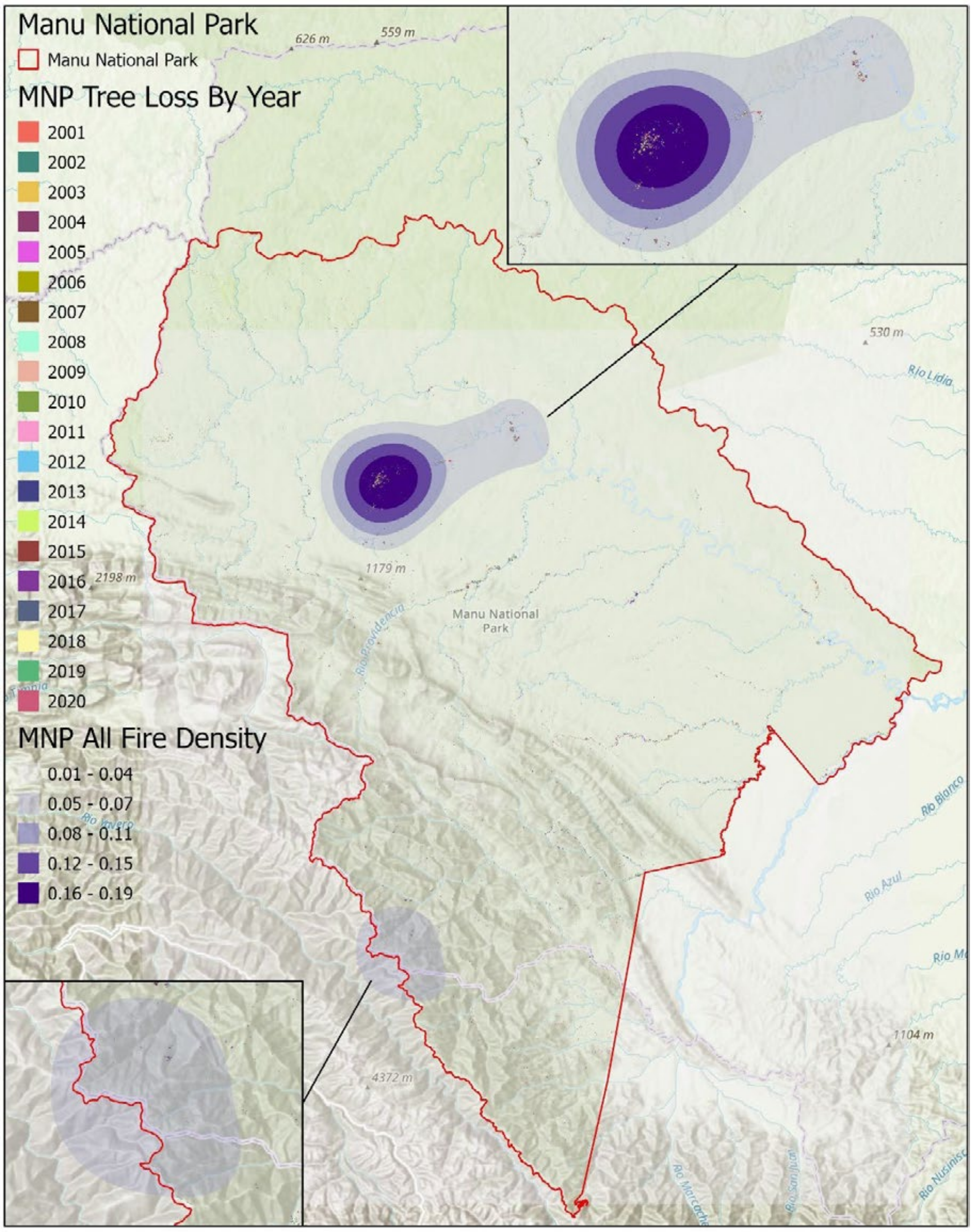
The top left panel shows all fires and all tree cover loss. The top right panel shows 2015 fire density with 2016 tree cover loss. The bottom left panel shows 2018 fire density with 2019 tree cover loss. The bottom right panel shows 2019 fire density with 2020 tree cover loss.

Figure A17: Alto Purus National Park



This map shows fires and tree cover loss across all years.

Figure A18: Manu National Park



This map shows fires and tree cover loss across all years.

Annex 4: Research instruments

The questionnaire used to investigate fire management practices is included below.

SEI & Verra: Questionnaire on fire management

This brief survey is meant to help better understand challenges and opportunities for NCS projects in managing fire risk. Your responses will greatly help in developing knowledge, which we hope will contribute to better outcomes in the future.

This questionnaire has 8 questions and it should take about 15 minutes to complete.

* Required

1. **Please mention your name, organization/company, VCS project ID number, and email address.** *

   Example: [First Name] [Last Name], [Organization], VCS ID 1234, name@email.com

2. **Question 1.** *

On a scale of 1 to 4, how much of a threat do fires pose to the project's carbon stocks?

Please select the level that best describes fires near or within the project area.

Mark only one oval.

- 1: Fires pose near zero threat... Fires almost never occur near or within the project area. And when fires occur, they are only superficial.
- 2: Fires pose a low threat... Fires rarely occur near or within the project area. And when fires occur, they are limited in their extent or intensity.
- 3: Fires pose a moderate threat... Fires occasionally occur near or within the project area. And when fires occur, they are sometimes widespread or intense.
- 4: Fires pose a significant threat... Fires commonly occur near or within the project area. And when fires occur, they are often widespread or intense.

3. **Question 2.** *

On a scale of 1 to 4, how much of a priority is fire mitigation for the project?

Consider ranking the project's operational priorities by the amount of time and budget allocated. Then select the level that best describes the priority level for fire mitigation.

