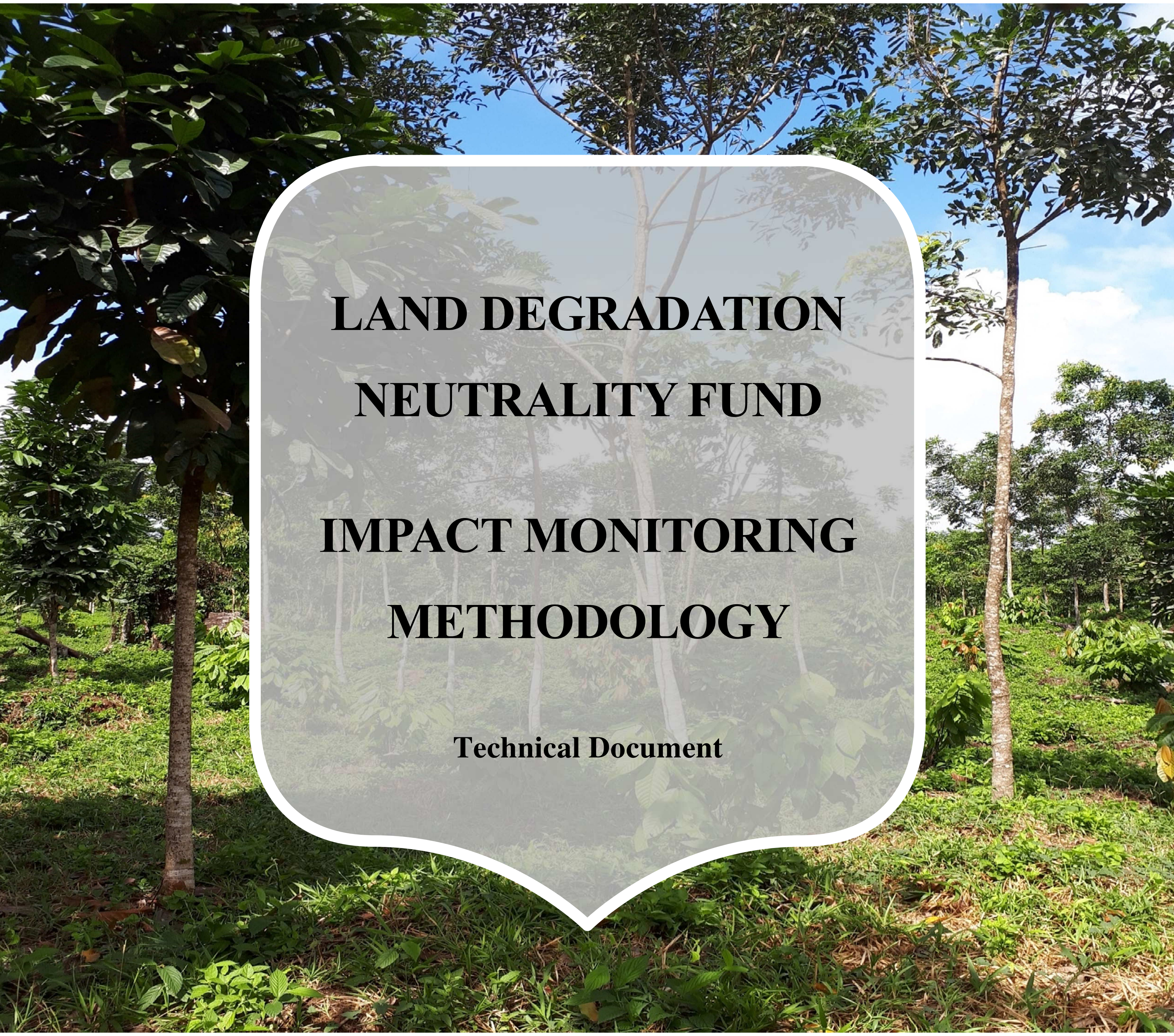

LAND DEGRADATION NEUTRALITY FUND

IMPACT MONITORING METHODOLOGY

Technical Document

Developed by

Funded by

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ABOUT IDH, THE SUSTAINABLE TRADE INITIATIVE

IDH convenes companies, civil society organizations, governments and others in public-private partnerships. Together, we drive the joint design, co-funding and prototyping of new economically viable approaches to realize green and inclusive growth at scale in commodity sectors and sourcing areas. IDH is supported by multiple European governments, including our institutional donors: the Netherlands Ministry of Foreign Affairs (BUZA); the Swiss State Secretariat of Economic Affairs (SECO); and the Danish International Development Agency (DANIDA). We also receive support on specific projects and programs from donors, including the Norwegian, American, British, and French governments. We work with over 500 companies, civil society organizations, financial institutions, producer organizations and governments in 11 sectors and 15 landscapes in over 50 countries worldwide.

LAND DEGRADATION NEUTRALITY FUND
IMPACT MONITORING METHODOLOGY

Prepared in support of the Land Degradation Neutrality (LDN) Fund, and commissioned by the LDN Technical Assistance Facility managed by IDH The Sustainable Trade Initiative

September 21, 2020

Authors: Alex Zvoleff[1], Mariano Gonzalez-Roglich[1], Ichsani Wheeler[2], and Tomislav Hengl[2]

[1]Moore Center for Science, Conservation International, Arlington, VA, United States of America.

[2]OpenGeoHub, Wageningen, the Netherlands.

Contacts at IDH Land Degradation Neutrality (LDN) Technical Assistance Facility:

Dagmar Mooij, Nienke Stam

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EXECUTIVE SUMMARY

This is the technical briefing document, commissioned by IDH as manager of the Land Degradation Neutrality Technical Assistance Facility (LDN TAF). In addition to this document, a practical guide for LDN Fund investees and other project developers will be made available.

Land degradation – the reduction or loss of the productive potential of land – is a global challenge. Over 20% of the Earth's vegetated surface is degraded, affecting over 1.3 billion people (*1*), with an economic impact of up to USD 10.6 trillion (*2*). Land degradation reduces agricultural productivity and increases the vulnerability of those areas already at risk of impacts from climate variability and change. The international community has organized around the concept of Land Degradation Neutrality (LDN) to address the challenge of land degradation. Sustainable land management (SLM) and land restoration are essential for achieving LDN, but finance is needed to support these efforts.

To promote investment in profit generating SLM and restoration projects the LDN Fund was created[1]. The Fund requires that each project in which it invests contribute to the achievement of LDN. Consistent with the agreed-upon indicators for assessing achievement of LDN, each project is therefore expected to monitor three different indicators: land productivity, land cover, and soil organic carbon.

The methods and framework for monitoring achievement of LDN at a national scale have been established by United Nations Convention to Combat Desertification (UNCCD) and other key stakeholders through the development of the scientific framework for LDN and the standardized approaches that have been developed for national reporting to the UNCCD, and for monitoring Sustainable Development Goal Target 15.3.1. This document outlines a monitoring approach that adapts these existing national-level indicators to scale of a Fund investment.

This document outlines the recommended approach for monitoring the impact of LDN Fund investments, and for assessing the overall contribution of each project to achieving LDN. While targeted towards Fund investees, this document has broader applicability to any project team interested in monitoring the contributions of a project towards the achievement of LDN.

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[1] The Land Degradation Neutrality Fund is a Luxembourg Special Limited Partnership (Société en Commandite Spéciale), open to subscription to eligible investors as defined by the fund's regulation. Mirova is the management company. The supervisory authority approval is not required for this fund. The fund is exposed to risk of capital loss, deal flow risk, operational risk, liquidity risk, country risk, market risk, legal and regulatory risk, currency risk, counterparty risk, project risk, valuation risk. Past performance is no guarantee or reliable indicator of current or future performance

SUMMARY OF MONITORING REQUIREMENTS FOR LDN FUND INVESTEES

The Land Degradation Neutrality Fund (LDNF) requires that each project in which it invests contribute to the achievement of LDN. This document outlines the recommended approach for monitoring the impact of LDN Fund investments, and for assessing the overall contribution of each project to achieving LDN. While the full guidance should be reviewed by those implementing the monitoring program, and project managers are responsible for complying with the full guidance in accordance with the legal documentation applicable, this section gives a broad overview of the recommended elements for projects receiving finance from the LDNF.

General monitoring requirements:

- All projects receiving LDN Fund financing are expected to monitor and report on productivity, land cover, and soil organic carbon (SOC)
- The minimum frequency of monitoring that is recommended varies depending on the indicator:
  - Land productivity: monitor and report annually
  - Land cover: at minimum, monitor and report every 4 years at minimum
  - Soil organic carbon: at minimum report on SOC assessment strategy at beginning of project, and report on SOC end of project as appropriate given the chosen assessment strategy

General data requirements and estimate of associated costs:

The required minimum resolution and datasets that should be used for each of the above indicators varies depending on the type of project, total area covered by the investment, and median size of the investment areas within the project. Table 1 Below table outlines the general requirements for data to be used in support of the monitoring program.

As there are some exceptions identified in the guidance that might apply to a project depending on its particular characteristics, it is recommended that the full guidance document is reviewed by the project, in addition to the below table, prior to finalizing the monitoring program to ensure that it is consistent with the methodology.

<table>
<tr><th colspan="2">Project characteristics</th><th colspan="3">Minimum Data Requirements for Monitoring</th><th rowspan="2">Estimated Total Cost (USD) [3]</th></tr>
<tr><th>Median Investment Site Area[1]</th><th>Total Investment Area[2]</th><th>Productivity
(every year)</th><th>Land cover
(every four years)</th><th>Soil organic carbon (SOC)
(beginning and end)</th></tr>
<tr><td>< 10 ha</td><td rowspan="3">> 100 km²</td><td>Freely available and commercial imagery over subset of site</td><td>Freely available and commercial imagery over subset of site</td><td rowspan="6">SOC assessment costs do not directly depend on total investment area and investment site area, but rather on the type of project. See Section 5 for further guidance.

5000 USD is used as the basis for the cost estimate on the right.</td><td>> 15,000</td></tr>
<tr><td>> 10 ha,
< 10,000 ha</td><td>Freely available imagery, but with some expert input required</td><td>Freely available imagery, but with some expert input required</td><td>15,000</td></tr>
<tr><td>> 10,000 ha</td><td>Freely available imagery</td><td>Freely available imagery</td><td>7000</td></tr>
<tr><td>< 10 ha</td><td rowspan="3">< 100 km²</td><td>Freely available and commercial imagery</td><td>Freely available and commercial imagery</td><td>> 15,000</td></tr>
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< 10,000 ha</td><td>Monitor with freely available imagery</td><td>Monitor with freely available imagery</td><td>7000</td></tr>
<tr><td>> 10,000 ha</td><td>Monitor with freely available imagery</td><td>Monitor with freely available imagery</td><td>7000</td></tr>
</table>

Table 1. *General guidance on data and costs for monitoring a project receiving LDN Fund investment.*

[1]*An investment site represents the finest level of spatial granularity in the allocation of LDNF funds. This may be a site, plot of land, or parcel affected by actions funded by the LDNF.*[2] *As most LDNF projects will benefit multiple sites, the aggregate of investment sites within a relatively homogeneous biophysical and socioeconomic region comprise an investment area. While the investment sites within an investment area are likely to all be engaged in similar activities and be receiving similar support from actions funded by the Fund, sites may vary in terms of landowner, size, date of onset of support, or other characteristics.*
[3]*Estimated total costs that are listed are for a single assessment (for example for a baseline assessment) based on experiences from two LDNF investment projects (in Bhutan and Peru). Costs may vary significantly depending on the region, expertise of the project team, and pre-existing data for the project area, and some costs will recur for subsequent assessments throughout the monitoring period. See the full guidance for further information.*

1. INTRODUCTION

Land degradation – the reduction or loss of the productive potential of land – is a global challenge. Over 20% of the Earth's vegetated surface is degraded, affecting over 1.3 billion people (*1*), with an economic impact of up to USD 10.6 trillion (*2*). Land degradation reduces agricultural productivity and increases the vulnerability of those areas already at risk of impacts from climate variability and change. Addressing land degradation is essential to improve the livelihoods of those most affected, and to build resilience to safeguard against the most extreme effects of climate change.

The international community has organized around the concept of Land Degradation Neutrality (LDN) to address the challenge of land degradation. The aim of LDN is to "maintain or enhance land-based natural capital and its associated ecosystem services" (*3*) by minimizing losses and counterbalancing unavoidable losses with gains through measures like restoration. Achieving LDN by 2030 is critical to achieving Sustainable Development Goal Target 15.3, to "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world". LDN is also a central piece of the United Nations Convention to Combat Desertification (UNCCD) Strategic Framework for 2018-2030 (Decision 7/COP.13).

Sustainable land management (SLM) and land restoration are essential for achieving LDN, but finance is needed to support these efforts. The LDN Fund (the Fund) was officially launched at the UNCCD COP13 in 2017 to promote investment in profit generating SLM and restoration projects. The success of projects supported by the Fund will be evaluated in part based on their contribution to achieving LDN.

The methods and framework for monitoring achievement of LDN at a national scale have already been established – the 13th Conference of the Parties (COP.13) of the United Nations Convention to Combat Desertification (UNCCD) adopted the scientific conceptual framework for LDN (ICCD/COP(13)/CST/2), and the indicators within that framework mirrors those of the indicator for SDG Target 15.3 (SDG indicator 15.3.1), as accepted by the Inter-agency Expert Group on SDG indicators (IAEG-SDG) in 2017.

This document outlines a monitoring approach adapting the national-level indicators for SDG 15.3 for monitoring the Fund's investments. The Fund requires that each project in which it invests monitors the three agreed-upon indicators for SDG 15.3: trends in land cover, trends in land productivity, and trends in carbon stocks[2]. Drawing on the scientific conceptual framework

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[2] Note that though the scientific framework for LDN recommends tracking trends in carbon stocks above and below ground, the agreed upon indicator for carbon stocks, due to data availability globally, is soil organic carbon. This is consistent with discussions undertaken by UNCCD partner organizations and the Inter-agency and Expert Group on SDG Indicators (IAEG-SDGs) when finalizing the definition of the SDG 15.3.1 indicator.

for LDN and indicator for SDG target 15.3, this document outlines the recommended approach for monitoring each of these three indicators at the project scale, and for assessing the overall contribution of a project to achieving LDN.

2. DEVELOPING A MONITORING PLAN

2.1. Defining area of interest

Landscape versus investment area

The first step in developing a monitoring plan is defining the area. The area of interest can be defined on three levels (not every project will need to utilize each of these three levels):

1) **Investment site** (or sites): Represents the finest level of spatial granularity in the allocation of LDNF funds. This may be a site, plot of land, or parcel affected by actions funded by the LDNF.
2) **Investment area** (or areas): Most LDNF projects will benefit multiple sites, the aggregate of investment sites within a relatively homogeneous biophysical and socioeconomic region comprises an investment area. While the investment sites within an investment area should all be engaged in similar activities and be receiving similar support from actions funded by the Fund, sites may vary in terms of landowner, area, date of onset of support, or other characteristics.
3) **Investment landscape** (or landscapes): The broader context within which the investment areas are located define the investment landscape. The landscape includes the investment areas, but also the full set of land uses and land cover occurring in the region which should be evaluated as potentially affecting the Fund investments or being affected by the activities funded by the Fund.

Some LDN projects will focus the activities funded by the Fund at a single location, or **investment site**. More frequently, projects are likely to consist of several investment sites (for example multiple farms or parcels of land). Projects that benefit multiple investment sites will need to define the **investment area** (or areas). An ***investment area*** is made up of one or more ***investment sites*** within which the Fund is directly supporting similar activities that would be expected to affect achievement of LDN. The investment area might be made up of several spatially contiguous sites (but possibly with different land managers at each site, different start dates, etc.) or the sites might be scattered across a landscape.

For example, a project involving a number of large central plantations and contracted outgrowers could be defined as having two investment areas. One investment area would include the central plantations (each of which could be referred to as a site), while the second set would include the outgrowers (each of which would be referred to as second type of site). The central plantations and outgrowers would be different types of investment area, as the scale of operations and type of activities would vary (the central plantations would likely be much larger in area, with co-located processing facilities, while the outgrowers might be smaller-scale farms).

Next to defining the investment area(s), the project will also define the **investment landscape**. An investment landscape (Figure 1) might be a broader administrative area within which a project is focusing (for example a particular county, province, or watershed). While multiple sites within the landscape might be eligible for receiving support from activities supported by the Fund, the entirety of the landscape will not, by definition, be receiving support (for example for a project focused on coffee cooperatives, a project may focus on a particular landscape within which some, but not all, of the farmers are members of cooperatives receiving support from activities supported by the Fund). A landscape at minimum should be the investment area plus a 2 km buffer around them. In the case of a project where multiple investment areas are widely spaced across a country, there might be multiple landscapes, each containing one or more investment areas.

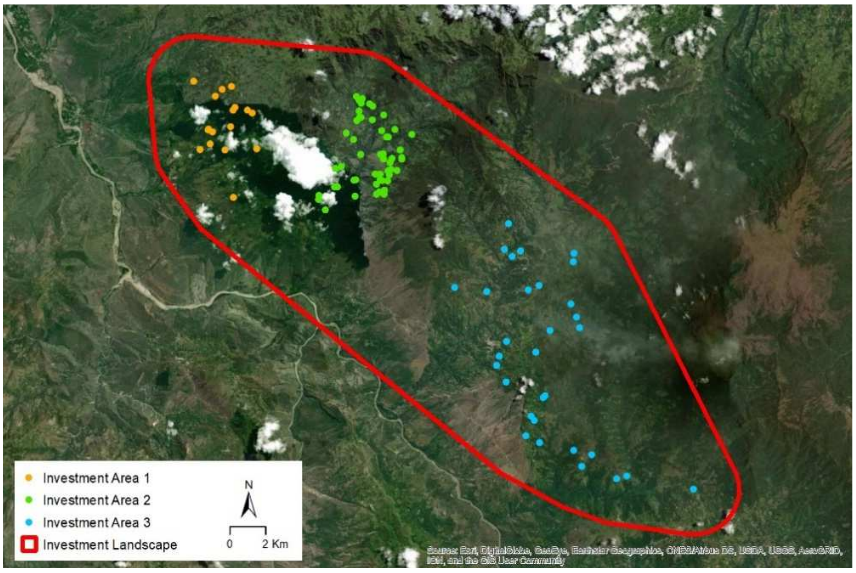

Figure 1. Example of investment sites (each individual point in the map represents a parcel in which enhanced coffee planting activities are taking place as part of the Fund investment), investment area (collection of sites within homogenous biophysical and socioeconomic conditions), and landscape.

While a project is responsible for monitoring those changes within the investment area, as these are the changes that are assumed to be most directly attributable to project activities, observing any changes occurring in the broader landscape, especially for land cover and productivity; can help to place those observed in the investment area in better context. Monitoring change within the investment landscape outside of the investment area is not required, and is not used directly as input to LDN Fund reporting, but is recommended in order to understand the context of those changes observed in the investment area. When project managers do choose to undertake monitoring of changes within the landscape, it is recommended that freely available data (for example globally data from a tool like Trends.Earth) be used for this optional monitoring (except for those portions of the landscape that fall within the investment area, for which the normal LDN Fund monitoring guidance in this document applies).

How to store monitoring areas for use in a Geographic Information System (GIS)

To design an optimal monitoring program and to track progress through time, both the landscape and the investment area(s) need to be defined in a format usable in a Geographic Information System (GIS). There are various formats that can be used in a GIS, but the preferred formats for storing spatial data are (in order of preference): 1) GeoPackage[3], 2) KML (Keyhole Markup Language)[4], and 3) Shapefile[5].

While there are advantages and disadvantages to each format, GeoPackage is preferred for storing spatial data as it is free and open source, is broadly supported among common GIS software, can handle coordinate systems more flexibly than KML, and addresses several issues with handling special characters (accents, tildes, etc.) that can be a problem when using Shapefiles.

In addition to the file format, the data type (point, line or polygon) needs to be chosen for the spatial data defining the sites, area and landscape. Polygons are used to define the **investment area and landscape**. , as polygons define an area explicitly, giving information on the shape and size of that area. For identifying the investment sites, the project can consider polygons or points, where points may be appropriate for storing the location of sites that are very small (individual farms of only a few hectares, for example). Lines are unlikely to be an appropriate data type for storing information on sites, investment areas, or landscape areas, although they might be useful for defining contextual information (such as rivers or roads) that is useful in interpreting monitoring data.

In addition to spatial information, it is useful to collect additional information for each point or polygon, particularly for sites. For investment sites, at a minimum this should include the site name (in local language), contact information for the land manager at that site (farmer, for instance), date of initiation of any supported by the fund at that site, and any available information on current and historical land use at that site.

Often, projects may not have significant existing GIS information such as all farm or field boundaries on hand at the time of initial investment from the Fund. When this is the case, it is important that new spatial information be added to the project database as new investment sites are identified and added to the project.

[3] https://www.geopackage.org/
[4] https://developers.google.com/kml/
[5] https://doc.arcgis.com/en/arcgis-online/reference/shapefiles.htm

2.2. Determining the frequency of monitoring

To assess project impact, monitoring of the three LDN indicators is required at minimum at the start (baseline) and end (termination) of the project (with variable alternatives in the case of SOC – see Figure 4). In addition to these assessments, more frequent monitoring of the indicators may be useful to assess interim project performance, and to support adaptive management. In all cases, monitoring of the LDN indicators ought to be seen as an integrated assessment that supports effective functioning of the LDN project, allowing for adaptive management in response to changes in the values of the indicators, and if possible contributing to greater understanding of LDN activities (*4*).

The appropriate frequency for interim monitoring varies among the three indicators, as the processes that result in a change in each indicator vary in their speed, and the indicators therefore can be expected to vary at different rates (examples in table 1). Productivity can change quite rapidly throughout the year as vegetation responds to changes in temperature, rainfall, and management, while, when considered as a longer-term average, changes in the mean productivity of a unit of land can occur more gradually. Land cover change on the other hand can be quite rapid in some cases (e.g. deforestation), while changes in soil organic carbon (SOC) occur more slowly due to the slower rate of the ecosystem processes that determine SOC.

	Land productivity	**Land cover**	**Soil organic carbon**
Agroforestry coffee cooperative, planting trees when coffee was already grown	ST: Early signs of improvement LT: Improvement	ST: Stable LT: Improvement	ST: Stable LT: Improvement
Tree nuts, land clearing of fallow agriculture land to plant trees	ST: Decline LT: Improvement	ST: Degradation LT: Improvement	ST: Degradation LT: Improvement

Table 2. Example of the changes that might be expected in each the SDG 15.3 indicators for two different types of scenarios within the same project type (agroforestry). Short term changes (ST, 1-3 years), long term changes (LT, 3-5 years or longer).

