TerraBio Reporting Template To Café Apuí-Draft

Background

In compliance with the roles and responsibilities agreed upon through the Memorandum of Understanding signed between the International Center for Tropical Agriculture – CIAT on behalf of the **Alliance of Bioversity International and CIAT**, and **Amazônia Agroflorestal Comercialização de Produtos Agroflorestais Ltda** (hereafter referred to as “Amazônia Agroflorestal”), we submit the following TerraBio results report according to clause 2.2.4.

Following the collaborative application of TerraBio in Amazônia Agroflorestal's coffee initiative called Café Apuí, which took place on September 13th through the 16th, 2022, this report summarizes the data finding corresponding to the environmental monitoring and evaluation indicator requirements by the Amazon Biodiversity Fund (ABF). TerraBio indicators are aligned and respond to ABF Key Performance Indicators (Annex 1).

TerraBio is a methodological framework that provides monitoring, evaluation, and reporting for environmental impact assessment. It supports businesses that commercialize forest and sustainable agriculture products and invest in sustainable business models. The methodology was developed by the Alliance of Bioversity International and CIAT, in partnership with USAID, Spatial Informatics Group (SIG) and the SERVIR-Amazônia program, under the Catalyzing and Learning through Private Sector Engagement (CAL-PSE) program.

Previously the TerraBio team had shared a report containing the biodiversity results only. This was due to missing information on the total number of farms formerly engaged in the Cafe Apui initiatives supported by ABF. Here we provide an updated version of the 2022 report including the geospatial results. This information was required for TerraBio to provide an integrated understanding of the biodiversity and geospatial impacts of shaded coffee in Apui. TerraBio focuses on the presence of arthropods (a taxonomic group that includes insects, insects, myriapods, arachnids, crustaceans) to assess the number and type of species in the soil. The present document describes the baseline information from which to compare the performance and impacts of agroforestry systems on biodiversity conservation through the expansion of activities by Amazonia Agroforestal.

Table 1. TerraBio Indicator Alignment with ABF's Key Performance Indicators

ABF Theme	ABF KPI	TerraBio Metric
Climate: Net positive impact on climate change	CO_2e reduction	Carbon Storage & Sequestration – Emission Reductions
Ecosystems: Restoring degraded land, protecting and enhancing ecosystems.	Improved biophysical conditions	Regenerated/Restored Area (ha) within intervention sites
	Landscape conservation	Disturbance Monitoring in Forest Conserved Area (ha) within farm boundary and excluding intervention areas.
Species: Improve the presence of native species and the conservation status of threatened and endangered species	Improved species presence	Effective Species Richness
		Paired-site Species Composition Comparison
		Description of Species Assemblage
	Habitat Protection (# ha)	Change in Patch Connectivity Function
	Conservation of Important Species	N/A*

***ABF's Conservation of Important Species is not spatially explicit and thus not applicable to TerraBio.**

About the Amazon Biodiversity Fund (ABF)

The Amazon Biodiversity Fund is an impact investment fund registered in Brazil. The Fund is managed by Impact Earth and was developed in partnership with USAID and the Alliance of Bioversity International and CIAT. Launched in 2019, the Fund seeks to overcome financial challenges inherent to sustainable businesses located in the Amazon, by offering flexible long-term capital to initiatives with potential positive impact on biodiversity and communities in the region.

ABF invests in a range of sectors including sustainable agriculture, extractive activities, and the improvement of technology and finance for biodiversity-friendly enterprises. The Fund is structured to consider four pillars or investment pathways: Conservation, Reforestation and Community

Livelihoods, which aims to strengthen forest conservation by promoting extractive value chains and community livelihoods in protected areas and traditional territories (Pillar 1); Smallholder Value Chains, which is focused on strengthening buffer zones and forest-dependent value chains of smallholders in and around biologically significant areas (Pillar 2); Sustainable Agriculture , which aims to recover degraded farming lands through ecological restoration and reforestation (Pillar 3); and, Innovation in Biodiversity Services, Finance and Technology, which aims to improve and increase access to biodiversity friendly business services, technology, and/or innovative finance (Pillar 4).

Café Apui

The municipality of Apuí, where Café Apuí is produced, is located in the south region of the state of Amazonas in Brazil. The region is a high deforestation risk zone ranking third in the state (Cardoso Carrero et al. 2020). According to estimates by the national spatial research institute INPE (per its acronym in Portuguese), by 2023 deforestation in the state itself had almost quadrupled, relative to 1990 – 2000[1]. Under this scenario, Amazonia Agroflorestal is supporting and expanding the adoption of organic agroforestry systems for coffee production. In 2022, a total of 31 farmers were engaged in the initiative, but only a few had established shaded agroforestry systems (SAF). The average farm size is 126 ha, and the average coffee agroforestry plot is 1.08 ha, roughly representing about 0.9% of the farm area. In addition to the agroforestry system, forest areas across Cafe Apuí farms have an average size of about 47.7 ha, representing approximately 37.8% of the property area. In 2022 the geospatial analysis of TerraBio was applied in 31 farms that combined have a total area of 3,927.6 ha. These farms were extracted from the total farms engaged as they had clearly identified the location where the shaded coffee systems would be implemented. Yet, the TerraBio biodiversity assessment focused soil data collection efforts in farms with established coffee production systems (8 in total), though these were established at different times. In each of these farms, at least three land use systems were assessed (see Figures 2 – 5 in the next section). In the case of the agroforestry systems, five plots were sampled that had a combined total area of 14 ha. Three replicates were collected for each land use site for a total of 48 samples and 4 land use systems.

[1] http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates

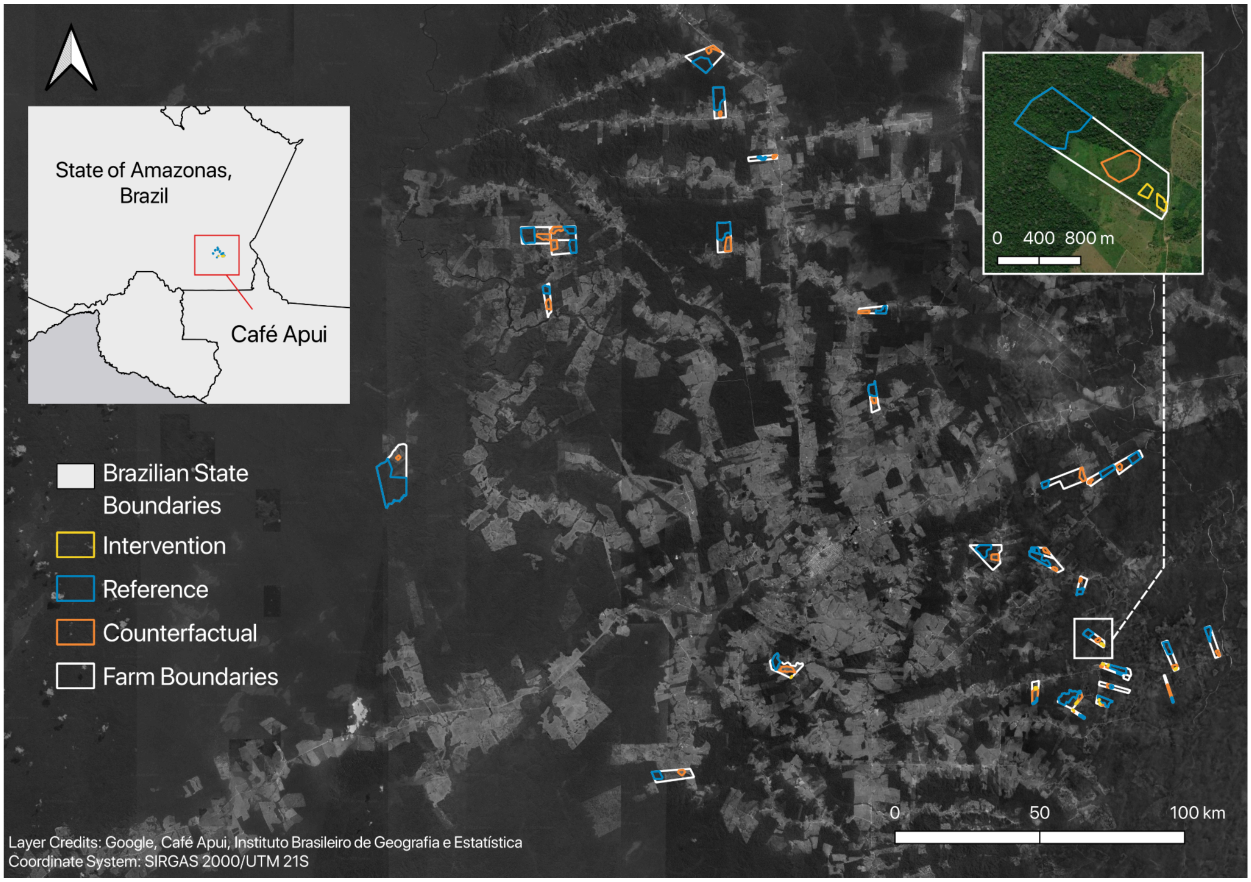

Figure 1. Location of Cafe Apui farms in the Raulino vicinal in Apuí, State of Amazonas, Brazil. The geospatial baseline assessment was carried out for a total of 43 farms that signed contracts with Amazonia Agroflorestal.