Mark only one oval.

- 1: Fire mitigation is a very low priority compared to others... Fire mitigation ranks at or near the bottom of operational priorities.
- 2: Fire mitigation is somewhat a priority... Fire mitigation ranks between bottom and middle of operational priorities.
- 3: Fire mitigation is a moderate priority... Fire mitigation ranks between middle and top of operational priorities.
- 4: Fire mitigation is an essential priority... Fire mitigation ranks at or near the top of operational priorities.

4. **Question 3.** *

On a scale of 1 to 4, what level of knowledge / training to implement fire mitigation does the project team have?

Please select the level that best describes current fire mitigation knowledge / training.

Mark only one oval.

- 1: Knowledge / training is near zero... The project uses a makeshift approach to fire mitigation. The team responds to fires as needed.
- 2: Knowledge / training is limited... The project engages in limited fire mitigation planning and implementation; this work is not assigned to dedicated team member(s). The team sometimes uses best practices for the project.
- 3: Knowledge / training is moderate... The project includes non-expert team member(s) tasked with fire mitigation planning and implementation. The team uses best practices for the project.
- 4: Knowledge / training is advanced... The project includes expert team member(s) tasked with fire mitigation planning and implementation. The team develops and/or uses best practices for the project.

5. **Question 4:** *

What specific mitigation activities does the team implement?

Please select all that apply.

Check all that apply.

- [ ] Clearing of forest litter and/or other possible fire fuel
- [ ] Use of fire-break plantations
- [ ] Prescribed fire operations (controlled burns)
- [ ] Revegetation activities
- [ ] Re-wetting peatland (where applicable)
- [ ] Awareness building programs with local communities
- [ ] Use of patrols to scout the project area
- [ ] Use of drones to observe the project area
- [ ] Use of early warning systems, including weather forecasting and/or satellite-based fire alerts
- [ ] Local community fire monitor groups
- [ ] Professional fire fighters
- [ ] Local community fire fighters
- [ ] Private security services
- [ ] Other: ____________

6. **Question 5.** *

On a scale of 1 to 4, what level of equipment and other assets for fire mitigation does the project team have?

Please select the level that best describes current fire mitigation equipment and other assets.

Mark only one oval.

- ◯ 1: Equipment and other assets are near zero... The project does not have the equipment it needs to effectively prevent, monitor, and suppress fires
- ◯ 2: Equipment and other assets are limited... The project has some of the equipment and other assets needed to effectively prevent, monitor, and suppress fires. But more equipment/assets would help the project significantly improve fire mitigation.
- ◯ 3: Equipment and other assets are moderate... The project has most of the equipment and other assets needed to effectively prevent, monitor, and suppress fires. More equipment/assets would help the project improve fire mitigation only marginally.
- ◯ 4: Equipment and other assets are advanced... The project has all of the equipment and other assets needed to effectively prevent, monitor, and suppress fires to the extent possible.

7. **Question 6:** *

What kind of equipment and other assets does the team have?

Please select all that apply.

Check all that apply.

- [ ] Computer systems for weather forecasting / fire alerts
- [ ] Communication tools, including: radios, mobile phones, satellite phones
- [ ] Monitoring posts and/or watch towers
- [ ] Drones (any type)
- [ ] Hand tools, including: axes, shovels, hooks, etc.
- [ ] Power tools, including: generators, chainsaws, flame throwers, etc.
- [ ] Fire tanker trucks
- [ ] Automobiles, including: SUVs, trucks, cars
- [ ] Watercraft, including: patrol boats, fireboats, etc.
- [ ] Aircraft, including: surveillance / firefighting airplanes or helicopters
- [ ] Other: ____________________

8. **Question 7.** *

On a scale of 1 to 4, what level of financial resources does the project team have to invest in fire mitigation?

Please select the level that best describes current level of financial resources for fire mitigation investment.

Mark only one oval.

- 1: Financial resources for fire mitigation are insufficient... The project does not have the financial resources it needs to effectively prevent, monitor, and suppress fires.
- 2: Financial resources for fire mitigation are limited... The project has some of the financial resources needed to effectively prevent, monitor, and suppress fires. But more financial resources would help the project significantly improve fire mitigation.
- 3: Financial resources for fire mitigation are moderate... The project has most of the financial resources needed to effectively prevent, monitor, and suppress fires. More financial resources would help the project improve fire mitigation only marginally.
- 4: Financial resources for fire mitigation are fully sufficient... The project has all of the financial resources needed to effectively prevent, monitor, and suppress fires to the extent possible.

9. **Question 8.** *

About how much of the project's annual operational budget is allocated to fire prevention, monitoring, and suppression? This includes team members' time (knowledge), training, equipment, and other assets.

Use your best reasonable estimate. And if allocation varies significantly from year to year, by about how much?

Example: The project allocates about 12% of annual operational budget to fire prevention, monitoring, and suppression. We usually allocate from 10 to 15% of operational budget on fire management.

The questions posed during the focus group discussion are included below.

Section 1: Targeted questions

1. What are major drivers of forest loss near project areas? For example, is there naturally occurring forest fire, agricultural expansion, or unauthorized logging?

2. Fire-mitigation performance results will vary across countries and regions due to other factors. What other factors could influence project performance?

3. Permanence can be a sensitive topic. Do you have any feedback on communicating these findings?

4. Verra sees potential for projects to gather and share lessons learned or best practices in fire management. Would you be interested in joining a community of practice on this topic?

Section 2: Open-ended questions

1. What feedback do you have on the geospatial results and methodology?

2. Are there effective government programs to mitigate fire and forest loss?

3. What are some knowledge gaps or best practices in fire management?

4. What should the public know about projects' fire management practices?

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