LDN Fund investment projects are expected to report annually for the productivity indicator (though if required and/or approved by the LDN Fund a different frequency may be applied if required for a particular project). The methods used to derive annual values for each of this indicator can be implemented at a low cost, and it is reasonably likely that changes might result on an annual time scale. For land cover, reporting every four years is recommended, as this will allow alignment with annual reporting cycles to UNCCD, and minimize costs from repeated land cover mapping. For SOC, annual reporting through direct measurement is not recommended due to high costs and the limited utility of attempting annual estimates of SOC change given its slow rate of accrual. LDN Fund investment projects are this required to report on Soil Organic Carbon at start and at end of the project. However, where LDN compliance for the SOC indicator is tied to another indicator's performance (e.g. where land productivity increasing will most likely indicate at least a stability if not an increase in SOC), and/or where process models are used, annual reporting is possible. Similarly, where alternative metrics such as agricultural production statistics and tracking of adoption is possible, then annual estimates of these alternative metrics are required.

Minimum required monitoring frequency as required by the LDNF

- Land productivity: Annual
- Land cover: Every four years
- Soil Organic Carbon: Start and end of project

Refer to the specific subsections on each indicator for guidance on monitoring frequency for different project types.

2.3. Determining the spatial resolution for monitoring

In addition to determining the frequency of monitoring, the spatial resolution at which each indicator is to be monitored should be determined. The LDN indicators each have varying data requirements for assessing them. Land productivity and land cover can both be assessed using freely available global satellite imagery, and at fine scales land cover can be assessed using commercially available imagery. For SOC, global datasets such as SoilGrids (https://soilgrids.org) or OpenLandMap.org are available that map SOC (as well as other soil characteristics) for a broad swath of time, but assessment of change in SOC at the scale of a landscape cannot be performed with any suitable level of confidence from global data alone. Therefore, the resolution applicable to SOC will be determined by the sampling approach and the monitoring scheme selected for the project.

Please refer to the specific indicator sections below for further guidance on how to identify the spatial resolution best suited for different project types.

2.4. Need for a representative area approach in some cases

When developing the monitoring plan, the size and spatial distribution of the investment sites, area, landscapes and type of intervention (avoid/reduce/reverse degradation) in relation to SOC, should be critically assessed. Preferably, the monitoring should cover the full portfolio of investment sites providing wall to wall information for the baseline, progress reports, and end of project report. In cases in which investments will be allocated to relatively few and large, contiguous sites (> 10,000 ha), freely available global datasets will suffice for providing reliable assessments for productivity and land cover on the contribution of the project towards LDN. In these same cases, monitoring SOC, though covering a large area, is relatively straightforward due to very large, contiguous parcel sizes. However, in cases in which the project is funding a multitude of interventions distributed among hundreds or thousands of small plots/micro-sites within the investment landscape, a wall to wall assessment approach is unrealistic. In such a case, higher spatial resolution commercial remote sensing data will be required for a subset of the sites to analyze productivity and land cover due to the very small plot sizes required (as discussed later in this document imagery would not be required for all of the sites due to cost limitations). For the same reason of unrealistically escalating costs of data collection, a representative area approach can be used to assess SOC in these cases.

The below guidelines should be followed when developing a monitoring plan for large projects (> 100 sq km) with very small (< 10 ha) plot sizes:

- Assessed area should cover at least 10% of the investment landscape (if logistically or economically not feasible, explain rational and proposed plan to the LDNF before implementation)
- Assessed area should as much as possible be representative of the overall biophysical and socioeconomic characteristics present in the investment area without itself becoming unrealistic.
- Baseline, progress reporting, and end of project report should be completed in the same area.

Please refer to the specific indicator sections below for further guidance on each indicator.

2.5. Coordinating different reporting requirements

Projects may be subject to different reporting requirements depending on project specific goals, governing structure, funding, or government established requirements. Projects funded by the LDNF are required to report on the three sub indicators agreed upon for assessing progress towards LDN: changes in land cover, land productivity, and soil organic carbon. Data collected by other monitoring protocols could potentially be used for reporting to the LDNF. For example, if a sustainable forest management project is monitoring changes in tree cover as part of their REDD+ program under Verified Carbon Standard guidelines, that data can be used for reporting on changes in land cover under LDNF, with clear description on the implications of changes in tree cover in the contexts of LDN for the investment area.

To maximize the success of each specific project LDN goals, flexibility in the monitoring framework is allowed, but any significant deviation from the proposed guidelines in this document require prior approval by the LDNF.

3. MONITORING LAND PRODUCTIVITY

Land productivity is the biological productive capacity of the land, the source of all food, fiber and fuel that sustains humans (*5*). Net primary productivity (NPP) is the net amount of carbon assimilated after photosynthesis and autotrophic respiration over a given period of time (*6*) and is typically represented in units such as kg/ha/yr. NPP is a time consuming and costly variable to estimate and, therefore, we rely on remotely sensed information to derive indicators of NPP. One of the most commonly used surrogates of NPP is the Normalized Difference Vegetation Index (NDVI), computed using information from the red and near infrared portions of the electromagnetic spectrum. Following the UNCCD Good Practice Guidance (GPG) for SDG Indicator 15.3.1 (*5*), it is recommended that NDVI be used as an indicator of productivity, as it is well-correlated with actual changes in productivity based on measurement on the ground, and as there is a long-term record available to allow comparison of changes in NDVI in a particular year with how NDVI has changed in the past. To understand the characteristics of the changes observed in the NDVI signal, and whether they indicate degradation, stability, or improvement, algorithms can be used to assess three different sub-indicators of land productivity: trajectory, performance, and state.

Satellite imagery can be used to monitor changes in land productivity in LDN Fund investment areas, without the need for ground data collection, given the strong relationships that have already been established between satellite data and NPP. The most appropriate satellite-derived dataset to use for monitoring land productivity depends on the type of assessment (baseline, annual, or terminal) and characteristics of the investment area (Table 3). MODIS (250 m) should be used in combination with Landsat and Sentinel imagery (~30 m) to establish a baseline.

	Baseline	Progress reporting	End of project
Input remote sensing data	MODIS, Landsat / Sentinel	Landsat, Sentinel	Landsat, Sentinel
In-situ data collection	None	None	None
Other inputs	None	None	None
Data processing	Productivity time series analysis in Trends.Earth using Trajectory and State indicators	Productivity time series analysis in Trends.Earth using Trajectory and State indicators	Productivity time series analysis in Trends.Earth using Trajectory and State indicators
Output dataset	Raster (see Figure 2 for guidance on resolution)	Raster (see Figure 2 or guidance on resolution)	Raster (see Figure 2 or guidance on resolution)

Table 3. Procedure to derive productivity indicator.

MODIS is the only sensor with a sufficiently long time series (at least 15 years is recommended) to establish a baseline prior to 2015 (Figure 2). After 2015, the combination of the Landsat and Sentinel records allow continuous monitoring of productivity at higher resolution than MODIS.

With the increasing availability of higher-resolution satellite sources (defined here as 10 to 30m pixel size), the development of higher-resolution indicators, based on NDVI or other variables such as fractional cover (i.e. the relative proportional representation of different land cover within a given pixel), is now feasible. For example, the harmonization of Landsat and Sentinel products opens the door to high spatio-temporal analyses which were only possible at 250 m resolution until now (the year 2020). Initial studies have highlighted the utility of Sentinel-2 data (using NDVI as one component) for improved degradation mapping, especially forest degradation due to its high spatial resolution, frequent revisit time, and spectral characteristics. For annual monitoring purposes the Harmonized Landsat Sentinel-2 record shows great promise (*7*). While this dataset is still under development, its utility for ongoing monitoring is recommended with the recognition that LDN Fund investees will need to monitor projects over the next 10-15 years, and this harmonized product will soon be operational and available to support general use. The spatial resolution of this product (~30 m) will allow better discrimination of changes in productivity within smaller investment areas (down to 1 hectare).

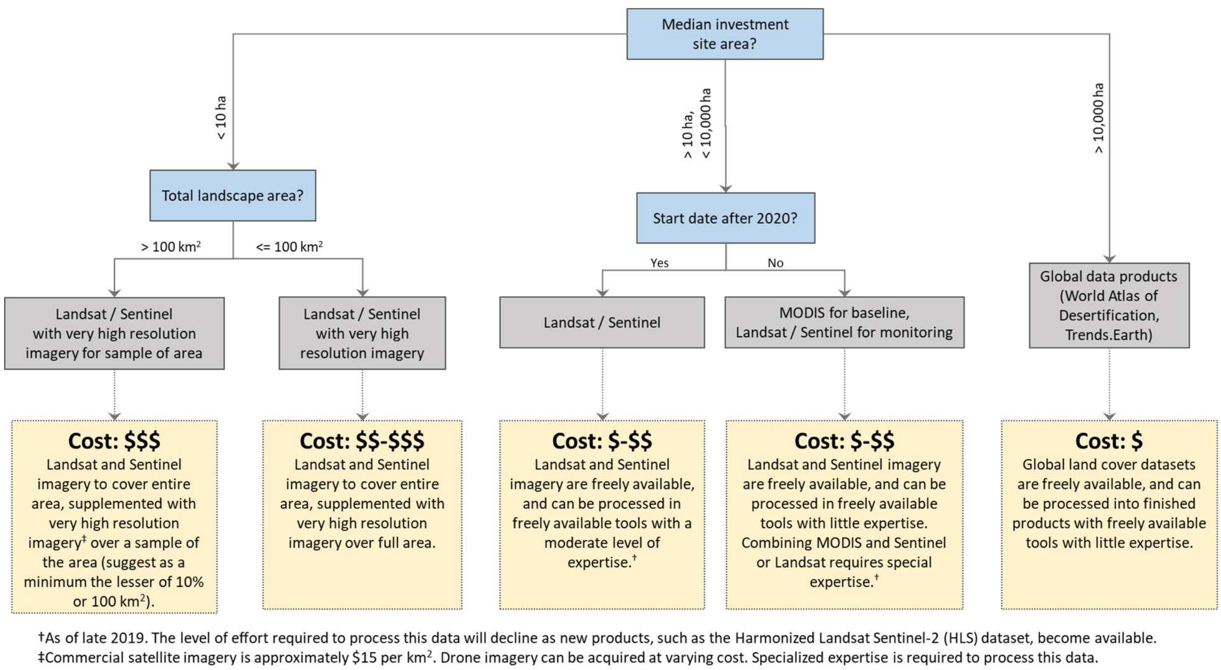

Figure 2. Flowchart for determining relative costs of data acquisition and processing for each reporting cycle of land productivity. $" indicates < 1000 USD, "$$" indicates 1,000 - 5,000 USD, "$$$" indicates > 5,000 USD. Refer to section 6 for estimation full monitoring costs through project lifespan.

As noted in Figure 2, the resolution of the data used for assessing land productivity may vary depending on the median size of the investment sites. In some cases, there might be multiple kinds of investment areas within the project and therefore multiple types of site. For example, in the case of an out grower scheme with a number of central processing facilities and contract farms, the central processing facilities would be one type of investment area, and the out grower farms a second. In this case, the median site area should be calculated for each of these two types of investment area (central facilities and farms), and the smallest of the two median areas should be used while considering the flowchart in Figure 2.

3.1. Assessing productivity sub-indicators

3.1.1. Assessing productivity trajectory

Productivity trajectory measures the rate of change in primary productivity over time. This rate of change can be assessed using linear regression at the pixel level to identify areas experiencing changes in annual primary productivity for the period under analysis. Annual integrals of NDVI summarize productivity over the full year and the period of analysis is defined in years. This analysis does not capture intra annual variability in productivity. A Mann-Kendall non-parametric significance test is then applied, considering only significant changes those that show a p-value ≤ 0.05. Positive significant trends in NDVI indicate potential improvement in land condition, and negative significant trends potential degradation.

3.1.2. Assessing productivity performance

Productivity performance measures productivity in a given area relative to the productivity of other areas of similar vegetation and land cover types. Trends.Earth uses the unique combination of soil units (soil taxonomy units using USDA system provided by SoilGrids at 250m resolution) and land cover (full 37 land cover classes provided by ESA CCI at 300m resolution) to define these areas of analysis.

To compute productivity performance:

1. Define the analysis period in years, and use the time series of NDVI to compute mean the NDVI for each pixel.
2. Define ecologically similar units as the unique intersection of land cover and soil type. All areas within the same investment landscape with the same unique combination of land cover type and soil type will be compared to each other.
3. For each unit, extract all the mean NDVI values computed in step 1, and create a frequency distribution. From this distribution determine the value which represents the 90th percentile (we don’t recommend using the absolute maximum NDVI value to avoid possible errors due to the presence of outliers). The value representing the 90th percentile will be considered the maximum productivity for that unit.

4. Compute the ratio of mean NDVI and maximum productivity (in each case compare the mean observed value to the maximum for its corresponding unit).

If observed mean NDVI is lower than 50% than the maximum productivity, that pixel is considered “low performing”. It is critical to have a clear understanding of the potential impact of the proposed land management interventions on productivity, since recently harvested areas, or areas in which vegetation rejuvenation occurs, will identified as low performing by this indicator. Explicit explanation on the causes for the relatively low or decline in productivity will need to be added to the Fund report.

Note that as the productivity performance calculation relies on comparison of a land units to other similar land units to evaluate how a land unit is performing relative to them, it is important that the performance calculation be performed over a sufficiently large area that there are both units that are high performing (higher than expected productivity) as well as low performing (lower than expected productivity). For this reason, it is recommended that when the performance calculation is performed in software like Trends.Earth, that it be performed over an area larger than the landscape itself (the landscape plus a 5 km buffer). This buffer is merely to allow a larger sample of land units to be available for the performance calculation – when calculating final statistics on an investment area (as outlined in 3.2 below), this area can be excluded.

3.1.3. Assessing productivity state

The Productivity State indicator allows for the detection of recent changes in primary productivity as compared to a baseline period. The indicator is computed as follows:

1. Define the baseline period (historical period to which to compare recent primary productivity).
2. Define the comparison period (recent years used to compute comparison). It is recommended to use a 3-year to avoid annual fluctuations related to climate.
3. For each pixel, use the annual integrals of NDVI for the baseline period to compute a frequency distribution. In case the baseline period missed some extreme values in NDVI, add 5% on both extremes of the distribution. That expanded frequency distribution curve is then used to define the cut-off values of the 10 percentile classes.
4. Compute the mean NDVI for the baseline period and determine the percentile class it belongs to. Assign to the mean NDVI for the baseline period the number corresponding to that percentile class. Possible values range from 1 (lowest class) to 10 (highest class).
5. Compute the mean NDVI for the comparison period and determine the percentile class it belongs to. Assign to the mean NDVI for the comparison period the number corresponding to that percentile class. Possible values range from 1 (lowest class) to 10 (highest class).

6. Determine the difference in class number between the comparison and the baseline period (comparison minus baseline).
7. If the difference in class between the baseline and the comparison period is ≤ 2, then that pixel could potentially be degraded. If the difference is ≥ 2, that pixel would indicate a recent improvement in terms of primary productivity. Pixels with small changes are considered stable.

3.2. Interpreting land productivity changes

Projects under the LDNF are expected to contribute to Land Degradation Neutrality national plans as measured by the three sub indicators, of which land productivity is key. Productivity can be assessed on an annual basis using annual integrals of NDVI, and as previously discussed, different trends analysis can be performed for assessing short- and long-term changes in productivity. The “state” indicator (*5*) is better suited for identifying of early signs of improvement or degradation. The state indicator, when calculated with a baseline of 5 years prior to project implementation, should be compared to the mean annual integral of NDVI from the year of project implementation until the reporting period (note this functionality is freely available in the Trends.Earth tool). This annual assessment allows for quick identification of changes in productivity in the investment area. It is important to note that some activities implemented in these projects could cause temporary declines in primary productivity. Such examples include, stand rejuvenation, harvest and replanting. If the project being monitored includes such temporary changes in productivity, which will be identified by the indicators, those actions and anticipated long term effects should be noted as reporting annually to the LDNF.

At the end of the project, a long-term trajectory analysis (*5*) should be performed to assess in a statistically robust way the magnitude of the changes identified in the investment area. To determine which areas have improved or declined based on productivity at the end of a project, the three productivity sub-indicators should be combined. The indicators are combined as outlined in Table 4, following the recommended guidance of the UNCCD Good Practice Guidance (*5*), and following the naming conventions for describing change in land productivity used in that guidance and by the World Atlas of Desertification (WAD) (*8*).

To determine whether a land unit is improving or declining, a 3-class land productivity product is needed, one indicating degradation, stability, or improvement. However, for ongoing monitoring purposes, a more detailed 7-class product can be used to understand the characteristics of observed changes in productivity within the investment area. This product is similar to the Land Productivity Dynamics product used in the WAD, with the exception of providing additional detail in those pixels experiencing improvement.

The Trends.Earth tool can be used to fully automate the generation of both the 3 and 7 class productivity products following the rules in Table 4, and is therefore recommended for both the baseline and terminal evaluations, as well as ongoing monitoring of the productivity indicator. Full details on how to use Trends.Earth to perform these calculations, including step-by-step tutorials, are available online at http://trends.earth.

Trajectory	State	Performance	3 Classes	7 Classes
Improving	Improving	High performance	Improving	Improving
Improving	Improving	Moderate performance	Improving	Improving
Improving	Improving	Low performance	Improving	Improving
Improving	Stable	High performance	Improving	Improving
Improving	Stable	Moderate performance	Improving	Improving
Improving	Stable	Low performance	Improving	Improving
Improving	Declining	High performance	Improving	Improving
Improving	Declining	Moderate performance	Improving	Improving
Improving	Declining	Low performance	Improving	Improving
Stable	Improving	High performance	Improving	Early signs of improvement
Stable	Improving	Moderate performance	Improving	Early signs of improvement
Stable	Improving	Low performance	Improving	Early signs of improvement
Stable	Stable	High performance	Stable	Stable high performance
Stable	Stable	Moderate performance	Stable	Stable mod performance
Stable	Stable	Low performance	Declining	Stable low performance
Stable	Declining	High performance	Declining	Early signs of declining
Stable	Declining	Moderate performance	Declining	Early signs of declining
Stable	Declining	Low performance	Declining	Early signs of declining
Declining	Improving	High performance	Declining	Declining
Declining	Improving	Moderate performance	Declining	Declining
Declining	Improving	Low performance	Declining	Declining
Declining	Stable	High performance	Declining	Declining
Declining	Stable	Moderate performance	Declining	Declining
Declining	Stable	Low performance	Declining	Declining
Declining	Declining	High performance	Declining	Declining
Declining	Declining	Moderate performance	Declining	Declining
Declining	Declining	Low performance	Declining	Declining

Table 4. Combination of productivity sub-indicators to derive indicator of degradation.

4. MONITORING LAND COVER

As with any mapping activity, trade-offs exist when considering the most appropriate spatial resolution of the imagery to map land cover. Higher resolution imagery allows greater precision in terms of the number and specificity of land cover types that can be mapped. Accuracy, however, is generally lower as the number of classes mapped from a given image (or set of images) increases, and the availability of repeated imaging of a location (during different times of the year, for example) is generally lower as image resolution goes up. Higher resolution imagery also brings increased costs in terms of acquisition and processing. Given these considerations, the most appropriate input data for monitoring LDN Fund investments will vary depending on the type and spatial scale of the investment. Therefore, we recommend that the monitoring approach taken to assess land cover vary depending on the scale of the investments (Figure 3), and on whether the goal is to establish a baseline, produce a progress report, or conduct a terminal evaluation (*Table 5*).

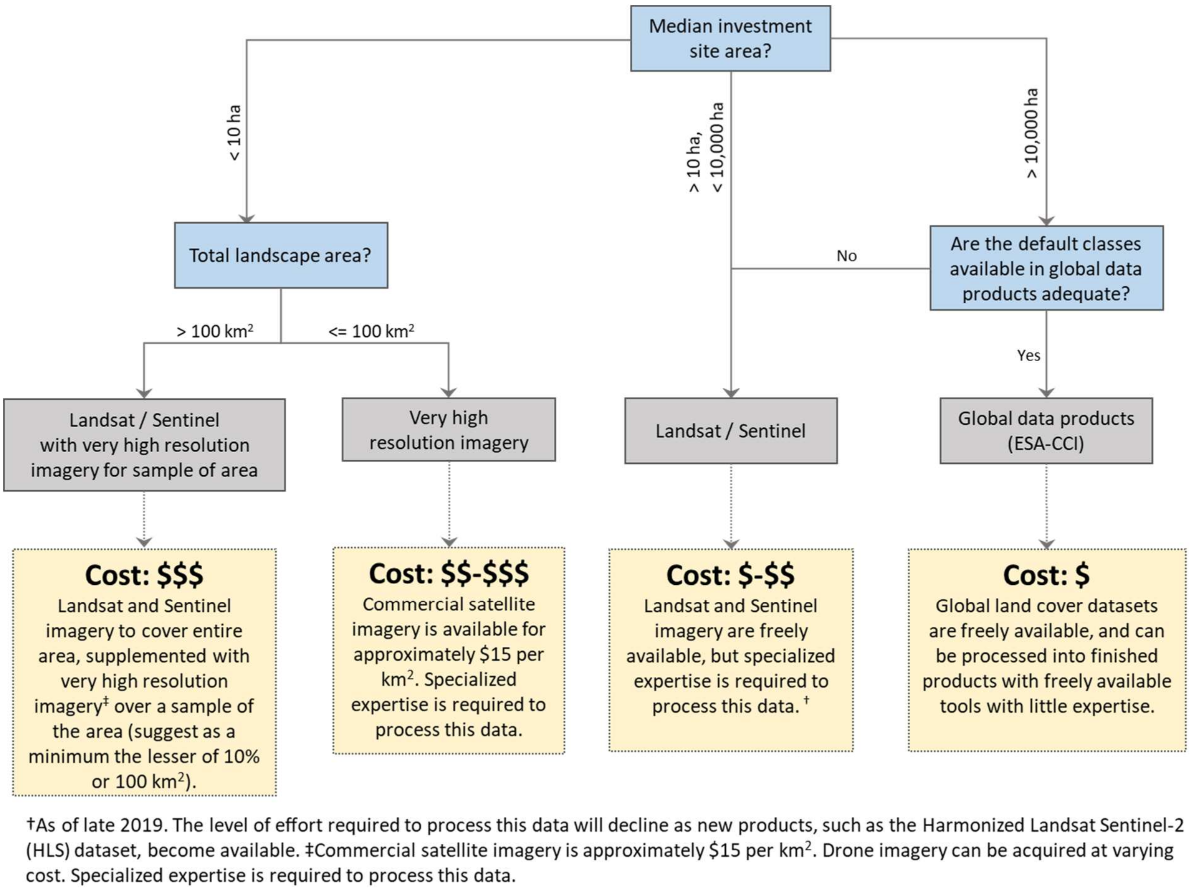

Figure 3. Flowchart for determining relative costs of data acquisition and processing for each reporting cycle of land cover. $" indicates < 1000 USD, "$$" indicates 1,000 - 5,000 USD, "$$$" indicates > 5,000 USD. Refer to section 6 for estimation full monitoring costs through project lifespan.

