TERRAFUND FOR AFR100
HOW WE MONITOR, REPORT AND VERIFY (MRV)

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ACKNOWLEDGEMENTS

This document was compiled by Dow Martin for TerraFund for AFR100 partners with substantial contributions from Margaret Vernon from One Acre Fund; Teresa Muthoni, Peace Grace Muhizi, and Ross Bernet from One Tree Planted, and Luni Libes from Realize Impact.

The authors of this framework would like to express their thanks to the team at World Resources Institute and Conservation International, whose Tree Restoration Monitoring Framework informed the geospatial indicators and analyses in this document (Conservation International, 2023. Tree Restoration Monitoring Framework: Field Test Edition. Lead author: S Sprenkle-Hyppolite).

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GLOSSARY OF TERMS

Term	Description
Project	A project can consist of a single site or of multiple noncontiguous sites. In the latter case, each site may have different interventions (e.g. tree planting, agroforestry) or the same interventions in separate locations of the same locality such as village.
Site	An individual site is the most important unit for reporting, demarcated as precisely as possible to cover the exact areas where intervention activities are happening. A site must be a continuous area of land. It may contain several different interventions stratified by intervention types or a single intervention type.
Boundary	A boundary is the outline of the site or project
Polygon	A polygon is used in Geographic Information System (GIS) to describe the data representing a site's boundary. It is NOT a point or a line and must be a shape that demarcates an enclosed area.
Shapefile	A shapefile refers to a commonly used terminology in GIS to represent vector data as opposed to raster data. Shapefile refers to the polygon(s) which are your site's boundary outlines.
Project Developer	A term used to refer to TerraFund grantees that are non-profits and small-and-medium sized enterprises.
Project Manager	A term used in this document refers to One Tree Planted, World Resources Institute, or other TerraFund partners employee assigned to oversee progress and keep constant contact with TerraFund grantees.

1 OVERVIEW OF INDICATORS

Tier 1 indicators will be available for projects that provide polygons and 6-month reports

- Indicator 1: **Trees restored** –The total number of trees restored across all sites, across the entire project. This number is based on a review of 4 sub-indicators:[1]
  - 1.1 Number of trees under restoration annually and over a 5-year period
  - 1.2 Number of seedlings or saplings grown in nurseries annually and over a 5-year period
  - 1.3 Number of trees counted at Year 0, Year 3, and Year 6 and change in tree count from Year 0 – 6 across all sites
  - 1.4 Percent tree cover at Year 0, Year 3, and Year 6 and change in percent tree cover in restored area across all sites
- Indicator 2: **Hectares under restoration** – The total area measured in hectares with active restoration intervention. This indicator includes hectares under restoration disaggregated by intervention.[2]
- Indicator 3: **Number of jobs** – Number of jobs created by restoration project or enterprise.
- Indicator 4: **Livelihoods**[3] b**enefits** – Number of people who have reported increased annual income and increased knowledge and skills as a result of TerraFund.
- Indicator 5: **Financial growth** – Annual change in revenue for enterprise and non-profit.

Tier 2 indicators will be available for selected projects with relevant interventions and high quality data

- Indicator 6: **Carbon sequestered** – Biomass carbon sequestered.
- Indicator 7: **Ecosystem services enhanced** – Restoration is a means to many ecological goals such as improved hydrological flows, reduced erosion, moderated climate, and increased species diversity; field work is required to measure the long-term effects of restoration years after the project is complete. Based on the intervention, studies could assess the effects of restoration on soil, water, plant and animal diversity, community well-being, food production, energy, and sustainability.

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[1] Conservation International, 2023. Tree Restoration Monitoring Framework: Field Test Edition. Lead author: S Sprenkle-Hyppolite.
[2] Conservation International, 2023. Tree Restoration Monitoring Framework: Field Test Edition. Lead author: S Sprenkle-Hyppolite.
[3] Definition of livelihood is defined by DFID as a means of making a living that encompasses people's capabilities,assets and income required to secure the necessities of life.

2 MEASURE AND MONITOR

The primary purpose of documenting TerraFund MRV methods is for our matrixed team, TerraFund project management, TerraMatch product, and TerraFund MRV teams, and our growing partnership to be on the same page. The secondary purpose is to openly share our methods and hard-earned lessons with other Portfolio Managers and restoration funds in hopes that more nature-based solutions and nature climate solutions restoration initiatives will continue to improve the rigor and systematic nature of tracking progress and impact. We hope that other funds will draw from our methods instead of reinventing similar but slightly different MRV. We also hope that more organizations will choose to collaborate with us to improve the cost-effectiveness and accessibility of these methods and their results for the benefit of the restoration community, especially many locally led organizations and restoration ventures across the globe.

For Partners and Portfolio Managers who are not familiar with TerraMatch, you can request a demo here. TerraMatch is a 2-way platform we use to 1) collect and store three types of reports from Project Developers and 2) for WRI to share summary results of progress back to Project Developers.

Before we delve into the indicators and methods, it is important to note that every question we ask Project Developers through TerraMatch is deliberate and intentional. We link every question to 7 indicators and their sub indicators as the primary purpose of TerraMatch is to collect and share back valuable data that could strengthen project management and planning. We aim to ask no more than needed and constantly make trade-offs on what's enough to add value to TerraFund partnership portfolio management and for project developers. TerraFund partners are committed to making changes within various product and publication timelines to meet demand from project developers, donors and partners. Suggestions for improvements are welcome through this form.

TerraMatch Set up

All projects are required to complete 2 steps during the set-up stage: 1) create a TerraMatch Profile with accurate information associated with the contractual agreement signed under TerraFund and 2) submit site polygons.

Quality Assessments

The initial data collection phase, creating project profiles and submitting polygons, is critical to the success of tracking progress against each project's goals. We noticed several discrepancies in project profiles such as inconsistent tree planting and hectares for restoration goals. To fix this issue, we established a Quality Assessment process to ensure the alignment of project workplans and goals with agreed upon contracts. Since every project's progress will also be measured against their own set goals and targets, ensuring that goals and targets are accurate and aligned across contracts and project profiles on TerraMatch will improve the MRV that takes place throughout the life of each project.

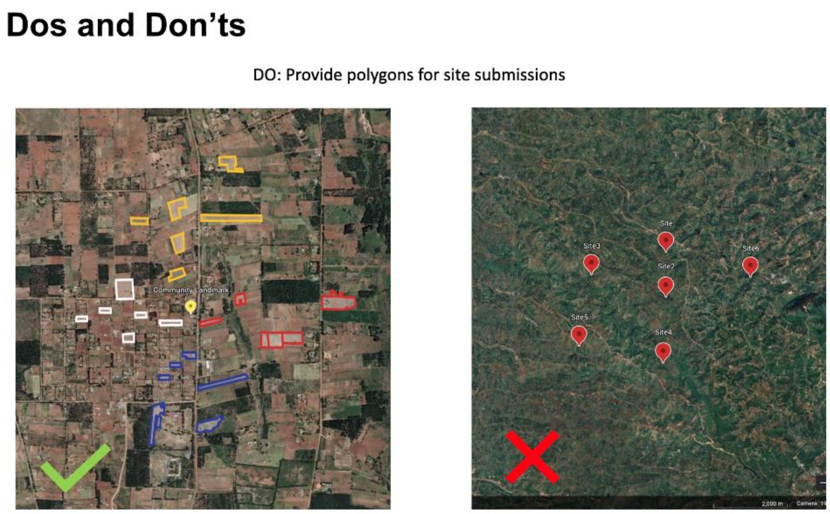
We employ a similar Quality Assessment for 6-month reports and aim to complete this process for the first three 6-month reports (e.g. due on July 2023, January 2024, and June 2024), and we will assess based on the quality of responses whether we will continue beyond the first three reports. The process is used in parallel with data analysis of 6-month report responses to understand:

1. Do the responses seem reasonable within the context of the project funding, project goals and timeline?
2. Do project developers understand the intent of the question and therefore provide answers that TerraFund partners are looking for to track progress that will highlight their work to investors and donors? If not, how can we improve the way we ask the question?
3. Do we need to provide training or extra guidance to project developers to achieve what we're asking?
4. Can we improve TerraMatch to enable quality responses for portfolio evaluation?

Our 6-month report review surfaced issues such as unreasonable jobs created numbers, unrealistic planting numbers based on budget, and responses that do not reflect activities that have been completed. To fix this problem, we continue to work on a combination of solutions such as improving the language of the questions and text description, webinars or direct engagement with project developers, and adjusting the product.

Lastly, we employ a Quality Assessment for Site Polygons submitted on TerraMatch. Polygons are the foundation of how we independently measure progress of 4 out of 8 indicators. Once a polygon has been created and uploaded, WRI quality assesses and segments polygons to ensure precision of the area that will enable project developers to receive credit for their work (e.g. hectares under restoration, trees restored, tree cover change). Through our first quality assessment, we discovered issues which include no polygons submitted, only GPS coordinates, inaccurate polygons, overlapping polygons, and missing attribute tables with polygons. To fix this problem, we have created a guidance document here, a webinar here, and a support unit request form here that provides hands-on guidance to project developers.

Figure 1 | Example of Guidance for Sharing Polygons, Not Point Locations



The slide was presented in a "How-to" webinar to demonstrate the difference between polygons and GPS point locations.

Indicator Reference Sheet
This section describes each indicator in detail, which includes definitions and related sub-indicators. We explain why the indicator is important for progress monitoring and justify why we selected this indicator. For each indicator, we also describe the method, data sources, data analysis, means of verification, and references we drew upon to derive at our decision for choosing each method.

TIER 1 INDICATORS

Indicator 1: Number of Trees Restored

The total number of trees restored across all sites, across the entire project. This number is based on a review of 4 sub-indicators:[4]

1.1 Number of trees under restoration annually and over a 5-year period
1.2 Number of seedlings or saplings grown in nurseries annually and over a 5-year period
1.3 Number of trees counted at Year 0, Year 3, and Year 6 and change in tree count from Year 0 – 6 across all sites
1.4 Percent tree cover at Year 0, Year 3, and Year 6 and change in percent tree cover in restored area across all sites

Indicator 1.1

Number of trees under restoration: This indicator combines 2 numbers: number of trees planted and number of trees grown through assisted natural regeneration practices in planned site areas. This indicator represents aggregated number of trees planted, including applied nucleation, and number of trees grown through assisted natural regeneration (e.g. enrichment planting, direct seeding) across sites over a 5-year period. This indicator is updated with the submission of every 6-month progress report, which continues for 5 years after the final planting occurs.

Created by Dow Martin, WRI.

Guidance for Users
The protocol describes how the total number of trees under restoration is calculated per site and aggregated for each project.

Importance
This set of numbers, total by site and total by project, is used to understand the progress of project implementation throughout the 5 years.

[4] Indicator 1 and the associated sub-indicators were developed in consultation with Conservation International and were informed by CI's Tree Restoration Monitoring Framework. (Conservation International, 2023. Tree Restoration Monitoring Framework: Field Test Edition. Lead author: S. Sprenkle-Hyppolite)

Methodology
The submitted number of trees by species, via TerraMatch, are reviewed by the team to flag errors or gaps for further discussion with the project developer. Once the quality of the report has been assessed and compiled into an annual total by site and project, the numbers will be displayed on TerraMatch against the project's tree growing goal submitted during the application process.

Data Source
Project developers are required to submit the number of trees planted disaggregated by species to TerraMatch as often as they plant. For trees grown through assisted natural regeneration practices such as enrichment planting and direct seeding, stay tuned for additional guidance for how to submit trees planted numbers.

Data Analysis
The number of trees planted results will be quality assessed and verified by site and added across sites to represent the total for each project. This is completed every 6 months after the 6-month progress reports. This data will be used in conjunction with tree count and tree cover in indicators 1.3 and 1.4.

Indicator 1.2

Seedlings grown in nurseries: Number of Seedlings grown in nurseries for tree planting/growing across sites and projects.

Created by Dow Martin, WRI, Siyabulela Sokomani, Nguni Nursery, and Elijah Townsend, One Acre Fund.

Guidance for Project Developers
This protocol describes how to provide a final seedling/young tree count with evidence to be submitted to TerraMatch. This protocol is used prior to the tree planting for each site.

Importance
Nursery tree count is an intermediary progress indicator for the number of trees planted/grown. In the early stages of project implementation, when seedings or saplings have not been planted, projects can still report progress on their seedlings, showing partners and investors that their tree planted/grown target are in progress.