Land Use Assessment at Café Apui

Fig.2. Intervention: Agroforestry Systems (SAF)
Organic shaded coffee is produced in farmer property areas of one to three hectares. The coffee trees are planted at a density of 6 by 2 meters, and frequently mixed with guarana production planted in rows of 6 by 4 meters. The agroforestry systems promoted by Cafe Apui includes additional multipurpose species for soil nutrient enrichment such as beans and soil cover such as crotalaria species. As shade, Cafe Apui systems promote the use of timber species such as Andiroba, Cedro Itaube, Jatoba, Ipe Amarelho at a density of 10 by 10 meters. Additional

	production species could be introduced at different coffee growth stages including intercropping with cassava, maize, melon, passion fruit shrubs, and banana palms.
	**Fig. 3. Forest Reference** Forest areas are used in TerraBio as reference sites to compare biodiversity data and to monitor land cover degradation and/or deforestation. Within the properties engaged in Cafe Apui, forest conservation areas are assessed for soil collection. Conservation areas within properties can be considered secondary forests following previous deforestation processes. At the assessed Café Apuí farms in 2022, the secondary forest areas had closed canopies and established trees with varying heights between 10 to 20 meters. The understory was densely composed of shrubs and palms, and the soil was fully covered with a thick layer of leaf litter.
	**Fig. 4. Secondary Succession/Fallow Area** Fallow areas within farms were assessed in Café Apuí as these land cover areas are likely converted into the project's shaded agroforestry systems. Fallow areas are abandoned plots where secondary succession processes are taking place, returning previously forest-cleared areas back into forest-like ecosystems. This natural process is slow and dependent on multiple factors including the dispersion of seeds and early successional species in the landscape. At the Café Apuí farms assessed, fallow areas are locally called "Juquiras" or "Capoeiras". Their fallow periods can vary from 3 to 8 years, and the older systems can include softwood tree species, palms, shrubs and grass vegetation.

Fig. 5. Degraded Pasture
Low intensity pastures for cattle grazing are the dominant land use system in the Apuí landscape. Brachiaria species are commonly used for animal grazing, and the pastures are managed with fire regimes. The pastures assessed within CAfe Apui farms showed little organic matter content and were very rocky. Soil cover with grass or shrub vegetation was patchy with high incidence of exposed soil areas.

Summary of Results

Table 2. Summary of Cafe Apui 2022 Results

TerraBio Metrics	Baseline Result	Short Interpretation
Biodiversity Indicators		
1. Effective Species Richness	Pasture: 22 (n=3) SAF: 37 (n=5) Succession: 68 (n=4) Forest Reference: 84 (n=4)	Compared to pasture areas, coffee agroforestry systems (SAF) had a larger number of arthropod species, but lower than that found in natural succession and forest reference areas.
2. Paired-site Species Composition Comparison	Most similar: Pasture and SAF, & Pasture and Succession. Least similar: SAF and Forest, & Forest and Fallow. Midway similarity: Pasture and Forest, & SAF and Succession.	It is assumed that the species found in pastures are common throughout the landscape and found in other land cover/use systems, leading to high similarity between pastures and other systems, including SAF systems. SAF systems were more similar to succession areas than to forests, highlighting their transitional state.
3. Species Assemblage Across Sites	Communities on Forest sites were distinct from the other land use types, along with. SAF plots. Pastures were the most similar to the other land use types.	The composition of species in Café Apuí's SAF system were most similar (closest) to the successional and counterfactual pasture sites. The pasture sites were highly homogenous, while SAF, succession, and forest sites have greater between site differences.
Geospatial Indicators		
4. Regenerated/Reforested Area (ha) within Intervention Sites*	2.3 ha ± 1.0 ha	An estimated 2.3 ha of tree/palm canopy cover was gained within the intervention sites from 2017 to 2021. This is about 16% of the total 14 ha of the defined intervention areas.
5. Conserved Forest Area (ha) within Farm Boundaries*	1,827 ± 200 ha	Within the farm boundaries (excluding the intervention sites), a total of approximately 1,827 ha of tree/palm canopy cover remained undisturbed from 2017 to 2021, and is thus classified as being conserved.
6. Change in Patch Connectivity Function*	Forest Core: 1,964.63 ha Edge: 273.34 ha Branch: 65.93 ha Bridge: 24.21 ha Loop: 12.70 ha Island: 27.32 ha Perforation: 42.48 ha Core-opening: 33.60 ha Border-opening: 604.79 ha Background: 882.83 ha	At baseline, the intervention is currently contributing very little (0.07%) to forest connectivity. This is likely due to the SAF systems not being mature enough. As the trees in the SAF system grow, part of the intervention may resemble a forest cover habitat, and may be detected as islands or branch forest patch areas increasing the connectivity of the landscape.
7. Carbon Sequestration-Emission Reductions	9,391.46 tons of Carbon (34,466.68 tons CO2 equivalent)	Between 2017 and 2021, approximately 9391.46 tons of carbon were sequestered as plant biomass within the farm boundaries.

*Uncertainty is expressed as a ± 95% confidence interval.

TerraBio Application Results

Biodiversity Indicators

1. Effective Species Richness

Biodiversity monitoring was carried out using environmental DNA (eDNA), which helps detect the number of species (effective species richness) present at a given site. As TerraBio's first application in Café Apuí, effective species richness measures will be used as baseline values to compare annually moving forward. According to the results, shaded coffee agroforestry systems (SAF) had an average of 37 species detected (n = 5; Fig. 6). Secondary succession (fallow) areas had an average of 68 species (n = 4). The conventional pasture sites had the lowest average values at 22 species (n = 3), while reference forest sites had the highest average at 84 species (n = 4).

The SAF sites assessed included a mixture of recent and older implemented shaded coffee production plots (single sites were assessed that were planted in 2014, 2019, and 2021, and four in 2022). This variability in the planting and establishment period of the SAF systems has direct implications on the aggregate results to compare from and to measure impact. Yet, at the time of this report, regardless of the date of implementation, the design and composition of the agroforestry systems was characterized by having a mostly open canopy, and a limited number of shade and intercropping species (with the expectation of the Amazonia Agroflorestal demonstration plot which was included among the SAF sites visited). However, the ground of the SAF plots was covered with leaf litter which can protect the plant's root system and maintain soil moisture. In general, SAF sites had on average more species than the counterfactual pasture sites. These initial results may suggest that even in the early stages of the SAF systems, there is a higher number of arthropod species present than in counterfactual sites. However, in general the effective species richness of SAF systems remain significantly below the forest reference and fallow sites.

Secondary succession/fallow areas were characterized by having a greater number and density of plant species compared to the SAF systems. In some of the succession areas assessed, the canopy was completely closed resembling a patchy forest area, while in others tall grasses and vines covered the majority of the site. These biophysical characteristics likely explain the increased number of effective species richness compared to the agroforestry system. Fallow periods are often used to allow previous agricultural areas to regenerate and restore lost soil properties and nutrients depleted during the production years. The TerraBio results in Café Apuí highlight the conservation value of succession areas in providing habitat to a larger community of arthropods compared to agricultural areas.

The results for Cafe Apui in 2022 follow the expected pattern, with pasture at the lower end of species richness, followed by the early SAF systems, secondary succession/fallow areas, and forest reference areas. The present results provide the baseline to monitor changes in species presence and thus, use of these habitats in the future. As the forest overstory develops in SAF systems, we expect the effective species richness values in the shaded coffee plots to increase and more closely resemble those in the secondary succession/fallow sites and forest areas.