For project sites where the median site area is less than 10 hectares (for example LDN Fund investments with smallholders and small field sizes), very high resolution imagery (resolution < 2 m) is recommended for the baseline and terminal evaluation, and Landsat and Sentinel imagery (resolution ~ 30 m) for reporting (Figure 3). An exception to this rule is a project active with a number of small investment sites distributed over a large investment landscape, in which a representative area approach could be used (see section 2.4 for specific guidance on overall sampling design to be used in this case). In cases where the area of the broader landscape(s) in which activities are occurring exceeds 100 km^2, a representative area approach may be used in which very high-resolution imagery is acquired for only a subset (100km). For those projects where the median site area is greater than 10 hectares, we recommend monitoring using Landsat and Sentinel imagery for the baseline, terminal evaluation, and annual reporting. For very large areas (greater than 10,000 hectares), globally produced datasets like that from the European Space Agency (ESA-CCI) are another possibility to be used at all stages of monitoring, provided the classes and accuracy are sufficient for the particular investment site.

	Baseline	**Progress reporting**	**End of project**
Input remote sensing data	Dependent on median size of site and area of landscape.	Landsat / Sentinel, reported every four years	Dependent on median size of intervention site and area of landscape.
In-situ data collection	None	None	None
Other inputs	Training data collected from imagery	Transition matrix defining improvement and degradation developed in collaboration with local stakeholders	Transition matrix defining improvement and degradation developed in collaboration with local stakeholders
Data processing	Classification conducted in Trends.Earth or other software either in cloud or locally	Classification conducted in Trends.Earth or other software either in cloud or locally, using baseline training data	Classification conducted in Trends.Earth or other software either in cloud or locally, using baseline training data
Output dataset	Raster, with resolution varying depending on median site area and landscape area	Raster, with resolution varying depending on median site area and landscape area	Raster, with resolution varying depending on median site area and landscape area

Table 5. Procedure to derive land cover indicator. See also Figure 3 for guidance on which datasets to use for monitoring.

As is the case for land productivity, the resolution of the data used for assessing land cover may vary depending on the median size of the sites for the project. In this case, the median site area should be calculated for each of the types of investment area that is supported by the project (for example central facilities and out grower farms), and the smallest of the median areas should be used while considering the flowchart in Figure 3.

4.1. Developing a land cover map

Land cover maps should be developed as the first step in baseline, progress reporting, and end of project monitoring. Producing land use and cover change (LUCC) products from remotely sensed imagery has traditionally required several steps, including acquisition of raw imagery, preprocessing of the raw imagery to certain geometric and spectral standards, production of LUCC data products, and, finally, evaluation of the accuracy of finished LUCC products. Recent advances in cloud processing, including the Google Earth Engine platform, have simplified this process, as pre-processed imagery that is ready for analytical use is now widely available.

The classes that should be monitored should in general match the basic classes used in UNCCD reporting:

1. Forest
2. Grassland
3. Cropland
4. Wetland
5. Artificial area
6. Bare land
7. Water body

If required by a project, further classes may be added, but only if:

1) these changes are discussed and agreed to in advance by LDN Fund and investee, and, if required by the Fund, the LDN Technical Assistance Facility, and
2) a legend is provided that allows aggregation of the full set of monitored land cover classes into the basic set of seven classes used in UNCCD reporting.

Depending on project requirements (refer to *Table 5*) either very high resolution imagery (< 2 m) or 20-30 m resolution imagery should be used. In the case of 20-30 m imagery, continuing development of harmonized products combing Landsat and Sentinel-2 imagery makes it likely that these products will be widely available for usage in monitoring LDN Fund investments. However, until these harmonized products are widely available, it is recommended that users needing 20-30 m imagery choose either Landsat or Sentinel-2 imagery as the basis for their land cover classification. If data of different spatial resolution is used, clear indication on how mismatching pixel sizes between reporting periods was handled is required.

Once the input satellite imagery is collected, GIS software can be used to develop a classified land cover map of the investment area (or full investment landscape, if desired by the project developer), using training data from a product like the ESA CCI land cover dataset, and supplemental data digitized from the imagery and freely available high-resolution imagery sources such as Google Earth as needed. Training data can also be collected in the field, to achieve higher accuracy and more precise class definitions, but this will result in higher costs due to the need for ground data collection.

Once the training data is collected it should be used to develop a land cover map, by training a machine learning algorithm (Random Forest is recommended for its high accuracy and availability in open source platforms) to classify the input imagery based on a suite of variables derived from the input imagery. In the case of Landsat or Sentinel imagery, it is recommended that a dense layer stack comprising multiple images over a one-year period be used to develop this suite of variables, in order to take advantage of the additional temporal information this can provide, while also addressing potential issues with missing data due to cloud cover. As an example, for Landsat a 24 band stack could be created from the 7 reflectance bands (median across the year, 15 normalized difference indices representing all the possible combinations without replacement of the 6 optical bands, and 2 NDVI specific bands representing the maximum and the standard deviation of NDVI for each particular pixel).

4.2. Assessing data quality

Following completion of a custom land cover map, it is essential to assess the quality of the product. The quality of finished LUCC data products is measured using the accuracy assessment process. There are several metrics for measuring accuracy. This section briefly reviews these metrics, discusses standard levels of accuracy for LUCC products, and provides an overview of the basic approach for conducting an accuracy assessment.

Standardization of LUCC product metadata and accuracy assessment methods is an ongoing problem in the remote sensing community. However, there have been several attempts at standardization (*9*). The most common means of reporting accuracy is inclusion of a contingency table tabulating the predicted versus known class for each in pixel in a testing dataset. The contingency table also should include overall, user's, producer's, and per class accuracies.

A commonly cited accuracy target is 85% overall accuracy (*9, 10*). Thomlinson additionally suggest a 70% minimum per-class accuracy (*9*). However, many widely used products and some highly cited studies in the published literature use classifications with accuracies not meeting these guidelines. While accuracy targets (like 85% overall accuracy) are useful to guide analysts working on LUCC data products, the accuracy target itself should be determined based on specific project goals. LUCC products that use a large number of classes will generally have lower overall accuracy, while simpler products like forest/non-forest classifications can usually be produced with higher accuracy. Data limitations are also important, as spatial and spectral resolution will both affect accuracy.

As a guideline, an overall target of 85% accuracy is recommended for monitoring LUCC in support of assessing impact of Fund investments. If a lower accuracy achieved, this needs to be clearly stated in the report and should be accompanied by reasoning why this is acceptable.

How to assess data quality

The standard for assessing the accuracy of a gridded LUCC product is a comparison of predicted output (such as a land cover map) with an independent "testing" dataset. The testing dataset must be independent of any data or processes used in preparation of the product – testing data must not have been used in any way in the production of the product itself (for instance as training data for a machine-learning algorithm).

To allow unbiased statistical assessments to be made, the testing data must be collected from locations chosen using a random sample, and the sampling method must be accounted for when calculating accuracy statistics. While a simple random sample may be used for selecting locations to collect testing data, a stratified random sample is recommended, to ensure statistically significant statements can be made regarding the accuracy of classes that occur relatively infrequently in the data. Cluster or systematic sampling designs can be used, if necessary, to ensure coverage of classes infrequently observed in the data. The accuracy of the testing data itself can be a key determinant of the results of an accuracy assessment (*11*). For this reason, ground reference data should be collected either in-situ or from high-resolution satellite imagery .Google Earth, for example, provides a comprehensive record of very high spatial resolution data which can be used for creating a ground reference dataset. Further guidance on accuracy assessment can be found in (*11*), or in any basic remote sensing text.

Multiple free and open source tools exist for supporting land cover classification and accuracy assessment. The "teamlucc" R package (R is a system for statistical computation and graphics) includes functions to assist with measuring the accuracy of image classifications. In addition to the standard contingency tables often used for describing accuracy, the teamlucc accuracy function also calculates quantity disagreement and allocation disagreement, supports calculating unbiased contingency tables from stratified validation samples, and supports calculating error-adjusted estimates of per-class areas and confidence intervals around these estimates (*12*). Using the teamlucc package, or a similar approach that allows calculation of unbiased statistics, is recommended for analyzing the accuracy of LUCC classifications.

4.3. Mapping land cover change

Simple comparison of land cover maps from two different dates (referred to as post-classification comparison) can lead to high errors, as inaccuracies on each of the individual maps are compounded when they are combined. To avoid this problem, alternative approaches can be used, such as Change Vector Analysis in Posterior Probability Space (CVAPS) (*13*). Compared to other approaches, the CVAPS method has the advantage of being able to better handle imagery acquired on different dates, or even from different seasons, when vegetation may be in different phenological phases (*13*).

The CVAPS method works as follows: for each of two input images and for each of m cover classes $c_1, c_2, \ldots c_m$, 1) calculate for each pixel in each input image the vector of posterior probabilities of class membership in each of the m cover classes $P = (p_1, p_2, \ldots\ p_m)$, 2) compute the vector representing the difference in probabilities of class membership between image 2 and image 1, defined as $\Delta P = P^{(2)} - p^{(1)}$, and 3) compute the magnitude of change in the posterior probability $\|\Delta P\| = \sqrt{\sum_{i=1}^{m}\left(p_i^{(2)} - p_i^{(1)}\right)^2}$.

The CVAPS method is implemented in the free and open-source "teamlucc" R package, which is the recommended tool for applying the method and calculating the final indicator. To map land cover transitions using CVAPS, a threshold must be applied to the change magnitude image $\|\Delta P\|$ to define those pixels that have experienced change. A pixel changing from 100% probability of belonging to one cover class to 100% probability of belonging to another (complete change) would have a change magnitude of $\sqrt{2} = 1.41$). Although automated threshold selection algorithms exist (and are implemented in the teamlucc package, we recommend using a threshold of .75 as a starting point for determing change versus no change across all sites. After thresholding each change magnitude image, the direction of land cover and land use change (LCLUC) in "change" pixels is determined by calculating the direction of the change vector ΔP in comparison to the "change basis vectors" for each transition, as discussed in (*13*).

4.4. Determining land cover degradation

To determine which types of land cover transitions are considered degradation, and which are considered improvement, it is recommended that investees agree upon a project-specific transition matrix defining which transitions are improvement, which stability and which degradation, and that this matrix be used for the full investment period. The UNCCD-provided matrix (Figure 4) can be used as a default, but for some areas this default matrix may need to be modified (whether transition from grasslands to forest is degradation or improvement, for example, depends on local conditions – this could be woody encroachment in some areas, while it could be reforestation in others). Once the matrix is agreed upon, Trends.Earth can be used to apply the matrix to calculate areas of land cover degradation, stability, and improvement, as outlined in the tutorials for performing this calculation at http://trends.earth. The above calculation should be performed on a recurring basis (every four years), as well as at the terminal evaluation, to track changes in land cover across the investment area. A comparison of changes in the investment area as compared to the investment landscape will allow for an initial and general understanding of the context in which the project is being implemented, and to assess its contributions towards LDN.

Land cover in target year

Land cover in baseline year	Forest	Grassland*	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	0	-	-	-	-	-	0
Grassland*	+	0	+	-	-	-	0
Cropland	+	-	0	-	-	-	0
Wetland	-	-	-	0	-	-	0
Artificial area	+	+	+	+	0	+	0
Bare land	+	+	+	+	-	0	0
Water body	0	0	0	0	0	0	0

Legend

Degradation	Stable	Improvement
-	0	+

*The "Grassland" class consists of grassland, shrub, and sparsely vegetated areas (if the default aggregation is used).

Figure 4: Example of a land cover transition matrix used to define degradation as identified by changes in land cover. This matrix should be defined by the project team based on their knowledge of the study area.

5. MONITORING SOIL ORGANIC CARBON

Monitoring change in soil carbon due to project interventions requires the project proponent to consider several different decision points related to SOC and overall LDN project achievement. Recent guidance prepared by the Science-Policy Interface of the UNCCD (*4*) can be applied to project descriptions to obtain guidance regarding investment into SOC assessment for LDN. The methodology guidance for SOC provided here assumes that target investment areas have already been identified and those areas are likely already engaged in some form of sustainable land management (SLM). Such target investment areas may or may not be expanding in membership or hectares and may be at an initial or more established stage of development. However, all investments should offer some 'yet to be realized' contribution to LDN.

The generalized methodology for SOC compliance for the LDNF is outlined below and draws on Tables 2, 3 and 4 and on Figure 4 of the SPI guidance (*4*):

1. Determine the for the General Intervention Type from the options under each LDN response action, which best describes the project. Note the minimum primary indicator for SOC for that intervention type (from either Table 6, Table 7, Table 8)
2. Based on the outcomes of 1) above, if the intervention type is not easily categorized under the General Intervention Types (e.g. it is 'novel'), or its primary monitoring indicator is other than SOC, determine if the project aims would benefit from additional SOC monitoring in circumstances such as:
    a. Expected strong gains in SOC and/or desire to participate in C offset markets (voluntary or otherwise),
    b. Desired project out-scaling to larger areas with many participants (where the broader landscape-scale effects of an intervention might vary from those experienced at an individual site - for example downstream impacts on water availability from revegetation),
    c. Deploying a novel approach, or
    d. Any other reason that the project may benefit from added rigor regarding SOC (e.g. substantiation of project claims, collaboration with local universities and institutions, to be used in branding etc.)
3. Determine if a project will use wall-to wall measurement/monitoring or a representative measurement area for all indicators (see section 2.4 for guidance),
    a. If a representative measurement area is chosen to describe all indicators for a wide-scale project, and if SOC is required to be measured or modeled based on the above, then the project should measure or model SOC in the same representative area used for the other two indicators, unless it can demonstrate to the Fund (before project commencement) that it is unnecessary or onerous to do so

4. If SOC measurement/modelling is indicated, consult suitable expertise in sampling design and assessment in order to devise an appropriate sampling design and monitoring plan. Much guidance is available on this topic however it is expected that the design:
    a. Uses the same representative area as the other indicators if the entire project area is too large,
    b. Establishes a baseline condition and at least a cessation assessment (where SOC is the primary indicator) else at least uses a suitable space-for-time substitution to establish a project baseline and predict project outcomes (where SOC is not the primary monitoring indicator but additional efforts are being deployed for other reasons).

5.1. Determining primary monitoring index for SOC outcomes

Depending on the activity, land productivity or land cover could instead be used as the "primary monitoring index" and provide sufficient information to assess a project's consistency with achieving LDN. This concept builds on the guidance provided by the UNCCD SPI (*4*) on assessing SOC in support of achievement of LDN Tables 2, 3 and 4 and Figure 4 of that document. Table 2, Table 3, and Table 4 of that guidance summarize the information from that report on how to determine a primary monitoring index – the guidance from that report is broadly useful in informing project managers.

After considering Table 6, Table 7, Table 8, and locating the most similar General Intervention Type to the activities being implemented by the project of interest, the user will have identified the minimum Primary Monitoring Indicator for SOC as either:

- Land cover (LC) monitored via remote sensing
- Land productivity (LP) monitored via remote sensing and agricultural production statistics or
- SOC monitored via measurement and or modelling

In all instances it is ideal to measure or model SOC itself in the project area to scientifically substantiate project claims. Partnering with local universities or government organizations to conduct such research is also ideal, as is utilizing local expert & laboratory capacity where possible. However, the requirement to measure/monitor SOC in some intervention types, especially over very large areas, could be considered onerous, inefficient and potentially yielding redundant information (e.g. monitoring SOC for 'land conversion control' where no change in SOC could be reasonably expected due to avoiding degradation).

Therefore, if the primary indicator for SOC is not SOC itself, then at an absolute minimum the primary indicator should show a positive trend in the project area as a basis to assume at least SOC stability under the general intervention type. However, where a project is conducted at a scale where directly measuring/monitoring SOC is possible (given available expertise, capacity, etc.) and that technology is expected to be deployed at larger scales in the future, under the LND Fund the project is highly recommended to conduct baseline and monitoring assessments of SOC regardless of the minimum indicator above (e.g. scaling up agronomic measures that avoid degradation such as vegetative strip covers or contour ploughing/planting, or structural and vegetative measures such as terracing and controlled grazing densities respectively, which reverse degradation).

Regarding activities that **avoid** or **reverse degradation** especially, and use either LC or LP as the primary monitoring indicator, there is no requirement in the simplest approach to directly measure or model the effect of activities on SOC stocks where:

1. The primary monitoring indicator is reported as having a positive trend over many years (including positive production statistics if required), and
2. The non-primary indicator for SOC status (being alternatively either LP or LC) is at least stable and not degrading

Assessment of the above two bullets can be conducted at coarse scale using freely available information from Trends.Earth (see the relevant sections of this guidance for further details on how to assess land cover and land productivity with Trends.Earth). SOC measurement or modeling is not required in these cases as because SOC stocks are expected to be largely stable under activities that avoid degradation and most likely positive under projects that reverse degradation, monitoring them ought to show no to positive change due to project activities. There may be exceptions to this stability, but it is reasoned they should be positive, and vice versa for reversing degradation and increasing SOC gains. Situations that call for LP and monitoring of production statistics infer that production statistics would be tracked, and the total number of participants and land area accounted for on an annual basis. The assumption here is that if production statistics are positive compared to the business as usual management then there ought to be a benefit to SOC stocks from the listed intervention types. These assumptions rely on scientific literature values of examined cases.

Project situation where SOC measurement or modelling would be well justified include situations where project interventions are due to be scaled to cover large areas and are suspected to lead to SOC gains (e.g. a collective action targeted at ‘runoff management’) and could additionally benefit from quantification of SOC impacts for a representative area. This contrasts with a project consisting of ’land conversion control’ where SOC levels are expected to be stable due to prevention of LC change. For all examples there will likely be exceptions. It is therefore up to the project proponent to justify choices and seek approval from the LDNF before project commencement.

Similarly, for activities that **reduce or reverse degradation**, and where LC or LP is the primary monitoring indicator, there is no requirement in the simplest approach to directly measure or model the effect of activities on SOC stocks. Again, both the primary indicator and non-primary indicator for SOC level should at least demonstrate a positive trend and a stable to positive trend respectively, in order to claim stability no degradation in SOC / stable levels.

Where the primary monitoring indicator is SOC, the requirement for LDN achievement at the simplest level under the LDNF is the *use of SOC measurement or modelling* to substantiate project assumptions for the given activity. This need not be an onerous task and may be paired with gathering other highly relevant agronomic information.

5.2. Determining LDN Response Type

A (not exhaustive) listing of intervention types and project activities that avoid, reduce, or reverse degradation is outlined in Table 6, Table 7, Table 8, including the minimum primary monitoring index that is required to report on the SOC indicator.

Determining which LDN Response Type to use for a project can be tricky in some instances, especially if a novel (unlisted) intervention type is used. In general:

- Avoided degradation is intended to *avoid* degradation occurring by preventing total LC change or preventing some specific degradation processes from occurring within a LC type (e.g. rotational or strip fallowing).
- *Reducing* degradation is about changes in management practices to fewer damaging forms (and so can also be slowing the rate of loss that would otherwise occur) e.g. crop rotation.
- *Reversing* degradation is about restoring some dramatically rehabilitated state in terms of landscape function e.g. reforestation.

When in doubt it is good practice to document reasoning, assumptions and motives of the interventions in use by the project, and conclusions regarding LDN Response Type, and to discuss with the LDNF. As a general guidance: if a particular type of response action and intervention type can be confidently written in promotional material without concern (or where it can not be subject to public criticism) then it is likely a matter of identity distinction and ought to be sufficient (e.g. agroforestry vs reforestation).

It is important to note that while a primary monitoring index other than SOC may be indicated for an activity, a project might still choose to monitor SOC as an LDN indicator. For example, when there are both resources and expertise available, and when SOC monitoring might be advantageous to other project goals (e.g. marketing, due diligence, local expert engagement, carbon trading, as feedback to adaptive management).

LDN Response Action	SLM Type	Class	General Intervention Type	Minimum primary indicator for SOC*
Avoid Degradation	Collective Actions	Structural measures	Community land use planning	LC
			Runoff management	LC
		Vegetative measures	Vegetation corridors	LC
			Sand dune stabilization	LC
	SLM Approaches	Land use policies	Land conversion control	LC
			Declaring National Protection Zones	LC
			Land titling	LP + production statistics
			Land reform	LP + production statistics
			Infrastructure planning	LC
			Payment Ecosystem Services Scheme	LC
	SLM Technologies	Agronomic measures	Rotational or strip Fallowing	LP + production statistics
			Vegetative strip cover	LP + production statistics
			Contour ploughing/planting	LP + production statistics

*Table 6. Summary of minimum monitoring index for SOC indicator for various general intervention types expected to **'avoid' degradation** and contribute to LDN. Table compiled from Table 3 and Decision Trees 4 in "Realizing the Carbon Benefits of Sustainable Land Management Practices: Guidelines for Estimation of Soil Organic Carbon in the Context of Land Degradation Neutrality Planning and Monitoring". Key: Land cover change (LC), Land productivity change (LP), Soil organic carbon (SOC).*

LDN Response Action	SLM Type	Class	General Intervention Type	Minimum primary indicator for SOC*
Reduce Degradation	Collective Actions	Vegetative measures	Reduce / control herd densities	LP + production statistics
	SLM Approaches	Land use policies	Watershed planning support	LC
			Grazing agreements	LP
			Soil & water conservation programs	SOC
			Set aside/Resettlement	LC
			Promoting fertilizer	SOC
			Biomass burning regulation	SOC
			Extension services	SOC
			Taxation/Subsidies	LP + production statistics
			Alternative fuel schemes	LC
	SLM Technologies	Agronomic measures	Agroforestry	SOC
			Live fencing	SOC
			No/minimum tillage	SOC
			Crop rotation	SOC
			Intercropping	SOC
			Green manuring	SOC
			Composting/Mulching	SOC
			Manuring	SOC
			Integrated crop/Livestock systems	SOC
			Conservation agriculture	SOC
			Fertilizer use	SOC

*Table 7. Summary of minimum monitoring index for SOC indicator for various general intervention types expected to '**reduce**' degradation and contribute to LDN. Table compiled from Table 3 and Decision Trees 4 in "Realizing the Carbon Benefits of Sustainable Land Management Practices: Guidelines for Estimation of Soil Organic Carbon in the Context of Land Degradation Neutrality Planning and Monitoring". (4). Key: Land cover change (LC), Land productivity change (LP), Soil organic carbon (SOC).*

LDN Response Action	SLM Type	Class	General Intervention Type	Minimum primary indicator for SOC*
Reverse Degradation	Collective actions	Structural measures	Flood control	LP + production statistics
			Terracing	LP + production statistics
			Tile Drainage	LP + production statistics
			Irrigation schemes	LP + production statistics
			Gully control	LP + production statistics
		Vegetative measures	Natural regeneration	LC
			Reforestation	LC
			Afforestation	LP
			Wetland restoration	LC
			Woodlot/plantations	LP
			Exclosures	LC
			Tree nurseries	LP

*Table 8. Summary of minimum monitoring index for SOC indicator for various general intervention types expected to "**reverse degradation**" and contribute to LDN. Table compiled from Table 3 and Decision Trees 4 in "Realizing the Carbon Benefits of Sustainable Land Management Practices: Guidelines for Estimation of Soil Organic Carbon in the Context of Land Degradation Neutrality Planning and Monitoring". (4). Key: Land cover change (LC), Land productivity change (LP), Soil organic carbon (SOC)*

5.3. Determining available capacity for monitoring SOC

The capacity needed for monitoring SOC per project is essentially a resource availability/priority setting question. First, the project should determine the minimum levels of investment into SOC monitoring suggested in the recent guidance (Table 6, Table 7, Table 8, modified from UNCCD SPI recent guidance). Decisions are presented in Figure 4 and provides limited options, basically outlining that for many situations, some form of baseline assessment is the minimum compliance. In some instances, alternative primary indicators can be used as a proxy for SOC stability, as both LC and LP are collected for all projects. Options are given for when to deviate from a minimum compliance and with the SOC indicator.