Methodology
Seed cultivation and plant development can take from a few days to over a year, depending on the stage they will be planted either as seedlings or saplings. For restoration interventions that require germination in nurseries, each project can report the number of viable seedlings by species for each site. Viable seedling means that from seeds filled in sockets, at least 1 seedling was formed with 2-3 adult leaves. Seedings are counted as soon as they reach the viable stage, disaggregated by species, and each seedling is only counted once. The information can be

requested from the nursery or compiled in-house by the project developer to be submitted on TerraMatch.

(Optional) In addition, projects may provide evidence of nursery production progress at key moments following the example below. At target setting stage, if a project has a goal of planting 1,000 seedlings, they typically aim to have more seedlings in their nursery to mitigate risks of poor survival or seedling damage. At a later stage, a project's capacity to deliver on their target planting goal can be assessed during the nursery management stage by reviewing their plans for dealing with risky scenarios. All documentation should be uploaded to TerraMatch or shared with your project manager.

(Optional) Example
Once the site or sites in a project have been determined, each project can upload:
1) at target setting stage

- Site planting plans that include the estimated number of seedlings or young trees that will be planted,
- A schedule working backwards from the date of planting on site, delivery date, viable seedling care and maintenance period, successful germination, filling sockets with seeds, and acquiring seeds.

2) at assessment of capacity to deliver target seedling to site stage

- A sentence explaining any risks to not delivering the target number of seedlings such as low seed availability, high price of soil, limited space, etc.
- A sentence describing adjustments to seedling production towards site target based on capacity to deliver, inputs, and progress on execution.

References
ICRAF, 2021. "The Resources for Tree and Tree Planting Platform." https://tree.worldagroforestry.org/.

Indicator 1.3

Tree count: Remote baseline establishment and evaluation of change in tree count within site areas.

Created by Tesfay Woldemariam, WRI.

Guidance for Users
The protocol describes how to collect tree count data using satellite imagery, and it is used to count trees at three moments in time: Year 0, Year 3, and Year 6. Year 0 is defined as 6 months from the date of the first signed contract in the cohort, Year 3 is 3 years from the date of Year 0, and Year 6 is 6 years from the date of Year 0. For example, if the first signed contract happened on January 1, 2023, then the satellite image used for Year 0 will be the best available satellite data at plot level granularity on or as close as possible to July 1, 2023 and before the planting

date. Year 3 would be on July 1, 2026, and Year 6 would be on July 1, 2029. The results generated from this analysis, which is limited to trees that are large enough to be visible in the imagery, will be verified via comparison with available information from 6-month reports, geotagged photos, and drone imagery data.

Importance

This protocol generates data on the number of trees of a certain size visible within the plot at Year 0, Year 3, and Year 6, developed from best available satellite data at plot level granularity. The method is used as an independent data source to measure progress towards each project's tree planting target.

Methodology

Setting the baseline is a critical step for progress tracking because the data generated at the baseline will be used as a benchmark to track progress against the target number of trees to be planted as reported by projects. The objective of the baseline tree count is to know if there are any pre-existing mature trees and if so, how many, since these need to be accounted for in the calculations of progress tracking.

Software and Satellite Imagery

To set Year 0 and collect data on number of trees at Year 3 and Year 6), we use Collect Earth Online (CEO), which is a web-based platform that uses satellite imagery and a sample-based approach to count trees. The satellite imagery used for this protocol is purchased from MAXAR and has up to a 30-cm spatial resolution.

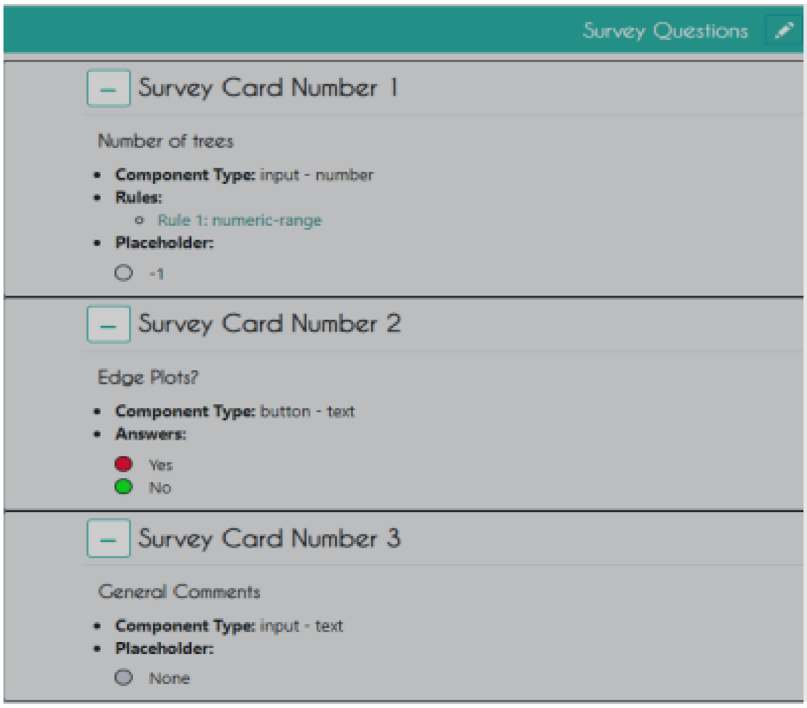
Sampling

We adapted the Winrock sample size calculator to determine the minimum sample size required for statistical soundness. We select random or systematic sampling design and plot shape based on the combination that would be optimal to generate the required sample size. We picked the option that gives us the number as close as to the sample size required but not falling below, which optimizes the cost of data collection while getting enough data for statistical soundness. When polygons are less than 5 hectares, however, we use a wall-to-wall inventory.

Survey

We customize the survey to focus only on tree count, using 3 cards, one for the number of trees (numeric) and the other two for general comments about the plot (text) when relevant. The information on the imagery date and source is automatically registered for MAXAR imagery. The survey created will be stored on the cloud on the CEO platform.

Figure 2 | Collect Earth Online Survey Cards

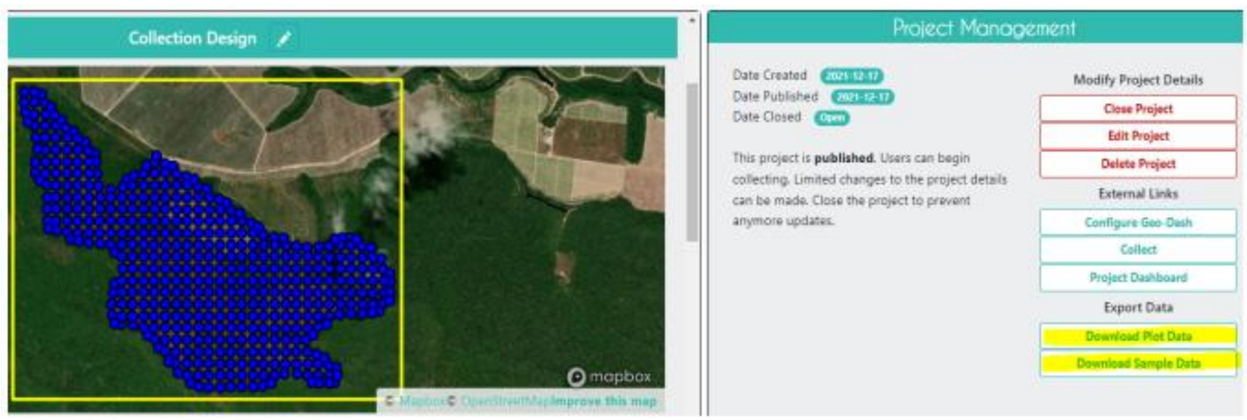


Data Source

Three to five consultants from Vielca, a geospatial data analysis firm, conduct the data collection by random assignment to minimize systematic bias associated with the operators' subjectivity. The best available MAXAR satellite imagery closest to but preceding the site establishment date, are used and operators count all trees inside a given plot. Visual image interpretation clues like the crown size, texture and shape, and shadows are used to differentiate bigger trees from young regeneration. When it is challenging to decide, the operators also use the zoom-in/out technics to compare the object (tree) with appearance of trees in the vicinity for decision.

The completed plot turns from yellow to blue. The CEO survey automatically creates two sets of data, namely the plot dataset and the sample dataset (Figure 3). The resulting CSV table will have a row for each plot with a column where the total count of trees per entire plot is recorded. Sample dataset is not relevant for tree count indicator in our design.

Figure 3 | Completed Collect Earth Online Survey



Quality Assessment

Quality assurance and quality control processes conducted include intensive training and piloting of photo interpretation ahead of the data collection. Additionally, cross-validation is used to account for potential operator bias or error. To perform cross-validation, 5% of the Collect Earth plots are randomly selected using a Python script. A different operator photo-interprets and fills out the survey for these validation plots. Once all validation plots have been reassessed, they are compared with the original results, providing an estimation of the uncertainty of the photo-interpretation results.

Figure 4 Example of Quality Analysis of Results for Project 1

Re-evaluated Plots (ID)	Tree count Quality Control (2nd operator)	Tree count (1st operator)	Difference
14	0	0	0
29	2	5	-3
115	4	16	-12
124	1	5	-4

Re-evaluated Plots (ID)	Tree count Quality Control (2nd operator)	Tree count (1st operator)	Difference
172	2	6	-4
185	5	10	-5
191	3	7	-4
218	1	11	-10
231	1	1	0
233	0	9	-9
255	0	8	-8
287	0	1	-1
288	0	5	-5
291	6	16	-10
323	8	10	-2
339	0	0	0
374	1	8	-7
384	0	8	-8
385	5	9	-4
396	0	4	-4
407	0	0	0
414	1	8	-7
418	1	7	-6
438	0	2	-2
468	0	4	-4

Year 0 Data Analysis

We typically see 2 types of areas at Year 0: (1) an area that is bare or without trees and (2) an area with residual trees. The more common of the two is an area with scattered residual trees where we must determine how many trees existed at the time of site establishment prior to new restoration activities.

At Year 0, we only count mature trees because we want to quantify pre-existed 3-5m trees before the start of TerraFund interventions. That way, we do not include trees that existed prior to TerraFund interventions in the total number of trees restored by Year 6. The total number of trees per site is then calculated by:

Number of trees in sampled area (count)* Site area (ha) / Total size of sampled area (ha).

Figure 5 | Example Summary Results

Site Area (ha)	Plot Area (ha)	Number of Plots	Sampled Area (ha)	Average Number of trees per Plot	Standard Deviation	Number of trees per Sampled Area	Average Number of Trees per hectare	Number of Trees per Site
165.00	0.43	331.00	142.33	38.50	2.85	8,737	90	10,129
13.00	0.09	26.00	2.34	4.23	4.37	110	47	611
176.00	0.09	201.00	18.09	6.88	5.00	1,382	76	13,446
114.00	0.09	217.00	19.53	8.23	4.59	1,786	91	10,425
17.00	0.09	107.00	9.63	0.60	1.00	65	7	112
9.00	0.09	69.00	6.21	1.10	1.42	73	12	107
20.00	0.09	137.00	12.33	0.40	1.46	52	4	85

Year 3, Year 6, and Change in Tree Count/ Area Analysis

In Year 3 and 6, we will go back to the same plots and collect tree count data again. All mature trees will be counted.

Using the same approach and analysis, a similar table as shown above will be generated for Year 3 and 6 for each site. Each cell value will be compared to the baseline. The change in tree count will be calculated using the difference (number of trees in year 6 - number of trees in year 0). Trees recorded in Year 0 should be discounted from the total in Year 6 as those trees pre-dated the intervention. The analysis results will be used in coordination with information from 6-month reports such as the number of trees under restoration from planting and assisted natural regeneration practices, and target number of trees promised during site establishment report.

References

Data Collection Manual, Spring 2020. CEO Team

Institution & Project Creation Manual, Spring 2022. CEO Team

Walker, S.M., Pearson, T., Brown, S. 2007, 2014 Version. Winrock's CDM A/R Sample Plot Calculator Spreadsheet Tool.

Indicator 1.4

Tree cover: Remote baseline establishment and evaluation of change in tree cover within site areas.

Created by John Brandt, WRI, and Justine Spore, WRI.