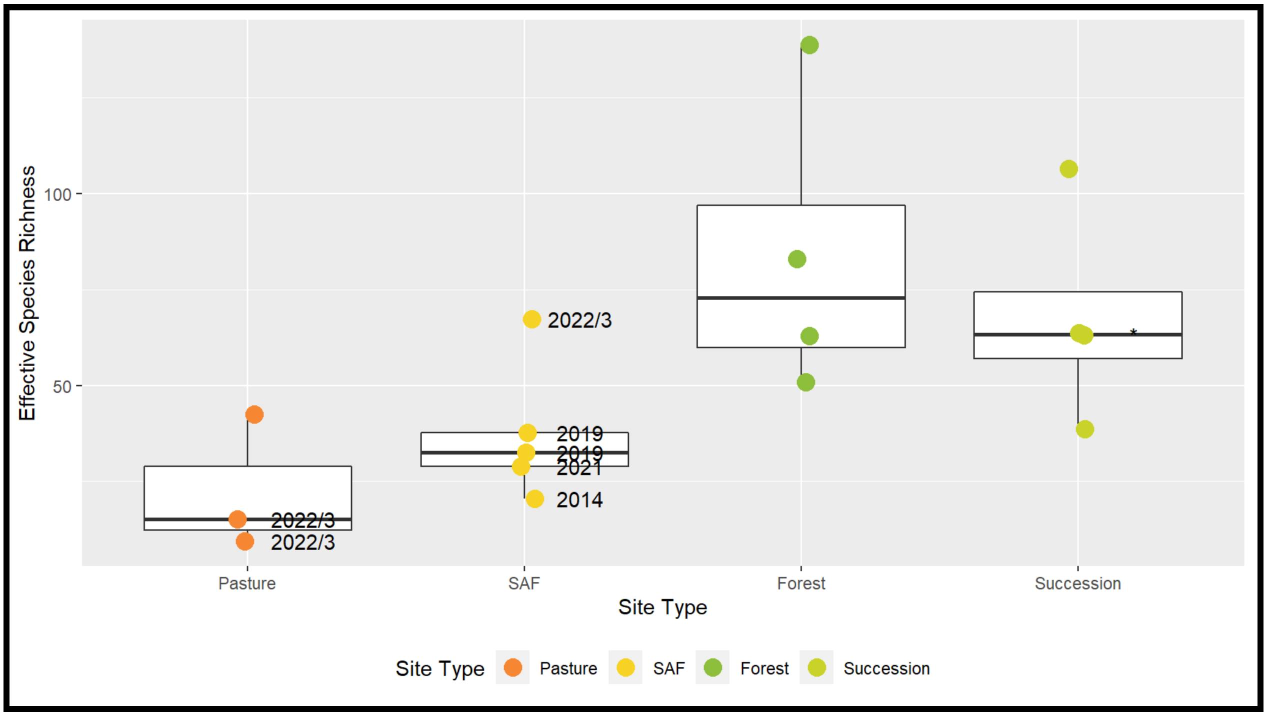

Figure 6. Effective species richness for each land use site type sampled at Cafe Apui. Each dot represents the pooled number of species detected across all three replicates for each farm field sampled. The boxes illustrate how the data (the dots) are distributed, summarizing their central tendency (the median; half of the values are above that value, and the other half are below) and their spread (50% of the data are between the values at the top and bottom of the box). The years are based on information from Café Apuí, on which we are still waiting for confirmation. At each farm field, 2.4 liters of soil was collected in one bag and three replicates were taken from this bag.

Box 1. Measuring Species Presence using Environmental DNA (eDNA) and Effective Species Richness

Effective species richness is a "true diversity" measure that represents the number of equally abundant species for a site. Effective species richness allows for accurate comparisons between different sites and land uses.

The effective species richness values for Café Apuí should be interpreted as the number of equally-abundant arthropod groups (technically called Amplicon Sequence Variants (ASVs) which approximate species or subspecies) observed in each sample. They can be compared directly, where a sample with 60 effective species has twice the diversity as a sample with 30 effective species.

2. Paired-site Comparison of Species Composition

The goal of comparing the species composition between different land use types is to see how many species (or ASVs, in the case of eDNA) the sites have in common. Species composition can be thought of as the pool of specific arthropod species detected at each site, along with their relative abundance. How many species are shared between pairs of sites provides insights about how ecologically similar these communities are. From a theoretical perspective, the more similar the habitat, including tree species, stand age, and vegetation structure, the more similar the community of arthropods detected should be. Ideally, the community of arthropods detected in a mature intervention area, such as the SAF system, should resemble the community of arthropods detected in the forest environment more closely than that of a degraded pasture site due to similarities in their habitat. When the number of species in common between an intervention and a forest system is high, we have strong evidence of the positive impact of that sustainable productive system in conserving local ecological communities, by improving the complexity and/or availability of potential habitat.

At Cafe Apuí, a larger number of species shared between the SAF and the forest reference area, would indicate that more arthropods found in forest habitat are using the shaded coffee system plot areas as habitat to eat, rest, and mate. The Aitchison distance plot (Fig. 7) is used to visualize how similar or dissimilar the arthropod communities belonging to different sites are from one another. Aitchison measures distance to represent similarity/dissimilarity, where lower distance values mean more species in common, while higher values mean fewer species in common. In the chart below, land use pairs with similar species compositions would look yellow, and land use pairs with different species compositions would look dark green.

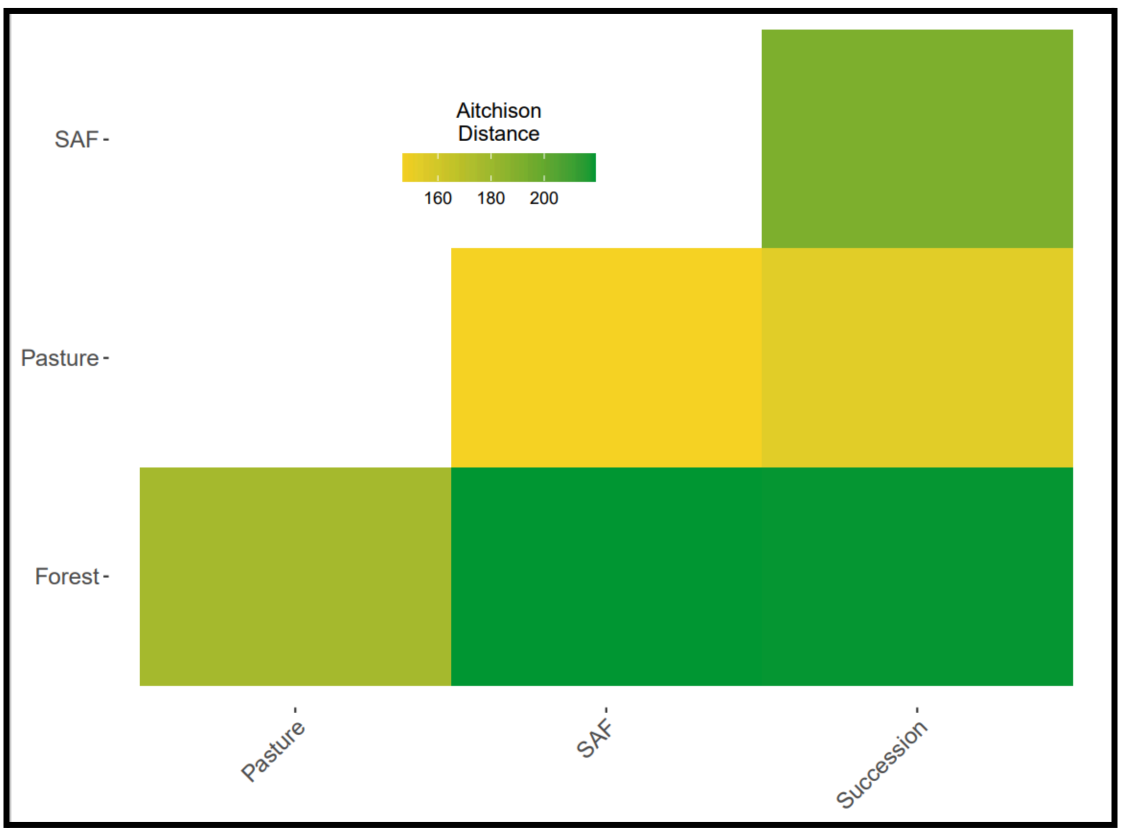

Figure 7. Aitchison distance between paired pooled land use types. Pairs with lower Aitchison distance values have arthropod communities that are more similar to one another (yellowish cells), while pairs with higher Aitchison distance values have arthropod communities that are less similar to one another (greener cells). Note that the pasture (n = 3) had fewer samples than the other groups (forest and secondary succession n = 4; SAF n = 5), however species accumulation curves indicated that this land use type was more fully sampled than Succession and SAF sites.

At Café Apuí, the pasture and SAF sites were closest to one another (lowest distance) in terms of species similarity. This was followed by the pasture and secondary succession/fallow comparison. The pasture and forest pair, along with the SAF and secondary succession/fallow pair, were in the middle. Furthest from one another (highest distance) were the forest and secondary succession/fallow pair, and the forest and SAF pair comparison. These results indicate that the species currently hosted by the SAF system may not be forest-dwelling species. As the SAF systems are fairly young, and thus have been recently disturbed by planting, these results are expected. However, as the Café Apuí SAF systems matures, this should change and the species composition similarity between the SAF system and the forest reference sites should increase (Fig. 8). This will depend, however, on multiple landscape-scale factors, including how quickly planted trees grow and provide habitat for arthropods, the use of biodiversity-friendly management practices, and how easily forest species can move from nearby forests to colonize SAF sites.

Figure 8: A member of the field team stands in front of a secondary succession/fallow site. The site is beginning to develop vertical vegetation stratification, with a growth of a defined canopy and under-canopy vegetation layers.

