Manual

Food forest monitoring and evaluation study

WAGENINGEN UNIVERSITY
WAGENINGEN UR

EcoVredeGaard
Voedselbos in Park Lingezegen (Elst nabij Arnhem-Nijmegen)

Food Forest
Consultancy and Support

Fieldwork manual for the volunteers of EcoVredeGaard

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THIS MANUAL IS A PRODUCT OF THE ACADEMIC CONSULTANCY TRAINING (ACT)

This manual was constructed under the supervision of Kees van Veluw and was commissioned by EcoVredeGaard, part of Park Lingezegen and Wageningen Environmental Research.

Cover and manual drawings by Nalini Mahesh

Hello!

Food Forests should to be monitored regularly in order to understand how the system develops over time. This manual can be used as guidance for some important measurements in EcoVredeGaard. The data can be further used to strengthen our current understanding on Dutch food forests and will help policy and decision makers to see the relevance of these systems!

This manual will provide methods for:

Carbon sequestration

Aboveground

Belowground

Soil enrichment

Bulk density

Infiltration rate

Soil pH

Biodiversity

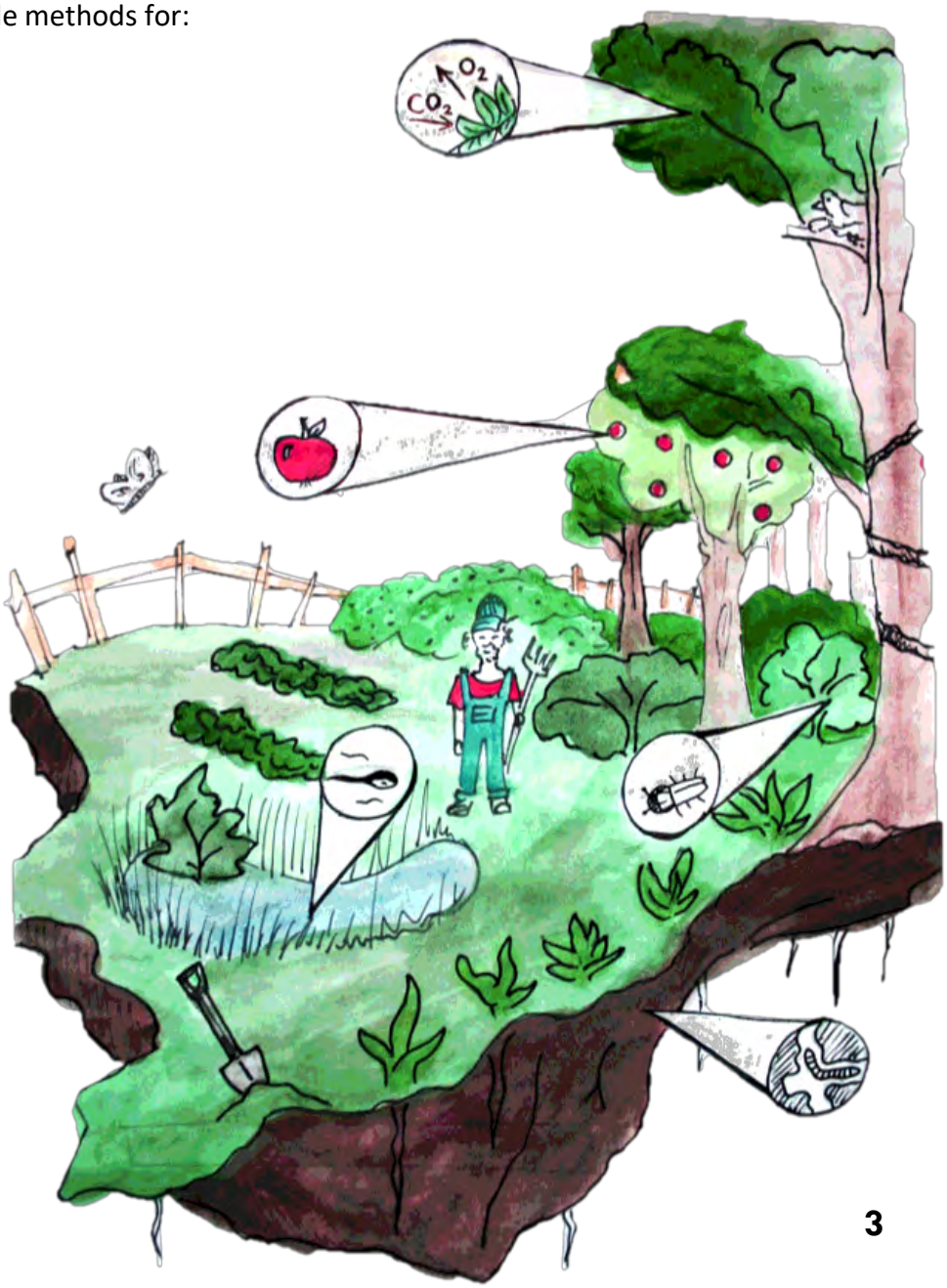
Vegetation

Animals

Production

Crop count

Harvest count

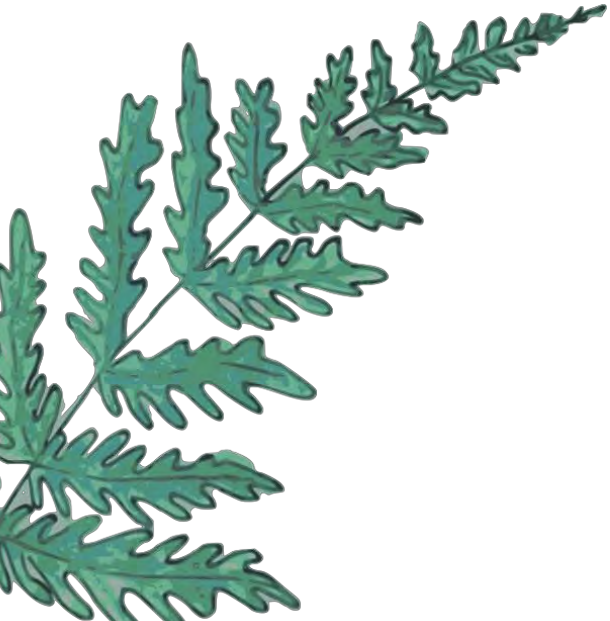


Contents

The best moment to monitor

To get the best possible results, all parameters may be measured at the right moment. The table below shows the best moment to perform the monitoring measurement (indicated in Green).

Method	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Aboveground C sequestration												
Belowground C sequestration												
Bulk density												
Infiltration rate												
pH												
Vegetation biodiversity												
Earthworms												
Beetles												
Pollinator species (Bees)												
Productivity												



Sampling designs

It is highly recomended to implement a sampling design to perform the measurements in the food forest, and be consistent over time. This design may be applicable for the majority of the methods as indicated throughout the manual.

Taking a cluster arrangement of 1 hectare, it is suggested to perform either a systematic or random-stratified sampling design (Figure 1). These are optional designs; another approach may be selected according to previous analysis of the area.

The systematic design (A)

The systematic design consists of equally spaced sample locations (plots), covering uniformly the area and accounting for spatial variation and changes over time.

The random-stratified design (B)

The random-stratified design consists of randomly selected sampling locations (plots) within pre-defined habitats, considering the heterogeneity of the area in its early stages.