Guidance for Users

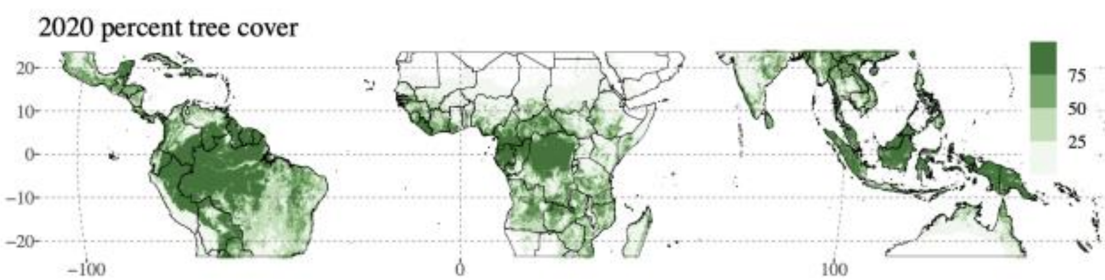
The protocol describes how tree cover will be calculated for all sites in a project. Year 0 is defined as the year of the TTC data that matches 6 months from the date of the first signed contract year. For example, if the first signed contract happened on January 1, 2023, then the

TTC data year is the 2023 or closest available data. Year 3 would be TTC data year 2026, and Year 6 would be TTC data year 2029.

Importance

The Tropical Tree Cover (TTC) dataset (Figure 6) and analyses establish Year 0 tree cover, Year 3 tree cover, Year 6 tree cover, as well as the change in tree canopy cover for all sites in a project. This is an impact indicator that shows the growth of trees over the lifetime of the project. The result can be used for adaptive management. For example, if a project used the same methods in two sites, but have different changes in tree cover percent across the project lifetime %, this insight can be used to understand the contributing factors of project success and/or failure (e.g. soil type, aspect, slope, project size, planting month).

Figure 6 | Tree cover in the tropics. Pixel values are average resampled from 10 meters to 10 km.



Methodology

Baseline Tree Cover Analysis

TTC data will be used to analyze tree cover within all site polygons to calculate the baseline tree cover percent at the year of site establishment (Figure 7). The analysis will be shared with project managers to estimate/adjust the target canopy cover at Year 5. We average tree cover percent across the site for Year 0 to set the baseline. Then, we calculate percent error and a plus/minus tree cover percentage for each site to reflect the accuracy of the baseline number. There is uncertainty involved in measuring biophysical characteristics of a landscape, and accounting for error enables users to make informed interpretations with the data.

We consider four sources of error in the data: subregion, land use/land cover category, site boundary and site size, and calculate percent error for each source using Formula 1. The percent error is then propagated into one accuracy metric for each site using Formula 2. We calculate percent error by generating an expected value of the site's average tree cover at baseline and an observed value based on the site's characteristics from the four error sources above.

$$\frac{(Observed - Expected)}{Expected}$$

Formula 1. Percent error formula.

$$\sqrt{\sqrt{(error_1)^2 + (error_2)^2 + (error_3)^2}}$$

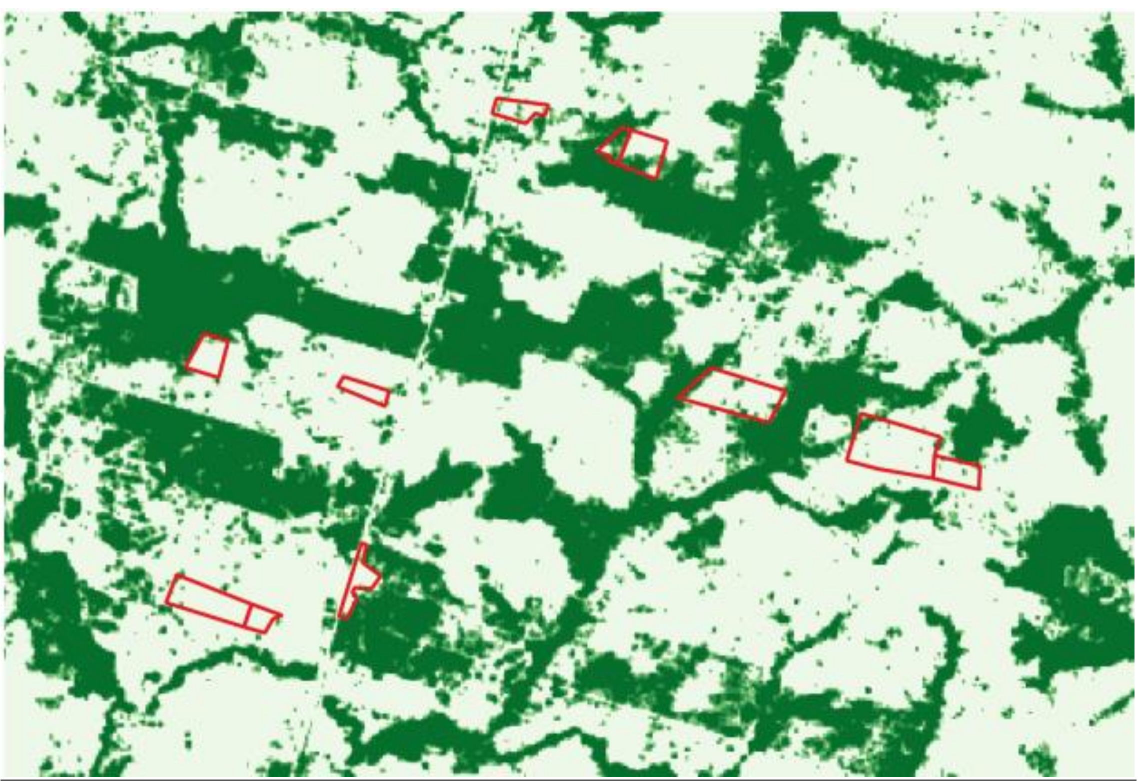
Formula 2. Error propagation formula.

Expected values for subregion and land cover/land use are derived from published accuracy metrics for the TTC data, considering how well we expect the data to perform in different regions of the world and on different types of land.

Error related to the site boundary considers the landscape directly surrounding the site, in the event that the polygon provided for the site does not perfectly capture the boundaries of where the intervention is occurring, as well as accounting for imagery co-registration error. We shift each site boundary in nine cardinal directions by 12m, the co-registration performance at 95% confidence for 2020 Sentinel products (Sentinel, E. S. A.), and calculate an expected value based on the shifted site boundaries.

Lastly, the minimum mapping unit for TTC tree cover data is at 70m resolution, so for sites that are smaller than a half-hectare we add a fourth error source to the propagation formula. This number is derived from calculated accuracy at different pixel scales and extrapolated for different resolutions and average tree cover percent.

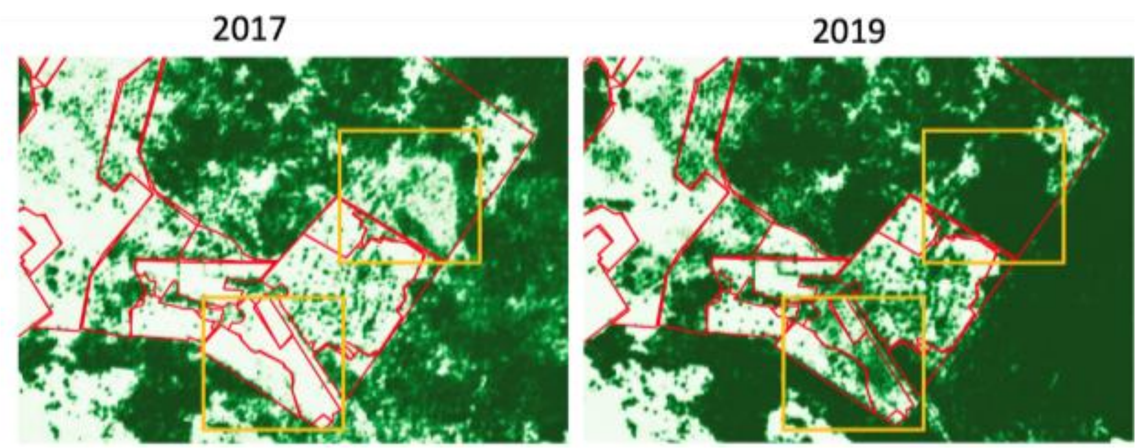
Figure 7 | Example baseline tree cover data in green for project polygons in red



Change in Tree Cover Analysis

The change in tree cover between Year 0, Year 3 and Year 6 will be calculated by applying change detection methods from Wu et al. (2017) to the corresponding years of TTC data for each site polygon (Figure 8). This change detection method uses Bayesian soft fusion to adjust the simple difference in tree cover based on an unsupervised change detection algorithm (iterative slow features analysis) on the satellite imagery. This minimizes the impact of seasonality, camera angle, and other random effects on the calculated tree cover change. The intrinsic and extrinsic errors for each year of TML data will be compounded and applied to remove change events that are not statistically significant.

Figure 8| Shows an illustrative example of how the TML dataset presents change in tree cover visually in a mixed agroforestry and reforestation area in Mexico in red. The yellow squares highlight an increase in tree cover.



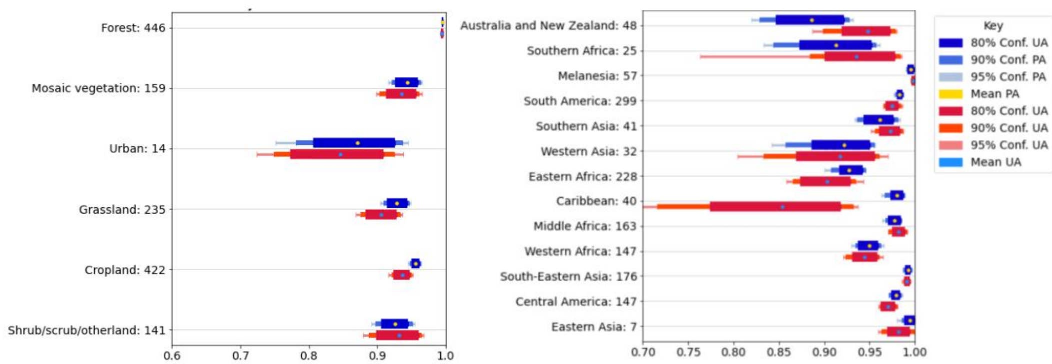
Data Source

WRI developed a new deep learning methodology to create a globally consistent tree cover dataset at the 10-meter scale. The methodology addressed many of the barriers to deep learning in large scale remote sensing identified in Ma et al. (2019) by incorporating recent approaches to improving generalized and per-pixel accuracies of convolutional neural networks. A full description of the methodology can be found in Brandt and Stolle (2020). WRI modified the methodology to improve detection of small and scattered trees:

- Training the model on 18,100 2-hectare photo-interpreted plots
- Applying terrain flattening to Sentinel-1 data
- Improving cloud shadow detection
- Altering the neural architecture to improve generalizability through improved hyperparameter tuning and model architecture searches
- Adjusting the input remote sensing indices based on hyperparameter tuning

The 2020 TTC data enables accurate monitoring of trees in urban areas, agricultural lands, and in open canopy and dry forest ecosystems. TTC maps tree extent with high accuracy across the tropics, achieving an average of 97% user's and producer's accuracy (Figure 9).

Figure 9 | User's accuracy (UA) and producer's accuracy (PA) for 1,418 test plots, totaling 278,000 10x10m pixels, disaggregated by subregion and land use/land cover. Error bars represent the 80, 90, and 95 percent confidence intervals derived from 10,000 bootstrap iterations.



References

Brandt, J., Stolle., F. A global method to identify trees outside of closed-canopy forests with medium resolution satellite imagery. International Journal of Remote Sensing 42, 1713-1732 (2020).

Brandt, J.,Ertel., J., Spore, J., Stolle, F., 2022. The extent of trees in the tropics. Working Paper. Ma, L., Liu, Y., Zang, X., Ye, Y., Yin, G., Johnson, B. Deep learning in remote sensing applications: A meta-analysis and review. ISPRS Journal of Photogrammetry and Remote Sensing 152, 66-177 (2019).

Sentinel, E. S. A. "L1C Data Quality Report." (2).

Wu, C., Du, B., Cui, X., Zhang, L. A post-classification change detection method based on iterative slow feature analysis and Bayesian soft fusion. Remote Sensing of Environment 199, 241-255 (2017).

Explore data on Global Forest Watch, and the code and methodology on GitHub

Indicator 2: Hectares Under Restoration[5]

Indicator 2.1

Hectares under restoration – The total land measured in hectares with active restoration intervention based on polygons and data submitted by projects.

Hectares by intervention – The total land measured in hectares with active restoration intervention, disaggregated by intervention.

Created by Ed Saenz, WRI, Tesfay Woldemariam, WRI.

