

EM Notebook + Sessions

Tags	Data	Notes	Revision
Date	@December 12, 2022		
Notes	Notebook + sessions combined for revision		

General:

Two types of **data**:

1. That which will be analysed (independent and dependent variables)
2. Extra data (**metadata**): date, time, location (grid references or GPS coordinates), weather (temperature, wind speed, humidity, other conditions), aspect, elevation,
...
 - a. Grid references (only applicable to the UK, gives northings and eastings) → each further degree will increase the accuracy of the location:
 - i. The first number gives a 100km by 100km square, then 10km by 10km, then 1km by 1km, ... (as the grid size decreases, the accuracy increases):

- b. GPS measures the distance between the device and 3 satellites (will give a 2D representation; a 3D representation (with elevation) can be obtained from 4 satellites)
 - a. Will give latitude (eastings) and longitude (northings) in degrees

Quality assurance → making sure your data is of the highest possible quality (have your own copy, copy directly from collector, double checking, ...)

Data tables: make them before you collect data

Short data table: useful for making multiple observations of different variables in one area

	Variable 1	Variable 2
Plot 1	X1	Y1
Plot 2	X2	Y2

Long data table: useful for tallying (think PCE practical 2)

Plot:	Observation
Plot 1	X1
Plot 1	Y1
Plot 1	Z1

Error:

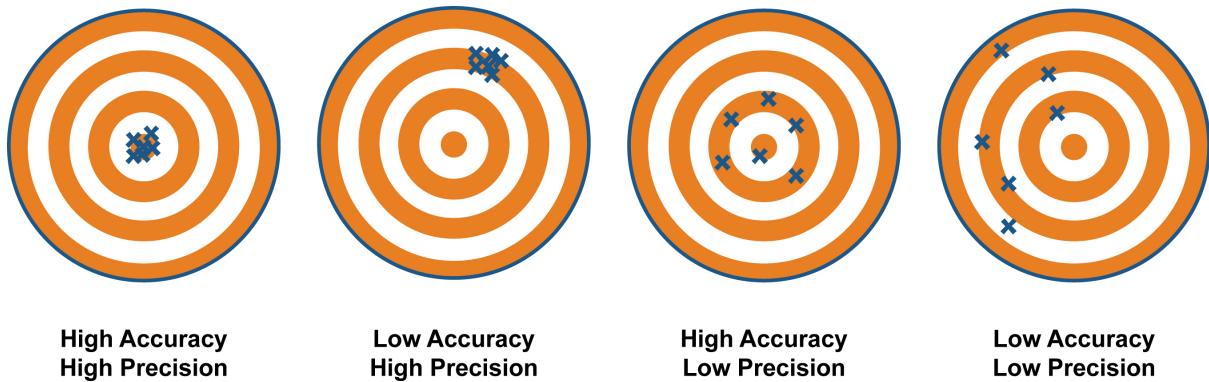
Random error is noise (can be controlled for by taking multiple measurements and calculating their mean) → most often human error

Systematic error is bias (can be controlled for by calibration against a standard reference) → calibrate before measurement to avoid any issues.

Accuracy → how close is the measured value to the actual value (a measure of systematic bias)

Precision → how close are the measured values to each other (a measure of random error)

Resolution → how many significant figures on the reading



Types of sampling plots:

1. Circular

- Position centre pole, use measuring tape to create the plot (place additional pole at your starting point to avoid overlap in measurement)
- Used in forest science, but otherwise not commonly used
- Anything within the circle is measured → you have to decide whether half in/out is included (consistency!!) and how to estimate what half in/out is

Advantages:

- Centre pole can be used for reference (e.g., canopy size)
- Minimised edge effect
- Easier to sample systematically

Disadvantages:

- Time consuming

2. Square:

- Random plot selection → start at any one corner, then use a compass to find right angle (easy if you use cardinal directions). Then measure the side length and place another pole → continue until you have a square
 - You can double check yourself with Pythagoras's theorem
- Can be used for subsampling and to create grids

- Easier to mark and fence off
- Easier to judge in/out
- Difficult to set up
- Difficult to sample systematically

Minimum 7 plots (replicates) to allow for statistical analysis.

Near-ground remote sensing:

Two types of sensors:

1. **Passive sensors** → use reflected light or thermal radiation emitted by objects to construct an image
 - a. Thermal cameras measure thermal infrared radiation that's emitted by an object
 - i. Higher temperatures = higher frequencies = lower wavelengths
 - ii. Used for tracking animal movement(s) and drought-stress mapping
 - b. Multispectral cameras contain 9 sensors that are all sensitive to a distinct part of the infrared spectrum
 - i. Results in a finer spatial scale
 - ii. Used in early onset stress signalling in trees
 - c. Photogrammetry uses images taken from various angles to construct a 3D point cloud of an area
2. **Active sensors** → send out energy and analyse what comes back (e.g. lasers)
 - a. LIDAR sends out streams of lasers and detects the speed of return (from the speed of light) to construct a 3D image with distances and locations
 - i. Shoots 160,000 - 180,000 pulses/second
 - ii. Not dependent on an external energy source
 - iii. Can be flown at night (under cloud cover)
 - b. Radars use electromagnetic radiation
 - i. No interaction with clouds → can be used for airplanes etc

Why is remote sensing useful?