Material for sampling design set-up

Measuring tape
Compass or GPS
PVC or woody sticks as reference for plot centre

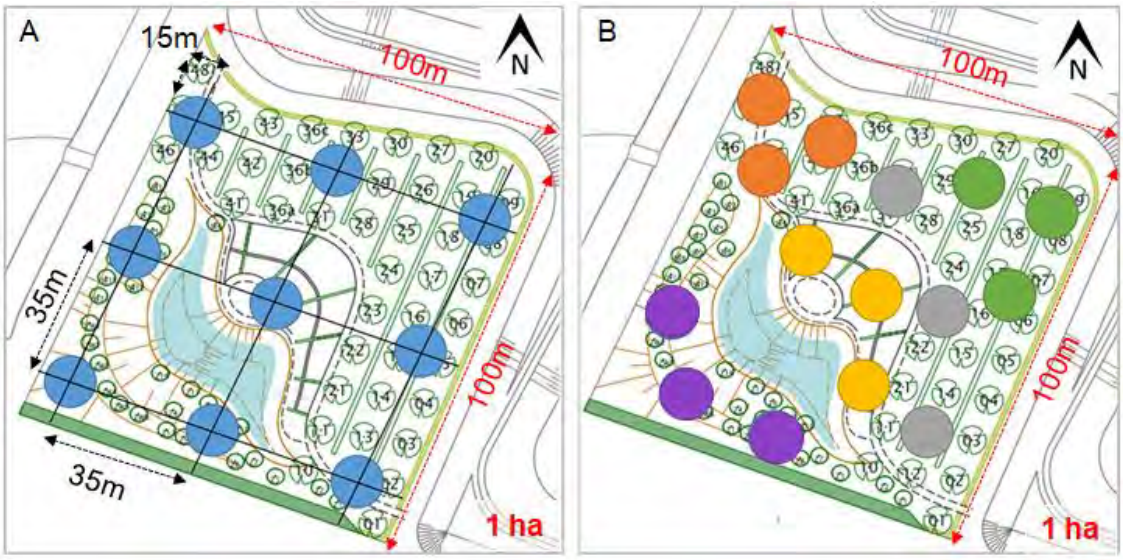
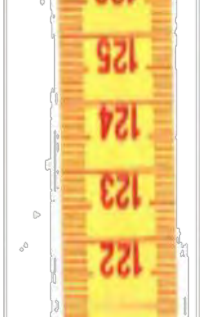


Figure 1. Systematic (A) and random-stratified (B) sampling designs for conducting measurements over time in EVG. Plot with same color in figure B refer to plots in the same habitat.



Measuring aboveground Carbon sequestration with Stem Wood Biomass

Measurement plan

This measurement may be performed once a year. It does not matter in which season the measurement is performed, but it is of importance that there's a full year between the measurements. Comparing the data from following years can tell how much C there is sequestered per hectare per year.

Precautions

When measuring the tree circumference the tape must be tightly held around the tree (Figure 2). Any loose bark should be removed. Any twigs or branches at 1.3 m have to be removed before measuring. If this is not possible than move the tape 10 cm up or downward.

Needed equipment

Measuring tape and Calculator

Performing the measurement

1. Measure the circumference around the tree at breast height (= 1.3 m from the ground) and write it down in cm
2. Measure the height of the tree stem (from the ground to the crown, so where the branches start to split) and write it down in cm
3. Calculate the diameter (d) of the tree according to:
    - Circumference = C = π x d
    - d = C/ π
4. Calculate the basal area of the tree according to:
    - Radius = r = d/2
    - Basal area = r^2 x π
5. Calculate the volume of the tree stem:
    - Tree volume = Tree basal area x Tree height
6. Calculate the stem wood biomass:
    - Stem wood biomass = Tree volume x Wood density
    - For wood density see Table 1
7. Calculate whole-tree biomass:
    - Whole-tree biomass = Stem wood biomass x 1.6
8. Calculate the carbon content of whole-tree biomass:
    - Carbon content = Whole-tree biomass x 0.5

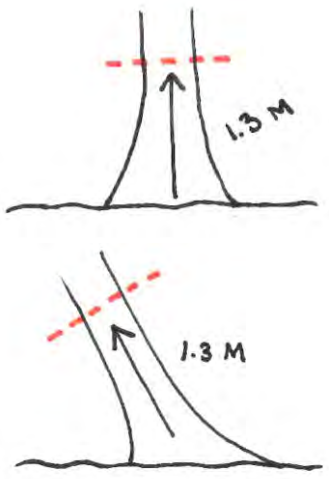


Figure 2. Measuring the tree circumference at breast height.

The result of the calculation provides the amount of carbon per tree in grams.
Perform this measurement for all the trees at EVG (use table 1).
Add up all the results. This number is the amount of carbon stored aboveground per hectare.
*Perform the measurement 1 year later again (**in the same period**). The difference between two following years is the amount of carbon that is sequestered per hectare per year.*

Table 1. Wood density per tree species present at EVG. No data was available for the species marked in red.

Dutch name	Scientific name	English name	Wood density (g/cm3)	Source
Appel	*Malus domestica*	Apple	0.745	1
Peer	*Pyrus communis*	Pear	0.57	2
Perzik	*Prunus persica*	Peach	0.59	3
Kroosjespruim	*Prunus cerasifera*	Cherry plum		
Pruim	*Prunus domestica*	Plum	0.6	2
Kweepeer	*Cydonia oblonga*	Quince	0.58	2
Kers	*Prunus avium*	Sweet cherry	0.54	2
Mispel	*Mespilus germanica*	Medlar	0.55	4
Kers	*Prunus avium x cerasus*	Sweet cherry	0.54	2
Steeneik	*Quercus ilex*	Holm oak	0.74	2
Abrikoos	*Prunus armeniaca*	Apricot	0.66	2
Japanse walnoot	*Juglans ailanthifolia*	Japanese walnut	0.362	5
Peerlijsterbes	*Sorbopyrus auricularis*	European pear		
Pecan	*Carya illinoinensis*	Pecan	0.6	5
Amandel	*Prunus dulcis*	Almond	0.69	2
Nashi-peer	*Pyrus pyrifolia*	Asian peer		
Uiensoepboom	*Toona sinensis*	Chinese mahogany	0.501	5
Grootbloemige magnolia	*Magnolia grandiflora*	Southern Magnolia	0.46	5
Sneeuwklokjesboom	*Halesia Carolina*	Carolina silverbell	0.42	5
Winterharde citroen	*Poncirus trifoliata*	Trifoliate orange		
Anna Paulownaboom	*Paulownia tomentosa*	Paulownia	0.28	5
Gele reuzenbamboe	*Phyllostachys vivax Aureocaulis*	Bamboo	0.35	6
Rozijnenboom	*Hovenia dulcis*	Japanese raisin	0.538	5
Ginkgo	*Ginkgo biloba*	Ginkgo	0.451	5
Vezelbanaan	*Musa basjoo*	Japanese banana		
Zoete bamboe	*Phyllostachys dulcis*	Bamboo	0.35	6
Hazelboom	*Corylus avellana x colurna*	(Turkish) hazel	0.47	2
Bamboe Shanghai 3	*Phyllostachys Shanghai 3*	Bamboo	0.35	6

1 http://www5.csudh.edu/oliver/chemdata/woods.htm

2 Crivellaro & Schweingruber, 2013. Retrieved from: https://www.researchgate.net/publication/262977593

3 ICRAF's Tree functional attributes and ecological database. Retrieved from: http://db.worldagroforestry.org/wd

4 http://jjdoreau.fr/index_en.php?url=essences.php&lang=en&tri=nom_la

5 Zanne et al. 2009. Retrieved from: https://datadryad.org//handle/10255/dryad.235

6 https://www.engineeringtoolbox.com/wood-density-d_40.html

Example of calculations

Circumference apple tree = 35 cm
Height apple tree to crown = 125 cm
Wood density apple tree = 0.745 g/cm^3

Diameter = 35 / π = 11.14 cm
Radius = 11.14 / 2 = 5.57 cm
Basal area = $(5.57)^2$ x π = 97.47 cm^2
Tree volume = 97.47 x 125 = 12.183,75 cm^3
Stem wood biomass = 12,183.75 x 0.745 = 9,076.89 g
Whole-tree biomass = 9,076.89 x 1.6 = 14,523.03 g
Carbon content = 14,523.03 x 0.5 = 7261.52 g C

Thus one apple tree contains 7261.52 g of carbon.

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Crivellaro, A., & Schweingruber, F. H. (2013). Atlas of wood, bark and pith anatomy of Eastern Mediterranean trees and shrubs: with a special focus on Cyprus. Springer Science & Business Media.

Dixon, R. K., Winjum, J. K., & Schroeder, P. E. (1993). Conservation and sequestration of carbon: the potential of forest and agroforest management practices. *Global Environmental Change*, *3*(2), 159-173.