Guidance for Users

The total area under restoration in hectares is calculated using the site boundary polygons and in unique situations polygons created by point data. The protocol provides guidance for how to calculate hectares under restoration and by intervention, which are used as input for measuring progress against 5 indicators.

Importance

Polygons and related attribute tables are critical to the assessment of impact and indicators 1.3, 1.4, 2, 2.1, and 2.2. They are the basis for generating accurate tree count, tree cover, and data for other indictors within each site area over the lifetime of the project. Polygons are required as input to create Collect Earth Online surveys used to collect tree count, estimate tree cover, and accurately estimate the hectares under restoration and by intervention.

Methodology

Data Source

Every project must submit a shapefile or KML of the site boundaries on TerraMatch. A site must be a contiguous plot of land that is subdivided into sections based on intervention type, with the intervention type specified in the attribute table. If the restoration project contains noncontiguous plots of land, then there is automatically more than one site (Figure 10).

The size of each site (in hectares) is calculated, and the area of all sites is aggregated by project in a GIS software.

[5] Indicator 2 and the associated sub-indicators were developed in consultation with Conservation International and were informed by CI's Tree Restoration Monitoring Framework. (Conservation International, 2023. Tree Restoration Monitoring Framework: Field Test Edition. Lead author: S. Sprenkle-Hyppolite)

Figure 10 | What is the difference between a site and project boundary

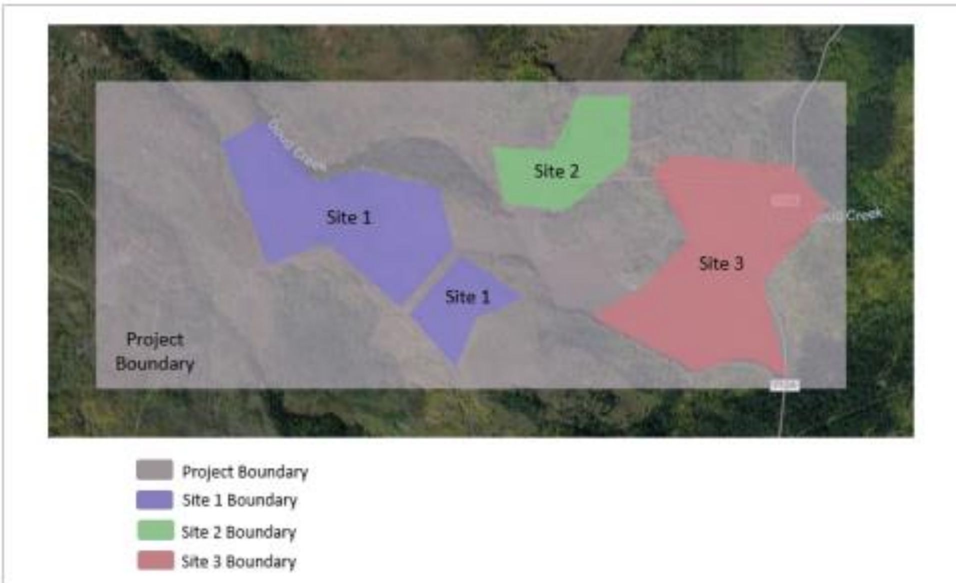
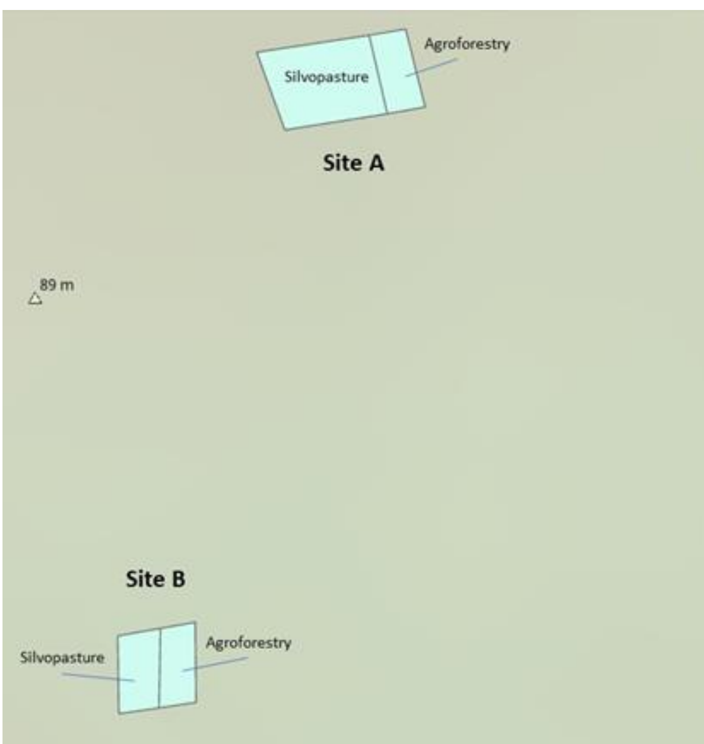


Figure 11 | Example of Projects with Multiple Sites and Interventions



A site boundary includes the area of active restoration. Each site polygon must contain a site ID, site name, and restoration intervention(s) in the attribute table (Figure 12). Additional attributes are welcome, but not required.

Figure 12 | Attribute Table

Name of Site	Intervention Type
Site 1	Silvopasture
Site 1	Agroforestry
Site 2	Direct Seeding

Quality Control

We review each submitted shapefile or KML to make sure it can be opened in GIS software or in Google Earth. We then ensure that the area reported in the application of the proposals is equivalent to the area of the submitted project polygon. Additionally, we will ensure that the attribute table fields, and coordinate system information are correctly reported.

Please see: Guidance - How to Create Boundary Data for TerraMatch.docx (sharepoint.com) for step-by-step details and definitions to share with Project Developers.

Indicator 2.2

10-year lookback analysis—The lookback analysis reviews land conditions and tree dynamics going back 10 years before the start of the project.

Created by Tesfay Woldemariam, WRI.

Guidance for Users

This section describes how and why we compiled this method to better understand land and tree conditions prior to any restoration activities. Lookback analysis surfaces historical disturbances going back to 2010 using satellite-derived data on tree cover loss due to fires and non-fires causes. This is different from personal accounts or documented accounts from people who know the land. The analyses described in this protocol are completed by data analysts to verify if deforestation occurred in the project area before planting, using remote sensing.

Importance

Major disturbances may include fire, flood, hurricanes, uncontrolled grazing, pest outbreaks, and intentional clearing. Some disturbances are natural, some are human-driven - and all can cause major setbacks to tree restoration efforts. We use the results of this baseline indicator to support project developers in planning or designing restoration activities and managing their projects.

Methodology
Project sites are uploaded to Global Forest Watch (GFW) using an API script. Data layers relevant to disturbances are selected, and after running the script, an Excel file is generated with an annual summary for each data layer used.

Data Selection Criteria
We developed the following criteria to choose the most fitting data layers:

- Relevance and feasibility: data must be relevant to land or tree disturbance and can be assessed remotely.
- Coverage: data must have global coverage as we would like to standardize this process no matter the geographic location of the project.
- Spatial Resolution: data must have 30m or higher resolution.
- Time scale: data must exist for the 2010–2021-time scale.
- Frequency: data must be aggregated at least every year. Finer resolution such as daily or monthly is acceptable.

Data Source
The primary source for lookback analysis data is from GFW. The following data layers were selected based on the above criteria.

- UMD tree cover loss (Global, 30m, annual, 2001-2020) Shows year-by-year tree cover loss, defined as stand level replacement of vegetation greater than 5 meters, within the selected area. Note that "tree cover loss" is different from "deforestation" – tree cover loss includes change in both natural and planted forest and does not need to be human-caused. The data from 2011 onward were produced with an updated methodology that may capture additional loss.
- Tree cover loss due to fires (Global, 30m, annual, 2001-2020) Identifies areas of tree cover loss due to fires compared to all other drivers of tree cover loss. This data is produced by the Global Land Analysis & Discovery (GLAD) lab at the University of Maryland and measures areas of tree cover loss due to fires compared to all other drivers across all global land (except Antarctica and other Arctic islands) at approximately 30 × 30-meter resolution. The data were generated using global Landsat-based annual change detection metrics for 2001-2020 as input data to a set of regionally calibrated classification tree ensemble models. The result of the mapping process can be viewed as a set of binary maps (tree cover loss due to fire vs. tree cover loss due to all other drivers).
- Global 30m forest cover loss map (Hansen et al 2013) for 2001-2020 is disaggregated into forest loss due to fire vs. other disturbance drivers. The map matches the sample-based area estimates of forest loss due to fire ± Standard Error for all continents except Africa. This allows producing sub-regional map-based area estimates with a measure of uncertainty. Code 4 (high certainty of forest loss due to fire) corresponds to sample area estimate minus SE, adding code 3 (medium certainty) to code 4 (high certainty) pixels results in map area matching the sample-based area estimate, and adding code 2 (low certainty) pixels to codes 3 and 4 (medium and high certainty) yields map area matching sample area estimate plus SE. Code 5 corresponds to all forest loss due to fire in Africa; code 1 corresponds to forest loss due to other (non-fire) drivers.

Data Analysis
A python script was developed to upload the site boundaries into GFW and run the analysis of tree cover loss in hectares. The analysis generates an annually aggregated table (CSV file) where each site would have a row showing tree cover loss value. The resulting row values are calculated by multiplying the number (count) of Landsat pixels affected (disturbed) by the area (ha) of each pixel (0.09ha).

Figure 13 | Lookback Analysis of Site Disturbances

Site Area	Year	Tree Cover Loss (ha)	Tree Cover Loss by Fires (ha)	Loss by Non-Fires (ha)	Percent Area Impacted
13.04	2015	12.6	0.3	12.3	96.63
13.04	2016	0.08	0	0.08	0.58
13.04	2017	0.15	0.15	0	1.16
176.26	2012	0.08	0	0.08	0.04
176.26	2015	165.91	1.14	164.77	94.13

References
https://glad.earthengine.app/view/global-forest-loss-due-to-fire#lon=-64.88890488795008;lat=- 25.14263539814906;zoom=4;

Global Forest Watch. "Tree cover loss in [country/province name]". Accessed on 24/05/2022 from https://www.globalforestwatch.org/

frsen-2022-825190 1.20 (umd.edu)

https://weme-2022.web.app/Getting_Started.html

Indicator 3: Number of Jobs Created

Number of jobs created by restoration project or enterprise.

Created by Will Anderson, WRI, Joan Kimaiyo, WRI, Dow Martin, WRI, and Teresa Muthoni, One Tree Planted.

Guidance for Users
Jobs created include all types of roles that directly support the project, including both jobs that already exist and are directly funded by the project and jobs that did not exist before the start of the project.

A "job" is defined as a person aged 15 years or older who has worked for pay, profit, or benefit for at least one hour during a given week, as defined by the International Labor Organization (ILO). Common jobs for restoration projects include trainers, nursery managers, seed collectors, tree planters, monitoring and maintenance staff, and administrative staff, along with other roles.

Project developers submit new jobs created every 6 months in their TerraMatch "project reports" by breaking down each job according to its job type – full-time or not full-time (e.g. part-time, temporary, seasonal, casual, or day labors – and the demographic categories that fit each employee within that job type – women or men and age group 15-35 or above 35). Project developers count each of the demographic categories that pertain to each employee, e.g., 1 full-time employee is counted as only one job but could be included in the tallies for the "women" and "age group 15-35" categories within the "full-time" job type.

Additionally, project developers are asked how many jobs are created in each function (e.g. project management, nursery management, site preparation, tree planting, tree and site maintenance, or transporting seedlings and inputs, or other).

Since these employees will be paid, project developers are asked to keep personnel list, salaries, and records on the functions of jobs performed (e.g. nursery management, site preparation, tree planting, tree and site maintenance, or transporting seedlings and inputs), and length of employment or contracts. These details should be included in the Financial Report Template.

Project developers are also asked to count unpaid volunteers, including tallies for "women" and "men" as well as "age group 15-35" and "above 35". Again, a volunteer can be a "woman" and included within "age group 15-35".

Definitions:

- *Full-Time Employees* are people that are regularly paid for their work on the project and are working more than 30 hours per week throughout the year.
- *Part-Time Employees* are people that are regularly paid for their work on the project and are working less than 30 hours per week throughout the year.
- *Temporary Employees* are people that are paid for their work on the project but work sporadically for less than four months in total per year.
- *Volunteers* are people that are freely dedicating their time to the project but are not receiving payment for their work.
- *Youths* are defined as people between and including the ages of 15 and 35, following the African Union's definition.

