# Table of contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table of contents</td>
<td>2</td>
</tr>
<tr>
<td>Glossary &amp; abbreviations</td>
<td>3</td>
</tr>
<tr>
<td>Summary</td>
<td>4</td>
</tr>
<tr>
<td>Before you begin</td>
<td>6</td>
</tr>
<tr>
<td>Why do we need to monitor &amp; evaluate?</td>
<td>6</td>
</tr>
<tr>
<td>Sampling design - Where do we start?</td>
<td>8</td>
</tr>
<tr>
<td>Time-frame</td>
<td>10</td>
</tr>
<tr>
<td>Documentation and communication of results</td>
<td>11</td>
</tr>
<tr>
<td>Indicator 1: Increased decomposition rate</td>
<td>12</td>
</tr>
<tr>
<td>Indicator 2: Increased topsoil</td>
<td>14</td>
</tr>
<tr>
<td>Indicator 3: Decreased soil erosion</td>
<td>15</td>
</tr>
<tr>
<td>Indicator 4: Decreased soil compaction</td>
<td>16</td>
</tr>
<tr>
<td>(a) Penetrometer Test</td>
<td>16</td>
</tr>
<tr>
<td>(b) Bulk Density Test</td>
<td>17</td>
</tr>
<tr>
<td>Indicator 5: Increased water retention of the soil</td>
<td>19</td>
</tr>
<tr>
<td>Water Holding Capacity (WHC) Test</td>
<td>19</td>
</tr>
<tr>
<td>(b) Infiltration test</td>
<td>20</td>
</tr>
<tr>
<td>Indicator 6: Improved pH</td>
<td>21</td>
</tr>
<tr>
<td>Indicator 7: Increased biological activity in soil</td>
<td>22</td>
</tr>
<tr>
<td>Indicator 8: Increase in biodiversity (flora)</td>
<td>23</td>
</tr>
<tr>
<td>Indicator 9: Increase in biodiversity (fauna)</td>
<td>24</td>
</tr>
<tr>
<td>Indicator 10: Reduced temperature differentials</td>
<td>26</td>
</tr>
<tr>
<td>Indicator 11: (LAB) Increase in Soil Organic- Matter (SOM) &amp; Carbon (SOC) content</td>
<td>27</td>
</tr>
</tbody>
</table>
Glossary & abbreviations

- **Adaptive management**: ‘an intentional approach to making decisions and adjustments in response to new information and changes in context’ (USAID 2018)
- **Baseline**: the documented starting point of your camp actin as control against which progress on restoration activities is measured; albeit less reliable, ‘control sites’ may also function as a references/points of departure
- **Datasheet**: refers to the place where you can log the data you are collecting at your camp.
- **Ecosystem**: a geographic area where a community or group of living organisms (e.g. plants, animals) interact between themselves and their physical/chemical environment (e.g. landscapes and weather) to form a microcosmos of life.
- **Ecological Restoration**: is ‘a practical management strategy that restores ecological processes to maintain ecosystem composition, structure and function.’ (Apfelbaum & Chapman 1997).
- **ERC**: the *Ecosystem Restoration Camps foundation*
- **Ecosystem restoration camps**: are locations for people around the world to participate in ecosystem restoration; living laboratories where effective ecosystem restoration techniques are developed and spread through education.
- **Evaluation**: the analysis of data collected during the monitoring period in relation to the established goals/outcomes
- **Indicators**: are clues or signs that tell us whether the outcomes are being met.
- **Land use or land management**: refers to the human arrangements, activities and inputs producing, changing or maintaining certain land-cover type (UNCCD 2016).
- **M&E**: Monitoring & Evaluation
- **Means of verification**: are the different tests used to measure the outcomes
- **Monitoring**: is the systematic process of collecting data within a given time frame
- **Outcomes**: are the goals we hope to reach at the camps. and enhance
- **Remote Sensing**: is the collection of Earth observation data from satellites, aircraft or other remote sources
- **Restoration**: ‘(...) a process that aims to regain ecological functionality and enhance human well-being across degraded landscapes’ (Buckingham et al, 2019).
- **Sample site**: herein broadly defined as the area that will be assessed/sampled; sample site(s) should be representative of the different zones.
- **Standardisation**: in our context, is the process of implementing/developing standards based on wide (scientific) consensus. Standardized methodologies help ensure compatibility, repeatability and quality of measurements.
- **Zone(s)**: refer to the different areas/locations of your camp as defined in the design of the site. The criteria used to designate each zone will vary per camp - could be based on the different forms of management (e.g. grazing, mulch), ecosystem types (e.g. forests, wetlands), altitudes, distance from communal area, etc.
### Summary

Below is part of the table that summarizes what the M&E framework is measuring.

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Indicators</th>
<th>Means of Verification</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOIL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved ecosystem health</td>
<td>Land cover change</td>
<td>Remote-sensing + ground</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>observations</td>
<td></td>
</tr>
<tr>
<td>Increased soil organic matter/carbon (at sites with reachable laboratories)</td>
<td>Soil organic matter/carbon is higher than baseline level</td>
<td>Loss on Ignition Lab test</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td>Increased biological activity in soil</td>
<td>More earthworms than baseline/control area</td>
<td>Earthworms test</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td>Increased water retention capacity of the soil</td>
<td>Water holding capacity higher</td>
<td>Water Holding Capacity</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Infiltration test</td>
<td></td>
</tr>
<tr>
<td>Decreased levels of soil erosion</td>
<td>Soil sediment levels in catchment areas higher than baseline</td>
<td>Soil Accumulation test</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td>Increase in topsoil</td>
<td>Thicker topsoil than baseline</td>
<td>Depth of topsoil</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td>Decreased levels of soil compaction</td>
<td>PSI levels are lower than baseline</td>
<td>Penetrometer test</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td></td>
<td>Bulk density lower than baseline</td>
<td>Bulk Density Test</td>
<td></td>
</tr>
<tr>
<td>Increased biodiversity</td>
<td>Fauna biodiversity increased</td>
<td>Nocturnal insects</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td></td>
<td>Flora biodiversity increased</td>
<td>Square method</td>
<td></td>
</tr>
<tr>
<td>Increased soil health (water, organic matter, biology)</td>
<td>Teabags decomposing quicker</td>
<td>Teacomposition Test</td>
<td>Spring (NH Mar-June; SH Sept-Dec)</td>
</tr>
<tr>
<td>Reduced temperature differentials</td>
<td>Temperature differentials lower than baseline/control sites</td>
<td>data loggers</td>
<td>NA</td>
</tr>
</tbody>
</table>
Before you begin