The Farmers Log, 1999. Tree and stand measurements. Retrieved from: http://www2.geog.ucl.ac.uk/~mdisney/fieldwork/misc/tree_measurement.pdf

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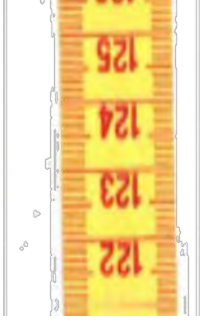

Measuring belowground Carbon sequestration with the Loss on Ignition method

Measurement plan

This measurement may be performed at least once a year. Since the results of this method rely on seasonality it is important to measure under similar conditions. The measurements may be performed in the winter during a dry period. For the long-term measurements it is important that the weather conditions are similar.

Precautions

Never touch crucibles with your hands. Your hand can transfer skin oils and add weight. Instead use a pair of tweezers or gloves. Make sure you tare the scale before measuring. Keep good notes for sample location and sample ID. It is important that you don't mix things up. Make sure that the used crucibles are cleaned before you start using them. No old soil should be left in the crucible before starting a new measurement.

Needed equipment

Ceramic crucibles
Soil sampling device (spatula or trowel)
An air-tight and dry place to store the soil samples
Oven that can heat at least up to 550°C
Weighing balance in grams to 4 decimal places
Permanent marker
Calculator
Sieve

Taking soil samples

1. Follow the stratified sample design for the location of the samples, take 3 samples per plot, this will result in 45 soil samples.
2. Remove the litter from the soil surface (this includes (rotten) leaves, roots, debris)
3. Take a soil sample with a spatula or trowel from the clean surface. Make sure to sample a sufficient amount (at least a full trowel).
4. Remove living roots or other rough material (e.g. stones or twigs) from the sample. This can be done with a sieve (more accurate) or by hand. Grind the sample to homogenize it.

Performing the measurement

1. Take the crucibles and number them with a permanent marker. Make sure you don't touch the crucibles with your bare hands.
2. Weigh the empty crucible and note the weight under **Crucible weight**.
3. Place approximately 25 g of soil in the crucible and weigh the total weight and note it down under **Initial sample weight.**
4. Heat the sample for at least 12 hours at 105°C.
5. After 12 hours turn the oven off and let the samples cool in the oven.
6. After cooling, weigh the samples in the crucibles again and note it down under **SW_{105}**. The difference in weight is the amount of water that was present in the soil and that is now vaporized.
7. Place the crucibles with the sample back in the oven and heat for 4 hours at 550°C.
8. After 4 hours, turn off the oven and let the samples cool in the oven.
9. After cooling, weigh the samples in the crucibles again and note it down under **SW_{550}**. The difference in weight is the amount of carbon that was present in the soil and that is now lost as CO_2.
10. The difference in weight from weight 105 and weight 550 is the amount of soil organic matter (SOM) present in the soil sample.
11. Calculate the SOM content in %:
    - $SOM = ((SW_{105} – SW_{550})/SW_{550}) \times 100$
12. Calculate the soil organic carbon (SOC) content in %:
    - It can be assumed that SOC is 50% of SOM
    - SOC = SOM/2

More than one sample can be put in the oven at the same time.
Make sure that you keep good track of which sample belongs that which location and crucible.
If you have to store the samples during the procedure make sure that the place is airtight and dry: for instance in a re-sealable bag.

Example of calculations

$SW_{105} = 23.574$

$SW_{550} = 22.748$

$SOM = ((23.574 – 22.748)/ 22.748) \times 100 = 3.85\%$

$SOC = 3.8/2 = 1.9\%$

References

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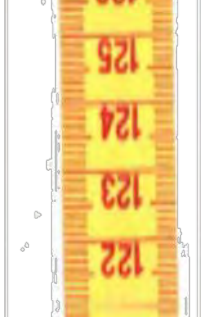


Measuring bulk density

Measurement plan

Measurements may be taken every two years in the same season. This should be in spring or autumn, ideally with similar soil moisture and temperature conditions between years, to increase the chance of adequate moisture levels. If soils are very dry, pour ~20L over the sampling site and wait three to four hours for water to drain. Sample according to the stratified sampling scheme to account for evolution of different zones.

Taking soil samples (for all soil types)

Samples should be taken from the mineral soil, which involves removing the organic layer: measurement at 0 cm corresponds to the top of the mineral soil with any organic layer removed. We recommend sampling at three depths: 0cm, 15cm and 40cm. The workload and time required increases considerably with each deeper sampling, but it will give a better idea of the effects of the food forest. Each sample must be taken directly below the higher sample, so sampling must proceed in the order given above. Take care not to cause compaction in the sample, or in any soil layers to be sampled below.

Method description for all soil types, <u>except stony or gravelly soils</u>

Needed equipment

75mm minimum diameter ring with a depth marker (*other diameters possible*)
Tough leather gloves
Lump hammer
Wooden block
Garden trowel
Flat-bladed knife
Marker pen
Scale (0.1 g precision)
Oven and thermometer
Aluminium cans or oven-safe containers easily large enough for sample.
You will need one can per sample, and these may be reused when drying is complete.
Worksheet

75mm diameter ring

75mm diameter ring
This can be made by cutting a piece of stainless steel round tube/pipe and sharpening the edge of one end, with the bevel on the outside (remove material from the outside). A depth mark can be added, also at around 75mm to keep sampling volume consistent. The sampler should be sharp and easy to push into ground without causing compaction, so use relatively thin-walled stainless steel tube.

Performing the measurement

1. Extract a sample

- Remove any litter and organic soil from the surface to expose the mineral soil.
- Using gloves, drive ring into soil so that the depth marker reaches the soil exactly. If it is not possible with gloves, use the lump hammer and block of wood to do this.
- With the sampling ring in the soil, remove enough soil from around the sampler to facilitate the removal of the sampler without losing any of the contents (Figure 3).
- Carefully extract the sampling-ring with the sample inside, using the trowel underneath to ensure no soil is lost; trim off any extra soil with the flat bladed knife so that it is flush with the bottom of the ring.

Figure 3. Soil core sampler

2. Weigh and record soil sample

- Use the scale to weigh a can. Record the weight.
- Disturbing the sample as little as possible, use the flat bladed knife to push the sample into the aluminium can. Label the can.
- Use the scale to weigh the sample in the can.
- Deduct the weight of the can from the value and record weight on worksheet.

3. Dry soil sample

- Dry the sample in its container for around 24 hours at 105ºC. You can check if it is dry by weighing the sample and returning it for another two hours, and then removing and weighing it again to determine if any more drying occurred in this time.
- Weigh the dry sample and record its weight, deducting the weight of the can.

Calculations

To ascertain bulk density, calculations are simple. Other related values that can be calculated based on data collected are described below, but do not need to be calculated. These can be calculated retrospectively as long as accurate record taking and retaining are observed.

Soil volume

Soil volume = core sampler volume = $\pi * \text{radius}^2 * \text{depth}$

Bulk density

Bulk density (g/cm^3) = weight of dry soil, (g) / volume of soil (cm^3)

Additional calculations

Water content

Water content (g water/g soil) = (Moist soil weight (g)- dry soil weight, (g)) / weight of dry soil (g)

The difference in weight between the subsample when it is fresh and when it is dry gives you the water content for the subsample. Divide this by the dry weight of the subsample.

Volumetric water content

Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)

Soil water filled pore space

Soil water filled pore space (%) = (volumetric water content x 100) / soil porosity

Porosity

Porosity (%) = 100 - (bulk density/particle density * 100)

= 100 – ((bulk density / particle density) x 100)?

To calculate porosity we assume a particle density of 2.65 g cm^{-3}

References

Figure 3. Soil quality monitoring. Retrieved from: https://www.marlborough.govt.nz/environment/land/soils/soil-quality-monitoring

Method description for stony or gravelly soils

Measurement plan

Measurements may be taken every two years in the same season. This should be in spring or autumn, ideally with approximately similar conditions, to increase the chance of adequate moisture levels. In stony soils sampling should ideally take place when soils are dry enough to pass through a 2mm sieve. Sample according to the stratified sampling design (with three measurements per plot) to account for evolution of different zones.