Importance

Investment in forest and landscape restoration is touted for creating jobs in rural areas. Therefore, both demographic information and the number and types of jobs created are necessary to quantify and assess the benefits of restoration projects.

Researchers can also use this data to complement additional surveys or focus groups to understand the types and quality of jobs within the restoration sector and which demographic categories benefit from the highest quality and full-time jobs. The information in this indicator is also connected to the livelihoods metrics covered by Indicator 4.

Methodology

Quality Assessment

Project developers establish their aggregate job creation goal when they first submit their project information on the TerraMatch platform. After a “project report” is submitted, an assigned project manager reviews these totals by following a standard quality assurance process and works with the project developer to ensure the reported figures are accurate. If there are any adjustments needed, the project developer recompiles the figures and updates them on TerraMatch. They are then considered accurate following a final check from the project manager.

Verification

Jobs created will be verified using personnel and salary lists that are part of the Financial Report Template, which contain information about any persons employed within the project period: name, identification number, village/places of residence, contact information and type of work undertaken by the specific person. The project developer is to keep such records of persons employed through the project or any other such document that could provide proof of employment for all the people engaged in the restoration process. The information on jobs will also be verified and checked to avoid double counting of persons directly engaged in the project.

Data Source

The source of the number of jobs created is the project manager-approved six-month reports submitted by project developers on TerraMatch. The data is verified through personnel lists provided by the project developer which should be submitted to the project managers upon request.

Data Analysis

To understand the overall job benefits of the TerraFund for AFR100 cohort, we aggregate:

- Total number of jobs created
- Number of employees with full-time and non-full-time jobs
- Number of employees that are women and men
- Number of employees within age group 15-35 and age group above 35
- Number of jobs by function
- Total number of volunteers
- Number of volunteers that are women and men
- Number of volunteers that are within age group 15-35 and age group above 35

The results are reviewed against project developer’s socioeconomic goals and targets established at the application stage. The data might also be presented in summarized forms using descriptive statistics and boxplot graphs such as below for project managers and partners to review across the TerraFund portfolio.

Figure 14 | Summary of persons employed

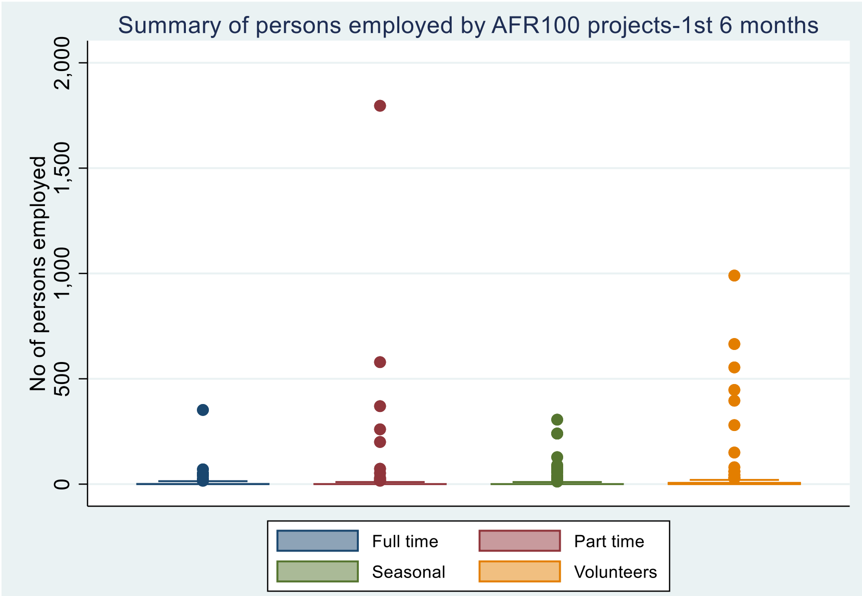
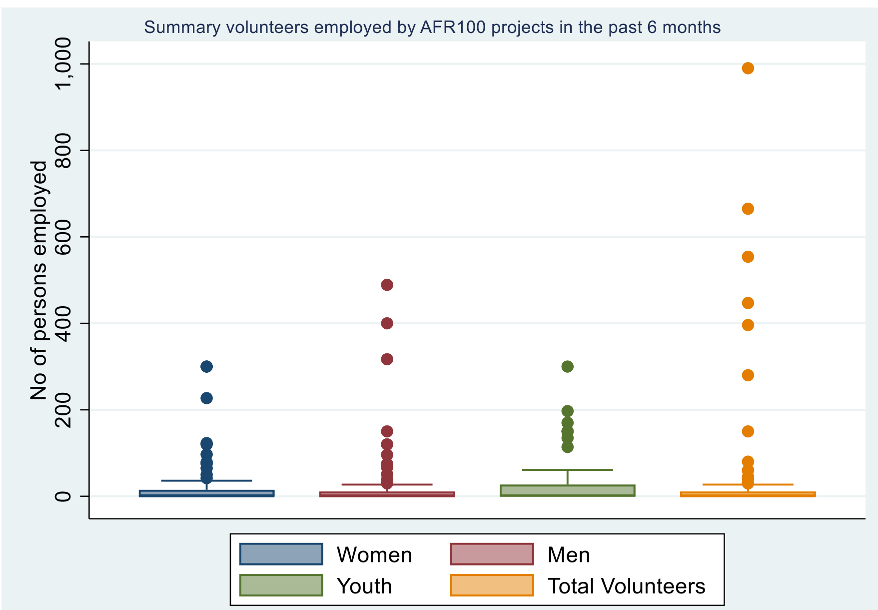


Figure 15 | Total Volunteers Disaggregated by Gender or Age



Analysts might also follow up with a select few projects to request additional information from projects through structured interviews, focus groups, or questionnaires to better capture impact narratives associated with job creation and multiplier effects on community incomes, local economies, women empowerment, and food security.

References

[International Labor Organization]

[African Union]

[FAO]

TIER 2 INDICATORS

Indicator 4: Livelihoods[6] Benefits

Entrepreneurs and projects are required to report on the number of people who have benefitted from TerraFund and how they have benefitted, including the types of benefits and the demographic categories of people.

Created by Joan Kimaiyo, WRI, Dow Martin, WRI, and Teresa Muthoni, One Tree Planted.

Guidance for Users
Project developers are asked how many people have benefitted from TerraFund and in which way have they benefitted. This is an open question that includes direct and indirect benefits. For example, project developers may choose to highlight benefits that is most important to them such as people that have increased yields or productivity on farms, farmers that have successfully adopted a sustainable practice, or people that have reduced food security risks.

Then, project developers are asked more specific questions on the number of people that have reported increased annual income and a short narrative of how they have increased their annual income as well as the number of people that have reported an increase in knowledge or skills through trainings, field demos or any other form of awareness raising and skills development. They are also asked to describe in which way people have gained knowledge or skills (e.g. received training or have visited field demonstrations).

These questions are asked every 6 months, and each question include demographic categories: men or women, smallholder or large-scale farmer, and age group 15-35 or above 35. Each category count is exclusive, meaning that we tally the total number in each category separately. As such, a woman who reported increased income can also be a smallholder farmer and in the age group 15-35.

Definitions

- *Smallholder Farmers* are farmers that operate on less than 2 hectares of land, as defined by FAO, often only for subsistence and are characterized by limited resources and often rely on family labor.
- *Large-scale Farmers* are farmers that operate on more than 2 hectares of land, undertake intensive agriculture often mechanized, and generate profits enough to sustain their livelihoods. These farmers produce for commercial purposes.

Importance
The co-benefits of restoration activities are difficult to capture accurately and consistently. Our intention is to simplify the quantification and use contextual narratives to support the number. Ultimately, we aim to showcase that restoration has other benefits beyond tree growth and

[6] Definition of livelihood is defined by DFID as a means of making a living that encompasses people's capabilities, assets and income required to secure the necessities of life.

support project developers to tell that story. We would also like to know how restoration benefits women and other disadvantaged groups in the restoration industry as well as other benefits they want to share such as increased community awareness of restoration efforts, improved knowledge and skills on restoration, improved productivity on farms, access to clean water, improved food security, etc.

Methodology

Quality Assessment

Project developers establish their livelihood and socioeconomic goals when they first submit their project information on the TerraMatch platform. After a "project report" is submitted, an assigned project manager reviews these numbers and narratives by following a standard quality assurance process and works with the project developer to ensure the reported figures are accurate. We flag errors made during reporting such as typos and outliers that seem logically unachievable within the reporting period. If there are any adjustments needed, the project developer updates them on TerraMatch.

Verification

The number of people that have reported increased knowledge and skills are verified by attendance or sign-in sheets or pre-and-post evaluation or feedback forms. Additionally, project developers may be selected to join focus groups or additional data collection if they have compelling impact stories.

Data Source

The number of people who have benefitted from TerraFund, the number of people that have reported increased annual income, and the number of people that have reported an increase in knowledge and skills, as well as how they have benefitted are reported by project developers through TerraMatch.

Data Analysis

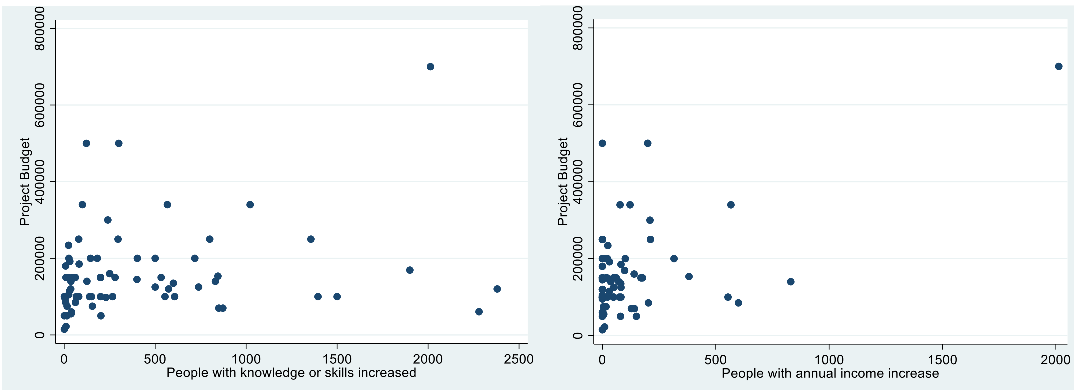
We compare progress to the project's socioeconomic goals and targets and aggregate project totals and narratives on each project report page. We also explore and present portfolio trends—breakdown by demographic category, correlation between budget size and number of people with increased knowledge or skills—to TerraFund partners, donors, and project managers. We aggregate:

- Number of people who have benefitted from TerraFund that are women and men, smallholder farmers and large-scale farmers, and in age group 15-35 and above 35.
- How people have benefitted from TerraFund by theme.
- Number of people that have reported increased annual income that are women and men, smallholder farmers and large-scale farmers, and in age group 15-35 and above 35.
- How people have increased annual income by theme.
- Number of people that have reported an increase in knowledge or skills through trainings, field demos or any other form of awareness raising and skills development that are women and men, smallholder farmers and large-scale farmers, and in age group 15-35 and above 35.

- How people have increased their knowledge or skills through trainings, field demos or any other form of awareness raising and skills development by theme.

And, we explore other trends. A sample figure of the correlation between project budget and the number of increased knowledge and incomes in the past reporting period is shown below.

Figure 16 | Scatter plot of project budgets vs people with increased incomes and increased knowledge or skills in the last reporting period (Jan- October 2022)



We may also follow-up with select projects with compelling data and stories to better understand the impact of restoration activities on increasing community incomes, increased knowledge and skills, improved local economies, women empowerment, and food security.

References

https://www.fao.org/3/ca6927en/CA6927EN.pdf

https://catalogue.unccd.int/616_article_GGW_1-s2.0-S0743016721002850-main.pdf

Indicator 5: Financial Growth

Annual change in revenue and net income for all projects in TerraFund.

Created by Will Anderson, WRI, and Shannon Williams, WRI.

Guidance for Users

TerraFund's financial reporting approach is designed to help project developers build stronger fiscal stewardship and demonstrate their growth over time. The ability to regularly produce and communicate this data can help convince additional funders to support their work.

One reporting requirement is common across both non-profit and for-profit organizations: the submission of audited annual financial statements through TerraMatch each July. In addition, non-profits submit a simple annual financial report that details the funding that they have spent in relation to the budget lines outlined in their contracts.