Collecting data at your camp is a vital way of learning about what is happening within your landscape. We know that each camp is unique and at different stages of development, but these are some things you need to consider before you start monitoring.

First, you need to become familiar with your ecosystems(s) and the kind of issues you wish to address. This will help you find out what you want to implement in terms of ecosystem restoration, which can be expressed as a design or sitemap of your camp. Alongside with the goals of your Ecosystem Restoration Camp projects, the ‘design’ is used to define what areas or interventions/techniques you will be monitoring over time. Having selected the areas you’re interested in studying, you can dive into the different sampling sites (i.e exact locations on your land where you will be collecting the data from or ‘sampling design’). Finally, collecting data helps you understand whether what you are doing in these areas is working or not.

For example, you have an area of your land that has high levels of erosion. As you may have expected, your baseline study shows low levels of topsoil/organic matter/vegetation in comparison with other areas. You need to decide what it is that you are planning to do to restore this area and promote healthy soil and vegetation there. This could then become one of the sites you monitor closely. Once you have collected the data from this site, you can analyse whether the practices you have implemented to resolve the ecological problems here have been working.

In short, our advice is not to start monitoring until you understand what is going on at your camp and define what you’re going to implement - or have implemented already - in terms of restoration on your land, and where. These conditions make the exercise of monitoring useful, efficient and possible to continue over time.

In case you have started restoration work without a ‘preconceived design’, select a few neighbouring/similar sites that resemble how you first encountered the land you are working with, to run your baseline study. Consider aerial images to inform the selection of control sites.
Why do we need to monitor & evaluate?

Monitoring & Evaluation (M&E) requires time and energy that otherwise might be allocated to help restoration activities on the ground. So, it is pertinent to ask why it is a wise and necessary investment of our resources. Out of many, three good reasons why M&E is worth investing stand out:

**Learning & Adaptive management**

Above all, the purpose of this guidance is to support continuous improvement of on-the-ground work through adaptive management. It demonstrates what restoration activities are undertaken worldwide, and how effective these activities are, ie how they are changing ecosystems. Although most cases will be highly complex and require context-specific solutions, lessons can be learned from other places with similar traits and/or pressures. In turn, these can help find and develop best practices at the camp-level.

**Evidence of impact & transparency**

This framework was designed to show ecological and social transformation taking place at ecosystem restoration camps. Once we have evidence of the impact of our work, we can share proven cases and stories with the world which will increase our legitimacy and credibility and increase our support base and income. Reporting on the progress of ecosystem restoration is key to engage policy-makers, partners, land owners and donors.

**Validate your hypotheses**

This framework may contain methods that help you study your own guesses about the ecology of your specific camp. To do this, we recommend including a conceptual model in your M&E report alongside with the research question(s) and the hypotheses you would like to test. You might for example decide to address these by using/adapting the methods herein proposed, studying how specific interventions or ecosystem traits influence the ecological patterns and/or attributes being measured.
Sampling design - Where do we start?

As we identify the different habitats and interventions that (will) shape the sites we are restoring, an important question is how do we study the impacts of our work? Ecologists recognise the difficulty of surveying entire zones, populations or habitats. Therefore, well considered sampling designs are key to learning about ecology and its context to ecosystem restoration.

Good sampling is key because (1) we want our samples to be representative of the areas we want to study and; (2) we want to understand, compare and aggregate findings across multiple ecosystem restoration camps.

Sampling units refers to the ‘camp’s zones’ that will be monitored over time. Sampling sites are the exact locations we collect data from, selected to represent each of these zones.

Define camp zones (or sampling units)

Therefore, it is crucial to establish on what basis different zones are distinguished. There are many factors that will define the zones on your camp. These will be site specific, but they may include;

- Restoration activities or types of land-use (e.g. a grazed, afforested)
- Landscape traits (e.g. soil type, altitude, moisture levels, etc.).
- Control areas (e.g. neighbouring plots that represent the initial status of degraded ecosystems)

In line with the vision and goals of your restoration project, current/future interventions are outlined in your camp design. A set of questions was developed to help camp managers and campers understand soil formation processes and study the landscape they are attempting to restore (in Appendix 1). Other zones may function as control areas against which progress of restoration work is studied through comparative temporal/spatial analyses.

Finally, we come up with different ‘homogenous units’ from which we can sample, based on management practices or landscape traits such as the type of soil, altitude and so on. These can then be overlayed on a camp’s polygon file or aerial images\(^1\). All of this helps deliver more accurate and useful findings to the growing community of ecological restorationists.

---

\(^1\) Recent aerial images tell something about different forms of present land-use and restoration activities in place. Old aerial images could provide reference scenarios/baseline data and help locate control sites for monitoring. If pertinent, get in touch with GIS specialist from ERC advisory board, Michiel Damen at michieldamen@icloud.com, who has access to specialist software to help you analyse the aerial images of your sites.
Ecological research is fundamentally concerned with comparisons. *Stratification* helps us compare different *strata* or 'subpopulations of a statistical population'. We are interested in comparing one zone to another zone, or a group of zones to a different group of zones.