Needed equipment

Plastic film
140cc syringe
Water
Garden trowel
Marker pen
2mm sieve
Scale (0.1g precision)
Oven and oven thermometer
Aluminium cans or oven safe containers easily large enough for sample. (You will need one can per sample, and these may be reused when drying is complete)
Plastic bag or large container
You will need one can per sample, and these may be reused when drying is complete.
Worksheet

Precautions

Choose a spot that is as level as possible if the site is sloped, to allow water to fill the hole evenly. If the soil is too wet to sieve, ignore the part in Step 2 about replacing rocks, 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.

Performing the measurement

1. Remove any litter and organic soil to expose mineral soil

2. Dig Hole

- Dig a bowl shaped hole 8cm deep and approximately 12 cm diameter using the trowel. Avoid compacting the soil in the hole while digging.
- Place **all** of the soil and gravel removed from the hole in a container or plastic bag.

3. Sieve soil [See "precautions" above if soil is wet]

- Using the 2-mm sieve, sieve the soil in the plastic bag to separate the gravel.
- Weigh the aluminium can and record the weight to be used in Step 6.
- Collect the soil in the aluminium can.
- Put the gravel aside to be used in Step 4.
- Label the can.

4. Line the Hole

- Line the hole with plastic wrap. Leave some excess plastic wrap around the edge of the hole.
- Place the sieved rocks and gravel carefully in the centre of the hole on top of the plastic wrap (Figure 4). Ensure that the pile of rocks does not protrude above the level of the soil surface.

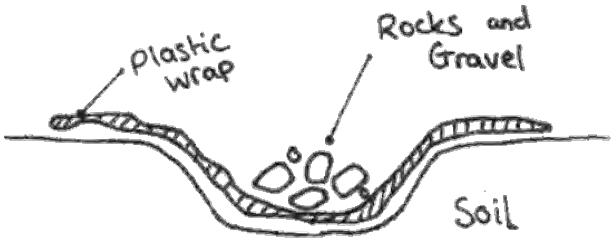


Figure 4. Line the hole with a plastic wrap.

5. Add Water to the Hole

- Use the 140 cc syringe to keep track of how much water is needed to fill the lined hole. The level of the water should be even with the soil surface.
- The amount of water represents the volume of soil removed. Record the total amount of water in cubic centimetres (1 cc = 1 cm^3) on the worksheet.

6. Weigh and Record Sample

- Use the scale to weigh the soil sample in its can. Record the weight.
- Deduct the weight of the can from the value and record on worksheet.

7. Dry soil sample

- Dry the sample in its can for around 24 hours at 105ºC. You can check if it is dry by weighing the sample and returning it for another two hours, and determining if any more drying occurred in this time.
- Weigh the dry sample and record its weight, deducting the weight of the can.

Calculations

The same calculations should be performed as on pages 14 - 15.

Measuring infiltration rate with the single ring infiltrometer method

Measurement plan

This measurement can be done in the same period of time as the bulk density measurement, which is either in spring or in autumn. For this also the stratified sampling design has to be followed (with three measurements per plot) and the measurement has to be performed at the soil surface. For long-term monitoring, samples should be taken from the same location. In dry soil, water can move and infiltrate fast, which is measured as the rate of first inch water infiltrate soil (initial infiltration rate). As increasing water replaces the air in the pores, the water tends to infiltrate slowly and arrive at a stable rate, so the second inch of water normally provides a more reliable estimate of infiltration rate.

Precautions

Before measurement, remove all vegetation, residues and stones on the sampling sites, make sure not to disturb the surface of soil. The test field should not be saturated, Wait for a couple of days until the soil is dry before taking measurements (Burt, 2009).

Needed equipment

A 15-cm diameter ring/cylinder (without top and bottom)
Hand sledge
Wood block
Water
Graduated cylinder
Plastic wrap
Timer

Performing the measurement

1. Make sure there is no vegetation, residues and/or stones on the sampling sites.
2. Label the ring/cylinder (8 cm from the bottom) with a zero line, and a 2.5 cm line (2.5 cm from zero line) on the outside of the ring/cylinder. Ensure the ring/cylinder does not leak and volume can be calculated with known height and diameter.

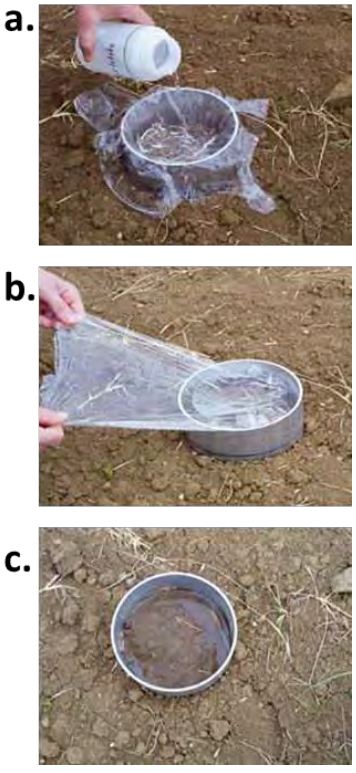


Figure 5. Performing the infiltration rate method

3. For one measurement, put the wood block on the ring/cylinder and drive it into the soil until the zero line using hand sledge.
4. Cover the soil and ring/cylinder with a sheet of plastic wrap completely.
5. Pour 444 mL of water (444 ml =1 inch=2.5 cm) into ring/cylinder covered with plastic wrap using graduated cylinder (Figure 5a).
6. Remove plastic wrap gently and leave water in the ring, as in Figure 5b.
7. Record time needed for the first inch (2.5 cm) of water to infiltrate the soil.
8. Stop timing when surface is just glistening (Figure 5c).
9. If soil surface is uneven inside the ring, record the time until half of surface is exposed and just glistening.
10. Repeat all the above steps with a second inch (2.5 cm) of water using the same ring/cylinder. Record time (Table 2).
11. If soil:water ratio is at or near field capacity, there is no need to measure second inch.

Calculation

I = (V/t)/A

A = π r^2

I represents the infiltration rate of water, **V** is volume of water infiltrated, **t** is the time needed for water decreasing from one 2.5-cm line and infiltrate water, and **A** is the area of ring/cylinder, so the infiltration rate can be calculated with a unit of cm/min.

Convert the unit of cm/min to inch/hour by 2.54.

Interpretation

Table 2. Infiltration rates and corresponding classes. Retrieved from USDA Soil Quality Test Kit Guide, 2001.

Infiltration rate (inch/hour)	Infiltration class
> 20	Very rapid
6 to 20	Rapid
2 to 6	Moderately rapid
0.6 to 2	Moderate
0.2 to 0.6	Moderately slow
0.06 to 0.2	Slow
0.0015 to 0.06	Very slow
< 0.0015	Impermeable

Example of calculations

V = 444 ml
t = 5.5 min
d = 15 cm
r = d/2 = 15/2 = 7.5 cm
$A = \pi \times r^2 = \pi \times (7.5)^2 = 176.71\ cm^2$
I = (V/t)/A = (444/5.5)/176.61 = 0.457 cm/min
I = 0,457 x 2.54 = 1.16 inch/hour
The infiltration rate is moderate.

References

Burt, R. (Ed.). (2009). *Soil survey field and laboratory methods manual*. National Soil Survey Center, Natural Resources Conservation Service, US Department of Agriculture.

USDA NRCS Soil Quality Institute staff (2001). Soil Quality Test Kit Guide. Retrieved from: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=nrcs142p2_053873.

Measuring soil pH with the pH-pocket meter method

Measurement plan

This measurement should be done once a year at any time. Samples should be taken according to the stratified sampling design (with three measurements per plot). Samples should be taken at the surface soil (0 – 30cm range: 10cm depth) and subsurface soil (30 – 100 cm range: 40cm depth). For the long-term monitoring, samples should be taken from the same location, the same depth as well as the same time of the year.