For-profits submit regular loan re-payments through SWIFT transfers to Realize Impact, which tracks this information through its PE Front Office loan management software. As part of their July TerraMatch project report, they also submit their company's total revenues in USD, total expenses in USD, net income in USD, the number of farmers that they work with, and the number of customers that they have sold to. Analysts then analyze this enterprise data to understand which companies are performing well and to assess the growth of organizations across the portfolio.

Financial data will remain private between the TerraFund team, its donors, and the project developers themselves, but the aggregate trends will be highlighted in impact reports and in public communications.

Importance

Many TerraFund project developers struggle to produce high-quality audited financial statements, which are the backbone of the health of an organization. For small-and-medium enterprises, this is especially important: The lack of a financial statement, where investors can track revenue changes over time, calls into question the ability of that enterprise to pay back any debt or report back to their shareholders. By providing a standard format for all TerraFund recipients to submit their audited financial statements, in addition to profit & loss statements for enterprises, TerraFund can build up the expectation of collecting accurate financial data for growing for-profits and non-profits.

Methodology

For-profit and non-profit, project developers have different characteristics that require project managers to assess financial health in different ways. Both submit financial data annually.

Non-Profits

All TerraFund non-profit applicants submit their financial statements from the three years before implementation, which aids the selection committee to determine the financial health of an organization.

After funding is distributed, non-profits report on their financial health in two ways:

1. As part of their July project report on TerraMatch, project developers submit an audited annual financial statement for their entire organization from the past year, which their project manager briefly reviews. They can use their own format or can follow a sample format provided by TerraFund.
2. As part of the same project report, project developers submit a simple financial report (template here) that highlights the funding that they have spent in relation to the budget lines outlined in their contracts. The project manager reviews this document, checks it against the budget lines outlined in the contract, and then either approves it or asks the project developer for clarifications before approving it.

For organizations that are unable to submit financial information that meet TerraFund standards, WRI and OTP may provide training or additional financial reporting requirements until the project developer can submit accurate financial reports. In the event that accurate financial information cannot be submitted, future payments may be terminated.

For-Profits
All TerraFund for-profit applicants submit their audited financial statements, along with their profit & loss statements, from the three years before implementation, which aids the selection committee to determine the financial health of an organization.

After funding is distributed, for-profits report on their financial health in three ways:

1. Enterprises pay Realize Impact through SWIFT wire transfers. The Realize Impact team logs each repayment and the amount left in the loan to repay through its PE Front Office loan management software.
2. As part of their July project report on TerraMatch, project developers submit an audited annual financial statement and a yearly profit & loss statement for their entire organization, which their project manager reviews. They can use their own format or can follow a sample format provided by TerraFund.
3. As part of the same project report, project developers separately submit their company's total revenues in USD, total expenses in USD, net income in USD, the number of farmers that they work with, and the number of customers that they have sold to. The project manager reviews these figures in conjunction with the audited financial statement and profit & loss statement, and then either approves the report or asks the project developer for clarifications before approving it.

For organizations that are unable to submit financial information that meet TerraFund's standards, WRI and Realize Impact provide training or additional financial reporting requirements until the project developer can submit accurate financial reports. In the event that financial information cannot be submitted, eligibility for future finance may be terminated, and the relevant financial authorities may be notified. As loan finance is issued at once, WRI and Realize Impact have no ability to withhold payments.

Data Source
Non-profit and for-profit project developers submit their financial information as part of their July six-month updates on the TerraMatch platform. Project managers quality assure the submitted data.

Information on loan repayments is catalogued whenever a payment is made by an enterprise through the PE Front Office loan management software, operated by Realize Impact.

Data Analysis
Analysis on financial growth focuses on for-profit project developers. Once the financial information is checked for quality and approved, analysts enter data into a master spreadsheet that contains each enterprise's total revenues in USD, total expenses in USD, net income in USD, the number of farmers that they work with, and the number of customers that they have sold to from each enterprise.

The analysts track this data beginning three years before the loan is issued and ending five years after the final funded tree begins to grow. They then calculate the percent change in each category year-on-year, as well as the total percent change across the enterprise's engagement with TerraFund.

Then, they calculate the year-on-year and total change of the company's total revenue and net income. They will also conduct a qualitative assessment interview once per year with each enterprise, following a standard assessment framework, to understand how the business has grown.

This information will remain private to the TerraFund consortium, its donors, and the enterprise in question. In aggregate, it will be reported publicly in TerraFund impact reports and in communication materials.

References
Example Financial Statement

Financial Report Template for Non-Profits

TIER 3 INDICATORS

Indicator 6: Carbon Sequestered

Biomass carbon sequestered. In pilot, coming soon in September 2023. Created by Edward Saenz, WRI, and Dave Skole, Michigan State University, Forestry Department.

Guidance for Users

Importance
Trees outside of forests are an important but often overlooked natural resource throughout sub-Saharan Africa, providing benefits for livelihoods as well as climate change mitigation and adaptation. The development of an individual tree cover map using very high-resolution remote sensing and a comparison with a new automated machine learning mapping product revealed an important contribution of trees outside of forests to landscape tree cover and carbon stocks in a region where trees outside of forests are important components of livelihood systems. The measurement of tree cover and carbon in these landscapes has important applications in climate change mitigation and adaptation policies.

Methodology
The first step in analysis was to acquire very high resolution (VHR) remote sensing data using the Worldview products. We reprocessed 2-m resolution multi-spectral data by sharpening with 0.5 m panchromatic data. These data are used to manually derive individual crown polygons for all trees in the test site and estimate tree cover and density parameters, which can be compared to tree crown products that use automated methods and to global tree cover products using Landsat data.

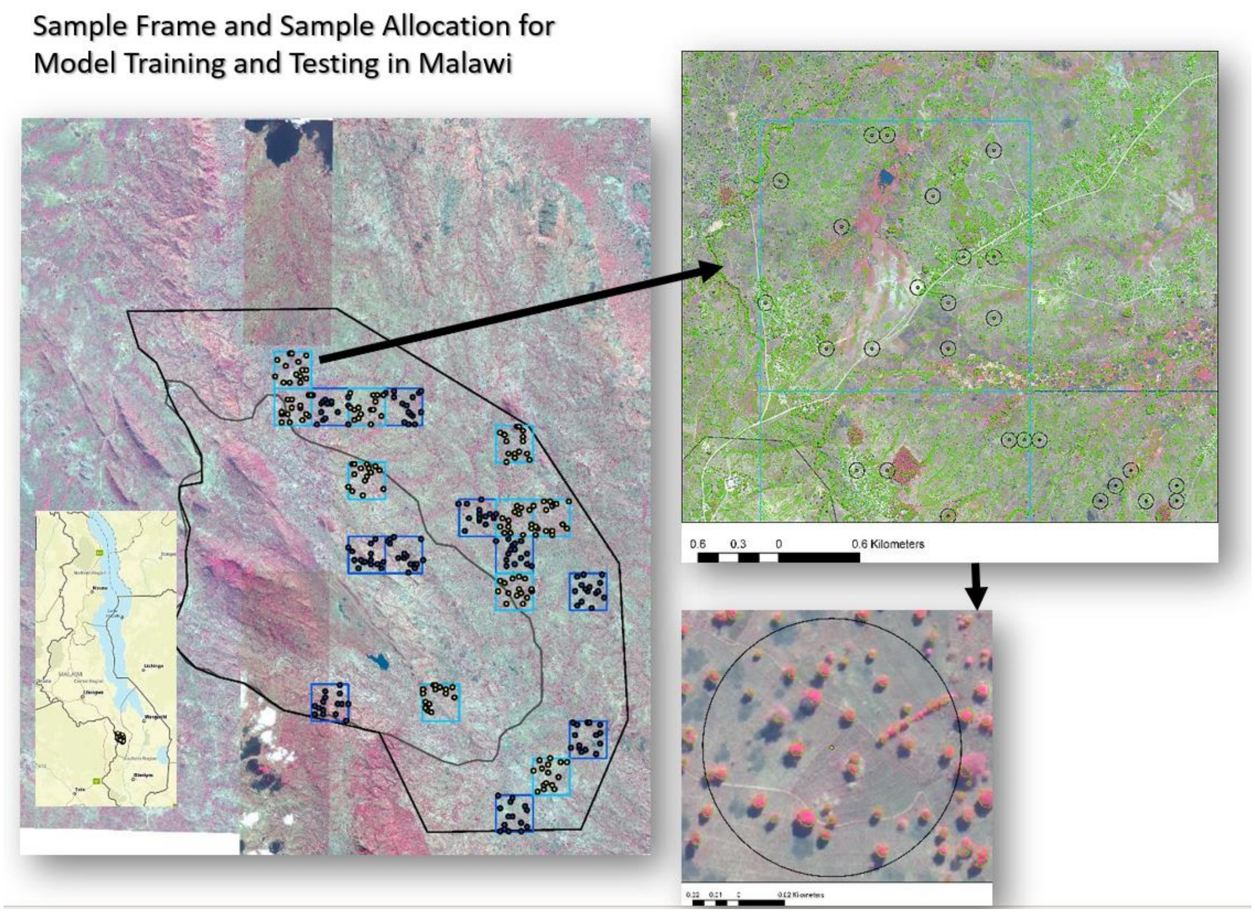
Within the test site, we deployed a field inventory to collect individual tree data on crown areas, standard allometric parameters (cf. diameter at breast height and crown projected area), species and landscape descriptions, and tree location information coregistered to the tree map products. A sample frame inventory was deployed using standard operating procedures for forest carbon inventories [23]. Allometric measurements from field plots were used to estimate diameter at breast height (DBH) from crown projected area (CPA) using linear ordinary least squares regression. The estimated DBH was used as an input parameter in the standard, local allometric equation to estimate tree biomass. The aim of estimating DBH from remote sensing, rather than directly estimating carbon, is so our approach is compatible with national forest inventory practices that routinely use tree and forest inventories from existing allometric equations.

Tree cover mapping
The project acquired VHR data (2 m multispectral, 0.5 m panchromatic) from commercial sources and the NASA Commercial Data archive for the study test site in which individual tree crowns were mapped. (Figure17) The VHR data were processed for geometric registration, and atmospheric correction. Panchromatic sharpening of the 2-m multispectral bands to the 0.5 m panchromatic bands was used to maximize spatial resolution and this product was used as the basic tree crown mapping dataset. Two methods were tested for the mapping of individual tree crowns and measurement of crown geometry. First, all trees with CPAs greater than 5 m2 were mapped using heads-up digitizing, which is a common method used in Senegal and in many other countries. This manual digitizing also has the advantage in that an individual tree and its landscape context can be immediately assessed by the analyst to prevent false clustering of overlapping crowns, which assured that we did not obtain multiple crowns merged into single polygons, which could skew the outputs from the allometric scaling model since it is non-linear. It also allows distinguishing trees from shrubs. It replicates the measurement protocol that would be deployed in field measurements, which calls for defining a circle or ellipse based measurement on the long-axis and its perpendicular axis. To capture the CPA polygon, each tree crown was digitized using the Arc/GIS Construction tool. A large area of forest in the study site, which was also used for grazing livestock, was excluded from tree mapping.

Field Sampling
Although the remote sensing analysis covered the entire test site area, the field parameters were collected on a sample basis. The VHR data were segmented into nine blocks of 400 ha each. Within the nine blocks comprising the study area, we selected three blocks with the highest tree densities to sample individual trees (Figure 17). In these sample blocks, we established 105 random sample plots in agricultural TOF land with isolated trees. Sample plots for plantations

were 0.1 ha in size, while sample plots for isolated agricultural trees were 1.0 ha. All trees in each sample plot with DBH > 10 cm were measured for allometric parameters following standard forest inventory methods: DBH, tree height, crown height, crown long axis diameter, and crown perpendicular axis diameter. Critical descriptor data were also recorded including species, stand plot type, block number, and tree location by GPS.

Figure 17 | Sample Frame and Sample Allocation for Model Training and Testing



Estimation of Tree Stem Diameters from Crown Projected Area

A map of all tree crowns was created from the VHR remote sensing dataset by heads-up digitizing or clipped from the Brandt et al. deep learning dataset in references. Areas of woodland forests were masked out. An ordinary least squares linear regression was estimated from the field-measured DBH and remote sensing CPA using the sample tree data. This produces a simple model to estimate DBH from remote sensing CPA, which can be used in standard allometric equations based on DBH.