Assuming that different camp's zones differ in surface area, we get the most out of *stratification* by knowing the specific sizes (e.g. m2 or km2) of each zone. This allows us to determine the relative size/proportion of each strata/sampling unit, which in turn helps with proportionate allocation of samples/sampling sites. See below a simple example of how this works in practice:

*All other things being equal, assume you are interested in studying a camp in which 20% of the land is (a) grazed, 15% (b) ungrazed and 5% (c) afforested. Proportionate allocation or probability sampling means that, if you take an amount of samples/sampling sites for the afforested zone \( N(c) = Y \), then \( N(a) = 4 \times Y \) and \( N(b) = 3 \times Y \).*
**Time-frame**

As we understand what restoration measures are needed and where, monitoring helps us to see changes in the state of the ecosystems we are working with. Increasing biodiversity, accumulated organic matter, soil fertility and crop yields are typical signs of ecological function. However, we know that the recovery of degraded ecosystems extends over the long term. So we may ask, when- and how often should we collect data?

In terms of timing, we propose collecting data during Spring, when seeds and animals come out of winter dormancy or hibernation and begin their reproductive and nesting activities. In rainy season-driven, non-temperate ecosystems with a less obvious spring, we suggest monitoring during or at the end of the rainy season. Regardless of your location, it is crucial to do these tests at the same time every year, to avoid introducing noise from annual cycles.

So, timing is a determining factor in measuring some of the M&E outcomes (e.g. biological activity in soil, biodiversity) and important to obtain standardised data for comparison between ecosystem-restoration initiatives worldwide.

Evidently, some indicators have high variation and others vary slowly. The rate of ‘observed change’ depends on the natural conditions of an ecosystem (e.g. seasonal and weather patterns) and the type of methods implemented for Monitoring & Evaluation. The indicators (such as decomposition rate) that involve a short period of time between sampling moments include a description of such procedures.

For the sake of harmonisation, we recommend monitoring all camp-relevant ecological indicators (at least) every year, for 5 years to assess how the work of restoration initiatives relates to established goals and flourishing ecosystems. If this is not done earlier, after the first 5 years camps are able to reevaluate their vision and associated practices. Depending on the findings and indicators used, monitoring efforts could be extended for another 5 years.
Documentation and communication of results

Beyond data collection at Ecosystem Restoration Camps, successful Monitoring & Evaluation depends on well documented data and findings. If done carefully, such exercise is both a useful tool to substantiate/improve on-the-ground work and a means of sharing effective restoration techniques with the world.

There are a few common elements that help storing data systematically, even when different people collect data in different moments and/or formats (i.e. using the online datasheet, on paper or via mobile applications in the future).

As described above, a few sampling sites will be selected to study the impact of restoration activities at camps. We know from complex ecological systems that the data may be explained by human interventions (e.g. soil amendments, land-use, etc), unplanned/spontaneous and abiotic factors (e.g. severe flooding, altitude) or - and most most likely - a combination of both through so-called ‘interaction-effects’ between variables.

Gradually, our ambition is to contribute to a holistic understanding of complex ecosystems and understand what is or could be our place within them. To become acquainted with the ecology of place and figure out how to serve ecosystems, we start off describing where/when the following tests take place.

1. **Record geo coordinates and environmental factors**

In your datasheet, record the exact geo coordinates of your sampling sites. You can do this by labelling pins at these locations and saving them in different lists for each of the indicators, using google maps (see also Appendix 2 How to record sampling locations). Besides, keep track of any environmental factors and unusual trends that call your attention such as temperature, light, salinity or proximity to pollutants. Depending on the objectives of your study, we recommend defining the environmental factors you would like to keep track of beforehand as part of your Monitoring project plan. This could help clarify unexpected variation in the data.

2. **Upload the data into camp’s database**

If you are not directly logging your data into a common datasheet (online), take the time to do so. Preferably, do this soon after data collection, while your observations and any unexpected encounters are ‘fresh’.

3. **Evaluate & communicate results**

Finally, we can compare and analyse the latest data against our baseline values and/or control sites. The process of drawing insights from our work is what we call ‘evaluation’. Evaluation of progress at restoration camps can then lead to substantiated case-studies, and who knows, published articles. We propose that each camp produces a report together with data collectors at the end of each monitoring cycle. We have developed a template to help with this task.
Indicator 1: Increased decomposition rate

Means of Verification: ‘Tea-composition’ method

The Why

Proving that restoration interventions improve the quality of soils is important because the health of plants, animals and crop yields depend on healthy soils. Healthy soil draws down carbon, strengthens plants against disease and pests, and stores and absorbs water.

The ‘Teacomposition test’ is a simple, cheap and standardized method that uses commercially available (green and rooibos) tea bags as pre-made “litterbags”. Ideally, this test is done in May/June at camps located in the Northern Hemisphere or in November/December for camps in the Southern Hemisphere. The remaining weight of teabags is measured in 4 different moments - 3 months after burial, and then 1, 2 and 3 years after burial.

Materials Needed:

- 8 Sticks/metal poles per zone
- 16x green tea bags and 16x Rooibos tea bags per zone
- Water-proof pen to label tea bags
- Zip-lock bags, tupperware or any other water-proof recipient(s) with lid
- Weighing scales
- Little spade
- Tape measure

The Method

1. Select two representative sampling areas of at least 1m², with gentle slope (avoiding very steep/flat sites along slope) within each zone
2. Physically mark these areas using sticks/metal poles/coloured stones so you can find them easily
3. Record altitude and GPS coordinates of these areas and if possible, the soil type
4. Label tea bags with a unique identifier code that represents the number of the tea bags (1-16), the type of tea, the zones you are studying and the sampling area you are studying (i.e. 1 or 2); for example: 2GRCOM1 = second green tea bag buried in ‘area treated with compost’ in sampling area 1.
5. Weigh the tea bags before burial (preferably on 4 decimal places) and record the weight
6. Place tea bags in zip-lock bag or (tupperware) box until burial
7. Note the starting date of incubation/tea burial
8. Using string and nails, mark 4 lines in each sampling area (each 40-cm long, with 10 cm between lines)
9. Gently dig 4 slots (approx. every 10 cm, at least 5cm deep) along each line, creating a pocket for the tea bags
10. In each line, bury 2 green + 2 rooibos tea bags roughly 5cm deep or in mineral soil layer making sure the identifier codes on the tags are visible on the surface
11. Plan the retrieval dates or sampling points in your calendar (3, 12, 24 and 36 months after burial)
Retrieval of tea bags...