The paired comparison of the pasture sites with the other three land use types showed the most species similarities (lowest distance). This may be because the species found in pastures are usually fewer and regionally common (generalist species) that can also be found throughout the landscape and in the other land use types. However, TerraBio does not make distinctions regarding the habitat preference of the community of species detected at a particular site. This type of information is species-specific and often lacking for arthropods in the Amazon. The TerraBio tool assumes that a species presence in a given location reflects its habitat preference, and is the reason for conducting paired-site comparison using forest areas as reference sites.

Box 2: **Because Composition Matters: Pair-site Species Comparisons, AKA Beta Diversity**

Beta diversity is a measure of the turnover in species assemblages between pairs of different sites or land uses. In other words, it estimates the number of species that are different between the two sites. The larger the difference, the larger the Beta diversity value.

Aitchison distance is a measure of Beta diversity. It measures how similar or dissimilar two species communities are. For example, if two communities share most of the same species, then the two communities will be very similar (low Aitchison Distance value). If two communities have almost no species in common, they will be very dissimilar and have a high Aitchison distance value.

3. Description of Species Assemblages

Visualizing the assemblage of species across sites helps understand how the different land use communities relate to one another. The species assemblage graphic can be interpreted simply, sites with more similar species compositions will appear closer to one another than sites with less similar species compositions. We use ellipses to encapsulate the results for each land use type at 95% confidence interval around the "average" community for that land use. When the ellipse for a land use type is small, the species detected among the samples are similar, thus we can interpret it as having low within-land-use variability. However, when the ellipse is large, it means that the communities among the samples were less similar, thus higher within-site-variability[2]. The visualization of the communities in space complements the information provided by the paired-site comparison analysis, as it looks at the spread of species across all sites assessed..

At Café Apuí, the visual representation of the sites supports the results from the paired comparison. The counterfactual pasture sites, which are clustered towards the center of the species assemblage graphic (Fig. 9), are relatively close to the other three land cover/land uses. Coupled with the low effective species richness results, it is likely that the species found in pastures are common species occurring in the landscape. The forest reference sites are the most different, both from one another and from the other land cover/land use types. This can be observed by the position of the forest sites (green circles) in the lower quadrants and the large ellipse size representing the confidence interval. One of the secondary succession/fallow sites is found within the forest ellipse (upper left quadrant), suggesting that the arthropod community in this particular secondary succession/fallow site is more similar to those found in the forest reference areas. If secondary succession/fallow areas are not converted into other uses, over time it would be expected for these sites to become forest areas and host a community of species characteristic of these habitats.

[2] To increase the accuracy of land use composition results, a larger number of samples is recommended to improve the detection of the arthropod species and thus of species using that land use.

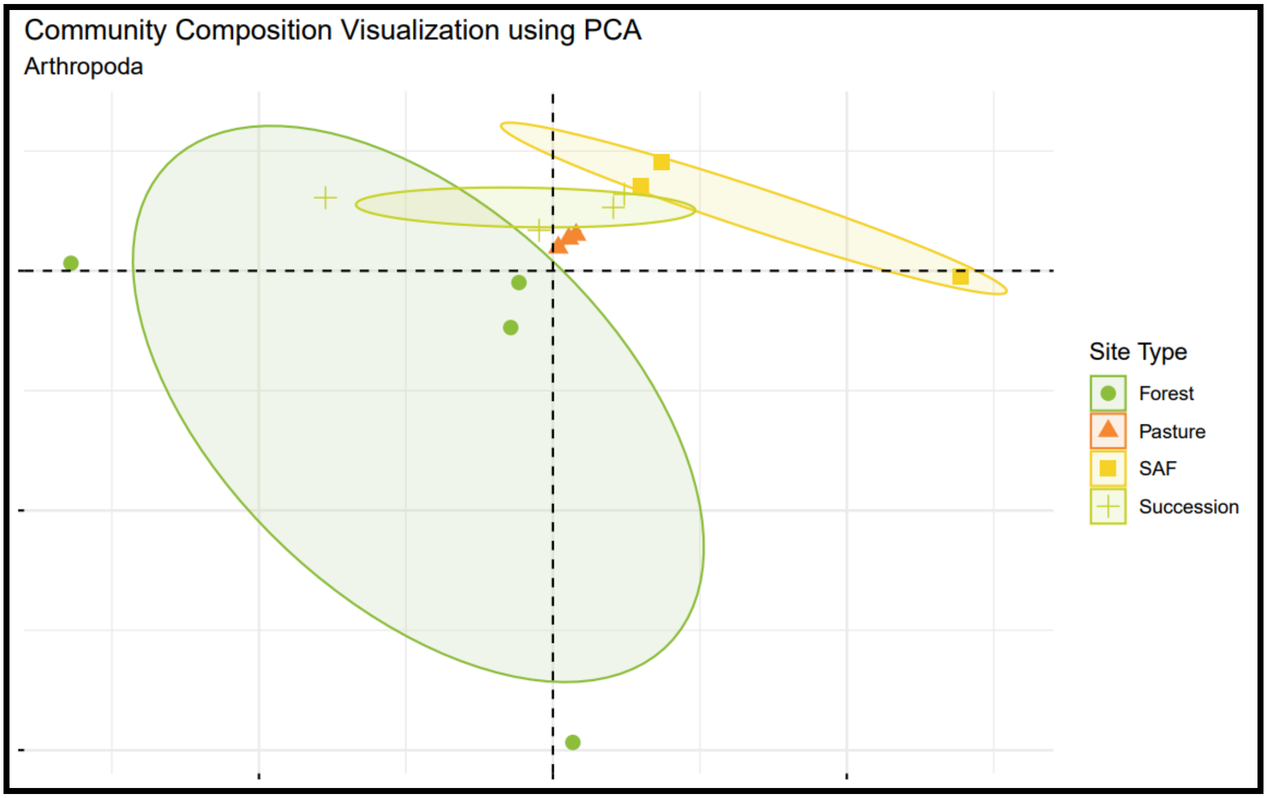

Figure 9. Visual representation of the arthropod community compositions at the four different land cover/use types assessed with TerraBio. Each point represents one sample, consisting of three pooled replicates. Points that are closer together in the graphic have more similar community compositions than points that are further apart. The ellipses help visualize the part of the graphic occupied by samples from each land cover/ use type. The size of the ellipse represents how similar the replicates within a site type are.

Box 3. Visualizing Information using Principal Component Analysis

Principal Component Analysis (PCA) is an ordination technique used to visualize information based on the level of relative similarity of samples or groups of samples. PCA translates datasets into an abstract two dimensional plot. Each axis represents an abstracted gradient along which the communities differ. TerraBio uses PCA to display the information contained in a distance matrix.

However, some caution should be used when interpreting this plot, as the axes are not as “strong” in describing the arthropod community as we might like.

Land Cover/Land Use Indicators

4. Regenerated/Reforested Area (ha) within Intervention Sites

The implementation of sustainable activities in ABF funded projects are monitored by measuring areas showing improved biophysical conditions through increases in tree/palm canopy cover over time. An increase in tree/palm canopy can be understood as an increase in tree cover, or more specifically, a land cover conversion from a non-forest area to a natural forest, planted forest, or agroforestry system. TerraBio uses satellite images to identify and compare gains in tree/palm canopy covered before, during and after project implementation. Within the boundaries of the 31 farms of Café Apuí, the estimation of regenerated/reforested areas was conducted only in eight farms where 13 SAF intervention sites had been clearly delimited by Amazonia Agroflorestal. Differences in tree/palm canopy cover at the 13 defined sites where shaded coffee was planted were analyzed for a 5-year period between 2017 and 2021. This time period was chosen as a historical baseline to compare moving forward for the TerraBio assessment. As some of these farms have established coffee plants, while newly added intervention sites in the subsequent years may be starting as recently tilled and planted plots, the interpretation of the results will need to consider the combined age of the shaded coffee plots. Areas of improved biophysical conditions are calculated as the number of hectares detected where tree/palm canopy cover was gained within the intervention site(s).

From the total previously established shaded coffee intervention sites within Café Apui by 2022, 8 farms with a total of 14.07 ha, TerraBio observed a total of 2.3 ± 1.0 ha (95% confidence interval) of tree/palm canopy cover gained from 2017 to 2021. This estimation roughly corresponds to 16% of the defined SAF planted area (see Fig. 10). In terms of the total area of the 31 farms assessed by TerraBio between 2017 and 2021, a total of 268 ± 120 ha of tree/palm canopy cover gain was observed.