One important instance is when a project activity is not clearer included in the existing advice. Where SOC is not the Primary monitoring index it can only be applied to interventions that are not ‘novel’ intervention activities. It is up to the project to provide proof of suitable scientific literature and to prove their variation of intervention relies on methods that are not so novel as to be unstudied in the scientific literature. Examples could include a literature review of existing peer reviewed studies on the effect of the specific intervention practice employed by the project, showing stable to positive effects on SOC in similar climate/soil types. Where a intervention practice can be considered novel and is only supported by circumstantial evidence (e.g. largely unstudied by scientific literature but should in theory increase SOC) then it is required to monitor SOC through time to verify effects.

It is important to note that as projects grow and complexity increases, the cost of annual collation of production statistics and participation rates may easily approach that of simple SOC monitoring or modelling systems. The time cost of tracking production statistics annually can vary from low (in the case where these statistics are already being collected regionally by government and where the project already maintains records of its own regional production statistics per ha); to high (where experts are required to collect and compile statistical estimates from multiple sources for more complex situations). In high cost instances, it may indeed be more cost effective to simply directly measure or model SOC as primary monitoring index.

Overall, the level of investment made into SOC monitoring will need to be taken at the project level in consideration of the characteristics, aims and operating space of project. The is much scope provided to projects to tailor the SOC monitoring to suit their commercial and agronomic needs.

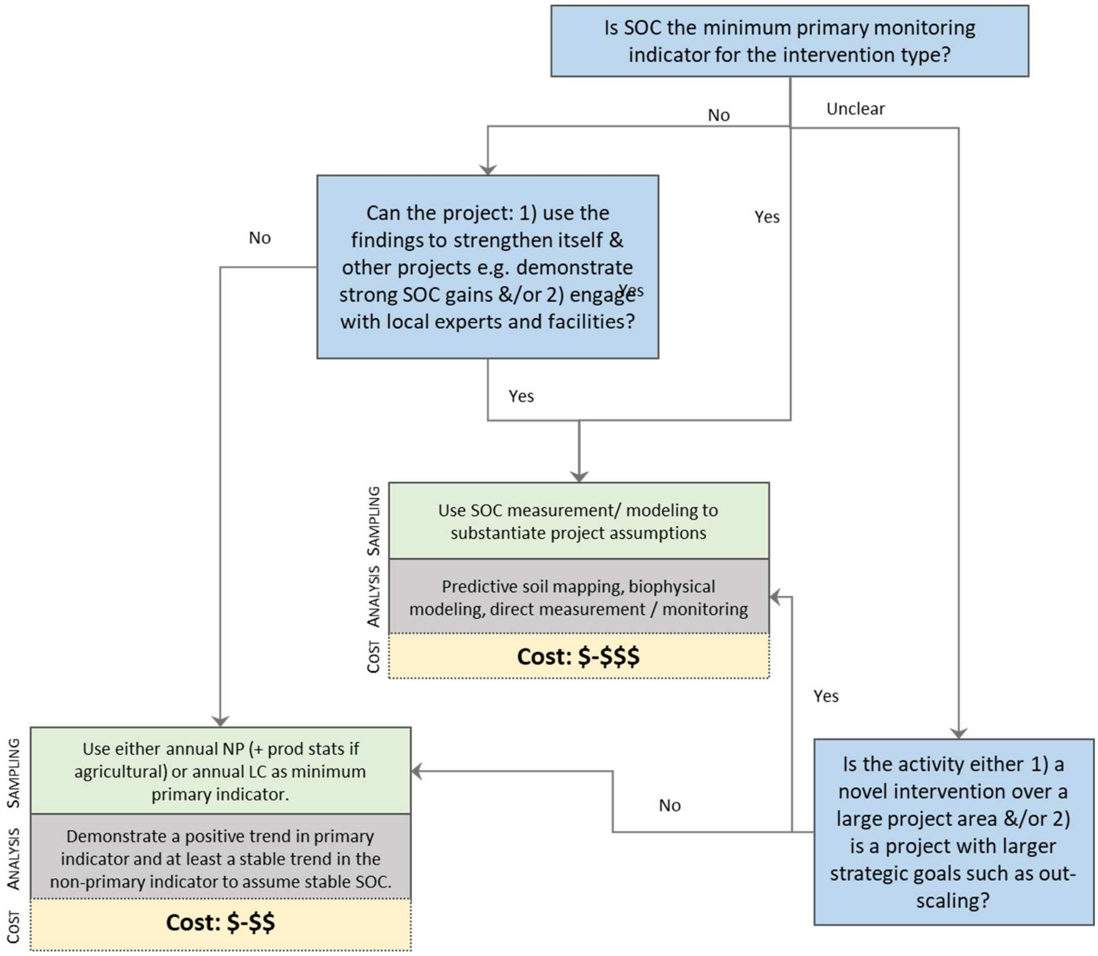

Figure 4. Flow chart for selection of approach for analysis to estimate change in SOC for projects of differing capacities.. $" indicates < 5000 USD, "$$" indicates 5,000 - 10,000 USD, "$$$" indicates >10,000 USD. Refer to section 6 for estimation full monitoring costs through project lifespan.

5.4. Using SOC monitoring to substantiate project assumptions

The simplest and often most cost-effective approach to establishing Soil Organic Carbon (SOC) stock change in an investment area is direct measurement of the area at baseline and after several years of altered management (Tier 3, direct measurement approach). There are several approaches to establishing such a difference in total stocks, and the most appropriate tends to depend on the aims and details of the project (total area, location, type of management change, the magnitude of expected SOC change, value of SOC change and value of other information), availability of field data and the understanding of the impact so the intervention on SOC levels (Figure 4).

Regardless of the exact sampling design, all estimates need to provide total estimated stocks at project baseline and cessation and the average difference of those stocks — including the sampling or model variance of the estimated/predicted average difference. The inclusion of the sampling/model variance of the mean difference in SOC stocks of a set time for a given area, contains the information relating to the quality of the assessment itself, and allows both comparison across differing sampling and inference strategies and the determination of a statistically defensible/'tradeable' amount of SOC sequestration (if desired). Similar requirements apply if space-for-time/paired plots are used, in addition to plots being representative of the entire project area in space.

5.5. Sampling strategy

5.5.1. Field sampling

The field guide (see Appendix 3) outlines the process for collecting samples in the field. In the vertical direction, SOC samples need to be collected using 0–30 cm aggregate depth (depth compositing) which matches the LDN specifications. Samples may be broken into smaller depth increments as desired, but it is not a requirement of this method.

Revisit times

We recommend data collection in the field at baseline, followed by 1–3 revisit periods. A project specific revisit time will be estimated from the baseline sampling strategy by considering spatial variation of SOC across the project and based on assumptions regarding the likely sequestration rates depending on the management strategies and interventions of each project. In general, the revisit time should be no shorter than a 5-year interval (and in its simplest form SOC will be assessed in the field at baseline and at the terminal evaluation of the project). For instance, where only the first survey is available and there is a desire to estimate an approximate revisit time for the second survey, the standard error of SOC stocks is assumed to equal that of the baseline sampling round (allowing calculation of the standard error of a potential difference). Sensible SOC sequestration rates (from the literature) over the time periods of interest (the project duration or shorter) are then substituted for the difference in stocks and the potential tradeable amounts are assessed on this basis. Such investigation allows determination whether tradeable differences are achievable based on the baseline standard errors and reasonable SOC sequestration rates and allows adjustment of the baseline sampling campaign if necessary/desired.

Sampling intensity/density

Depending on the spatial configuration of investment sites, a general estimate on the minimum number of samples per investment area should be between 1–3 samples per km^2 if employing wall-to-wall representative areas. This guidance would vary depending on local conditions and availability of time and resources for data collection.

Inclusion of additional soil variables
Collecting and measuring additional soil variables (beyond SOC) for both projects is highly recommended (especially since field work can often be the costliest part of survey) in order to greatly increase the agronomic utility of the data. These additional variables could include (see e.g. (*14*) pH, P, K, CEC (optional/back calculated), total N (especially if using CNS analyzers), Ca, Mg, Fe, Al, Zn, B, S. Once measured, these variables can be mapped and regional/geological constraints on agronomic production can be readily addressed with locally and sustainably sourced minerals and strategies. Though collecting these additional variables is highly recommended, the additional lab analyses needed increase lab costs (to about USD 50.00 per sample). Though these additional nutrients are not required for an analysis of change in SOC, analyzing soil samples to test for these additional variables is strongly advised due to the considerable agronomic and biomass benefits that can be derived from such data and applied across sites.

5.6. Sample analysis
SOC stock is a composite measurement and is derived using three soil variables (*15*) at minimum soil carbon content and bulk density need to be estimated in the lab (refer to Soil sampling guide in Appendix 3 for recommendations on soil sample collection):

Soil carbon stock [t/ha] = Soil carbon content [%] * oven-dry Bulk density [t/m3] * (1 - GF)

Where GF is the gravel fraction (0–1). For each soil sample, the following data will be recorded:

- GPS location (supplied by the sampling strategy, but recorded as each sample is taken),
- Diameter of core (mm) and the depth of recovered material,

5.7. Statistical analysis
Statistical non spatially explicit approaches will be suitable in most case to assess the impact of project activities on SOC, especially if space-for-time management substitution is selected. Depending on the sampling design specific statistical analysis may vary. Key elements to keep in mind when determining appropriate approach include:

- Objective: identify effect of land management in SOC. This can be evaluated with a time series analysis or a space-for-time approach
- Covariates: SOC is a soil property highly spatially variable, so including in the analysis covariates which minimize the effect of environmental variability is critical (refer to case studies for an example of using a cluster design to minimize environmental variability)

5.8. Predictive Soil Mapping

Depending on the sampling designed found most appropriate to assess the impact of project activities in SOC, predictive soil sampling could be an option for evaluating spatially such dynamics. Once soil sample points are collected, maps of SOC can be developed using a mapping procedure built using single machine learning approaches as described by Hengl and MacMillan (*16*), by using an Ensemble Machine Learning framework (building on the top of the mlr and SuperLearner packages in R). Hengl is currently developing a package called "landmap" which automates generation of spatial predictions based on Ensemble Machine Learning, and which includes geographical distances in the model estimation (*17*) and can be run in parallel and is designed to efficiently process large data sets. Soil mapping can produce increasingly more accurate predictions of soil variables, which is mainly due to the increasing availability of covariate layers (*18*) (see below).

Covariate	Source	1km	250m	100m	30m
ALOS AW3D30 surface elevation	http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm	❑	❑	❑	☑
DEM derived parameters (slope, upslope, downslope area, openness, TWI, MVRBF)	OpenLandMap.org	❑	❑	☑	❑
WorldClim v2, CHELSA climate and Global Precipitation Measurement Integrated Multi-satellitE Retrievals for GPM (IMERG) rainfall monthly images	OpenLandMap.org	☑	❑	❑	❑
MODIS MOD11A2 Land Surface Temperature	OpenLandMap.org	☑	❑	❑	❑
MODIS MOD09A1 surface reflectance	OpenLandMap.org	❑	☑	❑	❑
MODIS MOD13Q1 EVI monthly	OpenLandMap.org	❑	☑	❑	❑
Cloud Fraction based on MODIS MOD09 monthly images	http://www.earthenv.org/cloud	☑	❑	❑	❑
Copernicus Land products Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	https://land.copernicus.eu/global/products/fapar	❑	☑	❑	❑
Bioclimatic variables based on CHELSA climate	http://chelsa-climate.org/downloads/	☑	❑	❑	❑
Land cover based on ESA CCI product	http://www.esa-landcover-cci.org/	❑	☑	❑	❑
Lithological class based on the USGS EcoTapestry	http://gec.cr.usgs.gov/	❑	☑	❑	❑
Landform class based on the USGS EcoTapestry	http://gec.cr.usgs.gov/	❑	☑	❑	❑
Water Vapor based on NEO	http://neo.sci.gsfc.nasa.gov	☑	❑	❑	❑
Global Surface Water occurrence probability	https://global-surface-water.appspot.com/download	❑	❑	❑	☑

PALSAR/PALSAR-2 radar images bands HH and HV	http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/data/index.htm	❑	❑	❑	☑
Global 30m Bare Ground (circa 2010)	https://landcover.usgs.gov/glc/	❑	❑	❑	☑
GlobalForestChange project landsat bands NIR SWIR for 2000, 2014 and 2018	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html	❑	❑	❑	☑
Global Land Cover (GLC) maps based on the GLC30 project	http://www.globallandcover.com/	❑	❑	❑	☑

Table 9. Examples of publicly available layers of interest to be used as covariates for predicting soil properties.

6. ESTIMATING LIKELY MONITORING COSTS

The methodologies outlined in Sections 3-5 attempt to minimize cost and maximize accuracy, while remaining aligned with the LDN SCF, and with the Good Practice Guidance developed by the UNCCD for assessing SDG Indicator 15.3.1 (*5*).

Monitoring costs will, however, vary. The collective size and spatial distribution of the investment area(s), desired frequency of monitoring, the spatial resolution used for each indicator, costs for on the ground data collection and analysis, and the expertise of the project team, will all influence overall costs, as will which components of the monitoring program are carried out directly as opposed to being contracted. Costs can be minimized by ensuring that monitoring requirements are defined carefully at the outset of a project, and that information is collected only at the level of accuracy required to meet the goals of the monitoring program (i.e. if a project needs only to detect overall change in an indicator across the investment area, then a spatial map of that indicator may not be required). Table 10 gives an example of what a monitoring budget might look like. Further details on expected costs for monitoring each indicator are listed below.

	Baseline	***Annual***	***Terminal***	***Details***
Productivity	$ 1,000.00	$ 500.00	$ 1,000.00	Assuming two days of analysis time in baseline and terminal years.
Land cover	$ 2,000.00	$ 125.00	$ 2,000.00	Assuming four days of analysis time in baseline and terminal years, and recurring analysis every four years (so a total of $500 every four years)
Soil organic carbon	$ 13,500.00	$ 0.00	$ 13,500.00	Assuming 15 days at baseline and 5-15 days at termination/mid evaluation, if measurement of SOC is determined as necessary depending on project intervention. Process modelling likely to take similar time to collect info at initiation, and less time at terminal (5 days), but will be deskbound work. Using production statistics and tracking adoption rates will take a similar amount of time to direct measurement but spread through annual intervals (~30 days). Estimate $7500 expert time, $3000 travel at initiation, $7500 expert time plus $3000 travel at conclusion, and $3000 in lab costs at initiation and baseline. Note that lab costs could vary significantly depending on the country, and some projects might not require field visits at initiation and baseline.
Data purchasing	$ 3,750.00	Not applicable	$ 1,875.00	Assuming purchase of imagery to cover 25,000 hectares (at $15 per sq. km at

				baseline), and that imagery costs will decline by 50% by 2034.
Total	**$ 20,250.00**	**$ 625.00**	**$ 18,375.00**	Annual is multiplied by 13.

Grand total:	**$41,350.00**

Table 10. Estimated costs (in 2020 USD) of implemting monitoring program for a LDN fund investment of 25,000 hectares. All numbers are approximate, as costs will vary significantly with the region of implementation and type of project, and data collection and analysis costs will vary depending on the requirements of the project design, the consultant or institutions involved in carrying out the assessment, and expected continued development of monitoring tools. For soil organic carbon, data collection costs will be lowest if local capacity can be used to conduct soil data collection (therefore time costs of collection are excluded).

Further details on the costs of monitoring each of the three indicators are given in the following three sections.

6.1. Land productivity

The methods for mapping land cover and productivity will draw on the free and open source Trends.Earth toolkit when using global data in order to minimize monitoring costs. However, an expert will still be required to run the tool and generate reports, particularly when very high-resolution imagery is used. The estimated budget in Table 10 assumes approximately two days of analysis time in baseline and terminal years, and one day of analysis time per year for annual reporting.

6.2. Land cover

Costs for mapping land cover will vary depending on the type of project (as outlined in Section 4). For sites where high-resolution imagery is required, it will need to be purchased (at approximately USD 15.00 per 100 hectares at 2020 pricing). Increasing competition in the market for satellite imagery has led to a downward trend in these costs, and it is anticipated that these costs will continue to decline throughout the period in which the LDN Fund will be making investments.

To process the land cover imagery and land productivity the budget in Table 10 allows for approximately 3-5 days of analysis time (GIS/remote sensing analyst) per project for the baseline and terminal evaluation. If very high-resolution imagery is needed, then the required analysis time will be closer to 5 days. For annual reporting, no more than 1-2 days should be required per project, as training data will have already been collected at the baseline period, and the analysis of land cover will be readily supported by freely available tools (such as Trends.Earth) that continue to be improved and in support of monitoring the LDN indicators.

6.3. Soil organic carbon

The methodology for assessing change in SOC aligns with the Science-Policy Interface of the UNCCD (*4*) and indicates if SOC monitoring is necessary to comply with LDN and/or if changes in other indicators can be used as proxies. As described in Section 5, in some instances, there will be existing SOC and other data that allows the use of process-based models for demonstrating SOC compliance (*4*) but in general these approaches will require some additional expert costs. Direct measurement/monitoring may/may not be costly in comparison to other project documentation, but the actual costs of these options will vary significantly depending on the country and the character of the intervention project (e.g. size, spread, number of participants) and so estimates provided are to be treated as indicative only.

Where required and/or the expert capacity is available for direct measurement/modeling of the SOC indicator, the methodology utilizes direct measurement approaches consistent with de Gruijter et al. (*19*), the established Australian methodology (*20*), and is considered under the IPCC GPG 2019 (*21*) as a Tier 3, direct measurement approach. A Tier 3 approach is the most accurate level of approach available and maximizes the chance of detecting SOC changes due to land management change across an investment or representative sub-area. However, this type of approach requires ground data collection, and therefore often a larger budget is required for monitoring SOC than for land productivity and land cover. While it may at first appear that direct measurement is more costly, it must be noted that for other SOC compliance methods (such as annual tracking of production statistics and adoption rates) significant staff time will still be required to annually assemble and analyze the necessary data. Savings in staff time could be found where staff are already collecting production statistics at the project level, and regional production statistics are annually available from government sources.

Where direct SOC monitoring in employed, the baseline survey will incur lab costs of approximately $3000 USD (based on the 150 samples analyzed in each of the pilot studies conducted while developing this document). These rates will vary somewhat depending on the country, as well as availability of local lab capacity and staff time. As discussed in the SOC methods section, it would be advantageous to incorporate SOC assessment into wider project activities (e.g. by also analyzing several other soil variables to provide additional agronomic information can greatly increase the utility of the soil survey data). Where best practice investment strategy is possible, equations specifying how to draw conclusions on SOC change based on initial and final measurements, or on a space-for-time survey, can be used. However, costs for undertaking sampling design and data analysis would be expected if this expertise is not present on the project team.

7. EVALUATING PROJECT CONTRIBUTION TO ACHIEVING LDN

In addition to informing project management, a key goal of monitoring the LDN Indicators across LDN Fund Investments is to determine if investments are contributing to the achievement of LDN. To address this question, the three LDN Indicators should be assessed in combination. The problem of how to combine the three LDN indicators has already been addressed in the LDN Scientific Conceptual Framework (LDN SCF) which adopts the "one-out, all-out" principle. The "one-out, all-out" principle of the LDN SCF is applied to the three indicators (land cover, land productivity, and soil organic carbon) on a per unit of land basis in order to calculate whether a unit of land is degrading. Under the LDN SCF, if any of the three indicators indicates degradation, then a unit of land is degrading, regardless of the values of the other two indicators.

The main focus of the Fund is project-level monitoring. Given its project-level focus, the Fund has adopted a variant of the above one-out, all-out principle and applies it to project selection, and "only invests in projects where all three indicators are expected to improve or remain neutral" [within the project area].

The approach taken by the Fund simplifies the task of determining whether a project is contributing to the achievement of LDN. Under the LDN SCF and any national-level targets that are consistent with it, projects can cause degradation so long as that degradation is counter-balanced elsewhere in the country on a unit of land of similar land potential (*3*). In other words, under the LDN SCF an individual project that causes degradation *would not* necessarily be considered inconsistent with achieving LDN, as that project could be considered consistent with achieving LDN so long as any degradation that is occurring as a result of that project is expected, and planned to be offset appropriately (within land of similar type) elsewhere in the country. That same project, however, if funded under the LDN Fund, *would* be considered inconsistent with achieving LDN, given the expectation of the Fund that all projects will result in stability or improvement across all three indicators.

In other words, by applying the 'all stable or improving criteria' to the level of each LDN Fund investment project, the problem of relating each individual project back to a national-level frame of reference, in the case of a degradation to be compensated elsewhere, is neatly avoided. This approach allows project success to be considered on a per-project basis, even in those countries where LDN targets have not yet been established, by defining a project as contributing to LDN if and only if all three indicators improve or remain stable when aggregated across the project.