Needed equipment

⅛-cup (30 ml) measuring scoop
Graduated cylinder
Plastic container
Stir stick
pH pocket meter (Figure 6)
Standard buffer solutions for pH calibration (pH 7 and pH 4 or 10)
Distilled water

Figure 6. pH pocket meter

Performing the measurement

1. For one measurement, take 2 subsamples at 10 and 40 cm depth.
2. This means that from every plot there will be taken 6 subsamples in total
    - 3 samples at 10 cm depth
    - 3 samples at 40 cm depth
3. Mix all the 3 subsamples from every soil layer; this will result in 2 samples per plot, one at 10cm depth and one at 40cm depth.
4. Dry the sample in the air for 1 or 2 days, depending on how wet the sample it. After drying the soil should be not moist anymore.
5. Measure a ⅛-cup (30 ml) level scoop of air-dry subsample of soil (for one plot) and place it in the plastic container.
6. Add 30 ml distilled water into the plastic container, using the cylinder, to make the ratio of water to soil is 1:1.
7. Stir the mixture in the plastic container for 1 minute with an interval of 10 minutes.
8. After 30 minutes, insert the pH pocket meter into the top part of the solution; the pH pocket meter should be calibrated using buffer solutions before measurements.
9. Wait until the reading stabilizes (0-30 seconds) and record the digital reading on the sheet (Table 3).
10. Clean the electrode in the distilled water.
11. Maintain the pH pocket meter with a few drops of pH 7 buffer solution in the cap.

Calculations

For this method you don't need to do any calculations!

Interpretations

Table 3. Descriptive terms of pH ranges (Burt, 2009).

pH ranges	Descriptive terms
< 4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 -6.0	Moderately acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Slightly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
> 9.0	Very strongly alkaline

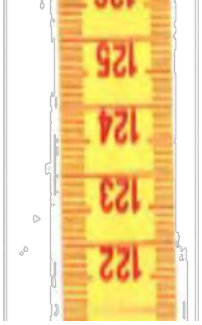
References

Smith, J. L., & Doran, J. W. (1996). Measurement and use of pH and electrical conductivity for soil quality analysis. p180. In *Methods for assessing soil quality* (Vol. 49). Soil Science Society of America Madison, WI.

Burt, R. (Ed.). (2009). *Soil survey field and laboratory methods manual*. National Soil Survey Center, Natural Resources Conservation Service, US Department of Agriculture.

Dick, R. P., Thomas, D. R., & Halvorson, J. J. (1996). Standardized methods, sampling, and sample pretreatment. p144. *Methods for assessing soil quality*, (methodsforasses), 107-121.

Figure 5. Example pH-pocket meter (retrieved from: https://hannainst.com/hi98107-phep-ph-tester.html)



Measuring vegetation biodiversity with the Quadrat method

Measurement plan

In general it is good to monitor vegetation biodiversity every year in the first 5 years because in early stage of food forest can be very dynamic. After that it can be monitored every 5 years. Vegetation can best be monitored twice a year in spring (end of March-June) since the determination of different plant species will be easier (e.g. flowers and reproductive organs are present). This to make sure a broad variety in plant species is captured and the ease of using the flowers in determination.

Use the systematic sampling design to monitor vegetation biodiversity. This will result in a total of 9 plots, distributed over the 1 hectare of EVG.

Precautions

Estimating the vegetation cover might be tricky because it is subjective measurement especially for the shrub layer. If there are few data collectors estimating the cover, then they can average the cover from individual estimation.

Vegetation monitoring can be conducted in any weather but convenient weather in preferable.

Needed equipment

Plant species identification guide
Magnifying lens (to help seeing small important organ on the plant e.g. flowers)
Rope (to make the plot)
Data collection form
Writing tool

Performing the measurement

1. Make a square plot of 10x10 m at each sampling site to measure the tree layer (Figure 7)
    - Within this 10x10m plot create a 5x5m plot to measure the shrub layer
    - Within this 10x10m plot create a 1x1m plot to measure the herb layer

2. In the 10x10m plot mark each tree and indicate the Dutch name of the species and count the number of individual trees of the species within the plot.

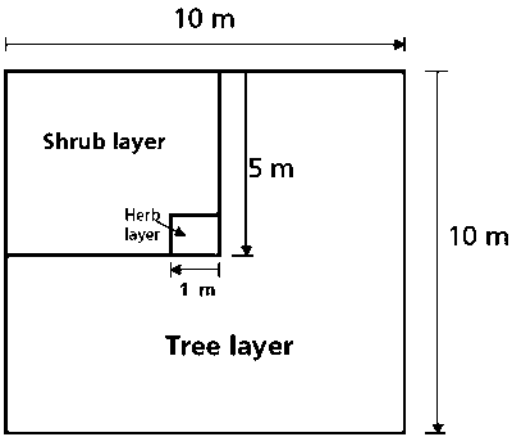


Figure 7. Drawing of what the square plots should look like. With a 10x10m plot for the tree layer; 5x5m plot for the shrub layer and 1x1m plot for the herb layer.

- Repeat this until you have all the trees species in the plot. In the end you have than counted all the trees in the 10x10m plot.
- Use the recommended guides to determine the species

3. In the 5x5m plot record the Dutch name of the shrub species that are present.
    - Use the recommended guides to determine the species
    - Then estimate the percentage (%) coverage of each species
        - To estimate the coverage use the cover scale of Londo and Braun-Blanquet (Table 4)

4. In the 1x1m plot record all the Dutch names of the low vegetation species.
    - Use the recommended guides to determine the species
    - Then estimate the percentage (%) coverage of each species
        - To estimate the coverage use the cover scale of Londo and Braun-Blanquet in table 4
        - To be more precise in the estimation of the coverage the 1x1m plot can be divided in 100 grids, in which 1 grid represents 1% (Figure 8)

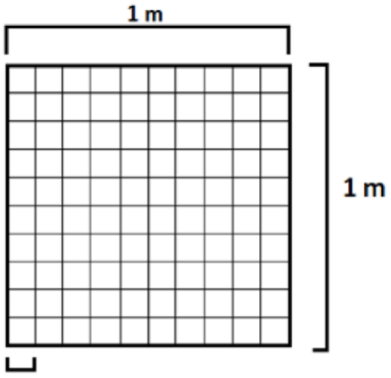


Figure 8. Subdivision of the 1x1m plot in 100 grids

5. Write down all the information on the table of data collection form
    - To analyse the collected data the Shannon diversity index and the Shannon equability can be calculated. This can be done after collecting all the data. **Note: This calculation can be challenging. An explanation and example of the calculation can be found in Annex I**

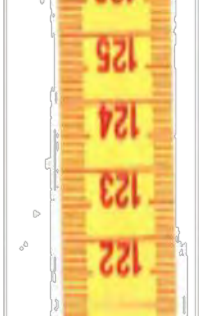
Recommended guides

Meijden, R. van der (2005). Heukels' flora van Nederland. Groningen: Noordhoff Uitgevers B.V.

Eggelte, H. (2007). Veldgids Nederlandse flora. Zeist: KNNV Uitgeverij.

Table 4. Visual measurement of vegetation cover (for ground vegetation and shrub) based on Londo and Braun-Blanquet scale.

Coverage scale%	Median value	Londo scale	Braun-Blanquet scale	Explanation
<1	0.5	*1	+	Rare individual
1-3	2	*2	1	Plenty individual
4-5	4.5	*4	2	Numerous individual
6-15	10.5	1		Abundance not indicated
16-25	20.5	2		
26-35	30.5	3	3	
36-45	40.5	4		
46-55	50.5	5		
56-65	60.5	6	4	
66-75	70.5	7		
76-85	80.5	8	5	
86-95	90.5	9		
96-100	98	10		



Measuring animal biodiversity

Sampling animal diversity in general

For sampling the species biodiversity the same plots as used for vegetation biodiversity will be used. These plots are set up according to the systematic sampling design. This means that there are 9 plots in total at EVG. Per plot 4 subplots will be taken for measuring animal diversity (Figure 9). This will result in a total of 36 subplots.

It is important to write down to which vegetation plot the species subplot belongs, as vegetation biodiversity influences species occurrence and abundance.