- Canopy structure and LAI
- Biomass measurements → tree heights can be more accurately calculated from LIDAR images (as opposed to using clinometers)
- Ecosystem mapping
 - Modelling species diversity through habitat structure - species diversity (HS - SD) relationships
 - Habitat heterogeneity as a driver of animal diversity (e.g., woodland foliage profiles affect songbird diversity)
- Topographic mapping (e.g., polar ice sheets, wetlands, under-forest mapping for hydrologic modelling, ...)

Hazards for the drone at Firbush:

- Trees (height or movement due to wind)
- Buildings
- People
- Low-flying jets (overlap of allowed areas of flight)
- Meteorology (wind, rain, thunderstorms, ice, ...)

Soil:

Soils are a medium for plant growth (nutrient cycling, water storage) and play an important role in C storage (especially in permafrost and peat). They are also the site of decomposition (and a habitat for a variety of micro and macroorganisms).

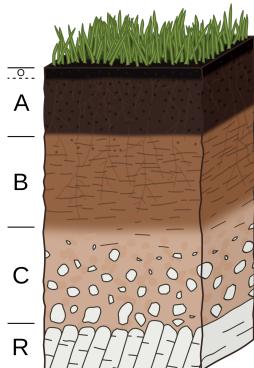
Soil is influenced by **CLORPT**

- Climate (and weather)
- Organisms (trampling, burrowing, ...)
- Relief (slope)
- Parent material
- Time (soil formation takes thousands of years)

- Soil formation usually occurs through chemical or physical weathering (e.g., wind erosion, water freezing (and expanding) in pores)

Soil particles are \leq 2mm in size and include **clay, sand, and silt** (the proportion of these particles determines soil texture and affects soil porosity)

Soil profiles:



O horizon: organic matter

A horizon: mineral topsoil

B horizon: subsoil

C horizon: parent material

R horizon: bedrock (not always parent material → e.g., the retreat of glaciers moved and deposited some rock in new areas)

Soil properties:

Chemical:

- pH
- Carbon
- Nitrogen + other nutrients

Physical:

- Bulk density
- Water content
- Porosity
- Texture

Biological:

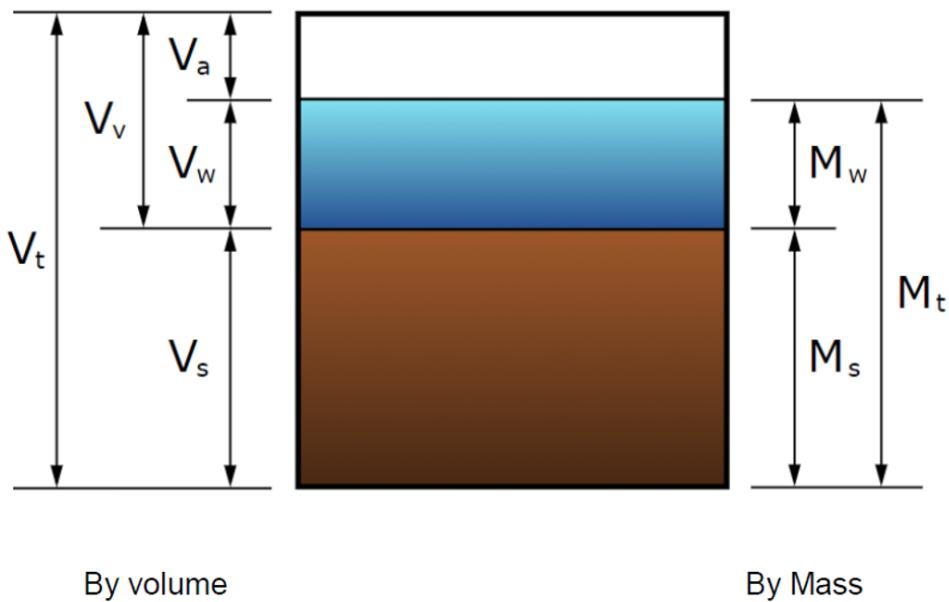
- Microbial communities

Soil moisture

Describes the water content of the vadose (non-saturated) part of the soil.