To aggregate the three indicators across each project, and consistent with the LDN SCF, the idea of land potential can be used to stratify the investment area into a set of similar units, or "land types". Land potential can be defined in multiple ways, and maps produced at national scale would be best suited for this. If local data is not available, one option is to define this homogeneous units by combining soil types classes (soil taxonomy units under the USDA system provided by OpenLandMap.org at 250m resolution) and land cover (using the baseline land cover map developed for the land cover indicator). The unique combinations of soil and land cover at the beginning of the project can be assumed to represent unique land types. To calculate whether a project has contributed to LDN, all three indicators should be calculated for each pixel in the investment area (possibly as average for SOC depending on the sampling plan), and the one-out, all-out principle applied in order to calculate the total land area degraded and the total land area improved within each land potential unit. Once the above calculation is performed, LDN has been achieved for those land units where there is stability or net improvement (recalling that some adjustments might need to be made to some of the indicators to account for expected short-term impacts of project activities – for example temporary declines in land productivity that may occur due to the initiation of activities to promote forest restoration).

Although it is allowable under the LDN SCF to offset degradation with improvements in other areas that are within the same land cover type, a site manager in consultation with the LDNF might set a ceiling for a maximum allowable percentage of the investment area that can experience a decline due to force majeure events or similar, in addition to the requirement of stability or increase in each indicator across all units of similar land potential. This requirement would ensure that LDN Fund investments be consistent with the vision of the Fund of supporting sustainable businesses and land restoration practices. A decision on the allowable maximum percentage of land area within a project that can be degraded should be determined in collaboration with IDH, LDN Fund managers, and local stakeholders.

APPENDIX 1: EXAMPLE ANNUAL REPORT

Note: also see [Excel worksheet here](). Worksheet will be accessible through future versions of Trends.Earth.

Trends.Earth SDG 15.3.1 summary table

Summary of SDG 15.3.1 Indicator from {date_start} to {date_end}

Summary by land area (sq km)

Improved	34.8	15.5	Improving
		19.3	Early signs of improving
Stable	94.3	70.4	Stable high performance
		15.0	Stable moderate performance
		8.9	Stable low performance
Degraded	3.4	2.0	Early signs of declining
		1.4	Degrading
No data	1.3	1.3	No data
Total	133.8	133.8	

Summary by percent of land area (%)

Improved	26.0%	11.6%	Improving
		14.4%	Early signs of improving
Stable	70.5%	52.6%	Stable high performance
		11.2%	Stable moderate performance
		6.7%	Stable low performance
Degraded	2.5%	1.5%	Early signs of declining
		1.0%	Degrading
No data	1.0%	1.0%	No data
Total	100.0%	100.0%	

Broader context

Describe any activities or changes known to be ocurring in this area that might be reflected in these monitoring data (for example agricultural intensification, forestry, natural regeneration, land abandonment, etc.). If known, specify when these activities or changes began (or ended).

(This box is to be completed by person preparing this report, with outreach as needed to other stakeholders)

In general, are the findings from the field and remote sensing data that are contained in this report expected or unexpected based on your understanding of activities that are ongoing in this area? Do the results, in general, make sense?

(This box is to be completed by person preparing this report, with outreach as needed to other stakeholders)

Give an example of an unexpected result (if any) reflected in the data in this report, and of the likely cause of that result (if known). For example, if there are improvements noted in productivity, are these likely to due to weather during the monitoring period? Or are they likely due to human activity (such as reforestation)?

(This box is to be completed by person preparing this report, with outreach as needed to other stakeholders)

Give an example of an expected result (if any) reflected in the data in this report, and of the likely cause of that result (if known).

(This box is to be completed by person preparing this report, with outreach as needed to other stakeholders)

For more information on Trends.Earth, see http://trends.earth, or contact the team at trends.earth@conservation.org.

Trends.Earth productivity summary table

Summary of change in productivity from {date_start} to {date_end}		
	Area (sq km)	Percent of total land area
Total land area:	0.0	#DIV/0!
Land area with improved productivity:		#DIV/0!
Land area with stable productivity:		#DIV/0!
Land area with degraded productivity:		#DIV/0!
Land area with no data for productivity:		#DIV/0!

* For the SDG indicator, areas are considered to be improved if they have "Improving" productivity, to be stable if they have "stable" productivity, and to be "degraded" if they are classified as "stressed", in "moderate decline" or "declining".

Area of land with improving productivity by type of land cover transition (sq. km)

Improving

Land cover type at start of period \ Land cover type at end of period	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas								*0.00*
Grasslands								*0.00*
Croplands								*0.00*
Wetlands								*0.00*
Artificial areas								*0.00*
Other lands								*0.00*
Water bodies								*0.00*
Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	***0.00***

Area of land with early signs of improving productivity by type of land cover transition (sq. km)

Early signs of improving

Land cover type at start of period \ Land cover type at end of period	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas								*0.00*
Grasslands								*0.00*
Croplands								*0.00*
Wetlands								*0.00*
Artificial areas								*0.00*
Other lands								*0.00*
Water bodies								*0.00*
Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	***0.00***

Area of land with stable high performance for productivity by type of land cover transition (sq. km)

Stable high performance

Land cover type at start of period \ Land cover type at end of period	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas								*0.00*
Grasslands								*0.00*
Croplands								*0.00*
Wetlands								*0.00*
Artificial areas								*0.00*
Other lands								*0.00*
Water bodies								*0.00*
Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	***0.00***

Area of land with stable moderate performance for productivity by type of land cover transition (sq. km)

Land cover type at end of period

Stable moderate performance

Land cover type at start of period

	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	Total:
Tree-covered areas								0.00
Grasslands								0.00
Croplands								0.00
Wetlands								0.00
Artificial areas								0.00
Other lands								0.00
Water bodies								0.00
Total:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Area of land with stable low performance for productivity by type of land cover transition (sq. km)

Stable low performance

Land cover type at end of period

Land cover type at start of period

	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	Total:
Tree-covered areas								0.00
Grasslands								0.00
Croplands								0.00
Wetlands								0.00
Artificial areas								0.00
Other lands								0.00
Water bodies								0.00
Total:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Area of land with early signs of declining productivity by type of land cover transition (sq. km)

Early signs of declining

Land cover type at end of period

Land cover type at start of period

	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	Total:
Tree-covered areas								0.00
Grasslands								0.00
Croplands								0.00
Wetlands								0.00
Artificial areas								0.00
Other lands								0.00
Water bodies								0.00
Total:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Area of land with declining productivity by type of land cover transition (sq. km)

Declining

Land cover type at end of period

Land cover type at start of period

	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	Total:
Tree-covered areas								0.00
Grasslands								0.00
Croplands								0.00
Wetlands								0.00
Artificial areas								0.00
Other lands								0.00
Water bodies								0.00
Total:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Area of land with no data for productivity by type of land cover transition (sq. km)

Land cover type at end of period

	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	Total:

No data	Land cover type at start of period								
	Tree-covered areas								*0.00*
	Grasslands								*0.00*
	Croplands								*0.00*
	Wetlands								*0.00*
	Artificial areas								*0.00*
	Other lands								*0.00*
	Water bodies								*0.00*
	Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	***0.00***

For more information on Trends.Earth, see http://trends.earth, or contact the team at trends.earth@conservation.org.

Trends.Earth soil organic carbon summary table

Summary of change in soil organic carbon from {date_start} to {date_end}		
	Area (sq km)	Percent of total land area
Total land area:	0.0	#DIV/0!
Land area with improved soil organic carbon:		#DIV/0!
Land area with stable soil organic carbon:		#DIV/0!
Land area with degraded soil organic carbon:		#DIV/0!
Land area with no data for soil organic carbon:		#DIV/0!

Percent change in soil organic carbon storage from initial to final: ***#DIV/0!***

Soil organic carbon change

	Initial soil organic carbon (tonnes / ha)	Final soil organic carbon (tonnes / ha)	Initial area (sq. km)	Final area (sq. km)	Initial soil organic carbon (tonnes)	Final soil organic carbon (tonnes)	Change in soil organic carbon (tonnes)	Change in soil organic carbon (percent)
Tree-covered areas					0.00	0.00	0.00	#DIV/0!
Grasslands					0.00	0.00	0.00	#DIV/0!
Croplands					0.00	0.00	0.00	#DIV/0!
Wetlands					0.00	0.00	0.00	#DIV/0!
Artificial areas					0.00	0.00	0.00	#DIV/0!
Other lands					0.00	0.00	0.00	#DIV/0!
		Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	

Soil organic carbon change by type of land cover transition (as percentage of initial stock)*

Land cover type at start of period	Land cover type at end of period: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands
Tree-covered areas						
Grasslands						
Croplands						
Wetlands						
Artificial areas						
Other lands						

* Trends.Earth calculates soil organic carbon change based on annual land cover transitions. This table shows change in soil organic carbon based on the initial and final date only. The final soil organic carbon value used to produce this table accounts for all land cover transitions that ocurred between the initial and final date. An empty cell indicates that transition was not observed over the time period.

For more information on Trends.Earth, see http://trends.earth, or contact the team at trends.earth@conservation.org.

Trends.Earth land cover summary table

Summary of change in land cover from {date_start} to {date_end}

	Area (sq km)	Percent of total land area
Total land area:	0.0	#DIV/0!
Land area with improved land cover:		#DIV/0!
Land area with stable land cover:		#DIV/0!
Land area with degraded land cover:		#DIV/0!
Land area with no data for land cover:		#DIV/0!

Land cover change by cover class

	Initial area (sq. km)	Final area (sq. km)	Change in area (sq. km)	Change in area (percent)
Tree-covered areas	0.00	0.00	0.00	#DIV/0!
Grasslands	0.00	0.00	0.00	#DIV/0!
Croplands	0.00	0.00	0.00	#DIV/0!
Wetlands	0.00	0.00	0.00	#DIV/0!
Artificial areas	0.00	0.00	0.00	#DIV/0!
Other lands	0.00	0.00	0.00	#DIV/0!
Water bodies	0.00	0.00	0.00	#DIV/0!
Total:	*0.00*	*0.00*	*0.00*	

Land area by type of land cover transition (sq. km)

Land cover type at end of period (columns); Land cover type at start of period (rows)

Land cover type at start of period	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas								*0.00*
Grasslands								*0.00*
Croplands								*0.00*
Wetlands								*0.00*
Artificial areas								*0.00*
Other lands								*0.00*
Water bodies								*0.00*
Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	***0.00***

For more information on Trends.Earth, see http://trends.earth, or contact the team at trends.earth@conservation.org.

APPENDIX 2: EXAMPLE ELEMENTS IN TOR FOR CONSULTANT TO ASSIST WITH MONITORING OF SOC

Description of assignment:

The selected consultant will be responsible for developing a baseline and estimation of expected impacts and/or a recurring monitoring approach for assessing the contribution of <*project x*> to land degradation neutrality, consistent with the recommended monitoring approach of the Land Degradation Neutrality Fund and focusing on the indicator of change in soil organic carbon (SOC).

Required expertise:

- Project lead must have Masters' or PhD level-experience in spatial statistics, geography, remote sensing, soil science, or related discipline
- Familiarity with LDN conceptual framework
- Demonstrated international M&E experience on LDN Fund, GEF, World Bank, or similar project
- Familiarity with open-source geospatial software including QGIS, Trends.Earth, and the R Statistical Computing Environment
- Expertise in sampling design, field data collection, and modeling for assessing change in soil organic carbon (SOC)

Key deliverables (exemplary, will vary depending on needs of project, and should be consistent with guidelines in this report):

Deliverable 1: Draft methodology for assessing change in SOC, consistent with LDN Fund recommended approach

- Draft methodology for assessing change in SOC during the period of investment
- (if required) Will outline field sampling requirements (if required) to develop baseline estimation / map of SOC, and to assess change in SOC over the period of investment
- (if required) Will describe recommended approach to develop baseline maps of SOC based on field sampling
- Will describe how to produce final estimates of change in SOC at the end of a project

Deliverable 2: Sampling design for project site

- (if required) Sampling protocol for project site for SOC data collection from 0-30 cm aggregate depth, based on recommended LDN Fund monitoring approach and any other relevant guidance's
- (if required) Will specify data collection locations and provide these to project in a format consistent with LDN Fund monitoring approach guidelines

- Will specify measurements required in the field at each sample location
- Will specify requirements for lab analysis of each sample to obtain estimate of SOC content

Deliverable 3: Baseline and final SOC assessments for project site

- Baseline and final SOC (or change in SOC) consistent with LDN fund approach

APPENDIX 3: FIELD GUIDE FOR SOC SAMPLING

Background

The purpose of the soil sampling to be undertaken is for the determination soil organic carbon (SOC) stock with the aim of evaluating project compliance to LDN guidelines. Before field data collection, a sampling framework needs to be designed considering the objective of the sampling and the statistical analysis to be used once lab results are obtained. Here a clustered sampling design with field determined randomness of points was selected due to the absence of spatial field boundaries and very small plot sizes. Once a cluster of land-uses was determined, within each cluster the area was divided into roughly equal areas and samples distributed amongst those sub-divisions to increase sample spatial coverage of the land-use unit.

Once in the field, take the following considerations before collecting the soil sample:

- Find a place at least 5 meters away from edges, fences, paths, cattle paths, roads or any other factor which could affect the soil conditions of the area you are trying to evaluate. We want to collect sample as representative as the overall area as possible.
- Sampling should be carried out as near to the GPS located sampling points as possible.
- Soil sampling is to a depth of 30cm in line with existing convention. If 30cm is not achieved or sample is not recovered, the collection should be attempted again. It is very important to recover a full 30 cm sample.
- The sampling point surface should be brushed clear of vegetation, manure, litter and in a cultivated soil, as close to normal soil surface as practical. Additionally, cultivated soils should be sampled in the same management time window (e.g. pre or post ploughing) to prevent too large uncertainties from wide fluctuations in bulk density.
- Taking soil samples is a professional skill and often also an art, which requires practice, and depending on the tool used and the soil conditions, several attempts may have to be taken before collecting a useful sample. For that reason, it is important to consider training a team member or contracting professional sampling services. .

Required equipment

Depending on the location and soil conditions of the area to be evaluated, different soil sampling equipment would be appropriate. In most cases, a handheld coring or augur tool would suffice (Figure 1). The relative low cost and ease of transport and operation make these augers the recommended tool. Before leaving for the field make sure you have:

- Soil sampling tool (e.g. soil probe sampler) with required implements to extract soil sample
- Flat shovel
- Machete (to clear vegetation)
- GPS unit (~ 5m accuracy). Most phones will have GPS capabilities with appropriate accuracy. If using a phone, make sure to download an application which allows to record sites (e.g. LandPKS)
- Digital camera. Most smart phones have a digital camera of sufficient resolution.

- Sealable plastic bags (e.g. ziplock). Bring at least 30 % more than the number of samples you are planning on collecting that day.
- Notebook
- Pens (several)
- Permanent markers to identify samples
- Plastic tarp to work on the field
- Plastic container transport samples and protect them from the direct sun light.
- Trolley to transport samples and equipment if working by foot

Figure 1: Soil probe sampler appropriate for collecting 30 cm deep samples for SOC stock estimations. Knowing tool dimensions is essential for estimating sample volume, needed to bulk density determination.

Collecting soil sample

1. Where sampling sites are pre-selected, navigate to the GPS point and find an undisturbed location within the error margin of the GPS. Where samples are selected on-site within the sampling area due to lack of spatial boundary information (e.g. via the random walk method) make sure to the sampling area
2. Clear the place from vegetation (only soil needs to be collected). While clearing the area, make sure not to compact the soil where the sample will be collected or to brush away soil materials < 2mm in size. Also, minimize disturbance around the point as much as possible,

in case multiple attempts need to be made before a suitable sample can be extracted. Sampling with larger cores reduces this need however likely requires machinery access (e.g. hydraulic corers)

3. Use the soil sampling tool and following the tool specifications collect a sample to 30 cm deep. For bulk density estimation, it is important that the core is recovered as much as possible to a full 30cm depth and not deeper. Cores which lose material, go deeper or encounter rocks will affect results.
4. Once an appropriate sample has been collected, place it inside the bag. One sample should be stored per bag.
5. Clearly identify the bag with the sample ID. Decide on the coding system for naming samples before going to the field, and make sure multiple people are checking on the sample names to minimize misnaming samples. As careful as you are it happens. Two people checking greatly reduces such field errors.
6. Place the bag with the samples in a location protected from the sun as other samples are collected.

Key information to record in the sample form:

- Date
- Name of person collecting the sample
- Coordinates
- Name of the farmer and contact information
- Current land use
- History of land use (oral recollection of history is sufficient)
- Make a diagram of the farm and location of the sample including key landmarks in the area
- Notes: Record any relevant site information which may inform the interpretation of results (e.g. presence of cattle in site).
- Photos: Take multiple photos of the site and sample location. North, East, South and west facing photos and sample photo at minimum
- Add any relevant notes which could be useful to interpret results (e.g. is the cattle present in the site?)

Delivering soil samples to the lab:

A laboratory with capabilities for determining soil C concentration, soil wetness, sample weights in field dry and oven dry conditions in the proximity of the area needs to be identified before going to the field. Once the samples are collected and clearly identifiable information is present in each bag, samples can be delivered to the laboratory. Depending on lab capabilities and workload, processing time could take between one to two weeks.

APPENDIX 4: PILOT 1: MOUNTAIN HAZELNUT VENTURES

1.Executive summary

As part of the "Land Degradation Neutrality Fund (LDNF) Impact Monitoring Methodology" developed by Conservation International and OpenGeoHub two pilot studies were completed. This document presents the pilot study for the Mountain Hazelnut Ventures, a fully traceable hazelnut production business in Bhutan. The pilot includes project baseline for the three LDN indicators, changes in land cover, land productivity and soil organic Carbon, which also includes recommendations on how to monitor the indicators over the project lifespan, and an appendix presenting an assessment of potential impact of project activities on the three LDN indicators which is intended to inform the implementation of the monitoring plan.

The Mountain Hazelnut Ventures LDN baseline found that:

- Land productivity: 7.8 % of the investment area is currently identified as degraded compared to 5.9 % within the larger investment landscape
- Land cover: 72.2 % of the investment area is currently classified as grassland or cropland, while those covers in the larger investment landscape represent only 17.4 %. The investment landscape, on the other hand, is dominated by tree covered areas (81.2 %) compared to only 25.3 % within the investment area.
- Soil organic carbon: Baseline SOC content within the first 30 cm of the soil was 73.9 tons C/ha in fallow sites, compared to 85.9 tons C/ha in hazelnut orchards with at least 6 years of age.

The proposed monitoring plan following the LDNF Impact Monitoring Methodology is:

- Land productivity: Wall to wall annual assessment using remote sensing data
- Land cover: Wal to wall repeated measures of land cover change every four years relying in land cover maps at 30 m spatial resolution produced by the national government. If those maps were not available within the required frequency, similar maps could be produced in house using freely available imagery. Very high spatial resolution data could be useful for producing land cover maps areas of particular interest to the company or the LDNF. fully traceable hazelnut production
- Soil organic carbon: Initial and final SOC measurements with in the same representative area used for the baseline and following the same cluster design. Annually, hazelnut production measures can be used to assess changes in productive capacity of the soil and impact of ongoing agricultural practices.

2.Mountain Hazelnut Ventures[6]

Mountain Hazelnuts (MHV) was founded in 2009 as Bhutan's first 100% foreign direct investment with a mission of creating a profitable business that provides long-term income for vulnerable rural communities by planting 10 million hazelnut trees on fallow and degraded mountain slopes. A Memorandum of Understanding (MoU) with the Bhutanese government allows farmers without land to participate in the project by leasing land from the Government. MHV has since established fully traceable hazelnut production, boosting the country's exports and providing income generation opportunities through direct employment, extending to its supply chain as well as hazelnut growers who sell their harvests to the Company.

To date, Mountain Hazelnuts has integrated 12,091 farming households in its value chain. Growers and community groups (e.g., nunneries) are provided with hazelnut trees and inputs, plus training on best agricultural practices, followed by regular extension visits. Each full-grown tree can yield 4 to 6 kilos of nuts. Mountain Hazelnuts buys all harvested nuts according to a guaranteed price structure that removes market risk for the growers and ensures a profitable crop. With the typical rural household in Bhutan earning a cash income of less than $500 a year, these incremental earnings based solely on the sale of the hazelnuts will help farmers dramatically boost their incomes. By improving the lives of these farmers MHV is also hoping to stem the crippling flow of younger Bhutanese villagers migrating to urban areas.

In addition to integrating more than 5,000 women farmers as suppliers of hazelnuts, Mountain Hazelnuts also directly employs 261 Bhutanese women from the rural communities it operates in and provides training and support for their health and personal finance. Mountain Hazelnuts takes a holistic approach to address household income generation, community development, cultural preservation, local ecosystems, and global climate change.

3.Defining the area of interest

Mountain Hazelnut Ventures works to date with 10,440 small farmers distributed throughout the country of Bhutan (Figure 1). Each of those 10,440 farmers represent an **investment site** (mean =0.46 ha, median = 0.40 ha, standard deviation = 0.45 ha), as defined in the LDNF Impact Monitoring Methodology. The aggregation of all those sites represent the full area of direct intervention the project will have in the region, referred to as the **investment area**. To better understand the context in which these activities will take place, and to compare the baseline conditions of the investment area to similar areas in the surrounding region, an investment landscape was defined for this project. Considering the highly heterogenous conditions of this

[6] Verbatim from: IFC & GASF. 2016. Bhutan: Blending Happiness and Hazelnuts with Finance. https://www.gafspfund.org/projects/blending-happiness-hazelnuts-bhutan

mountainous region, we defined the **investment landscape** for this project as all land within a 2 km buffer of the investment area (Figure 1).