12. Collect 2 bags of Green tea and 2 bags of Rooibos tea (avoiding pulling the rope and lift the soil to retrieve tea bags instead) from each plot (one ‘incubation’ line per sampling point)
13. This leads to 4 bags of Green and Rooibos tea retrieved per sampling point and zone
14. Clean tea bags from roots, soil etc (careful not to damage the bag/lose any tea!) and note if bag was damaged or found at surface
15. Place every tea bag in zip lock bag/box, checking the label (if missing, reconstruct based on previous/following bag number in the line)
16. Dry tea bags at 70deg for 48 hours
17. Determine weight of empty tea bag and note the weight
18. Record results in datasheet
19. Repeat procedure after 12, 24 and 36 months.

Results

Using the method above, we are able to calculate the % of tea that is decomposed in each zone. The decomposition rate says something about the biology and nutrient cycling of your soil. Besides carbon inputs from vegetation, decomposition rates are critical to forecast whether soils will lose or gain carbon in a changing climate. By comparing results across zones or even camps, management of ecosystem restoration interventions can be adapted accordingly. In the future, such data could be included in a vaster database, aligned with global research on soil ‘teacomposition’.

Additional references

- https://www.teacomposition.org/
Indicator 2: Increased topsoil

Means of Verification: Depth of topsoil

This is the indicator that demonstrates improvements in the composition and structure of your soils.

The Why
Natural regeneration and assisted ecological succession depend on growing healthy soils. Sustaining multiple plant and animal species in complex trophic cascades, fertile soils form the basis of biodiverse and resilient ecosystems. Measuring the thickness of the litter- and top soil (or organic matter) layers tells you whether your soil is being nurtured or negatively affected by certain interventions.

Materials needed:
- Shovel
- Tape measure

The Method
1. Select at least 3 points representing each of your land’s zones
2. Mark these points with markers of some kind, both physically and on your (digital) site map so that you are able to come back to them again for taking subsequent measurements
3. Label these sites with numbers, letters or names so that they are distinguishable from one another
4. Dig holes at least 50cm deep if possible (or until soil changes colour, from darker tones where roots thrive to lighter subsoil with little/no root mass)
5. If you cannot easily reach this depth, make a note in datasheet
6. Measure thickness of topsoil layer (cm) in each of the holes, from the surface until the edge with subsoil
7. Calculate the average topsoil depth for each zone
8. Record these values (in cm) in the excel datasheet and which of the bands it falls into: very shallow (VS) = <15 cm; shallow (S) = 15-30cm; moderately deep (MD) = 30-50cm; deep (D) = > 50cm
9. Repeat the process every year (digging holes roughly one-meter away from the marks, to avoid digging where soil was moved in previous measurements)

Results
Subtracting previous* topsoil measurement from your own measurements tells you whether certain interventions are helping to grow (if value is positive) or lose topsoil (if negative). Evidently, the magnitude of the value says something about the rate at which topsoil is growing or disappearing. All of this should help camp manager(s) adapt management.

*from baseline or last year’s study

Additional references
If you wish to know what is going on in your soil in greater depth, we recommend looking into your soil profile as described elsewhere:
- https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054308
- https://doityourselfforestryblog.wordpress.com/2016/05/27/what-are-the-different-soil-horizons/
Indicator 3: Decreased soil erosion

**Means of Verification: Soil Accumulation Test**

This is the indicator that shows that there has been an accumulation of soil, rather than a loss, thanks to the use of regenerative practices.

The means of verifying this is called the Soil Accumulation Test, with the instructions below:

**The Why**

Modern industrial land use is a major cause of soil erosion. When the soil is de-vegetated, the fertile topsoil becomes loose and can easily be blown away by the wind, or washed away by the rain. By reversing this trend, soil can actually be accumulated rather than lost.

**Materials needed:**

- 1 metre threaded rods (picked up from your local hardware store)
- Spray paint

**The Method**

1. Select 3 spots that best reflect each zone you are working on, preferably along contour lines if the camps use them, inside swales/sediment traps
2. Select a minimum of 2 control spots within fields/locations that are being managed conventionally
3. Push your pole halfway into the ground (so if the poll is 1 metre, push it into the ground 50cm deep), so that it’s in there securely and won’t move around on its own
4. Spray paint the level at which the pole goes into the ground
5. Return to the poles one year later and mark the current soil level
6. Record the coordinates of each spot where threaded rods have been installed

**The Results**

Take the average height difference amongst your zone-specific spots, and multiply that by the area size of your plot, to get the volume. This volume is what you should record as the average amount of soil accumulated/lost in each zone.
Indicator 4: Decreased soil compaction

This is the indicator that shows that there is a decrease in the compaction of the soil at your site.

**Means of Verification:** We suggest 2 different means of verifying this. The easiest one is the so-called (a) Penetrometer test, but if you do not have a penetrometer run the alternative (b) Bulk density test (for which you will need a microwave oven).