It is also advised to always use a standardized set of equipment per species measurement. The use of different materials over time can cause variations in the measurement.

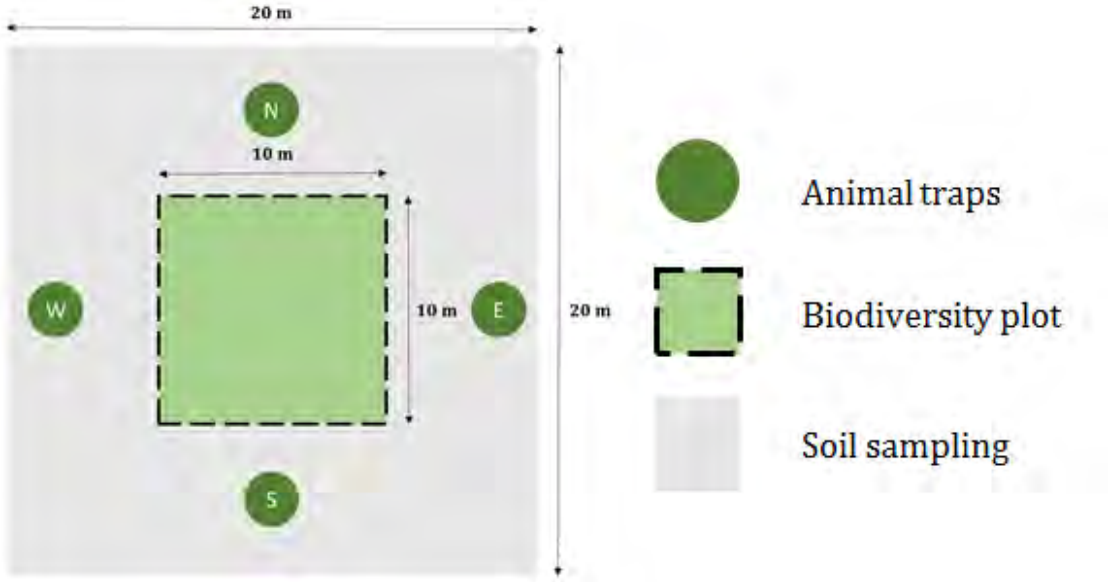
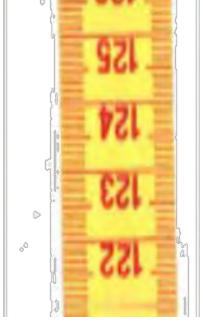


Figure 9 Subdivision of subplots to measure species biodiversity next to the vegetation biodiversity plots.



1. Earthworms: excavation and mustard method

Measurement plan

Animal diversity is best to monitor every year because they respond to minor changes in the system. Earthworm diversity can be best measured between March and June. Use the systematic sampling design to measure earthworms.

Precautions

Earthworms respond quickly to weather. Therefore it is more likely to find a higher number in earthworms after a few days of rain, compared to warmer and drier days. Please take note on the week and day specific weather condition.

Needed equipment

Earthworm identification pictures (Annex II)
Shovel
Rope (or plastic frame) to make the 30 x 30cm plot
Small closed tray with air holes in the lid, filled with water and marked with the location
Mustard solution

Performing the measurement

Preparations

The mustard solution can best be made at least 12 hours in advance

<u>Mustard solution (for 5 plots)</u>

1. Fill a 5L bucket half full of warm water
2. Weigh out 50 g of mustard powder
3. Pour the mustard powder into the bucket
4. Mix the solution thoroughly
5. Fill the 5L bucket the rest of the way with warm water
6. Let sit overnight

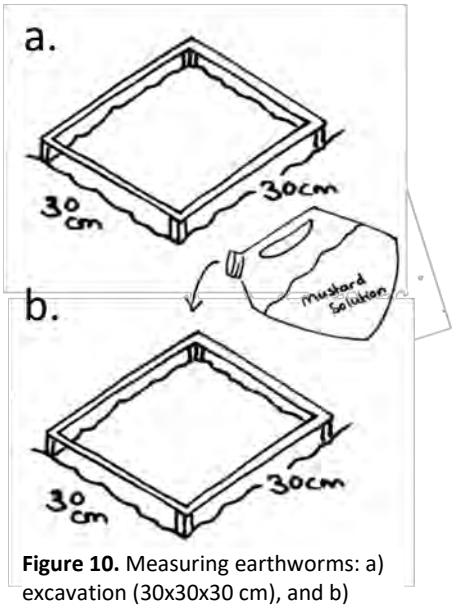


Figure 10. Measuring earthworms: a) excavation (30x30x30 cm), and b) adding the mustard solution.

Costs mustard powder (https://www.pit-pit.com/mosterdpoeder.html): around 6 euro/kilo.

In the field

1. Take the ruler and make a 30x30 cm plot.
2. Dig carefully a hole of 30x30x30 cm (thus 30 cm deep in the plot; Figure 10a).
    - If there is a litter layer present first remove the litter layer and collect any earthworms present in that layer.

- Collect the earthworms in the trays with water to prevent them from drying out

3. Search the soil that has been excavated for earthworms by hand.
    - Note: The worms are often rolled up in the soil
4. Collect all the earthworms that you find in one plot in the tray with water.
5. After the collection of the earthworms from the soil, fill the 30x30x30 hole with the mustard solution (Figure 10b)
    - Before adding the mustard stir it one more time
    - Start with adding 250 ml of the mustard to the hole (or enough to saturate the soil)
    - Set a timer at 20 minutes
    - During these 20 minutes, collect all the earthworms that come to the surface
        - As a result of the mustard solution the burrowing earthworms (anecic) will come to the surface
    - After 20 minutes again pour 250 ml of mustard into the hole and collect the earthworms
    - Continue doing this until in total 1 litre of mustard solution has been added
6. Write down the amount of earthworms that you have found in one plot at the worksheet
7. Use the earthworm identification sheet to determine what kind of species the earthworm is (anecic, endogeic or epigeic).
8. To analyse the collected data the Shannon diversity index and the Shannon equability can be calculated. This can be done after collecting all the data.
    - **Note: This calculation can be challenging. An explanation and example of the calculation can be found in Annex I**

References

Sandor, V., Vidican, R., Sandor, M., Stoian, V., & Sfechis, S. (2015). Tested Methods for Extracting Earthworms from Soil. Bulletin USAMV series Agriculture, 72, 1.

2. Beetles: pitfall-trap method

Measurement plan

Animal diversity is best to monitor every year because they respond to minor changes in the system. Perform the measurements for beetle biodiversity between May and August. Use the systematic sampling design to measure beetles.

Precautions

Start the measurement early in the morning. Then wait the whole day and harvest the beetles/insects at the end of the day. Make sure to always start and end this method at the same time.

Needed equipment

Beetle identification guide
Cup with a diameter of 15 cm
Shovel
Unscented detergent
Some wood material to make a shelter (Figure 11)
Binocular for identification

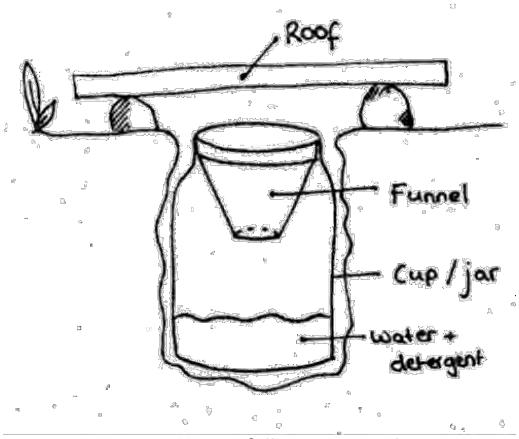


Figure 11. Pitfall-trap example

Performing the measurement

1. Dig a hole in which the cup can be placed
2. Place the cup in soil. Make sure that the edge of the cup is equal to the soil surface.
3. Fill the cup with a layer of water
    - This will prevent the beetles to climb out of the cup
4. Add a drop of unscented detergent to the water to break the water surface tension
5. Place a small roof over the cup to prevent the cup from flooding as a result of rain
6. At the end of the day take the cup out of the soil and collect all the beetles/insects
7. Use binoculars to identify different beetles on species level
8. Write down the species and the amount found in total in the worksheet.
    - Use the recommended guides to determine the species
9. To analyse the collected data the Shannon diversity index and the Shannon equability can be calculated. This can be done after collecting all the data.
    - *Note: This calculation can be challenging. An explanation and example of the calculation can be found in Annex I*

Recommended guides

Vorst, O. F. J. (2010). Catalogus van de Nederlandse kevers: catalogue of thSampling designsthe Netherlands. Nederlandse Entomologische Vereniging.