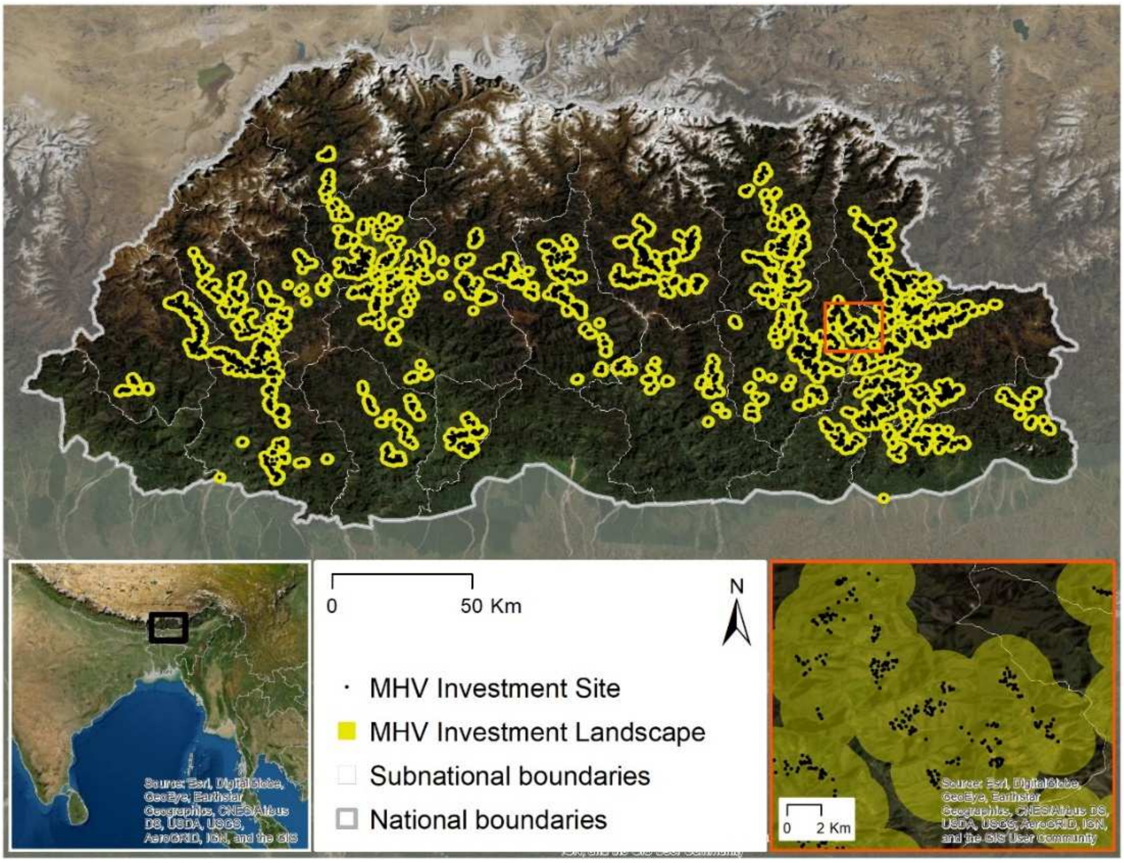

Figure 1: Mountain Hazelnut Ventures works to date in over 10,000 individual investment sites (black dots on the map). The investment area is the aggregate of all those sites. The investment landscape, in this case, has been defined as the area within a 2 km buffer around the investment area. Box on the lower right section of the figure presents a closer look to the distribution of sites and the surrounding landscape in South Eastern Bhutan.

4.The LDNF MHV project baseline

Projects part of the LDNF portfolio need to determine baseline conditions for each of the three indicators of land degradation (changes in primary productivity, land cover, and soil organic C), and monitor progress through the project lifespan. The LDNF Impact Monitoring Methodology provides guidance on how to complete baselines and set up the monitoring framework. In the sections below we present the baselines for the MHV project broken up by indicator.

4.1.Land productivity

Land productivity is the biological productive capacity of the land, the source of all food, fiber and fuel that sustains humans. Following the LDNF Impact Monitoring Methodology, it is recommended that the normalized difference vegetation index (NDVI) be used as an indicator of productivity, as it is well-correlated with actual changes in productivity based on measurement on the ground, and as there is a long-term record available to allow comparison of changes in NDVI in a particular year with how NDVI has changed in the past. Given the combination of small median size investment sites (0.40 ha) and large investment landscape (7,557.8 km^2), the recommended datasets for monitoring productivity would be at a resolution of ~30 m. However, presently only 250 m products are available for time series analysis as the ones needed for assessing productivity. For that reason, we computed productivity baselines using MODIS 250 m resolution data processed as recommended in the LDNF Impact Monitoring Methodology. For this baseline, we used Trends.Earth to compute the 5-class productivity indicator for the recommended most recent 15-year period 2005-2019 (Figure 2). The 5-class productivity integrates three sub indicators: trajectory, performance, and state.

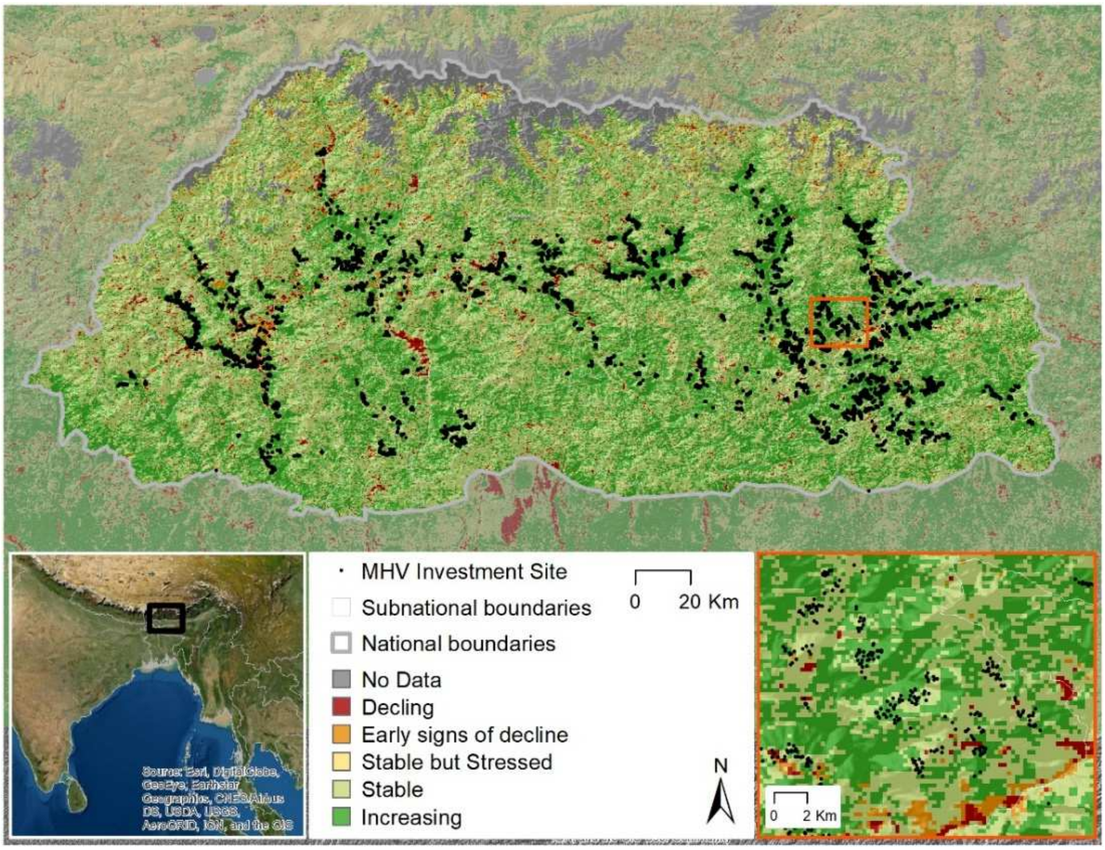

Figure 2: Productivity baseline map for the Mountain Hazelnut Ventures investments in Bhutan.

Overall, the investment area presents a baseline degradation level of 7.8 %, compared to 5.9 % degradation during the 2005-2019 period for the broader investment landscape. (table 1).

Productivity class	Investment Area	Investment Landscape
Declining	5.5 %	3.5 %
Early signs of decline	2.3 %	2.4 %
Stable but stressed	0 %	0 %
Stable	45.9 %	44.2 %
Increasing	46.3 %	49.9%
% Degraded	**7.8 %**	**5.9 %**

Table 1: Productivity baseline for the Mountain Hazelnut Ventures Investment Area and Landscape computed for the period 2005-2019.

Monitoring recommendations for productivity

Of the three LDN indicators, productivity if the most responsive to changes in land management and cover and any other condition which affects the productivity of the vegetative cover. For that reason, land productivity should be monitored annually to the LDNF following guidance from the LDNF Impact Monitoring Methodology. Through annual assessments of changes in land productivity, MHC and the LDNF will be able to monitor the impact of the investments on land degradation and adapt accordingly in order to maximize the contributions of the project towards LDN locally and at the national scale.

4.2.Land cover

Through the assessment of changes in land cover, major transitions in system structure and configuration can be monitored over time. It is critical to use a land cover product which aligns with the size and spatial distribution of the interventions being monitored, to have confidence in the reliability and usefulness of the results. The Government of Bhutan regularly produces land cover maps at 30 m resolution[7] which are used for national level reporting of LDN, among many other uses. In the case of the MHV project, the combination of small median size investment sites (0.40 ha) and large investment landscape (7,557.8 km^2), the use of a wall to wall maps at 30 m resolution was deemed appropriate for the baseline. Given resource availability, very high spatial resolution images in some focus areas could have been used if necessary, but based on the quality and coverage of the national level product, and the advantage of coordinating national and project level reporting needs.. Using the national land cover map from 2016 we developed the land cover baseline assessment for the investment area and landscape (Figure 3). The original

[7] FRMD, 2017, Land Use and Land Cover of Bhutan 2016, Maps and Statistics. Forest Resources and Management Division, Department of Forests & Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan. ISBN: 978-99936-743-2-0

land cover class scheme was aggregated to the 7 UNCCD recommended land cover classes: tree covered, grassland, cropland, bare, artificial, wetland, and water (Figure 3), and then summarized for the investment area and investment landscape (table 1).

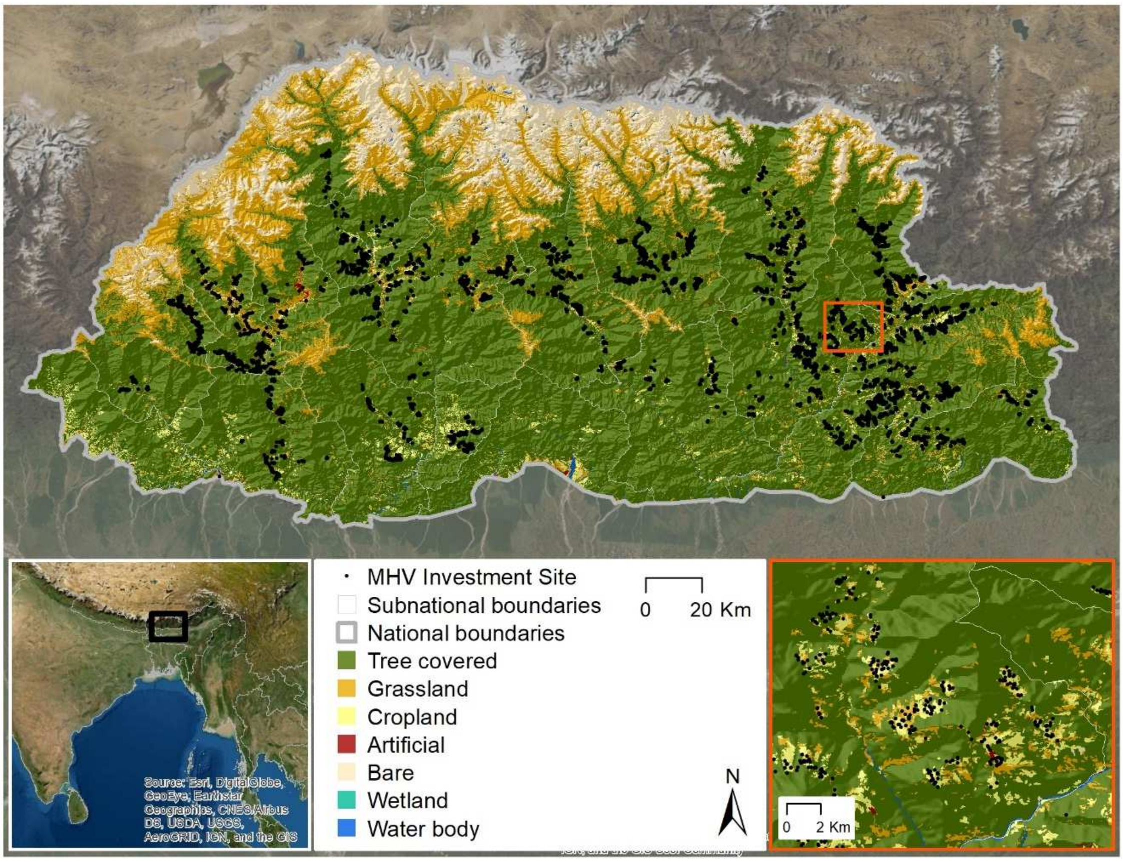

Figure 3: Land cover baseline map for the Mountain Hazelnut Ventures investments in Bhutan. Land cover data provided the Government of Bhutan (Land use and land cover of Bhutan, 2016) aggregated to the 7 UNCCD recommended land cover classes.

The baseline land cover distribution for the assessed area shows a dominance of cropland in the investment area (51.1%), while the overall landscape is dominated by trees (81.2 %). Combined croplands and grasslands represent 72.2% of the investment area as compared to only 17.4 % in the investment landscape. These results align with the objective of the project, which is to convert former agricultural lands not actively used to hazelnut orchards.

Land cover	**Investment Area**	**Investment Landscape**
Tree covered	25.3 %	81.2 %
Grassland	21.1 %	9.6 %

Cropland	51.1 %	7.8 %
Wetland	0.0 %	0.0 %
Artificial	2.3 %	0.7 %
Bare	0.0 %	0.2 %
Water body	0.1 %	0.6 %

Table 2: Productivity baseline for the Mountain Hazelnut Ventures Investment Area and Landscape computed for the period 2005-2019.

Monitoring recommendations for land cover

Changes in land cover tend to be slower than changes in primary productivity, for that reason, land cover is expected to be monitored and reported to the LDNF every 4 years at minimum. Given the track record of the national government in producing country wide land cover maps on a regular basis, it would seem appropriate to continue using those maps for reporting to the LDNF. Given resource availability and specific interest from the company or the Fund, very high spatial resolution images in some focus areas could provide useful insights and could be added to the monitoring plan and reports.

4.3.Soil organic carbon

Monitoring change in soil carbon due to project interventions requires the project proponent to consider several different decision points related to SOC and overall LDN project achievement. Recent guidance prepared by the Science-Policy Interface of the UNCCD can be applied to project descriptions to obtain guidance regarding investment into SOC assessment for LDN. The LDNF Impact Monitoring Methodology provides guidance on how to determine the appropriate monitoring in indicator depending on project objectives. Given the multi-purpose nature of the interventions being proposed by MHV, this project can be categorized as an agroforestry type of intervention. Agroforestry projects in the context of LDN are required to monitor SOC, through a combination of initial and final SOC assessments (either through field data collection or modeling) with production statistics as intermediate proxy variables for soil condition.

For this baseline, following guidance from MHV, the baseline sample area was identified in the eastern region of the investment landscape. This area representing 13.9 % of the investment landscape has the larger longer history in company operation and is centered around the company headquarters providing logistics, financial, and methodological advantages. During January 2020 2019, fieldwork was completed in this region (Figure 4). The main objective of the field work was to collect soil samples to produce the SOC baseline. Given the scale of the project and the significant landscape heterogeneity encompassed by that (due to the mountainous relief and quickly changing aspect), a clustered sampling design was implemented. Each cluster was defined in this case as a combination of fallow lands and hazelnut orchards with between 6 or 7 years since establishment, minimizing the variability in environmental factors which could contribute to the differences found in the response variables. Such a sampling design allows for achieving two main objectives: 1) completing the baseline SOC assessment (presented in this section), and 2) Applying a space-for-time substitution, to increase our understanding on the potential impact of the proposed interventions in SOC (presented in section 5).

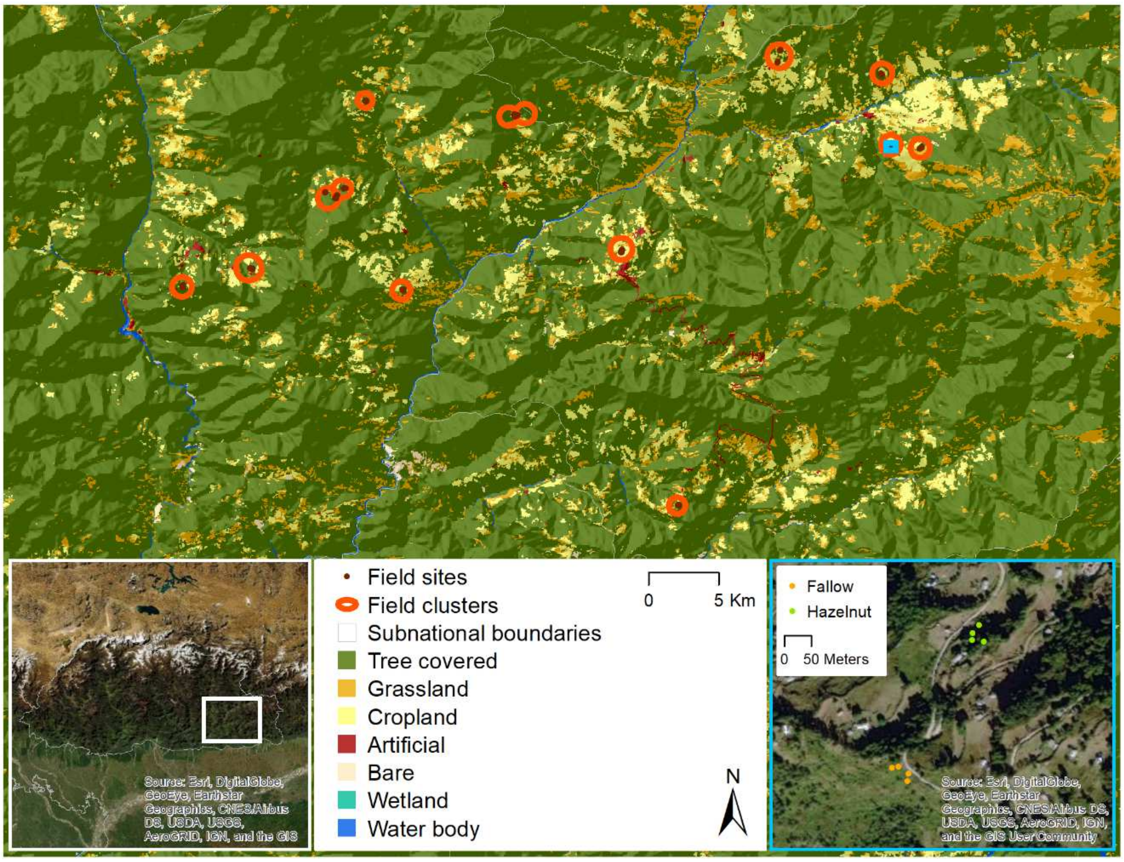

Figure 4: Sampling design for the soil organic carbon baseline of Mountain Hazelnut Ventures *in Bhutan. Land cover data provided the Government of Bhutan (Land use and land cover of Bhutan, 2016)*

During January 2020, fieldwork was completed in the south east region of the country of Bhutan, collected soil samples to 30 cm depth (4 samples per land cover and cluster, Figure 5). A total of 15 clusters were surveyed and within each cluster four soil samples were collected per fallow and orchard site (total 124 soil samples, see supplement material for details on protocol for soil sample collection and processing). Soil samples were collected with an auger to determine organic C concentration and bulk density for SOC stock estimations (see field guide for details

Figure 5. Field work photographs showing typical conditions in a fallow site (top left), seven-year-old hazelnut orchard (top right), soil sample (bottom left) and experimental crafting on native hazelnut varieties (bottom right).

on data collection). Soil samples were processed at the National Soil Services Center of Bhutan. In each point, coordinates were recorded, and history of use documented (current and before establishment of the orchard).

Soils are inherently spatially very variable, and the cluster design tries to minimize that variability to detect the significant differences. A two-way analysis of variance was used to assess the significance on the mean differences between the two interventions and controlling by the variability among clusters. Carbon content is very variable in the region, as can be observed by the high vertical spread in Figure 9. Mean SOC stocks were higher on average in hazelnut orchars (85.9 tons C/ha) than fallow agricultural sites (73.9 tons C/ha), and the differences were statistically significant (p-value < 0.01).

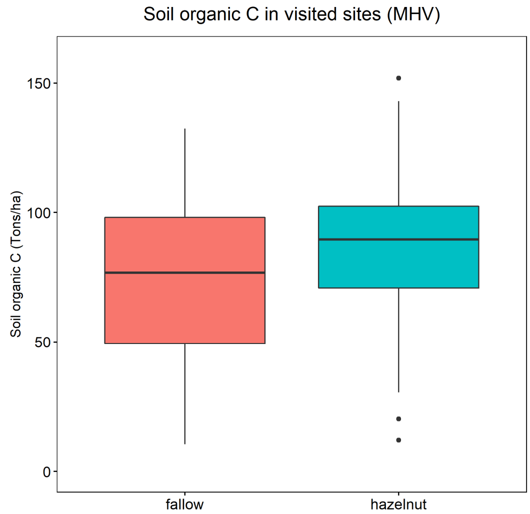

Figure 6. Mean SOC stocks in hazelnut orchards (85.9 tons/ha) and in in nearby fallow plots (73.9 tons/ha). Differences were significant to p-value < 0.01).

Monitoring recommendations for SOC

Soil organic carbon is, of the three LDN indicators, the most challenging to measure as EO data can only be of assistance, since SOC can not be directly measured from remotely sensed data. SOC is a slow changing variable, meaning that a long period needs to occur in order to detect significant changes in its magnitude after some type of intervention, such as the establishment of an agroforestry system. Moreover, field measurements are logistically challenging and require a significant resource. For that reason, the LDNF Impact Monitoring Methodology requires SOC to be measured (either with field data or modeled), at the beginning and end of the project, and using production measures (e.g. tons of hazelnuts produced per unit and area and time) as an intermediary proxy for understanding the changes in soil health to inform adaptive management measures which could be required in order to achieve LDN objectives.

5.Supplement I: Potential contributions to LDN

The cluster design implemented to produce the baseline for soil organic carbon, allowed us to produce some preliminary analysis on the potential contributions of the activities to be implemented as part of the Mountain Hazelnut Ventures project. Analysis presented in this appendix are not required as part of the LDNF Impact Monitoring Methodology, but are recommended, since the insights obtained can be useful at designing a locally relevant monitoring plan.