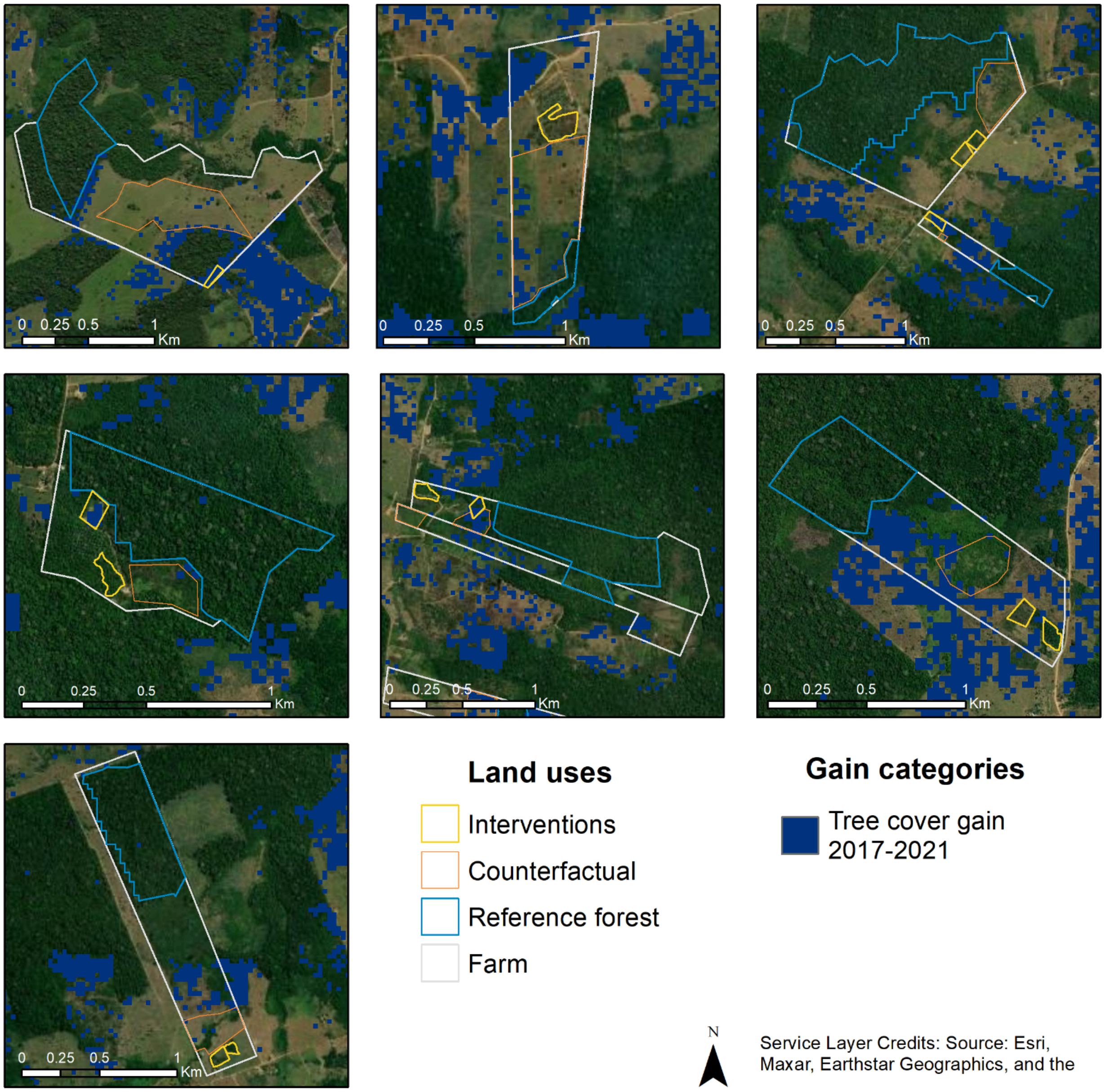

Fig. 10. Selection of farms within Café Apuí and their LandTrendr mapped areas of tree/palm canopy cover gain within and outside the intervention sites.

Box 4. Monitoring Gain of Tree/Palm Canopy Cover

Remote sensing helps visualize and quantify which areas have been gaining tree/palm coverage through time. The areas are mapped using the LandTrendr algorithm, which leverages time series analysis of satellite imagery. LandTrendr builds an image collection with one image per year that is a medoid—a member of the collection that minimizes the average dissimilarity (distance) to all other members of the collection—pixel-based composite to produce cloud-free images within defined temporal windows, using Landsat 5, 7, and 8 images (Kennedy et al., 2018). Here we used images from the dry months of June through September due to the persistent cloud coverage over the Amazon region. The LandTrendr algorithm aims to filter out inter-annual noise in spectral signals and generate trajectory-based time series estimates. It accomplishes this by simplifying multi-year spectral trajectories into several straight-line segments that capture land use changes (Kennedy et al., 2018). The tree/palm canopy cover gain monitoring algorithm was parameterized to select the "newest" gains.

The results from the LandTrendr algorithm monitors land use change, and are evaluated using a digital platform called Collect Earth Online (CEO). CEO contains satellite images and tools that allow observations and analysis of land cover. On this platform, some areas where change (gain or loss of trees/palms) and non-change occurred, are selected using a stratified random sampling statistical approach of "good practices for estimating area and assessing accuracy of land change" by Olofsson et. al. (2014). The result of this accuracy assessment allows the estimation of areas of changes/no changes and their respective margin of error.

5. Conserved Forest Area (ha) within Farm Boundaries

TerraBio's landscape conservation indicator provides information on the condition of forest land cover areas by estimating the amount of undisturbed tree/palm canopy covered land. TerraBio defines forest disturbance as both deforestation and degradation. TerraBio uses the term tree/palm canopy cover, rather than just forest cover, to include other forms of natural vegetation that may not fit into the definition of a forest. Forest area within the farm boundaries between 2017 and 2021 indicate a total of 1,827 ± 200 ha were conserved. This represents about 41% – 52% of the 31 Cafe Apui farms' total area (except within the identified intervention sites; see Table 1). However, during the same period, farms in Café Apuí registered 318 ± 118 ha of deforestation and 107 ± 89 ha of degradation. Overall, tree/palm canopy cover disturbance from 2017 to 2021 was about 425 ± 145 ha (7 – 15% of the farms' total area). These estimates were calculated via a sample-based assessment, interpreting imagery at representative sample areas selected via an initial map of tree/palm canopy cover disturbances (Fig. 11). Examples of what these disturbances look like are represented in Figures 12, 13 and 14.

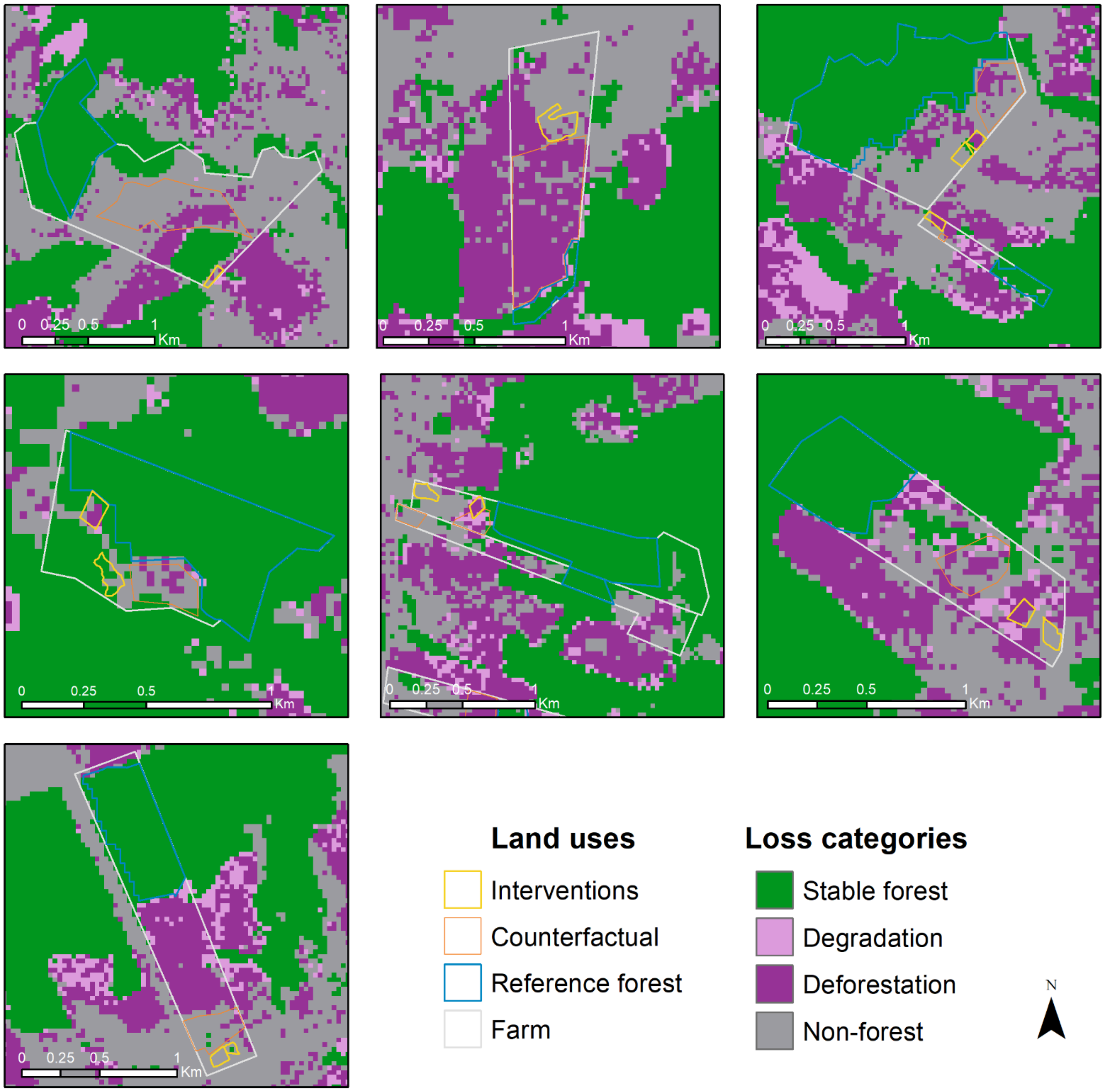

Fig. 11. The sample of maps above illustrate tree/palm canopy cover disturbances at Café Apui farms. The maps identify conserved tree/palm canopy covered areas (stable forest) and where tree/palm canopy cover loss and degradation has occurred. These maps were developed for each of the 31 farms used to inform the distribution of point samples in CEO to later calculate representative estimates of the extent of these disturbance events and estimates of conserved area 2017-2021.