**The Why**

Soil compaction greatly restricts the ability of plants to grow as their roots struggle to penetrate into the ground, and water and oxygen struggles to reach them. Measuring the compaction of your soil will allow you to ascertain whether what you plant will be able to survive, or whether more decompaction needs to be done. Soil compaction is caused by the removal of vegetation from the land and is a major cause of desertification.

(a) **Penetrometer Test**

**Materials needed:**
- A penetrometer
- Small flags or coloured stones or something to mark the fixed data collection points

**The Method**

1. Select one point for each zone
2. Label these points with numbers, letters or names both physically (marking) and on your site map so that you are able to come back to them again for taking subsequent measurements
3. Take the penetrometer and measure the PSI count of your sites and document the count alongside the name of the site in a spreadsheet
4. Pick a control site (a site that is closeby and has the same climate, soil type etc, but is not subject to the same forces of compaction, i.e. ploughing, etc). Repeat the process of selecting points and labeling them.
5. Use the penetrometer to measure the PSI count of these sites and record them in the same spreadsheet under the header of ‘control site’
6. Repeat the process again once a year, at the same time of year, in the same locations

**The Results**

You will end up with a set of PRI numbers between 0 - 400 PSI. The higher the PSI number, the higher the level of compaction you have. You should be aiming for a PSI level of around 200, depending on your soil type and moisture levels. The higher the clay content in your soil, the higher the PSI will be. The lower the moisture levels, the higher the PSI will be, so these factors should be taken into consideration when analysing your results.
(b) Bulk Density Test

Materials needed:

- Garden trowel
- (Flat) knife
- Sealable bag & marker
- Scale (0.01g precise)
- Spoon (1/8 cup or 30mL)
- 1 paper/glass/ceramic cup
- Microwave oven

For loose/sandy soils
- A top- and bottomless ring (or bottomless cake pan)
- A hammer/mallet and wood block (roughly as long as the diameter of the ring)

For gravelly & rocky soils
- Plastic wrap
- Graduated cylinder or container
- 2-mm sieve

The Method

- Select 1 point per zone - if these have been defined last year, walk 2 steps away from the former
- Label these points with numbers, letters or names both physically (marking) and on your site map so that you are able to come back to them again for taking subsequent measurements
- Record the labels in the datasheet

For normal soils
1. Measure height & diameter of ring to calculate its volume, then record on datasheet
2. Drive ring into soil with hand sledge and wood block
3. Dig around- and remove ring with trowel underneath it, preventing loss of soil
4. Remove excess soil with knife (bottom & top need be flat with the edges of the ring)
5. Place sample in bag and label

For gravelly & rocky soils

Considerations: Choose a spot that is as level as possible to allow water to fill the hole evenly. If the soil is too wet to sieve, ignore Step 3 and proceed to Step 4. Soil will have to be dried and sieved later. The volume of gravel will need to be determined and subtracted from the total volume of the soil sample taken in the field.

1. Dig bowl-shaped hole and place all soil/gravel/rocks removed in a plastic bag
2. Using the 2mm sieve, sieve soil into another plastic bag & put gravel/rocks aside (see considerations above if soil is wet)
3. Line the hole with plastic wrap, leaving excess around the edges and place sieved rocks/gravel carefully onto the plastic wrap in the hole
4. Add water to the hole from volumetric container keeping track of how much is needed to fill the lined hole (level of water should be even with surrounding soil)
5. Record the total amount of water added in cubic centimeters (= volume of soil removed)

Then, for both types of soils:

6. Weigh an empty plastic bag and record on datasheet
7. Weight the soil sample in its bag and record on data sheet
8. Mix sample thoroughly in the bag by kneading
9. Weigh the empty cup and record on data sheet
10. Take a 1/8 cup level scoop subsample of loose soil from plastic bag (not packed down) and place in the cup
11. Weigh the soil subsample in its cup and record on datasheet
12. Place the paper cup containing the subsample in a microwave and dry for 2 or more 4-min cycles at full power. Open the microwave door for 1 min between cycles to allow venting. Weigh the dry subsample in a cup and record in a datasheet.
13. Record soil bulk densities* for each of the zones in the datasheet

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4-minute cycle. When its weight does not change after a drying cycle, then it is dry.

*Formulas for final calculations (estimated automatically in last 3 columns of datasheet):

Soil water content (g/g) = \( \frac{\text{weight of moist soil} - \text{weight of oven dry soil}}{\text{weight of oven dry soil}} \)

Soil bulk density (g/cm³) = \( \frac{\text{oven dry weight of soil}}{\text{volume of soil}} \)

Soil porosity (%) = 1 − \( \frac{\text{soil bulk density}}{2.65} \)

The Results: Following this protocol in a systematic fashion gives an indication of how loose or compact your soil is (as well as information about the soil's porosity and water content). High bulk density means that there is little porosity and thus high compaction.

Additional references

Indicator 5: Increased water retention of the soil

Means of Verification: This is the indicator that shows that there is more water being held in the soil than there was before the camp began work. The (a) Water Holding Capacity Test is good if you have an oven that could be on for 24hrs and sensitive scale, but if you are looking for an easier/quicker means to assess the hydrology of your soil, do the (b) Water infiltration test.

The Why

Healthy soils hold and infiltrate water, unhealthy soils don’t. Soil moisture is the basis for photosynthesis and ecosystem functioning. WHC typically increases with organic matter and carbon content. Measure WHC before, during and after the restoration process to track changes.

If you cannot do the WHC test, measuring the infiltration of your soil tells something about the ‘sponge behaviour’ of your soil as well as other ecological functions of water storage and conservation.

The results of (one or both) of these tests could guide future soil management practices so as to promote water infiltration and reduce water loss from runoff and/or evaporation.