5.1.Land productivity

To date, MODIS remote sensing data is the only available NDVI product with a time series record dense enough to produce robust land productivity baselines over a 15-year period. However, Landsat and Sentinel harmonized collections are actively being developed, and will be made available to the public within a years' time. This harmonized collection provides the spatial resolution of Landsat and Sentinel products, but with a much higher temporal frequency than each of the original products[8]. Having high spatial and temporal frequency is key for evaluating interventions with a small spatial footprint and which require the evaluation over the course of the year, and not just at one point in time. The Normalized Difference Vegetation Index (NDVI) from a sample Harmonized Landsat and Sentinel surface reflectance product was compute, and the annual integral for the years 2017 and 2018 were derived following SDG 15.3 guidance (Trends.Earth, 2018). Annual NDVI integral values were extracted for the 124 visited locations and analyzed for each year using a two-way analysis of variance[9].

For the assessment of potential impact of MHV interventions on productivity, we used a space-for-time substitution approach, in which we assume that MHV activities will generate a transition from fallow to hazelnut orchards. No significant differences in primary productivity were found between fallow and hazelnut orchards for any of the two years analyzed (Figure 7). It is important to notice that the mean age of the orchards at the moment of visit in early 2020 was 7 years (standard deviation = 0.86), meaning that orchards had 4 to 5 years old at the moment the used EO data was collected. Continued monitoring is needed in order to fully assess the impact of these interventions on long term site productivity.

[8] Claverie, M., Ju, J., Masek, J. G., Dungan, J. L., Vermote, E. F., Roger, J.-C., Skakun, S. V., & Justice, C. (2018). The Harmonized Landsat and Sentinel-2 surface reflectance data set. Remote Sensing of Environment, 219, 145-161.
[9] Venables WN, Ripley BD (2002). Modern Applied Statistics with S, Fourth edition. Springer, New York. ISBN 0-387-95457.

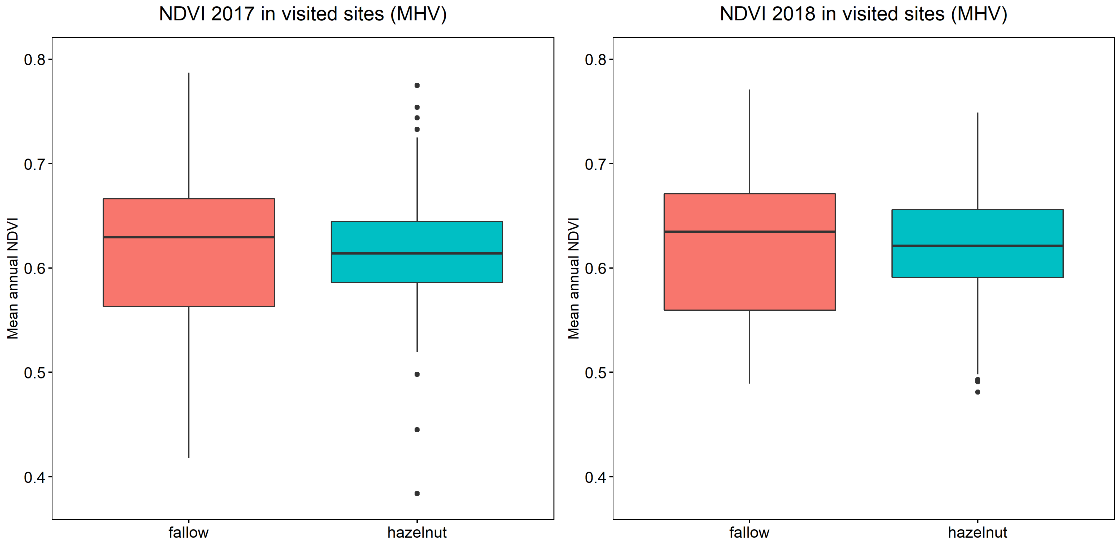

Figure 7. Frequency distribution of annual integrals of NDVI for 2017 and 2018 comparing hazelnut orchards and nearby fallow sites. No significant differences were found between them for any of the years (p-value = 0.30 for 2017 and p-value = 0.42 for 2018)

5.2.Land cover

The Government of Bhutan regularly produces land cover maps at 30 m resolution which can be used for developing the baseline and monitoring progress towards LDN. Using the national land cover map from 2016[10] we developed the land cover baseline assessment for the 10,440 orchards MHV is currently working on (presented in main document) and we evaluated the potential impact of the establishment and management of the orchards using the information collected in the field (Figure 8, right). Almost half of the orchards MHV has established throughout the country of Bhutan were classified as *kamzhing* agriculture (46.1%). This name is used to identify cultivated rain-fed areas in dry lands[5]. Forests represent 25.2 %, shrublands 19.9%, and *chuzhing* agriculture (irrigated and or bench terraced agricultural land for paddy-based cropping systems) 4.4 %.

A space for time substitution approach was used to assess the potential impact of MHV field activities in land cover. Sites identified as fallow for this analysis were selected by MHV personnel and had to be sites which presented similar environmental and management conditions to those in which mountain hazelnut orchards were to be established. By using the national land cover data, we see that most of the fallow sites were classified as agriculture or forest land, while the shrublands represent a significant portion of the sites in which orchards are established.

[10] FRMD, 2017, Land Use and Land Cover of Bhutan 2016, Maps and Statistics. Forest Resources and Management Division, Department of Forests & Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan. ISBN: 978-99936-743-2-0

Young orchards with not fully developed canopies would explain that difference (note that the national land cover map is from 2016, in which case the mean orchard age would have been of approximately 4 years. Continued monitoring would be required for definitively determining if the incipient increase in woody cover (trees and shrubs combined) identified by this analysis is sustained throughout the lifetime of the project.

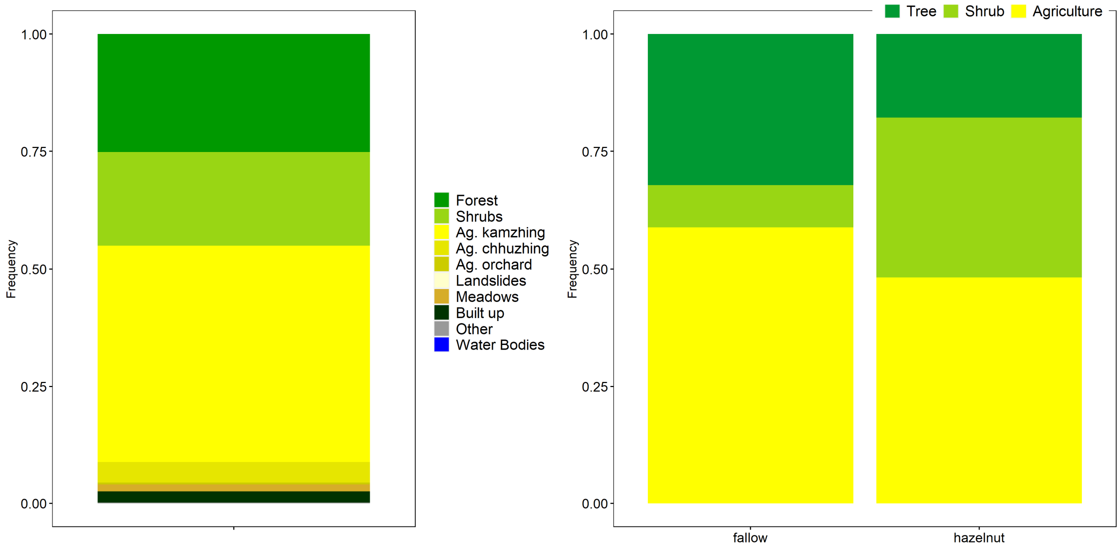

Figure 8. Land cover for MHV orchards in 2016 (left): Almost 50% of the MHV orchards were classified as rainfed agricutlture (Ag. Kamzhing) in 2016, followed by forests (25.2%) and shrubs (19.9%). By comparing land cover between fallow sites and orchards, an initial increase in woody cover is identified in areas managed by MHV.

5.3.Soil organic carbon

The analysis completed for the SOC baseline section, can be interpreted as a reference condition to which to compare progress over time, but they also serve to understand potential changes now of future interventions using a space for time substitution approach. Soil samples were collected using a cluster design to minimize variability in soil conditions among the three type of treatments evaluated within clusters. This design allows us to have an initial understanding on the potential impact of changes in management in SOC as part of the CSN project.
Soils are inherently spatially very variable, and the cluster design tries to minimize that variability in order to detect the effect of the intervention of interest, in this case, the establishment of hazelnut orchards. A two-way analysis of variance was used to assess the significance on the mean differences found between the fallow sites and the orchards, showing a significant increase in SOC stocks after controlling for the cluster effect (p-value < 0.01). Soil in hazelnut orchards had on average 11.9 tons/ha of C more than the fallow sites (Figure 9).

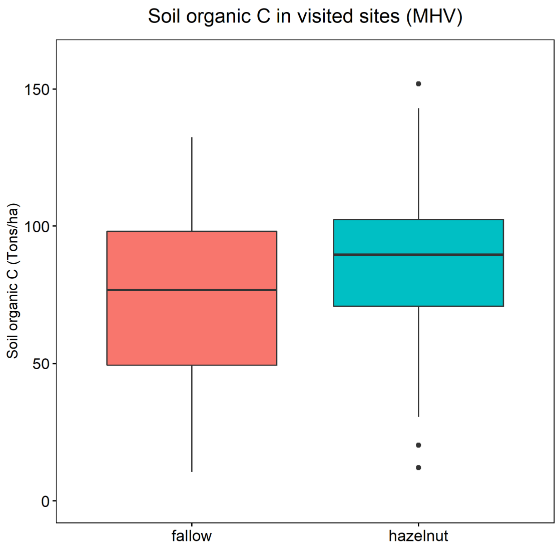

Figure 9. Mean SOC was significantly higher in hazelnut orchards (85.94 tons/ha) than in nearby fallow plots (73.97 tons/ha, p-value < 0.01).

APPENDIX 5: PILOT 2: CAFÉ SELVA NORTE

1.Executive summary

As part of the "Land Degradation Neutrality Fund (LDNF) Impact Monitoring Methodology" developed by Conservation International and OpenGeoHub two pilot studies were completed. This document presents the pilot study for the Café Selva Norte, a sustainable coffee production project in Northern Peru, part of the Urapi Sustainable Land Use programme, managed and operated by Ecotierra. The pilot includes project baseline for the three LDN indicators, changes in land cover, land productivity and soil organic Carbon, which also includes recommendations on how to monitor the indicators over the project lifespan, and an appendix presenting an assessment of potential impact of project activities on the three LDN indicators which is intended to inform the implementation of the monitoring plan.

The Café Selva Norte LDN baseline found that:

- Land productivity: 4.1 % of the investment area is currently identified as degraded compared to 4.8 % within the larger investment landscape
- Land cover: 86.3 % of the investment area, within the representative area assessed, is currently covered by woody vegetation (55.0 % tree covered and 31.3 % shrubland) as compared to 78.0 % in the investment landscape (47.1 % tree covered and 30.9 % shrubland).
- Soil organic carbon: Baseline SOC content within the first 30 cm of the soil was 109.7 tons C/ha in fallow sites, 97.9 tons C/ha in sun grown coffee, and 103.3 tons C/ha in shade grown coffee.

The proposed monitoring plan following the LDNF Impact Monitoring Methodology is:

- Land productivity: Wall to wall annual assessment using remote sensing data
- Land cover: Every 4 years repeated measures of land cover change within the same representative area used for baseline and using very high spatial resolution data. If wall to wall 30 m resolution products can be obtained or produced for the full investment landscape, those could completement the results obtained from the very high-resolution data.
- Soil organic carbon: Initial and final SOC measurements with in the same representative area used for the baseline and following the same cluster design. Annually, coffee production measures can be used to assess changes in productive capacity of the soil and impact of ongoing agricultural practices.

Based on the feedback from Ecotierra, it is important to notice the multiple activities are being implemented in the investment area, some intended to avoid, others to reduce, and others to reverse land degradation. Since the impact of each of those typologies of on the ground activities will be differently captured by the three indicators, it is suggested that the monitoring plan captures changes in land cover, productivity and SOC differently for those three types of activities.

2.Café Selva Norte Project[11]

The Café Selva Norte (CSN) project is located in the Amazonas and Cajamarca regions in north of Peru, with a total potential area of thousands of hectares. The Project area includes a set of dispersed coffee producers' properties in the mountainous region know and "*selva alta*" where coffee is mainly produced between 1200 and 1800 meters above sea level. The project area is one of the three main coffee production zones in Peru and is recognized for the quality of its production.

The project aims to meet its goals through a holistic approach including 3 components

1. Land use transition to:
   - Recover degraded lands with productive agroforestry systems,
   - Rehabilitate old, fragile agroforestry systems increasing their productive lifespan and therefore avoiding deforestation risk,
   - Protect remaining forest and stop slash and burn practices,
   - Reforest with a mix of timber species for sustainable logging in the future.
2. Value chain consolidation by:
   - Building infrastructure to strengthen co-op production capacity and positioning,
   - Creating and strengthening capacity,
   - Developing marketing tools and positioning products into specialty markets,

1.Revenue diversification through climate finance and strong monitoring systems using the Shade Coffee & Cocoa Reforestation Carbon Project (SCCRP) as a platform to:
   - Generate new revenue flows based on payment for environmental services (reforestation & forest protection),
   - Generate a robust set of key performance indicators to strengthen sales and obtain added value.

3.Defining the area of interest

The CSN project, managed by the Ecotierra, includes to date with 340 small coffee farmers located in the Amazonas and Cajamarca regions of northern Peru. Each of those 340 farmers represent an **investment site** (mean =1.10 ha, median = 0.98 ha, standard deviation = 1.04 ha), as defined in the LDNF Impact Monitoring Methodology. The aggregation of all those sites

[11] Verbatim from: Ecotierra. 2017. Café Selva Norte Peru project, Canopy project pipeline. https://www.cafeselvanorte.com/

represent the full area of direct intervention the project will have in the region, referred to as the **investment area**. To better understand the context in which these activities will take place, and to compare the baseline conditions of the investment area to similar areas in the surrounding region, an investment landscape was defined for this project. Considering the highly heterogenous conditions of this mountainous region, we defined the **investment landscape** for this project as all land within a 2 km buffer of the investment area (801,0 km^2, Figure 1).

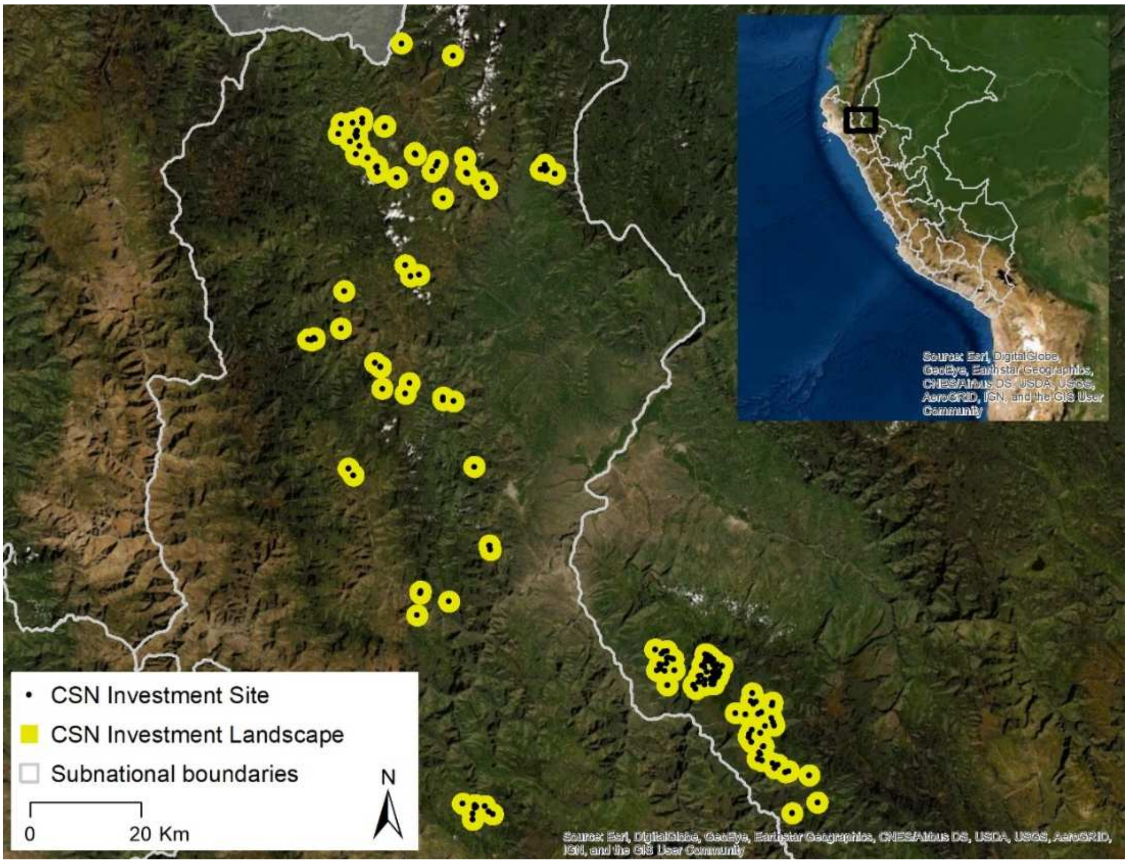

Figure 1: Café Selva Norte Project in Northern Peru is comprised of 340 individual investment sites (black dots on the map). The investment area is the aggregate of all those 340 sites. The investment landscape, in this case, has been defined as the area within a 2 km buffer around the investment area.

4.The LDNF CSN project baseline

Projects part of the LDNF portfolio need to determine baseline conditions for each of the three indicators of land degradation (changes in primary productivity, land cover, and soil organic C), and monitor progress through the project lifespan. The LDNF Impact Monitoring Methodology provides guidance on how to complete baselines and set up the monitoring framework. In the sections below we present the baselines for the CSN project broken up by indicator.

4.1.Land productivity

Land productivity is the biological productive capacity of the land, the source of all food, fiber and fuel that sustains humans. Following the LDNF Impact Monitoring Methodology, it is recommended that the normalized difference vegetation index (NDVI) be used as an indicator of productivity, as it is well-correlated with actual changes in productivity based on measurement on the ground, and as there is a long-term record available to allow comparison of changes in NDVI in a particular year with how NDVI has changed in the past. Given the combination of small median investment area size (0.98 ha) and large investment landscape (801,0 km^2), the recommended datasets for monitoring productivity would be at a resolution of ~30 m. However, presently only 250 m products are available for time series analysis as the ones needed for assessing productivity. For that reason, we computed productivity baselines using MODIS 250 m resolution data processed as recommended in the LDNF Impact Monitoring Methodology. For this baseline, we used Trends.Earth to compute the 5-class productivity indicator for the recommended most recent 15-year period 2005-2019 (Figure 2). The 5-class productivity integrates three sub indicators: trajectory, performance, and state.

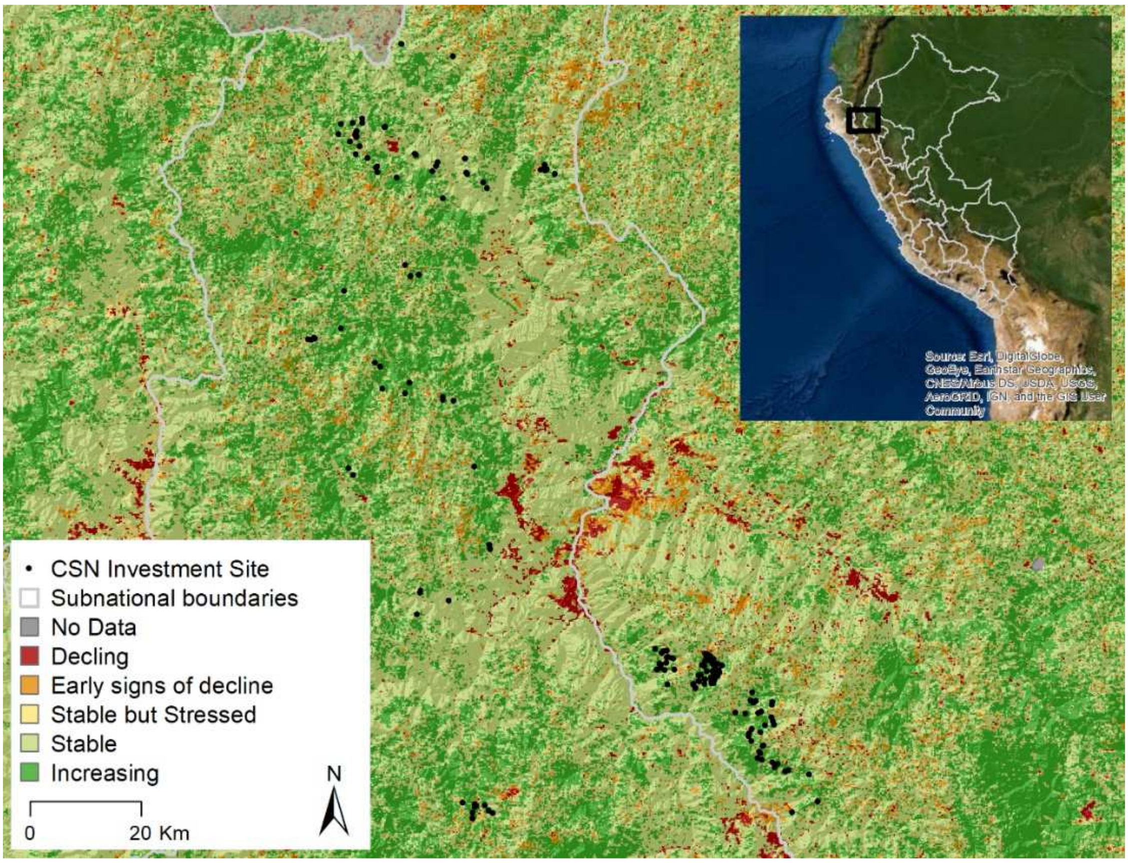

Figure 2: Productivity baseline map for the Café Selva Norte investments in Northern Peru.

Overall, the investment area presents a baseline productivity degradation level of 4.1 %, compared to 4.8 % degradation during the 2005-2019 period for the broader investment landscape. (table 1).

Productivity class	Investment Area	Investment Landscape
Declining	0.6 %	0.6 %
Early signs of decline	3.5 %	4.2 %
Stable but stressed	0.0 %	0.0 %
Stable	44.7 %	53.1 %
Increasing	51.2 %	42.1 %
% Degraded	**4.1 %**	**4.8 %**

Table 1: Productivity baseline for the Café Selva Norte Investment Area and Landscape computed for the period 2005-2019.

Monitoring recommendations for land productivity

Of the three LDN indicators, productivity if the most responsive to changes in land management and cover and any other condition which affects the productivity of the vegetative cover. For that reason, land productivity should be monitored annually to the LDNF following guidance from the LDNF Impact Monitoring Methodology. Through annual assessments of changes in land productivity, Ecotierra and the LDNF will be able to monitor the impact of the investments on land degradation and adapt accordingly in order to maximize the contributions of the project towards LDN locally and at the national scale.