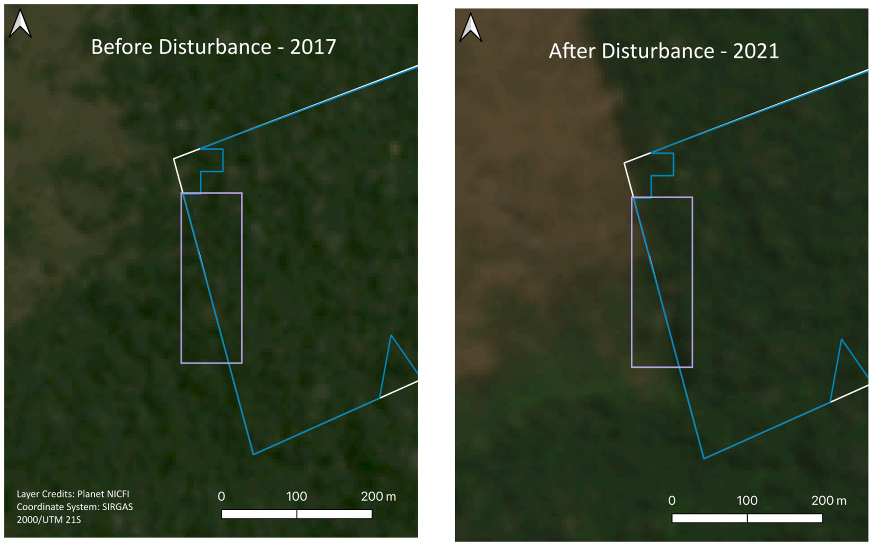

Fig. 12. Example of an area mapped as degradation. The canopy cover within the purple polygon is noticeably sparser after the disturbance. Before and after disturbance images are July-September Planet NICFi composites for 2017 and 2021, respectively.

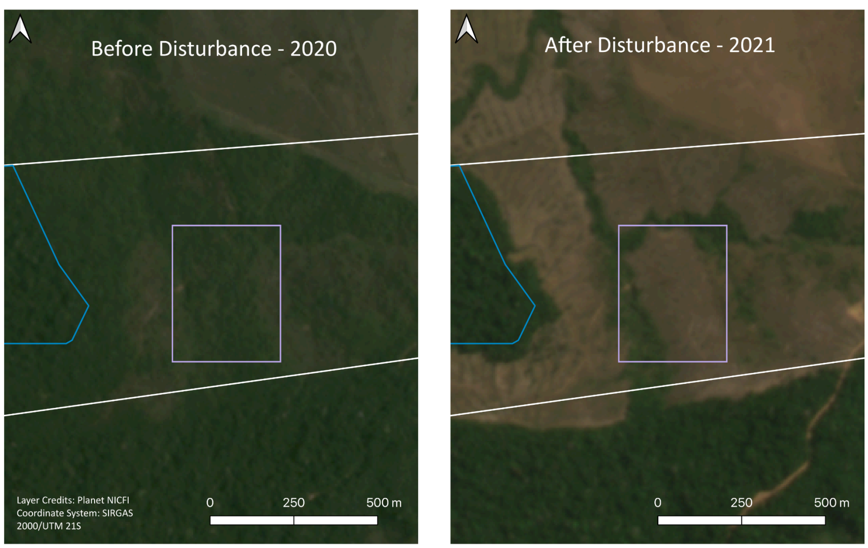

Fig. 13. Example of an area mapped as deforestation. The tree/palm canopy cover within the purple polygon was cleared in 2021. Before and after disturbance images are July-September Planet NICFi composites for 2020 and 2021, respectively.

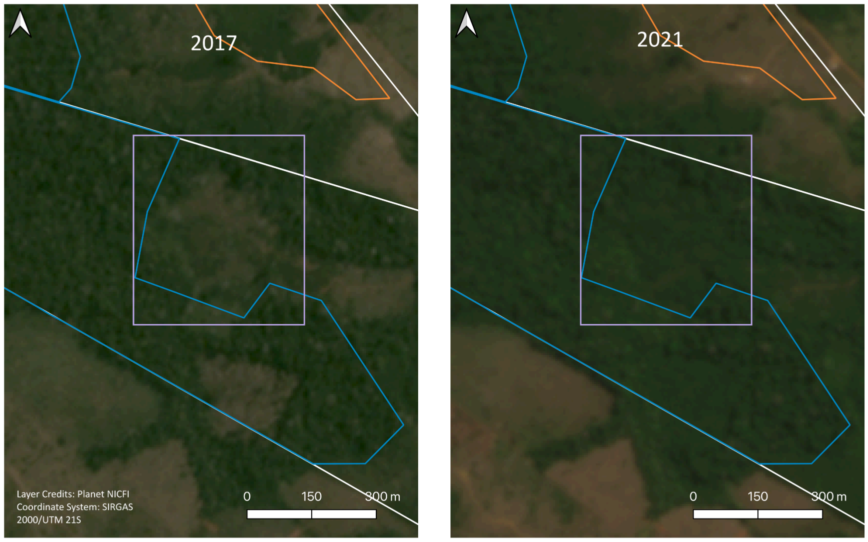

Fig. 14. Example of an area mapped as gain. The tree/palm canopy cover within the purple polygon becomes denser across 2017-2021. Images are July-September Planet NICFI composites for 2020 and 2021, respectively.

Box 5. Monitoring Forest Disturbances using Remote Sensing

Land cover change images help us understand how the landscape has changed over time. Conserved Forest area is calculated as the number of hectares classified as stable forest within the farm property, excluding the intervention site. The areas are mapped using the LandTrendr algorithm which is a time series analysis approach applied to the Landsat image archive (see Box 2). LandTrendr was parameterized to estimate the "newest" disturbances. Forest disturbances include high-impact events, such forest loss from fires or deforestation, to subtle and gradual processes, such as degradation caused by prolonged droughts, insects, or diseases (Cohen et al., 2017; McDowell et al., 2015).

Disturbances (deforestation/degradation) and non-disturbance areas were classified as deforestation or degradation, and as tree/palm canopy cover or non-tree/palm cover, respectively, using forest/non-forest (FNF) annual images (2017-2021) from a supervised classification using Planet NICFI imagery (downsampled to 30 meters to match the LandTrendr results). Disturbance areas were relabeled as deforestation if the pixels in the FNF image at the end year was labeled non-forest, and as degradation if the pixel were labeled forest. Non-disturbance areas were classified as stable forest if the pixels were always labeled as forest from 2017 to 2021, and as non-forest if otherwise.

6. Change in Patch Connectivity Function

Habitat protection is measured in Café Apuí by monitoring changes in spatial pattern of tree/palm covered areas within the landscape, following the implementation of ABF funded sustainable activities.

The Morphological Spatial Pattern Analysis (MSPA; see Box 4) is used to monitor how the areas of interest (e.g. intervention and forest conservation sites) are improving landscape connectivity over time and in relation to their surrounding environment. Forest and forest-like vegetation can contribute as habitat by connecting, expanding, and overall increasing the permeability of the fragmented agricultural landscape. Hence given their shape and location, forest and forest-like areas can function in several ways.

According to the MSPA results displayed in figure 14, within the 31 Café Apui farm boundaries, a total of 1,964.63 ha can be considered forest core (green), 65.93 ha are forest patches that branch out from the core (orange), 27.32 ha are forest islands (brown), 24.21 ha are forest bridges that connect other forest patches (red), 12.70 ha are forest loop that connect to the same forest patch, 42.48 ha are perforated areas inside forest patches, and 273.34 ha are considered forest edge areas to the foreground forest class. When considering non-forested areas, the sum of the cleared background, core openings, and border openings add a total of 1,521.22 ha (882.83 ha, 33.60 ha, and 604.79 ha, respectively).