Huijbregts, H. (2003). Beschermde kevers in Nederland (coleoptera). Nederlandse faunistische mededelingen, 19(1-34).

Felix, R., Muilwijk, J., Dekoninck, W., & Desender, K. (2010). Nederlandse namen voor de loopkevers van België en Nederland. Entomologische berichten, 70, 128-139.3.

3. Pollinator species (bees): bucket trap method

Measurement plan

Animal diversity is best to monitor every year because they respond to minor changes in the system. Pollinator species are best to monitor once a month from the end of April - September, with exact dates depending on the temperature and weather conditions.

Precautions

Place the buckets in the morning (around 8-10 am) prior to maximum pollinator activity and collect the species just before nightfall (between 4-6 pm).

Needed equipment

Bee or pollinator identification guide
Yellow buckets of 12L
Unscented detergent
70 % ethanol
Data collection form
Binocular for identification

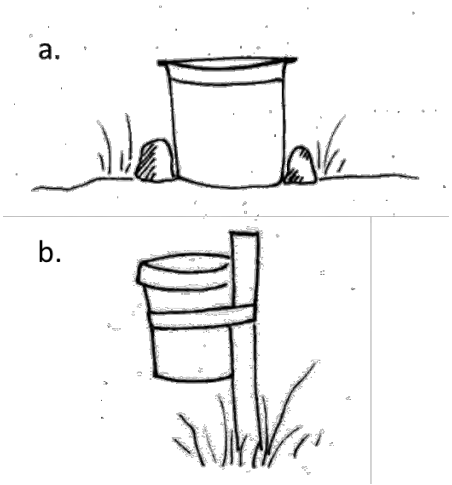


Figure 12. Bucket trap method: a. on the ground, b. on a pole.

Performing the measurement

1. Place the yellow bucket at the subplots as indicated in Figure 9 (Sampling species biodiversity).
    - The buckets can be placed on the ground or on a pole (Figure 12)
    - Place the bucket near a flowering tree or shrub
    - When placed on the ground: place some stones or sandbags next to the bucket to prevent it from falling over by the wind.
2. Fill the bucket with sufficient water
3. Add a few drops of unscented detergent to break the surface tension
4. Collect the species by the end of the day as indicated in the measurement plan
    - The insects can be removed from the buckets and placed in containers with 70% ethanol the preserve them.
5. Count and determine the taxonomic orders of the different insects species using binoculars
6. Use the recommended guides to determine the species in your system
7. Write down all the information on the table of data collection form
8. To analyse the collected data the Shannon diversity index and the Shannon equability can be calculated. This can be done after collecting all the data.
    - **Note: This calculation can be challenging. An explanation and example of the calculation can be found in Annex I.**

Pollinator species are best to monitor once a month from the end of April – September.
Exact dates depend on the local temperature and weather conditions.
Monitoring is best between 11:00-16:00 on days with a temperature of 13°C or higher.
Don't monitor with rainfall or strong winds, take note of the wind speed using the Beaufort scale (Table 5).
Don't monitor with high cloudiness unless there is a temperature higher than 17°C
Always go for the local weather conditions and don't trust on the weather forecast.

Table 5. Beaufort scale (for wind speed) to be indicated on data collection form

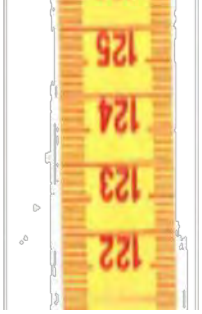
Code	MPH (miles/hour)	Description	Specification on land
0	0-1	Calm	Smoke rises vertically
1	1-3	Light air	Slight smoke drift
2	4-7	Light breeze	Wind felt on face & leaves rustle
3	8-12	Gentle breeze	Leaves and twigs in constant motion
4	13-18	Moderate breeze	Small branches move
5	19-14	Fresh breeze	Small trees sway
6	25-31	Strong breeze	Large branches move & trees sway

Recommended guides

Bos, F. (2002). Hommels in beeld. Utrecht: KNNV Uitgeverij. Breugel, P van (2014). Gasten van bijenhotels. Leiden: EIS Kenniscentrum Insecten en andere ongewervelden & NaturaliSampling designsenter.

Laget, D. (2005). Solitaire bijen determineren. Gent: Universiteit Gent, Faculteit Wetenschappen, vakgroep Biochemie, Fysiologie en Microbiologie.

Peeters, T.M.J. (2012). De Nederlandse bijen (Hymeoptera: Apidae S.L.). Leiden: Nationaal Natuurhistorisch Museum Naturalis, Leiden: European Invertebrate Survey – Nederland.



Measuring production with the crop count method

Measurement plan

This measurement plan may be carried out once per season for the entire area of EVG. A grid of 10x10m may be applied to the Food Forest and identify it with a proper ID. This zonation can be applicable for the long term, so the establishment of the grid is just needed at early stages. In each zone, the amount of edible plants per species should be counted, considering three vegetation layers, namely: tree layer, shrub layer and ground cover layer.

Needed equipment

Measuring tape

Crop count worksheet

Performing the measurement

1. Assign and ID to each grid zone that is being analysed, and note the dimensions if modified (m2, e.g. 10x10). It is convenient to do it per each simplified layer of the food forest, thus, each zone will consist of three layers.
2. Count the number of plants per type of crop and record it on the crop count worksheet. If counting is too exhaustive (e.g. herb species), a rough estimation might be enough.

Measuring production with the harvest count method

Measurement plan

This measurement plan may be carried out whenever there is a harvesting round. The same zonation as for crop count is applicable, so every time there is a harvest the harvesting zone should be noted down. The harvest is weighted with a basic weighing scale (Figure 13), and the amount of plants from which the product was harvested should be counted.

Needed equipment

Basket

Weighing scale

Harvest count worksheet

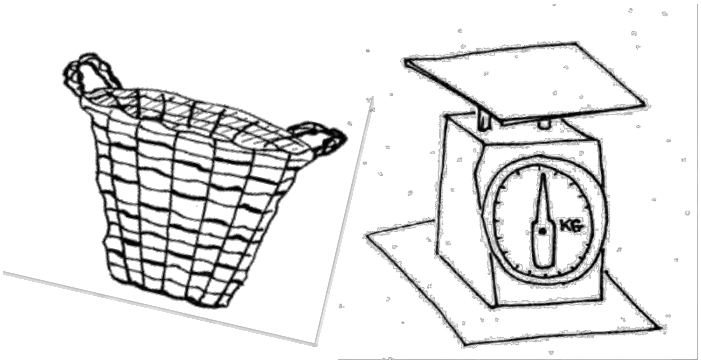


Figure 13. Needed equipment for the harvest count method

Performing the measurement

1. Weigh the amount of kg harvested per crop when there is a harvest round and also note from how many plants this harvest came from
2. Enter these values in the harvest count worksheet.
3. Average weights can be used to estimate the total weight of extensive harvests, by grouping the harvest in bunches and multiplying the average weight by the number of bunches.
4. Record if the harvest is a donation, and if so to which entity.

Worksheets

Worksheet aboveground Carbon sequestration

Name observer(s): .....

.....

Date: ..... / ..... / Start time: End time:

Fill in the data to perform the calculations. After the calculations, fill in the Carbon content.

Tree species	Tree nr.	Tree circumference (cm)	Tree height (cm)	Carbon content (g C)
Total aboveground C content				

Worksheet belowground Carbon sequestration

Name observer(s): ....

....