4.2.Land cover

Through the assessment of changes in land cover, major transitions in system structure and configuration can be monitored over time. It is critical to use a land cover product which aligns with the size and spatial distribution of the interventions being monitored, to have confidence in the reliability and usefulness of the results. In the case of CSN project, the combination of small investment sites (0.98 ha) and large investment landscape (801,0 km^2), a combination of regional maps at 30 m resolution with focus areas using very high spatial resolution data would offer the best approach.

For this baseline we evaluated the national vegetation cover map from 2015 (Mapa Nacional de Cobertura Vegetal del Peru, 2015). However, two main characteristics of such dataset deemed it not suitable for this baseline: 1) Date mismatch: The land cover map published in 2015 was produced with satellite images from 2011. Nine years is too large of a time gap for that dataset to be useful for this baseline, and 2) Minimum mapping unit of 16 ha (>16 times larger than the median investment site area) The production of a very high spatial resolution land cover map for a representative subset area was decided.

To develop the baseline for the land cover LDN indicator, a multispectral very high spatial resolution for the study area was acquired (SPOT 1.5 m resolution for November 2019). The area was selected for the following reasons: 1) it has the larger concentration of farmers, 3) it was the area visited in the field in December 2019, and 3) it is the same area in which SOC baseline was produced with field data. The area of this land cover map represents 20.3 % of the investment landscape (figure 3). Using an object-based classification approach a land cover map with four classes was produced: tree, shrub, grass, and built-up (overall accuracy = 77.5%, Figure 3). The grassland class includes grasslands and herbaceous covers such as annual crops.

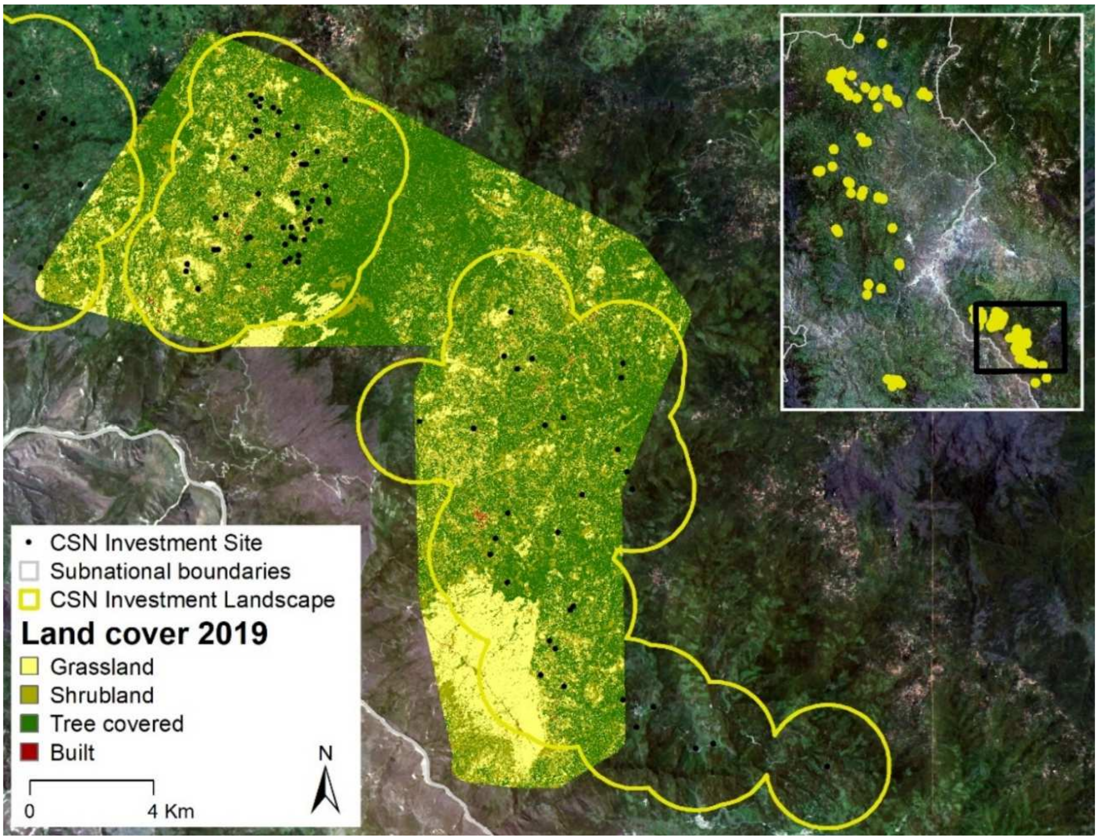

Figure 3: Land cover baseline map for the Café Selva Norte investments in Northern Peru.

The baseline land cover distribution for the assessed area shows a dominance of tree covered classes both in the investment area and the investment landscape, although higher in the investment area (55% vs 47%). Tree covered classes include both shade-grown coffee and natural forests in the region. Approximately 30% of the areas are covered by shrublands.

Shrublands in this assessment include sun-grown coffee and some intermediate stages of land abandonment and natural regeneration, with relatively low woody vegetation.

Land cover	Investment Area	Investment Landscape
Tree covered	55.0 %	47.1 %
Shrubland	31.3 %	30.9 %
Grassland & crops	11.3 %	21.6 %
Wetland	0 %	0 %
Artificial	2.5 %	0.5 %
Bare	0.0 %	0.0 %
Water body	0.0 %	0.0 %

Monitoring recommendations for land cover

Changes in land cover tend to be slower than changes in primary productivity, for that reason, land cover is expected to be monitored and reported to the LDNF every 4 years at minimum. For consistency, it is recommended that changes in land cover are monitored for the same sample area as used in this baseline and using land cover maps of similar spatial resolution (1.5 m pixel size) and class scheme. If during the project lifespan, 30 m resolution products appropriate for monitoring changes in land cover of this type of interventions became available, monitoring wall to wall would be recommended as a complementary measure.

4.3.Soil Organic Carbon

Monitoring change in soil carbon due to project interventions requires the project proponent to consider several different decision points related to SOC and overall LDN project achievement. Recent guidance prepared by the Science-Policy Interface of the UNCCD can be applied to project descriptions to obtain guidance regarding investment into SOC assessment for LDN. The LDNF Impact Monitoring Methodology provides guidance on how to determine the appropriate monitoring in indicator depending on project objectives. Ecotierra defines the Café Selva Norte project as an agroforestry type of intervention. Agroforestry projects in the context of LDN are required to monitor SOC, through a combination of initial and final SOC assessments (either through field data collection or modeling) with production statistics as intermediate proxy variables for soil condition.

For this baseline, following guidance from Ecotierra, the baseline sample area was identified in the southern region of the investment landscape. This area representing 20.3 % of the investment landscape has the larger concentration of farmers providing logistics, financial, and methodological advantages. During December 2019, fieldwork was completed in the southern section of the project area (Figure 4). The main objective of the field work was to collect soil samples to produce the SOC baseline. Given the scale of the project and the significant landscape heterogeneity encompassed by that (due to the mountainous relief and quickly changing aspect), a clustered sampling design was implemented. Each cluster was defined in this case as a combination of a sun grown coffee plot, a shade grown coffee plot, and a fallow site in close proximity, minimizing the variability in environmental factors which could contribute to the differences found in the response variables. Such a sampling design allows for achieving two main objectives: 1) completing the baseline SOC assessment (presented in this section), and 2) Applying a space-for-time substitution, to increase our understanding on the potential impact of the proposed interventions in SOC (presented in section 5).

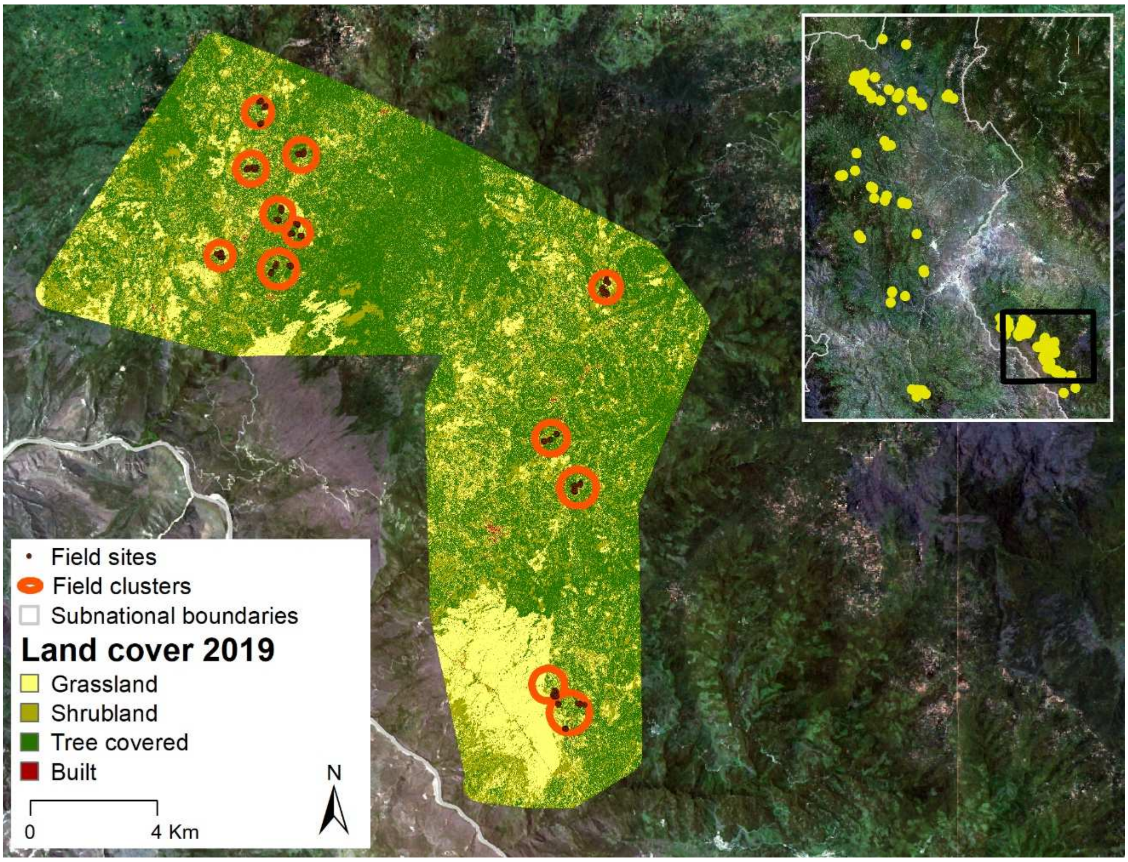

Figure 4: Sampling design for the soil organic carbon baseline for the Café Selva Norte investments in Northern Peru.

Following the cluster design, soil samples to 30 cm depth were collected in fallow sites, sun grown coffee and shade grown coffee farms. Soil samples were collected with an auger to determine organic C concentration and sample weight (back calculating bulk density) to obtain SOC stock estimations (see field guide for details on data collection). Soil samples were processed at the local soil lab in the city of Jaen, Peru. A total of 12 clusters were surveyed, collecting 137 soil samples, 46 in fallow sites, 45 in sun grown coffee farms, and 46 in shade grown coffee farms (Figure 5). At each point coordinates were recorded, and an oral history of use was documented (current and before establishment of the current land use, usually based on oral records).

Figure 5. Field work photographs showing typical conditions in a fallow site (top left), sun grown coffee (top right), shade grown coffee (bottom left) and a soil sample (bottom right).

Soils are inherently spatially very variable, and the cluster design tries to minimize that variability to detect the significant differences. A two-way analysis of variance was used to assess the significance on the mean differences between the three interventions and controlling by the variability among clusters. Carbon content is very variable in the region, as can be observed by the high vertical spread in Figure 9. Mean SOC stocks were higher on average in fallow sites (109.7 tons/ha) than on sun grown coffee (97.9 tons/ha) or shade grown coffee (103.3), but differences were not statistically significant (p-value = 0.134).

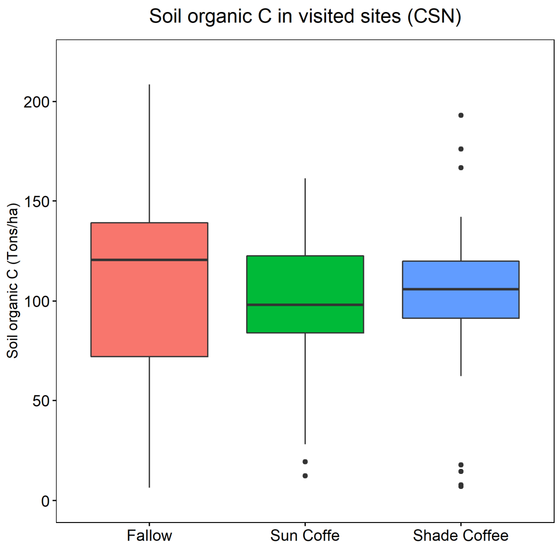

Figure 56. Mean baseline SOC for fallow sites, shade grown coffee and sun grown coffee farms (no significant difference at baseline, p-value = 0.134).

Monitoring recommendations for SOC

Soil organic carbon is, of the three LDN indicators, the most challenging to measure as EO data can only be of assistance, since SOC can not be directly measured from remotely sensed data. SOC is a slow changing variable, meaning that a long period needs to occur in order to detect significant changes in its magnitude after some type of intervention, such as the establishment of an agroforestry system. Moreover, field measurements are logistically challenging and require a significant resource. For that reason, the LDNF Impact Monitoring Methodology requires SOC to be measured (either with field data or modeled), at the beginning and end of the project, and using production measures (e.g. tons of coffee produced per unit and area and time) as an intermediary proxy for understanding the changes in soil health to inform adaptive management measures which could be required in order to achieve LDN objectives.

5.Supplement: 1: Potential contribution to LDN

The cluster design implemented to produce the baseline for soil organic carbon, allowed us to produce some preliminary analysis on the potential contributions of the activities to be implemented as part of the Café Selva Norte project. Analysis presented in this appendix are not required as part of the LDNF Impact Monitoring Methodology, but are recommended, since the insights obtained can be useful at designing a locally relevant monitoring plan.

5.1.Land productivity

To date, MODIS remote sensing data is the only available NDVI product with a time series record dense enough to produce robust land productivity baselines over a 15-year period. However, Landsat and Sentinel harmonized collections are actively being developed, and will be made available to the public within a years' time. This harmonized collection provides the spatial resolution of Landsat and Sentinel products, but with a much higher temporal frequency than each of the original products[12]. Having high spatial and temporal frequency is key for evaluating interventions with a small spatial footprint and which require the evaluation over the course of the year, and not just at one point in time. The Normalized Difference Vegetation Index (NDVI) from a sample Harmonized Landsat and Sentinel surface reflectance product was compute, and the annual integral for the years 2017 and 2018 were derived following SDG 15.3 guidance (Trends.Earth, 2018). Annual NDVI integral values were extracted for the 137 visited locations and analyzed for each year using a two-way analysis of variance[13].

For the assessment of potential impact of CSN interventions on productivity, we used a space-for-time substitution approach, in which we assume that CSN activities will generate a transition from fallow or sun grown coffee to shade grown coffee. Significant differences in primary productivity were found between the conditions assessed, with shade grown coffee presenting higher annual productivity than either fallow or sun grown coffee for the two years analyzed (Figure 77). Based on this results, it can be expected that CSN project will have a positive impact on land productivity, and a change of magnitude enough that the remote sensing products will be able to detect them as part of the monitoring framework.. Continued monitoring is needed to fully assess the impact of these interventions in long term.

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[12] Claverie, M., Ju, J., Masek, J. G., Dungan, J. L., Vermote, E. F., Roger, J.-C., Skakun, S. V., & Justice, C. (2018). The Harmonized Landsat and Sentinel-2 surface reflectance data set. Remote Sensing of Environment, 219, 145-161.

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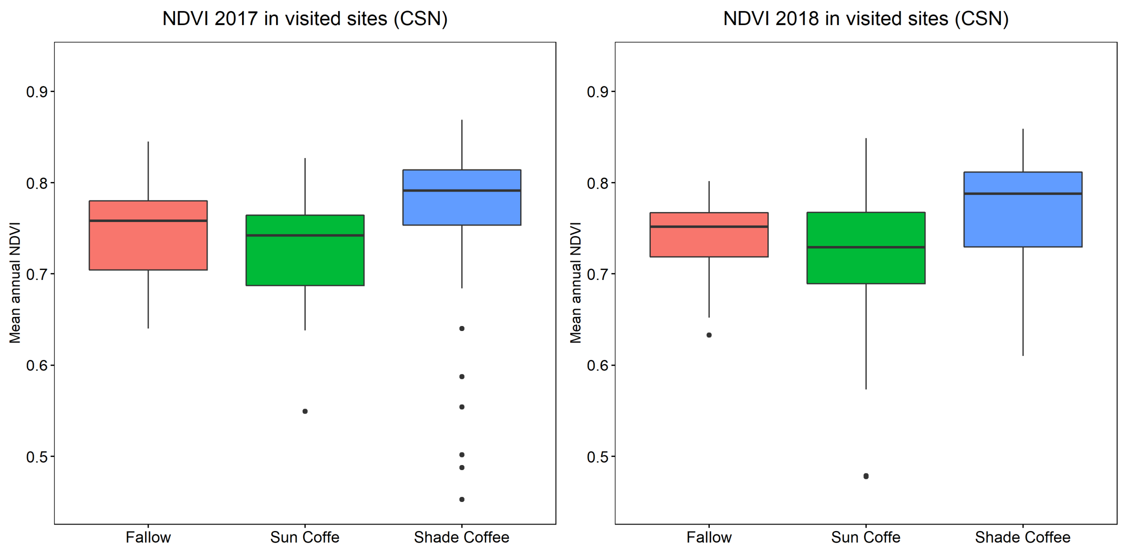

Figure 7. Frequency distribution of annual integrals of NDVI for 2017 and 2018 comparing fallow sites, sun grown coffee and shade grown coffee. Significant differences were found between shade grown coffee and the other treatments for both years (p-value < 0.01 in both cases)

5.2.Land cover

To evaluate the potential effect of CSN's proposed interventions in the land cover indicator, we used the same space for time substitution approach, and the same high spatial resolution land cover map produced for the baseline derived from SPOT 1.5 m resolution imagery for November 2019. Since one of the main activities of CSN will be gradually convert them to coffee plantations, first sun grown, and later shade grown as the canopy closes; we assessed the differences in land cover among the different types of farm, and we identified a potentially positive impact on the land cover LDN indicator (Figure 8). Keep in mind that of the three LDN indicators, land cover is the only one in which local conditions and specific objectives inform the interpretation of which changes constitute improvement and which one degradation. In the context of an agroforestry project with the objective of restore degraded lands, we consider increase in tree cover as contributing towards LDN. Results show that grass cover gradually reduces from fallow sites to shade grown coffee areas, as tree cover increases from 25% to over 70%. These results would suggest a positive impact of this intervention on the land cover indicator. It is important to notice that CSN will also focus on avoiding that shade coffee goes back to fallow or that forest goes to full sun coffee, reinforcing the importance of a continuous land cover monitoring system (every 4 years), in which results land cover change results are disaggregated based on the main objective of activities happening in each site.

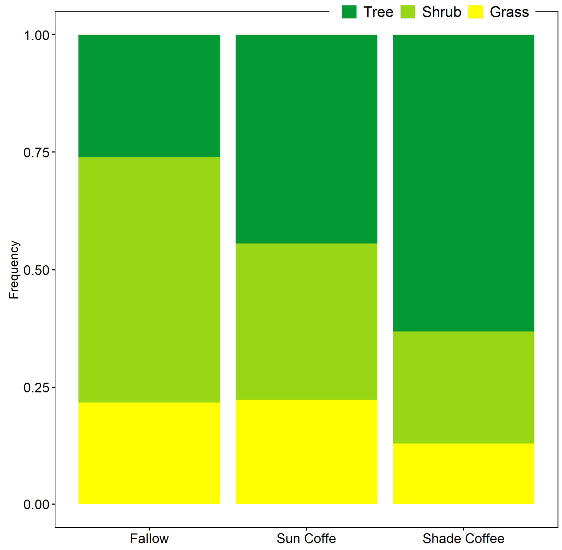

Figure 8. Land cover baseline condition for CSN project farms in 2019. Tree cover increases as sites are converted from fallow to sun grown coffee and shade grown coffee.

5.3.Soil organic carbon

The analysis completed for the SOC baseline section, can be interpreted as a reference condition to which to compare progress over time, but they also serve to understand potential changes now of future interventions using a space for time substitution approach. Soil samples were collected using a cluster design to minimize variability in soil conditions among the three type of treatments evaluated within clusters. This design allows us to have an initial understanding on the potential impact of changes in management in SOC as part of the CSN project. A two-way analysis of variance was used to assess the significance on the mean differences between the three interventions evaluated and controlling by the variability among clusters. Carbon content is very variable in the region, as can be observed by the high vertical spread in Figure 9. Mean SOC stocks were higher on average in fallow sites (109.7 tons/ha) than on sun grown coffee (97.9 tons/ha) or shade grown coffee (103.3), but differences were not statistically significant (p-value = 0.134). These results would indicate that the potential impact of the CSN project on SOC would be not significantly different, unless the drivers of the SOC distribution in the fallow case are understood and targeted (e.g. preferentially selecting low SOC fallow sites for development and avoiding high SOC fallow sites).

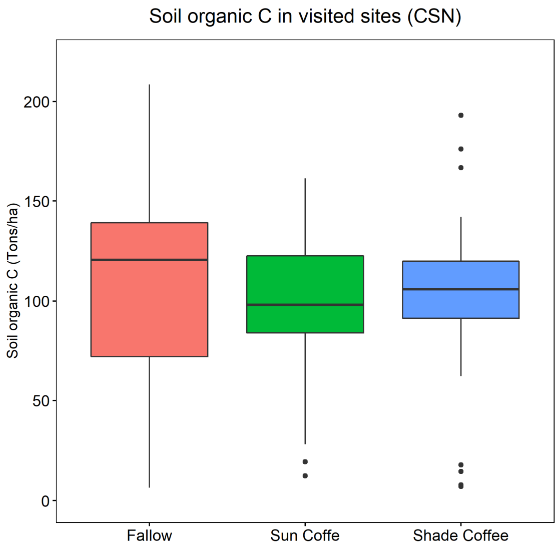

Figure 9. Mean SOC was not significantly different between fallow sites, shade grown coffee and sun grown coffee farms (p-value = 0.134).

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