Figure 18 | Biomass allometry and carbon estimation parameters

Estimate of Tree Diameter, DBH	$DBH = 0.5389 \times C_{rs} + 15.835$
Aboveground Biomass [26]	$AGB = 1.929 \times DBH - 0.116 \times DBH^2 + 0.013 \times DBH^3$
Aboveground Biomass [29–31]	$AGB = EXP(-1.996 + 2.32 \times ln(DBH))$
Aboveground Biomass [28]	$AGB = 0.091 \times DBH^{2.472}$
Belowground Biomass Factor	$BGB = AGB \times 0.26$
Biomass–Carbon Conversion	$C = (AGB + BGB) \times 0.5$

In these equations, AGB is the tree biomass estimate in kg, BGB is belowground biomass, and Ctree is the estimated carbon stock of trees. DBH is the remote sensing estimated diameter at breast height for the tree and Crs is the remote sensing mapped crown projected area.

Data Source

The projects acquire VHR data (2 m multispectral, 0.5 m panchromatic) from commercial sources and the NASA Commercial Data Archive. The automated detection algorithm was developed by Brandt et al. using their published dataset. This dataset is available from a publicly accessible repository at the Oak Ridge National Laboratory Distributed Active Archive (ORNL- DACC). And field measurement data from field deployments, primarily DBH, Crown size and Heights.

Data Analysis

Coming soon in September 2023

References

[Nation-wide mapping of tree-level aboveground carbon stocks in Rwanda | Nature Climate Change]

Indicator 7: Ecosystem Services Enhanced

Coming soon in September 2023

3 REPORT

Each project receives a summary report of progress on TerraMatch, and TerraFund partners also use aggregated TerraFund results for their organizational tracking, donor reports, and media materials.

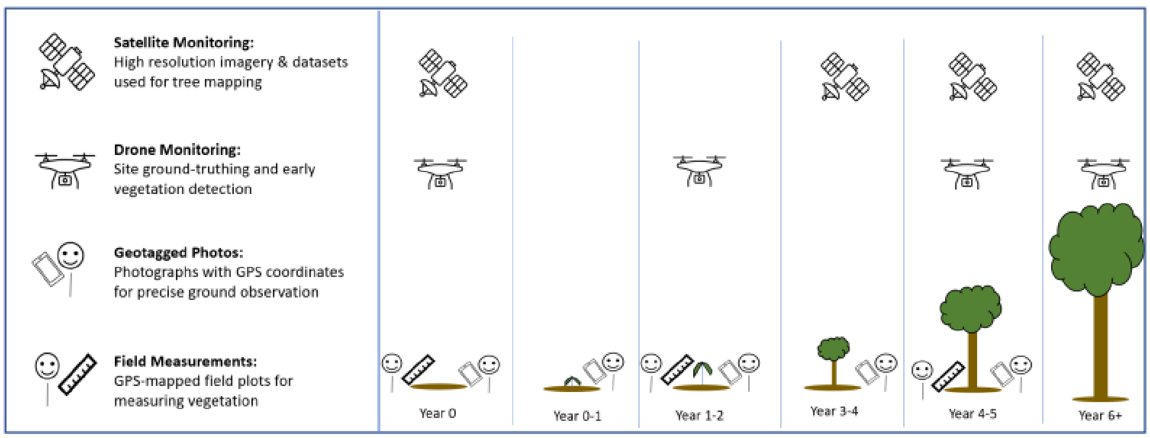
Example of One Tree Planted 2022 Report: 2022 Recap | One Tree Planted

4 VERIFY

[In Pilot, will be updated by September 2023]

Restoration is a fundamental component to aiding our battle with climate change. At WRI, we are pioneering a new approach that empowers locally led restoration projects with technological innovations to set a new global standard in restoration implementation. To prove what's happening on the ground, WRI has designed practical methods that provide reliable, repeatable and robust data to monitor projects throughout their entire lifecycle.

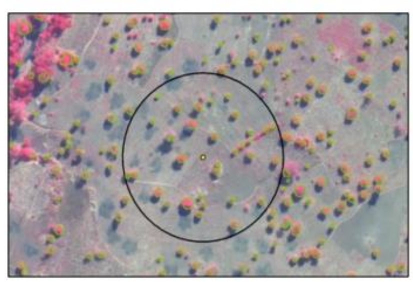
All "Top 100" projects are verified with 4 independent sources of information to cross-check and confirm the accuracy and completeness of reported progress.



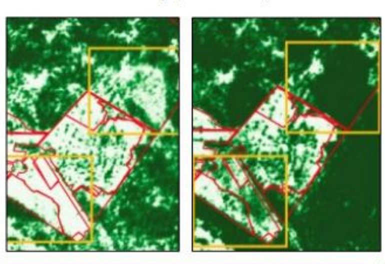
The 4 Ways We Verify

Geotagged Photos (of Planting Sites)

Field Measurements (Tree Count, Crown, Diameter)



Satellite Monitoring (Tree Cover)



Drone Monitoring

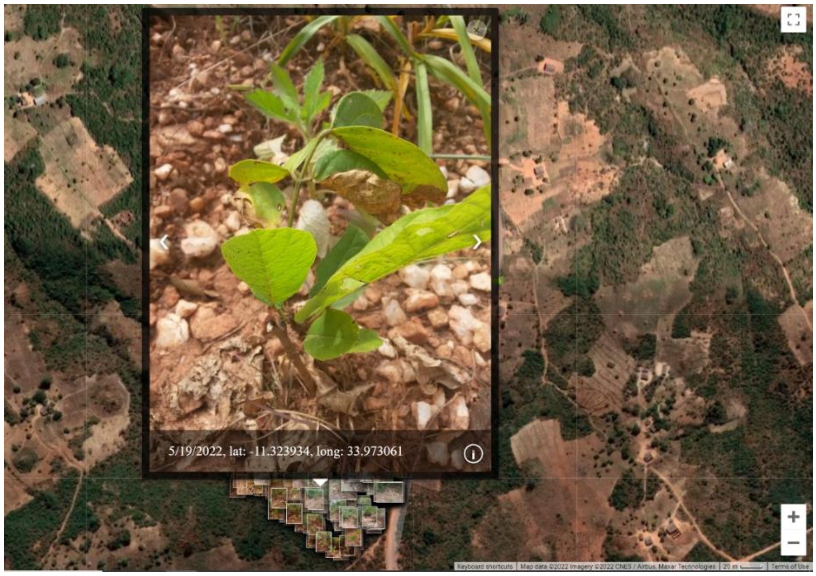
In the first 2-3 years of tree growing and landscape restoration, even the latest algorithm using high resolution satellite imagery can't see enough details to verify that projects are doing what they say. To address that limitation, our verification method brings together the best of field measurements, geotagged photos, drone images, and machine learning algorithms to verify what's truly happening at different stages of the project.

We use Wells for Zoe, a project based in Malawi, to demonstrate how verification works. First, Wells for Zoe submits their project polygon, indicating that the team has selected a site and began their preparation of the area for planting. They also report that they started to dig holes to prepare for a planting event with the community. A few months later, they submit a 6-month progress report through TerraMatch that they have planted 5 native species, totaling in thousands of trees within the area.

To verify these reports, a WRI verifier has 4 independent sources of information to determine the accuracy and completeness of progress reported. Where there is conflict, a WRI verifier flags the location for site visits. The verifier then prepares a verification document that provides a level of assurance, confirming that more than 1 source of direct factual evidence exists to corroborate the report leading to the resulting carbon accounting for the project.

1. Geotagged photos – A trained team takes photos of the current conditions after planting, which shows planted saplings and GPS locations of restoration activities. The team uses mobile phones and revisits the exact locations for additional site verification, as needed. Once taken, these geotagged photos are locked and their GPS locations cannot be tampered with. This method for verification is used as soon as the project starts, is collected based on activities, and is already being deployed at scale.

One of the toughest conditions to verify tree growing is when the planting area is already full of tall, mature trees. Satellites have a hard time distinguishing what was already there and what's new. With the geotagged photo and drone technology combined, the verifier can check that reforesting is needed and track the growth using the date and GPS coordinates of a seedling. The image below shows a planted seedling with a time stamp and GPS coordinates.



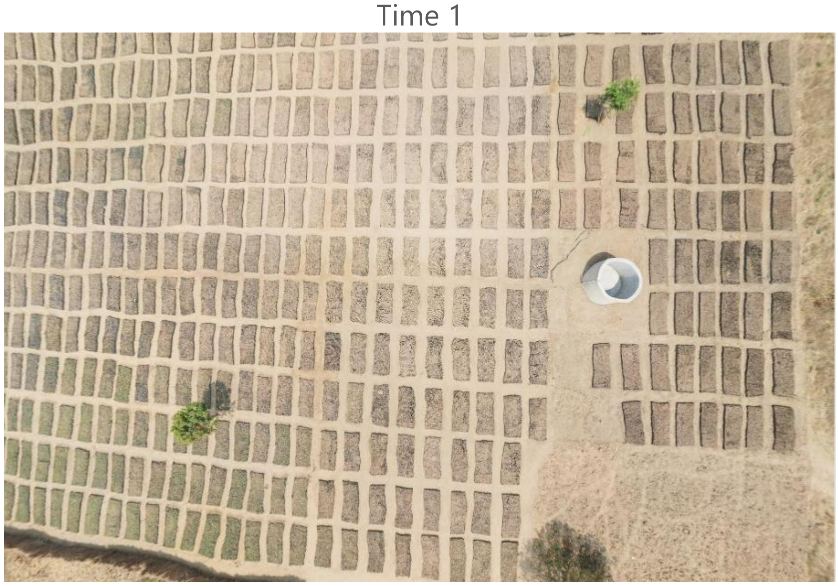
The drone image of the project area below shows very dense forest with red dirt marks, where reforestation is needed.

2. Drone imagery—With polygons of the project area and collections of geotagged photos, we can target our drone flights to specific areas to get a zoomed in view of progress. The image below shows areas with drone images and geotagged photos. This data source for verification is used as soon as the project starts and is available every other year until the end of the project.

Drones are programmed to take flights that correspond to the GPS locations of geotagged photos. The resulting images like the one below are a second source of information to verify if what's been reported matches what the verifier sees taking place.

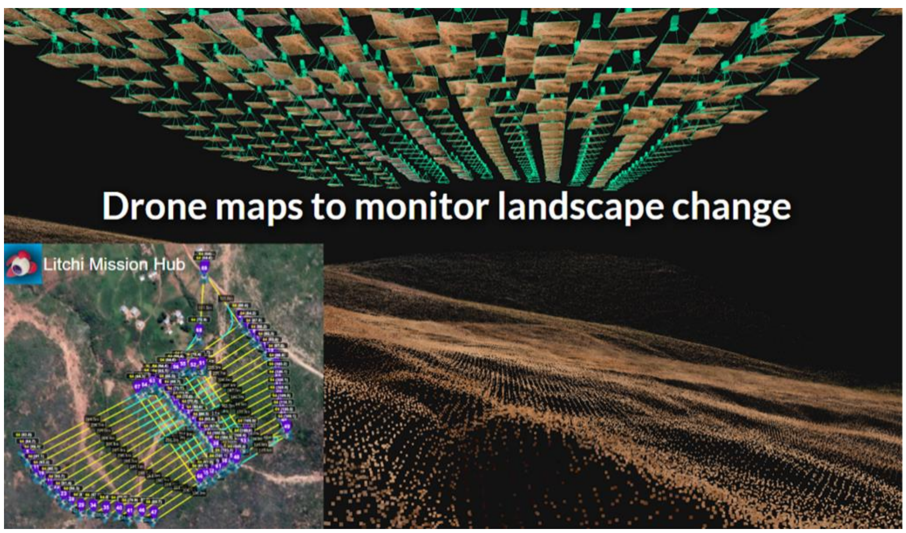
In the photo below, the drone image confirms Wells for Zoe's preparation for a tree nursery and nursery management activities taking place. The quality of the image is fine enough to see beds, water wells before seeding and after. Drone images are ideal for confirming important milestones before tree planting as well as detecting the extent of erosion and degradation in the land that warrants restoration activities.