Currently, as baseline for the year 2022, the intervention sites (13 sites totaling 14.08 ha) are mostly classified as background. The reference forest areas are for the most part considered core forest areas, with small perforations, core openings, and bridges. Inside of the Café Apui farms, the Counterfactual areas (31 sites totaling 395.9 ha) are mostly classified as background, with some boundaries containing areas of core forest.

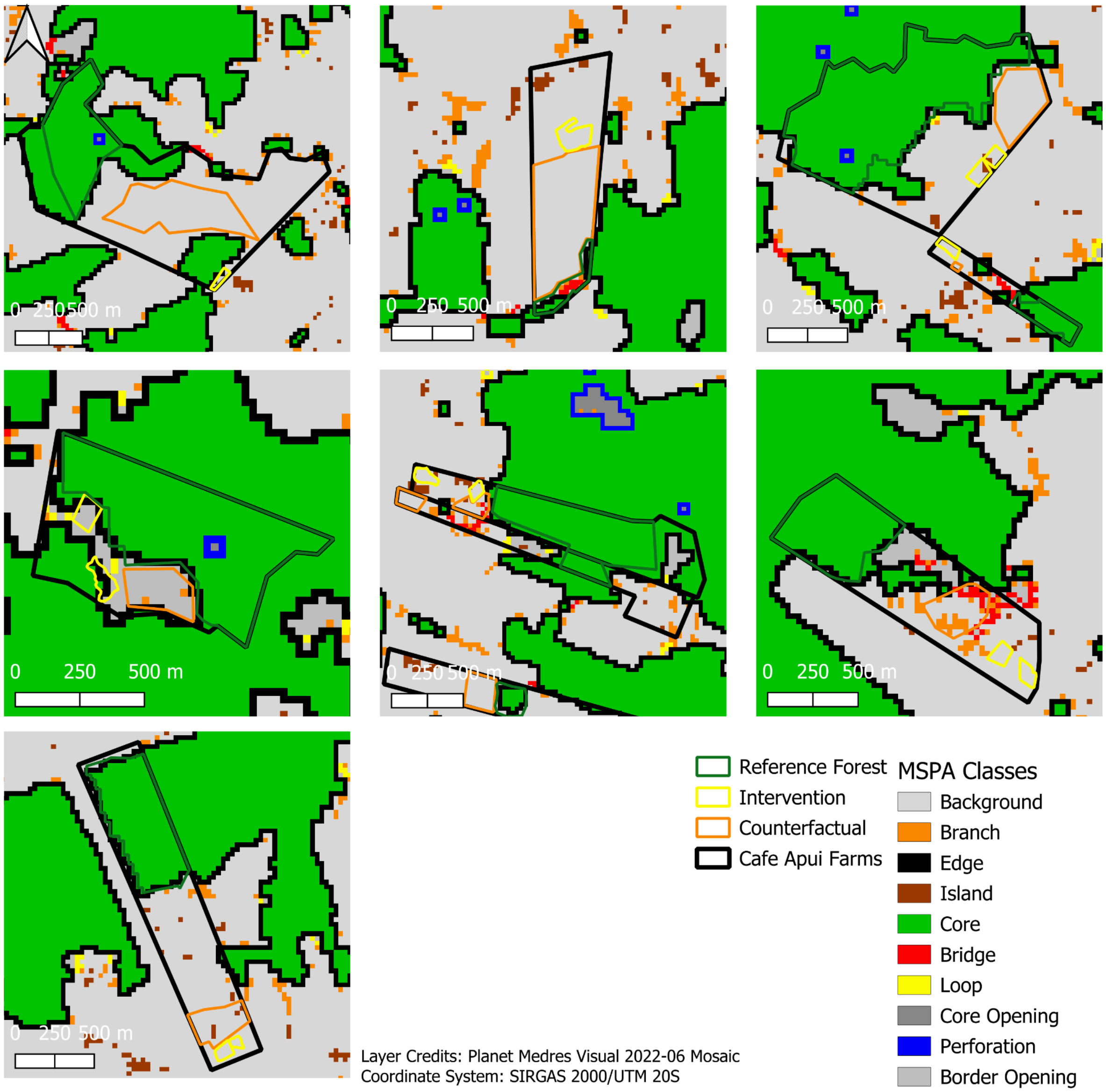

Figure 15. MSPA results within the Café Apui boundaries. As input for MSPA, a forest/non- forest image was generated from a supervised classification. MSPA results are described in the legend above. In the MSPA analysis, the edge class is considered 1 pixel (i.e. 30 meters from the forest edge to the forest core).

The habitat protection results for Café Apui provide insights about the current potential for Café Apui's property to serve as habitat for wildlife. Of the total area of the farms (∼3926 ha), 62% can be considered protected habitat. This does not comply with the Brazilian Forest Code for Amazon-biome based properties requiring land owners to set aside 80% of their property to remain intact native vegetation. The implementation of the intervention is currently contributing very little (0.07%) to the percentage of habitat protected areas. Given the early stage of the system, the system resembles a conventional agricultural system rather than a forest. As the system matures, part of the intervention may resemble a tree cover habitat, and may be detected as island or branch forest patch areas increasing the connectivity of the landscape.

Box 4. Morphological Spatial Pattern Analysis (MSPA) and Landscape Ecology

MSPA is used to assess and monitor landscape patterns based on the geometry and configuration of a targeted land cover in a particular landscape background. An example is classifying and measuring the area of forest patches in fragmented agricultural landscapes. MSPA is a customized sequence of morphological operators that takes a binary image, such as a forest/non-forest mask, and divides the foreground class (forest) into seven functional classes: Core, Island, Perforation, Edge, Loop, Bridge, and Branch.

MSPA can support landscape ecology research, which is an academic field interested in understanding the influence of landscape patterns on ecological processes, and thus, on biodiversity conservation. In fragmented agricultural landscapes, maintaining effective connectivity through remaining forest patches is important for wildlife survival. Forest species need to be able to move through the landscape in search of food, shelter, and for other reasons. Maintaining landscape connectivity may be more important to some groups of forest species (like tamarin monkeys), rather than others (such as parrots), and is the reason why isolated forest patches are usually biodiversity deficient. Sustainable interventions like agroforestry can help increase landscape connectivity by providing habitat between conserved patches of forest.

7. Carbon Sequestration - Emission Reductions

To estimate contributions to carbon dioxide (CO2) emission reductions, TerraBio estimates atmospheric CO2 removal as carbon sequestration through biomass accumulation based on land use type and forest age. TerraBio uses satellite imagery to monitor vegetation gains and losses (biomass change) across 2017 – 2021. The carbon stored during this period is considered to be the 5-year baseline value to compare with moving forward. This period was selected to provide historical land cover/land use context. Carbon sequestration was estimated annually in metric tons (t) at the farm level and across land use types (Table 3).

The results indicate that, overall, there was an increase in carbon stored in vegetation biomass across all farms (Figure 15). Carbon storage increased from 251,740.32 tonnes of carbon (tC) in 2017 to 257,858.76 tC in 2021—a 2.4% increase (6118.44 tC). The highest yearly increase in carbon storage occurred in areas not not being monitored, called undesignated areas, averaging 1453.65 tC per year , with the reference areas coming in second place at an average yearly gain of 78.44 tC per year. The intervention sites experienced the highest percentage of increase in carbon storage from 2017 to 2021 at 10.01%, with the undesignated sites coming in second with a 5.98% increase. Thirteen intervention sites were implemented between 2009 and 2021, which accounts for the marked increase in carbon stored within intervention sites. This increase is reflected in the sample-based estimates of canopy cover gain within intervention sites (see metric 4 - Regenerated/Reforested Area within Intervention Sites).

Table 3. Carbon storage and sequestration from vegetation biomass across 2017-2021 at the farm and site level at Cafe Apui, and corresponding carbon emission reductions (in CO_2 equivalent*).

Land Cover/Land Use	Carbon Stored in 2017	Carbon Stored in 2021	Net Change 2017 to 2021	Units
Farm Level **	251740.32	257858.76	6118.44	tC
	923886.97	946341.66	22454.69	(tCO_2-eq)
Intervention	247.1	272.19	24.78	tC
	908.01	998.93	90.92	(tCO_2-eq)
Forest Reference	156098.78	156412.54	313.76	tC
	572882.51	574034.01	1151.5	(tCO_2-eq)
Undesignated	97201.32	103015.94	5814.62	tC
	356728.84	378068.49	21339.65	(tCO_2-eq)

*The CO_2 equivalent (CO_2-eq) value is calculated by multiplying the carbon value by 3.67 (The atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44, because it includes two oxygen atoms that each weigh 16. So, one ton of carbon equals 44/12 = 11/3 = 3.67 tons of carbon dioxide).

**The summation of carbon of all land uses, intervention, reference forest, and undesignated, does not agree with the total carbon at the farm level. This difference is caused because there are limits or boundaries of land uses that share pixels between them. This situation occurs when the carbon calculations involve vector data (shapefiles) and raster information. Because of this, sometimes the same pixel is involved in the summation of carbon for two land uses. For this reason, and clarity purposes, we present the amount of carbon stored at the farm level.