(a) Water Holding Capacity (WHC) Test

Materials needed:

- 1 watering can and water (a hose and spray nozzle can also be used)
- 3 or 4 trash bags, small tarps, or pieces of thin sheet plastic
- 1 sensitive scale (0.01 g)
- 1 spade
- 1 clean bucket
- 1 clean Ziploc bag, glass jar, or container to hold the sample
- 1 kitchen sieve or screen material with ~2 mm holes
- Mortar and pestle or other way to grind/break up soil
- 1 Kitchen oven or toaster oven set to 105°C
- A glass, metal, or ceramic dish/container to hold soil in oven (withstand 105°C)

The Method

1. Select and mark out at least three sample sites in the zone(s) that you are restoring
2. Free a 1x1 m area of soil from vegetation and soak it slowly and for several hours with water until saturated (ideally after a substantial rainfall event with clear forecast for the next three days)
3. Avoid pooling and runoff
4. Cover with plastic sheet, pin it down and wait for 48-72 hours, the sheet will prevent evaporation
5. Remove the plastic sheet, take sharp spade and cut a soil sample (15cm deep, 5cm thick and the width of the spade), make sure that the slice represents the entire top 15cm of the soil, repeat this for all sample sites
6. Mix samples together and omit any roots or stones
7. Take about 3 to 6 cups of the mixed sample and put it on a pan or another high-temperature container
8. Zero the scale, weigh the soil and record its weight
9. Bake the soil in an oven at 105°C for 24 hours until the water has evaporated, let it cool.
10. Grind the sample with a mortar and sieve it through a 2 mm mesh, sift out all remaining stones and roots.
11. Weigh the now dry soil sample and record weight.
12. Weigh the empty clean pan and record weight.
13. Calculate the water holding capacity (WHC) of the soil sample using the equation:
   \[ \text{WHC} = \frac{(\text{PSw} - \text{PSd})}{(\text{PSd} - \text{P} - \text{RR})} \]
   1. \( \text{PSw} \) = weight of pan and wet soil together
   2. \( \text{PSd} \) = weight of pan and dry soil together
   3. \( \text{P} \) = weight of pan
   4. \( \text{RR} \) = weight of rocks and roots
14. Units for WHC are reported as kg H_2O / kg soil and can be converted to a percent (multiplying WHC by 100).
15. When repeating the test make sure to use the same procedure in order to get meaningful results.

(b) Infiltration test

Materials needed:

- hand sledge and wood block
- Empty food tin or bottomless cake pan
- Marker
- plastic wrap
- 500 mL bottle
- water
- stopwatch or timer

The Method

1. Remove top/bottom of tin or so you are left with a metal tube.
2. Randomly select one sample site per zone.
3. Label these points with numbers, letters or names (e.g. inf1) both physically (e.g. using marking sticks) and on your site map so that you are able to come back to them again for taking subsequent measurements.
4. Free a 1x1 m area of soil from vegetation and soak it slowly and for several hours with water until saturated (ideally after a substantial rainfall event with clear forecast for the next three days).
5. Clear sampling area/trim vegetation.
6. Drive the metal tube in the soil it is half-way in.
7. If soil is wet or near field capacity, go to step 8; If soil is dry, pour 500 mL water inside the ring & wait until the surface is exposed.
8. Start the timer as you pour 500 mL water as gently as possible into the tin.
9. Stop time when water is infiltrated (when surface is just glistening rather than submerged). If soil is uneven, count time until half of the surface is exposed and just shining.
10. Record time counts for each of the sample sites/management areas in datasheet.
The Results (WHC and infiltration test)

A small water holding capacity or long water infiltration could indicate the presence of a ‘hardpan’/high soil compaction and/or a small percentage of soil organic matter. (In general, clay-rich and shallow soils drain more slowly than sandy, deep soils). This could also lead to increased risks of surface runoff with heavy rainfall events. We therefore gain a better understanding of the soil health as well as insight on which strategies to prioritise. Repeating the test throughout the restoration process shows if restoration efforts are successful.

Indicator 6: Improved pH

**Means of Verification: pH test**

This indicator can be tested by pH testing paper (litmus paper), which is cheap and easily available online, at pharmacies, high school chemistry etc.

**The Why**

Establishing the acidity/alkalinity of your soil leads to useful insights about your soil’s needs and potential of growing healthy plants, vegetables or even trees.

**Materials needed:**

- Bag or box to mix soil
- pH paper & chart
- cup
- water

**The Method**

1. Mix soil from at least 3 points representing each of the zones that exist on your land
2. Fill your cup ⅔ full with soil
3. Add water to the cup so that the soil is covered
4. Stir well for 1 minute
5. Completely immerse pH strip in soil solution for 3 seconds
6. Remove strip and rinse quickly with water (from the same source as was used in the solution)
7. Hold pH paper up to the light and compare colour to color table below
8. Identify and record pH value in datasheet
9. Repeat the procedure for the other zones

**The Results**

Most plants need a pH between 6 and 7.5 to grow well, but some actually prefer more acidic or alkaline soils. This should help you ponder on what you would like to grow, or how you would like to feed your soil.

<table>
<thead>
<tr>
<th>Acid</th>
<th>Neutral</th>
<th>Alkali</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>
Indicator 7: Increased biological activity in soil

Means of Verification: Earthworms test

The earthworm test is not suitable for all ecosystems. Please get in touch if you would like to help us develop alternative tests for such cases.

This is the indicator that reflects the biologic activity as an essential component of building soil, cycling nutrients and much more.

The Why

Establishing the number of earthworms present in your soil is a proxy indicator for soil biological activity. These important creatures help with breakdown of organic residue and create channels that improve infiltration and aggregation (due to earthworm burrowing).