Date: ...... / ...... /   Start time: End time:

Fill in the table for every soil sample. SW = sample weight.

Sample location	Sample ID	Crucible ID	Crucible weight	Initial sample weight	SW_{105}	SW_{550}	SOM	SOC
						Average:		

Worksheet Bulk Density

Name observer: .....

.....

Date: ..... / ..... / plot no.: Location:

Start time:

End time:

Weather conditions:	Description plot/location:
	Other comments:

Sample number	Can weight (g)	Fresh sample weight with can (g)	Fresh sample weight without can (g)	Soil volume (cm^3)	Dry sample weight with can (g)	Dry sample weight without can (g)	Bulk density ($g\ cm^{-3}$)

Worksheet infiltration rate

Name observer: .....

.....

Date: …… / …… / plot no.: Location:

Weather (temperature):

Plot nr	Subplot number	First inch (2.5 cm) water		Infiltration rate (cm/min)	Second inch (2.5 cm) water		Infiltration rate (cm/min)	Remarks
		Start time	End time		Start time	End time		
1	1							
	2							
	3							
2	1							
	2							
	3							
3								

Worksheet pH

Name observer: .....

.....

Date: …… / …… / plot no.: Location:

Start time: Weather (temperature):

End time:

Plot number	Subplot number	Readings for pH	Remarks
1	1		
	2		
	3		
2	1		
	2		
	3		
3			

Worksheet Vegetation biodiversity (Quadrat method)

Name observer(s): .....

.....

Date: …… / …… / plot no.: Location:

Start time:

End time:

Weather conditions:	Description plot/location:
	Other comments:

For tree (plot size 10x10 m)

Scientific name	Dutch name	Number of individuals

For shrub (plot size 5x5 m)

Scientific name	Local name	Coverage scale

For ground vegetation (1x1)

Scientific name	Local name	Coverage sacle

Worksheet Earthworm monitoring (excavation and mustard method)

Name observer: .....

.....

Date: ..... / ..... / plot no.: Location:

Start time: Soil excavation undertaken: YES / NO

End time: Mustard method undertaken: YES / NO

Weather conditions:	Description plot/location:
	Other comments:

Species			
Dutch name	Scientific name	Tally	Number (total)

Worksheet Species biodiversity beetle species (pitfall-trap method)

Name observer: .....

.....

Date: ..... / ..... / plot no.: Location:

Start time: Size of pitfall-trap:

End time:

Weather conditions:	Description plot/location:

	Other comments:

Species			
Dutch name	Scientific name	Tally	Number (total)

Worksheet Species biodiversity pollinating species (bucket trap method)

Name observer: .....

.....

Date: ..... / ..... / plot no.: Location:

Start time: Colour of bucket:

End time:

Weather conditions:	Description plot/location:
	Other comments:

Species			
Dutch name	Scientific name	Tally	Number (total)

Worksheet crop count

Crop Count Worksheet	
Food Forest:	EcoVredeGaard
Data collector:	

Date:						
		Zone ID:	Zone ID:	Zone ID:	Zone ID:	Zone ID:
Crop name	FF layer	# of Plants	# of Plants	# of Plants	# of Plants	# of Plants

Worksheet Harvest Count

Harvest Count Worksheet						
Food Forest:	EcoVredeGaard					
Data collector:						
		Date:	Date:	Date:	Date:	Date:
		Zone ID:	Zone ID:	Zone ID:	Zone ID:	Zone ID:
Crop name	# of Plants	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)	Weight (kg)

Annex I
Biodiversity index

Calculating the biodiversity index

To indicate the biodiversity level of your system, you may perform the calculations of Shannon-Wiener diversity index and evenness. These indexes are commonly used by ecologist to measure biodiversity in a certain community. The Shannon-Wiener index shows how diverse the community is, by considering the number of species and abundance. The evenness index indicates how common the distribution of the species in the system is, in other words, if there any dominating species in the system.

Shannon-Wiener diversity index ranging from 0 to ∞, but it rarely exceeds 4. The evenness index ranges from 0 – 1 and reaches 1 when all species have the same number of individuals in the plot.

You need three types of data to perform the calculation:

- The total number of species (S)
- The number of individuals of each species (n)
- The total number of individuals organisms (N)

The Shannon-wiener diversity index and evenness can be calculated with the following equitation:

Shannon-wiener index

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

(H) : The Shannon diversity index

(p_i) : The proportion of species (number of individual of species *i* divided by total number of individual; n/N)

Evenness index

$$E_H = H / H_{max} = H / \ln S$$

(E_H) : Shannon's equitability (evenness)

(H) : Shannon diversity index

H_{max} : ln*S*

S : Total number of species

If you have to calculate the biodiversity index from coverage then you can directly use the median value of the coverage percentage scale as pi (n/N)

The calculation of diversity index and evenness index can be easily performed in excel

Calculation examples

Example 1. When the species do not really vary in abundance (with N = 33)

Species	Number of individual (n)	p_i (n/N)	ln p_i	p_i x ln p_i
Species 1	5	5/33=0,15	-1,89	-0,28
Species 2	7	7/33=0,21	-1,55	-0,33
Species 3	4	4/33=0,12	-2,11	-0,26
Species 4	8	8/33=0,24	-1,42	-0,34
Species 5	9	9/33=0,27	-1,30	-0,35

S : 5

N : 33

p_i : 5/33 = 0,15

ln p_i : ln 0,15 = -1,89

Σ (sum) pi ln pi = 0,15 x (-1,89) = -1.57

H :- Σ pi ln pi = - (-1.57) = 1.57

EH : H/lnS : 1.57/ln 5 = 0,97

The biodiversity index (H) is 1.57, which not really high (it is only 5 species) but all species are somehow evenly distributed (EH=0.97) meaning there is no dominant species in the system.

Example 2. When one species is more abundant than others (with N = 49)

Species	Number of individual (n)	p_i (n/N)	ln p_i	p_i x ln p_i
Species 1	1	1/49=0,02	-3,89	-0,07
Species 2	6	6/49=0,12	-2,10	-0,25
Species 3	30	30/49=0,61	-0,49	-0,30
Species 4	7	7/49=0,14	-1,94	-0,27
Species 5	2	2/49=0,040	-3,19	-0,13
Species 6	3	3/49=0,061	-2,79	-0,17

S : 6

N : 49

p_i : 6/ 39 = 0,12

Σ (sum) pi ln pi = 0,12 x (-2,10) = -1,22

H : - Σ pi ln pi = - (-1.22) = 1.22

EH : H/lnS = 1.22/ln 6 = 0.68

The biodiversity index (H) is 1.22, which is less than H in example 1 even though it has more species. It happens because the species abundances are not evenly distributed (E=0.68) indicating that one species (species 3) is dominant in the system.

Annex II Earthworms

Earthworms can be clustered in three functional groups: epigeic, endogeic and anecic (Table 1). The pictures are derived from Zanen (2013): 'Herkenningskaart Regenwormen'.

Table 1. Three functional groups of earthworms and the most common species in the Netherlands (bold).

Group	Species (Fraser &Boag 1998)	Specification
Epigeic	*L. castaneus*, ***L. rubellus***, *L. festivus*, *S. mammalis*	Top-soil dwelling species (0-10cm) and feed on the surface litter
Endogeic	***Al. chlorotica***, ***Ap. caliginosa***, *Ap. limicola*, *Ap. rosea*, *O. cyaneum*, *O. tyrtaeum*	Horizontal-burrowing (10-30 cm) species and feed mainly in the rhizosphere and subsoil
Anecic	***L. terrestris***, *Ap. longa*	Deep-burrowing species (>30cm) that create deep vertical burrows in the mineral soil but browse on the soil surface

A. *Lumbricus rubellus* (Epigeic)

B. *Aporrectodea caliginosa* (Endogeic)

C. *Allolobophora chlorotica* (Endogeic)

D. *Lumbricus terrestris* (Anecic)

References

Fraser, P. M., & Boag, B. (1998). The distribution of lumbricid earthworm communities in relation to flatworms: a comparison between New Zealand and Europe. *Pedobiologia*, *42*(5/6), 542-553.

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