Time 1



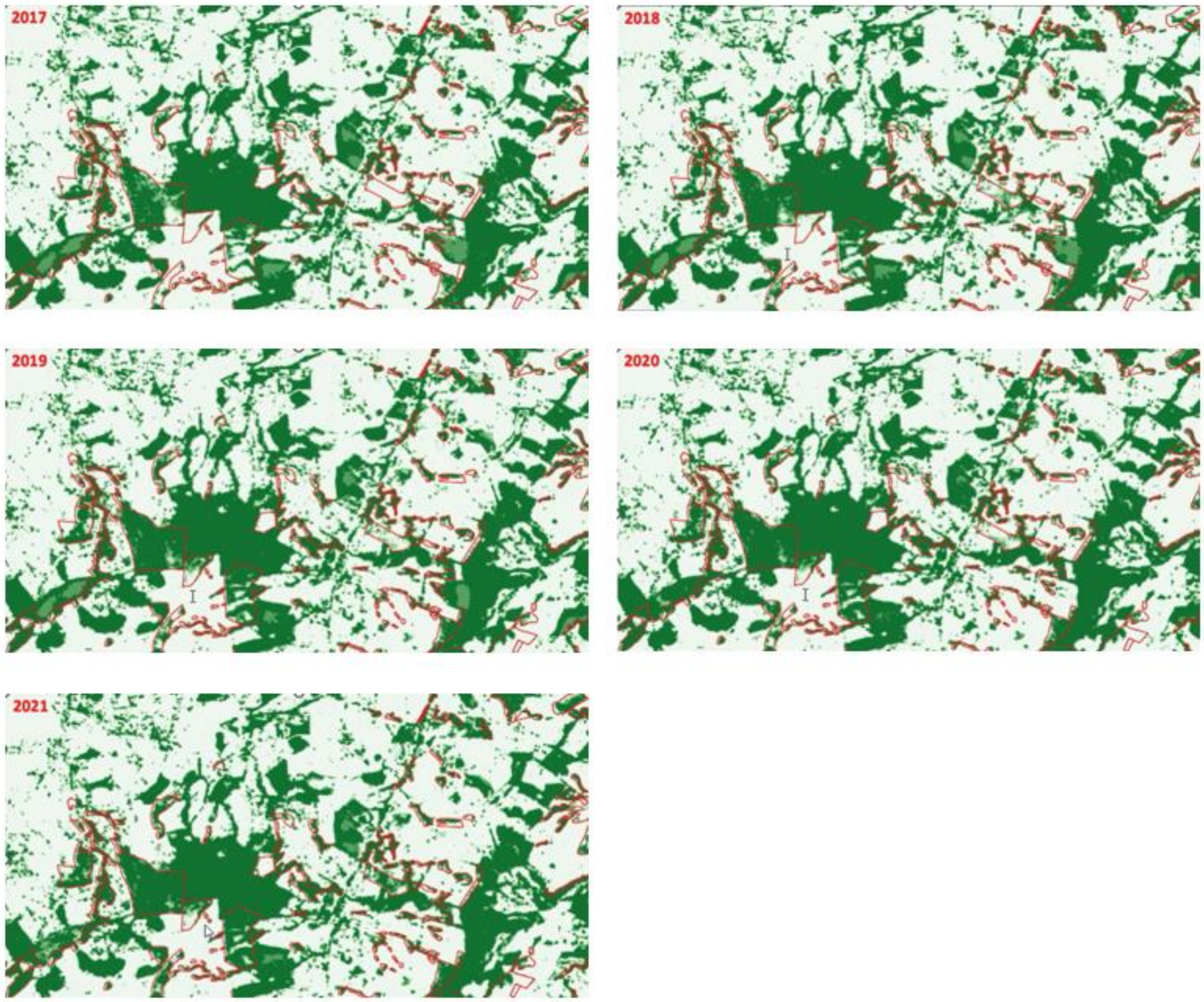
Time 2

Targeted drone flights are commissioned every other year, and over time drone map collections are used to create 3-D scans (3-D point clouds) of the surface. These 3-D scans can show tree growth over the years and conditions of the land.



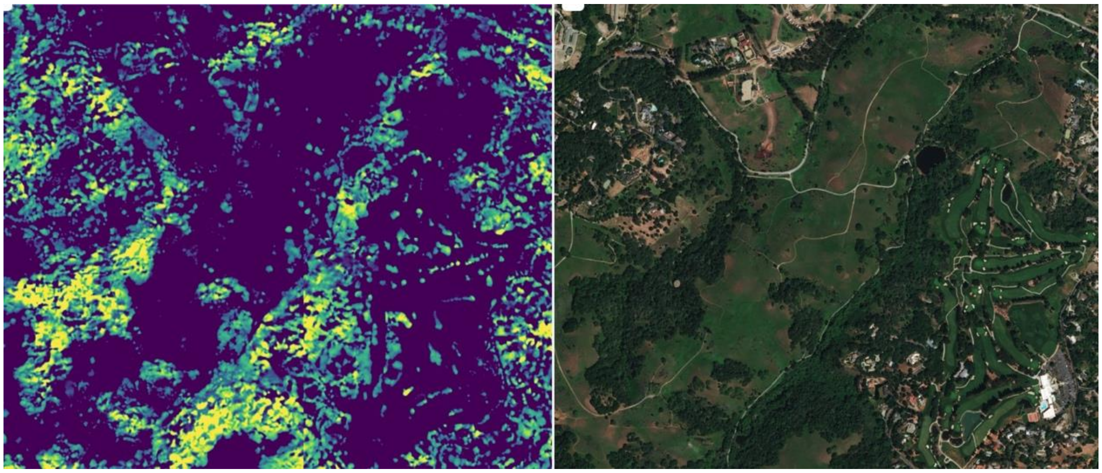
3. Satellite-based analysis – The third source of information is the first-of-its-kind tree cover data that can detect scattered trees and trees on farms. Below represents restoration sites in Brazil. The [prototype gif] and early results of the algorithm show the evolution over 4 years from 2017-2021. The algorithm, in review for publication[3], has an average of 97% accuracy. With this source of independent information and results by site, the verifier would see and quantify change in tree cover over time within a polygon with a confidence level. This method for verification is used after year 3.

[7] https://www.researchsquare.com/article/rs-2109093/v1



Project	**Site**	**% error+/-**	**% Tree Cover 2020**
Project 1	Site A1	7	11.91%
Project 1	Site A2	12.5	21.68%
Project 1	Site B	26.9	46.63%
Project 1	Site C	31.4	54.46%
Project 1	Site D	30.9	53.45%
Project 2	Site A	22.4	38.86%

WRI and Meta are currently partnering (see below figure) to improve the above approach to detect trees sooner, as early as year 1, using commercial Maxar imagery, and to estimate the crown cover and height of individual trees, both key ingredients for carbon calculation. If successful, this method would be the most scalable for monitoring tree growth and their carbon sequestration.

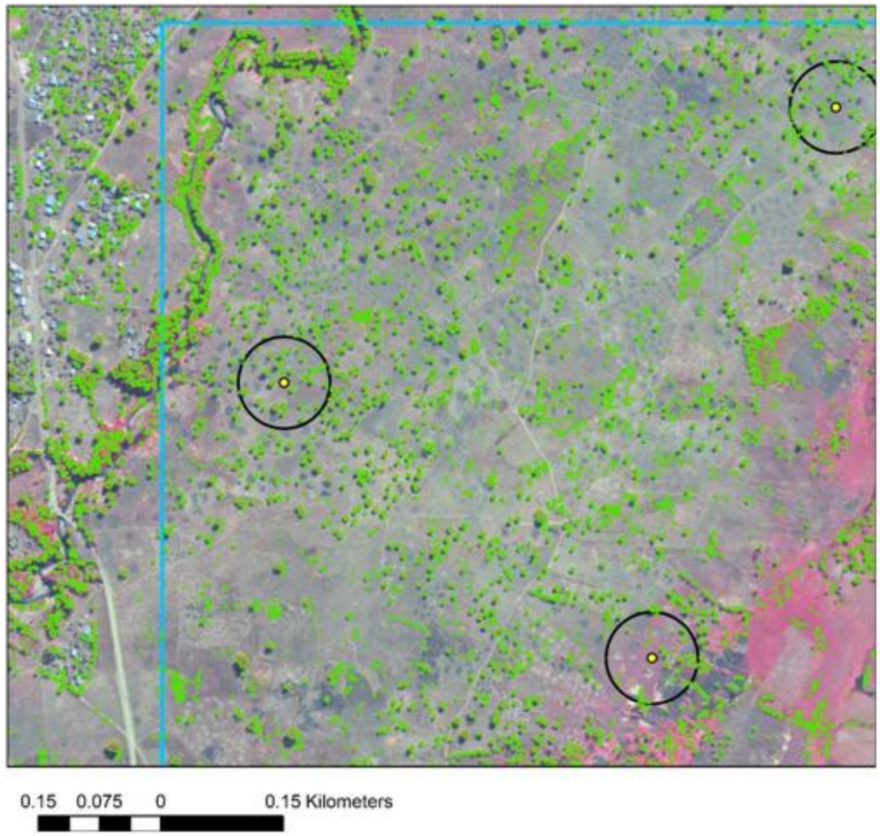


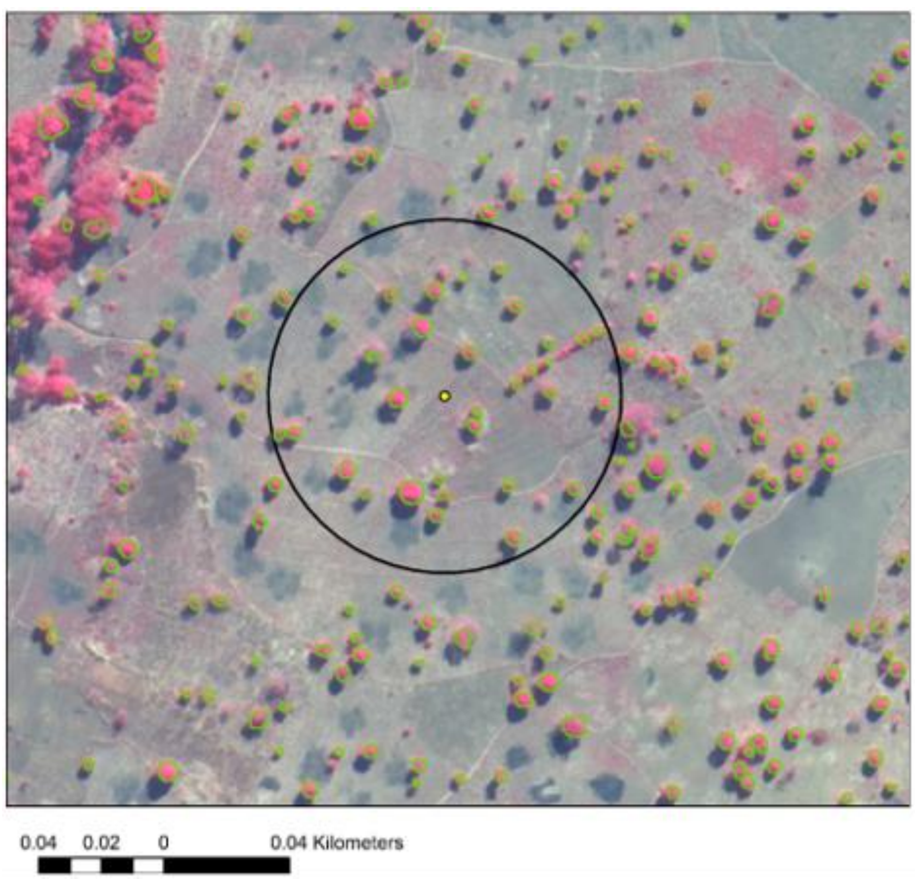
4. Field measurements – We partner with Michigan State University (MSU) Department of Forestry and their collaborating network across Africa to deploy their published method[4] to estimate tree biomass using field measurements (black circles with yellow dot). For each black circle, individual tree count, diameter at breast height, crown projected area, and tree species are collected alongside landscape description and coordinates. This 4th source of data is used to confirm that trees have been planted. This method for verification is used at Year 0 and Year 5.

   These field measurement plots will serve two purposes: anchor points for repeated visits and designated drone mapping locations. The combination of field measurement analysis and machine learning greatly advances our ability to map individual tree crowns covering large areas, making this solution more scalable than any other solutions currently available. This method also solves the most common challenges: crown clustering and distinguishing between trees and shrubs.

   Both images below show the output from a crown detection and mapping model of a Malawi landscape. The top image represents a subset of the entire area, and the bottom image zooms in to illustrate the high-quality crown delineation. Trees are adjusted to pink to contrast with the ground.

[8] Gathering info from source: **The Contribution of Trees Outside of Forests to Landscape Carbon and Climate Change Mitigation in West Africa** – David Skole et al 2021


0.15 0.075 0 0.15 Kilometers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5 EVALUATION

Coming soon in September 2023