Materials needed:

- 2 L tap water
- Hand trowel or shovel
- Large jar/container for worm collection & cleaning
- Mustard solution (2 tablespoons mustard powder in 2 liters of water)

The Method

1. Randomly select one sample site per management area
2. Label these points with numbers, letters or names both physically (e.g. using marking sticks) and on your site map so that you are able to come back to them again for taking subsequent measurements
3. Measure 30x30 cm square plot (NOTE: avoid sampling where earthworm populations might be affected i.e. mulch or compost piles).
4. Dig down 30 cm with a hand trowel/shovel, minimizing damage to the earthworms…
5. Count number of earthworms (against pale-colored background to help locate them)
6. Add mustard solution to the hole and wait for deep-burrowing earthworms to appear (usually within 5 mins).
7. Count the number of deep-burrowing earthworms and add to amount of 3 to obtain total # earthworms
8. Record yearly counts for each of the zones/sample sites in datasheet
9. Rinse earthworms in water and return them to the soil.

The Results

The total number of earthworms present in your sample sites gives a rough indication of ecological functions such as nutrient cycling, soil structure and fertility.
Indicator 8: Increase in biodiversity (flora)

**Means of Verification: Square method**

**The Why**

Tracking changes in plant biodiversity over time could tell you whether your interventions (or the absence of them) are attracting species and increasing the overall resilience and complexity of these ecosystems. You'll be hoping to see a greater diversity of plants within your site than you found in your baseline survey.

**Materials Needed**

- A one 1m² frame/quadrat (this can be made of wood or nails connected with string, any other material that you think would be suitable to use; this could also be a hoola hoop, so long as you know its area and it is always the same instrument!)
- A camera/smartphone
- A plant identification guide for your region
- Marking sticks (could be small coloured stones, small flags etc)
- (Tape measure if doing the square method along a transect)

**The Method**

1. Explore plant encyclopedias/local botany resources to help with flora surveying
2. Randomly select* different points within different zones (avoiding crop production areas where weeding by humans takes place if you can).
3. Label these points with numbers, letters or names both physically (e.g. using marking sticks) and on your site map so that you are able to come back to them again for taking subsequent measurements
4. Place the quadrat on each of the points
5. Count the number of different plant species you can see inside the quadrat
6. Record the values in the datasheet
   *(Optional)*
7. Take a picture of the quadrat
8. If possible, identify/record the species names found in each quadrat**

*For more scientific/systematic sampling, this can be done by sampling every (distance) m along transects and/or a certain amount of steps between each quadrat.

**If you are keen to know more about the occurrence of certain species at your sites, look into the tab (Additional) Plant frequency. The method is similar: the more quadrat samples you dive into, the more you learn about patterns of plant communities.

**The Results**

Assessing the number of diversity of plants on a given site reflect its biodiversity which in turn represents the overall health and resilience of the land. Repeating the test throughout the restoration process indicates whether we are successfully promoting the species desired in the ecosystem (depending on the goals of the project, we may be aiming at nitrogen fixing plants or native species).
Indicator 9: Increase in biodiversity (fauna)

Means of Verification: Nocturnal insects

The why

Observing nocturnal insects is a very simple method of observing levels of biodiversity on your land. Many species will play important roles in the ecosystem such as pollinators or species that help with pest/plague control.

The higher the quality of the ecosystem restoration, the more nocturnal insects you can expect to see. That is likely to be true for the number of species present (diversity) and also the number of individuals of those species (abundance).

As a proxy for biodiversity, nocturnal insects are a useful group to assess because you don’t have to actively look for them. Most nocturnal insects are attracted to light, so by using this simple method they will come to you.

If you can identify some of the species that’s great, but that is not necessary for this test to be successful/impactful. You can simply photograph the species for identification at a later time.

This test will allow us to assess changes in diversity and abundance of nocturnal insects over time.

Materials needed:

- Headtorch (to get to- and from site)
- Light source
- A light colored vertical surface (2x1.5m) to shine the light on
- Washing line/rope/string & pegs to hang your sheet
- Camera or mobile (cell) phone with camera function

The Method

1. Select one sample site per management area, far from other artificial lights (make sure that the different locations are a minimum of two football fields apart to avoid attracting insects from the other areas. If your site is not bigger than two football fields, one test is ok.)
2. Mark the location(s) both physically and on your (digital) site map so that you are able to take subsequent measurements
3. Select an evening that is dry & without wind
4. Find or set up a vertical surface of at least 2x1.5m in the areas you wish to survey (If using a sheet you can do this by attaching the rope to two trees or poles and hanging the sheet over the rope. Alternatively, hang your sheet over a branch or fence.)
5. One hour after sunset time (you can check this on your weather app), switch on the light so it is illuminating the whole surface area for 2 hours (depending on your situation, and the equipment you are using, you might need to adjust the position of the light source to maximise the amount of surface that is lit up)
6. Record date/time of survey
7. At the end of 2 hours take a photograph of the whole surface.
8. Look in more detail at the insects on your surface and take photographs of interesting species you see. You might be surprised by how many species turn up. Why not see how many you can identify using resources such as iNaturalist (see the note below about identification).
9. Send those photos to the ERC team for analysis.
10. Repeat the test in other areas as necessary. If you are doing this test at multiple locations it is okay to do this on different nights.

The Results

The photographs of the complete surface will be used to calculate how much ‘white’ area remains after 2 hours. Over time you can expect the amount of ‘white’ surface to decrease as habitat quality improves.
Indicator 10: Reduced temperature differentials

Means of Verification: Temperature measurements

The why
Temperature is a crucial ecological factor, regulating physiological and metabolic processes of plant and animal species (e.g. transpiration, photosynthesis, germination, respiration). We know living beings thrive in so-called optimum temperature ranges - not too cold, not too warm. Generally, photosynthesis stops at 40 °C in temperate ecosystems and at 50 °C in the tropics, while metabolic activity is low under 0 °C and above 40 °C.

On the other hand, changing temperatures influence other systems like the water cycle, precipitation patterns and/or overall (micro)climate. Therefore it is important to keep track of how temperature is changing at different zones within your camp.