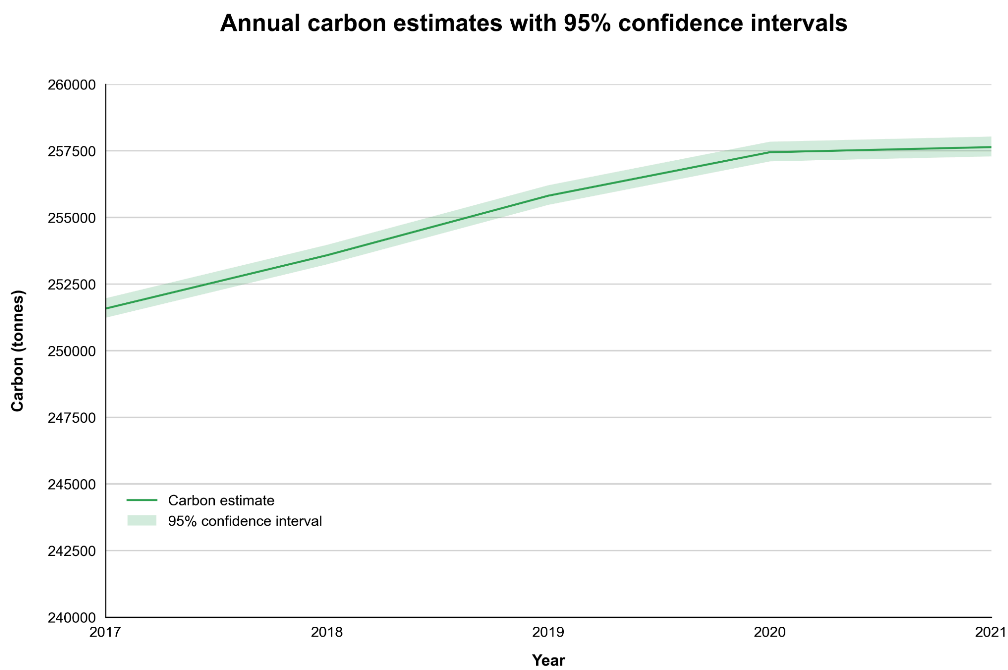

Fig 16. Estimates of carbon stored as plant biomass within Café Apui farm boundaries between 2017 and 2021.

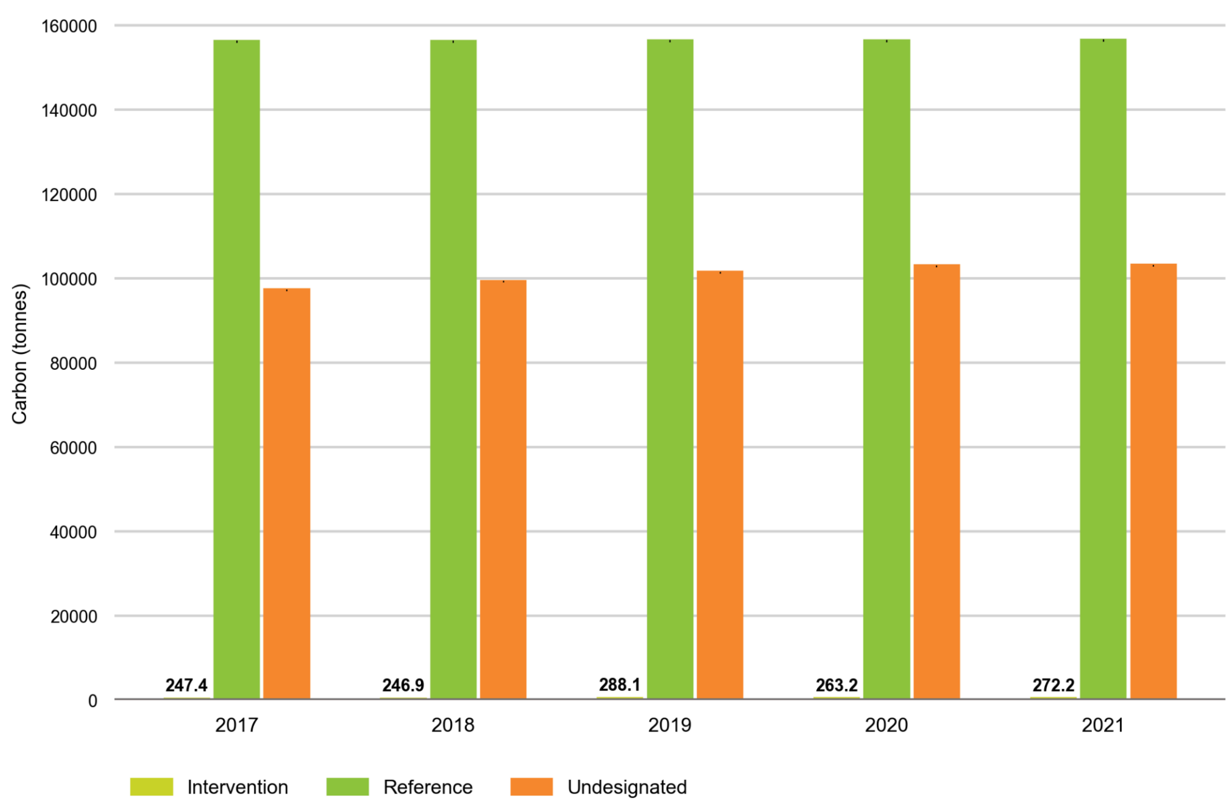

Fig 17. Metric tons of carbon stored as plant biomass in each land use system within the Café Apui farm matrix between 2017 to 2021, with 95% confidence intervals accounting for uncertainty in growth curve coefficients and IPCC carbon constants.

Box 5. Monitoring carbon sequestration using Remote Sensing

TerraBio utilizes remote sensing approaches to calculate the total metric tons of carbon stored yearly in plant biomass in both forested and non-forested areas. For forested areas, tree stand age is determined by combining LandTrendr loss and gain maps with forest/non-forest (F/NF) information from the MapBiomas initiative[3], Global Forest Change (Hansen et al., 2013), and Planet NICFI imagery (see Boxes 2 and 3. Monitoring Vegetation Gain Using Remote Sensing & Monitoring Forest Disturbance Using Remote Sensing). This involves 1) calculating the time since a tree cover loss event was detected with recovery; 2) calculating the length of time since planting was established in non-forest areas (vegetation gain events from LandTrendr); 3) assigning an age to tree cover that was established prior to 1985 (earliest images from Landsat). From there, yearly biomass is calculated using equations built on stand age growth rates developed by Bernal et al. (2018). The output in biomass estimates carbon stored as plant mass. Non-forest areas were assigned IPCC carbon constants (Gibbs et al., 2008) based on how they are classified by MapBiomas (pasture, temporary crops, etc.).

Concluding Remarks

The results represent a snap-shot assessment of species presence and composition at Café Apuí farms. The results describe the environmental impacts of a shaded coffee agroforestry system. As a first TerraBio application, the results from this report can be used by Café Apuí and Impact Earth as baseline information to comply with ABF's environmental KPI data requirements, to monitor changes over time and evaluate intervention impacts compared to a counterfactual and reference area.

The amount of conserved, lost, degraded, and gained tree/palm canopy cover land reported in this report provide the starting conditions to compare from in future years. Within the 31 farms examined for the Conserved Forest area, a total of 268 ± 120 hectares of tree/palm canopy cover were estimated to have been gained. This is reflected in the 2% increase in carbon stored with farm boundaries across 2017-2021. The intervention sites currently include 14 hectares of land, where 2.3 ± 1.0 hectares of tree/palm canopy cover gain have been estimated for 2017-2021. As intervention efforts continue it is anticipated that these areas of growth will expand and thus increase the available habitat for many species. However, according to the patch connectivity analysis, the intervention plots are not currently contributing to potentially increasing landscape connectivity for wildlife conservation. This is confirmed by the biodiversity indicator data.

While the number of species in the agroforestry system (SAF) is higher than that of the counterfactual and landscape dominant pasture areas, the community of species being hosted at the shaded coffee systems is more similar to the pasture sites than that of the secondary successional/fallow sites or forest

[3] https://brasil.mapbiomas.org/quem-somos/

reference areas. Yet, these results are positive and in agreement with the expectations for ealy project baseline data. Compared to the pasture sites, the increased number of species detected in the SAB system may be a result of the organic management practices, leaf litter covered soils, and remnant older trees in coffee plots. However, the SAB systems visited have fewer than expected shaded trees, and some of the sites were too young to be considered an agroforestry system.

As the coffee plants in the SAB system mature and the shade trees grow, the increased availability of microclimatic conditions ideal for forest-specialist species across various taxonomic groups, is expected to positively impact the presence and composition of species in these areas and across the fragmented landscape.

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