One method to do this is described below, but it can be as simple as manually logging surface temperature measurements in each season (just 2 - dry and wet - seasons in the tropics) in each of these zones. What matters is to do so in a consistent manner - taking and recording measurements of the same sites over time for subsequent interpretation.

Materials needed:

- Data loggers

The Method

1. Identify sample spots for the zones you wish to study (e.g. neighbouring control site, forest, (silvo)pasture, crop production, etc.)
2. Install data logger(s)
3. Record min/max temperatures, date, geo coordinates/labels, zone and height
4. Repeat the process in all the zones you wish to study

The Results

Monitoring how temperature changes across different sites and heights, helps you gain an understanding of energy flows. If you are able to reduce temperature differentials with your interventions (e.g. CAMP max surface temperature < BARE FIELD max surface temperature in hot days; CAMP min temperatures > BARE FIELD min surface temperature in cold events), you know you are helping with the process of homeostasis in/around your ecosystem, that it is more resilient to sudden climatic events & weather shocks. So it also stimulates proactive management in the face of potential disturbances (such as droughts or spread of fires).
Indicator 11: (LAB) Increase in Soil Organic-Matter (SOM) & Carbon (SOC) content

**Means of Verification: Loss on Ignition (LOI) Lab test**

This is the indicator that shows that more carbon is being sequestered into the soil than it was before the camp was in place and the ecosystem restoration activities had begun. This is measured in the following way:

**The Why**

If we want to know why Soil Organic Matter (SOM) is important, we must know what SOM means. SOM is the basis for fertile soils, healthy terrestrial ecosystems and climate: a complex component of the soil made up of microbial, plant and animal tissues in different stages of decomposition (Stockmann et al, 2013). It is also the largest terrestrial pool of organic carbon (SOC) (Liang et al, 20200), storing almost three times more carbon than the aboveground biomass, double that in the atmosphere and even more than the atmosphere and vegetation combined (Eswaran et al, 1993). Thus, increasing soil organic matter in the soil is also increasing organic carbon, which is why ecosystem restoration helps mitigate our changing climate. In turn, showing that carbon is being sequestered into the soil is a powerful sign to the world that this is a solution worth investing in.

Beyond carbon, organic matter is a crucial storehouse for nutrients and a major contributor to aggregate formation and stability, playing a central role in ecosystem functioning for all soil types (sandy, clay, loamy and all the ones in between). SOM influences fertility* and associated (primary or crop) productivity, soil trafficability** and hydrology (infiltration/runoff rates and flood regimes) (He et al, 2012; Hatten & Liles, 2019), as well as maintaining pH and perhaps most importantly, keeping decomposing organisms well-fed… That is, promoting a steady nutrient cycle. So, increasing SOM levels influences other soil-related outcomes such as decreasing bulk density, increased water holding capacity, infiltration and root proliferation (Hillel & Hatfield, 2005).

*SOM contains nearly all soil N and typically the majority of CEC

**defined as a soil’s capability to support agricultural traffic without degrading soils and ecosystems

**Materials needed:**

- 1 spade/auger
- 1 clean bucket
- 1 clean Ziploc bag to hold the sample

**The Method**

1. Determine and prepare locations of subsamples you will take: At least five to ten locations should be chosen that represent the zone you want to study, for example from the top, middle, and bottom of a slope; or scattered locations in a field, pasture, or garden bed. Avoid sampling in irregular and border areas.
2. At each of the selected zones, take two soil subsamples 5m apart, and mix the subsamples together into one sample in a ziploc bag.
3. Remove any residue or plant material above the soil surface.
4. Use the spade to dig a small hole in the center of the prepared area, about 8 inches deep. From the side of the hole take a vertical, rectangular slice of soil, aim for 6 inches deep and 2 inches thick. Remove any extra soil so that you have a more or less uniform “slice of soil” that is 6 inches deep, 2 inches thick and the width of the spade. Try to ensure that the slice represents the top 6 inches with equal representation across the depth of the sample. Place the slice of soil into the clean bucket.
5. Repeat the sampling procedure at each location that you chose for this area, and combine the soil in the bucket. Break up the soil and thoroughly mix the subsamples in the bucket.
6. Once the soil is sufficiently mixed, take an amount needed by the lab for analysis (specify that you want to measure Soil Organic Matter (SOM) using the Loss on Ignition (LOI) test, and transfer into the clean ziplock bag to transfer to the lab (0.7 litres of soil should be sufficient).

**The Results**

Once you have received your results back from the lab, you will be given a percentage of soil organic matter/carbon found in the sample that you sent off. Healthy soils have around 6% organic carbon content. Degraded soils have 1-2%. To work out how much organic carbon you have in your soil, multiply the number by 0.58. The answer gives you the amount of organic carbon in your soil (Ponce-Hernandez et al, 2004). Additionally, data from the lab can be used calibrate or validate SOC estimates based on satellite imagery and mathematical relationships)

**Additional** maps with predicted SOC values:
- [https://www.soilgrids.org/](https://www.soilgrids.org/)
- [https://www.isric.org/explore/soil-geographic-databases](https://www.isric.org/explore/soil-geographic-databases)
- (restor)
Appendix 1 Examples of landscape traits as criteria for sampling design

We formulated a set of questions that could help you navigate through the different layers of your landscape, as outlined below.

- **Where does the soil come from?** (What is the lithology & parent material of soil)
- **How is the soil formed?** (Could be through physical- (e.g. disintegration due to temperature differences and so on), chemical- (chemical reactions) and biological (related to life) weathering processes)
- **What has the soil been used for?** (What was the traditional land-use?)
- **What type of landforms are there?** (E.g. low hills, river valleys, etc)
- **What is the water gradient like?** (Look into the hydrology of the site, some areas have more or less water than others)
- **What is the orientation of different areas within your camp?** (Consider sun-orientation and wind exposure)