- Soil water content → how much water is stored in the soil
- Very variable with depth, soil porosity, and vegetation
- Can be measured in two ways:

1. **Gravimetric** soil moisture compares the mass of wet vs dry soil (dried at 105C for 24 hours; in g/g)
 - a. Is used to calibrate volumetric measurements (from gravimetric to volumetric measurements by bulk density)
 - b. Does not account for any of the air within the soil
 - c. Time-consuming and destructive (cannot repeat measurements)
2. **Volumetric** soil moisture compares the volume of water and soil (in m^3/m^3 ; reported in %) with probes that measure conductivity

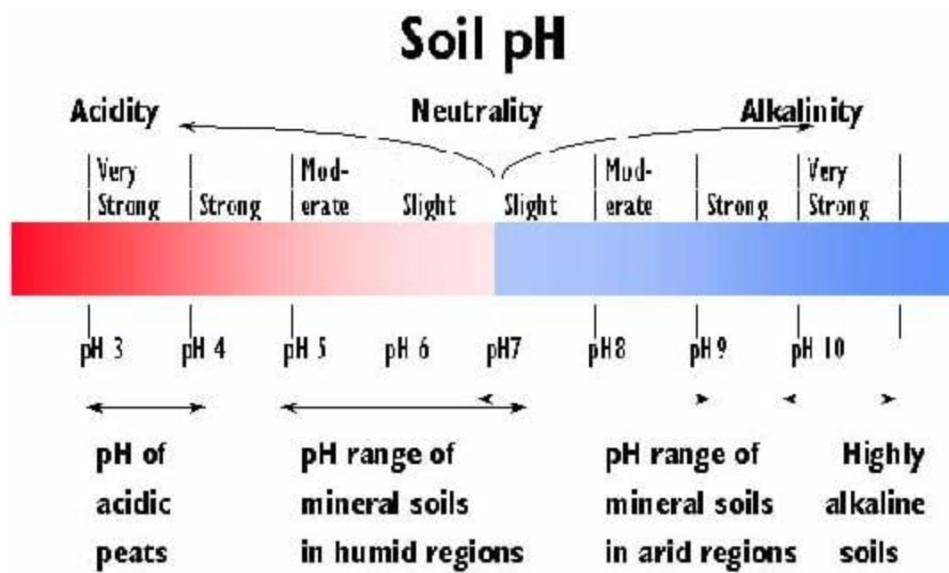


Soil pH

Is a master variable (impacts nutrient availability, cycling, and solubility) →
 $-\log[H^+]$

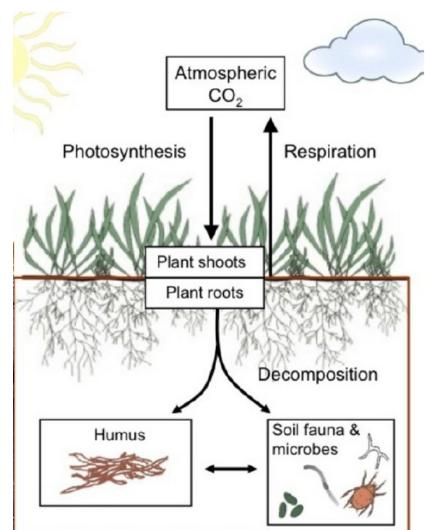
- Measures the soil alkalinity/acidity
- Controlled by parent material, temperature and rainfall (through leaching intensity and mineral weathering), soil texture, mineral (nutrient) content → generally CLORPT
- Affects the leaching of nutrients from soil and the nutrient availability to plants
- To measure soil pH:

- Calibrate the pH meter against two buffer solutions (pH 4 and 7)
- 1:2 soil:water ratio in a beaker (50ml water to 25 g soil)
- Shake for 20 minutes
- Immerse the pH meter electrodes into the solution and take a reading
 - Rinse the electrodes with distilled water between/after readings
- Typical soil pH values fall between **pH 3 - pH 10**



Soil carbon → The carbon balance within the soil is controlled by carbon inputs (photosynthesis) and carbon losses (respiration).

- Highly variable across the land surface
 - Photosynthesis + decomposition rates are higher in higher latitudes (think peat)
 - Earth's land surface is dominated by human land use
 - Huge C stores underpin plant production and water supply



- The soil C in the world is increasingly perturbed and degraded

Sequestration → the amount of carbon input into the soil is higher than the amount lost

Soil texture and bulk density:

- Bulk density varies with texture
- A very dense, compacted soil is difficult for plant roots to enter

Core volume (in cm³): $V = \pi r^2 h$

Where V is the volume (in cm³), r is the radius (cm), and h is the cylinder height (cm)

Dry mass of soil (in g): $M_d = M_w * \frac{S_d}{S_w}$

Where M_d is the core dry mass (g), M_w is the core wet mass (g), S_d is the sample dry mass (g), and S_w is the sample wet mass (g)

1 g H₂O occupies 1 cm³

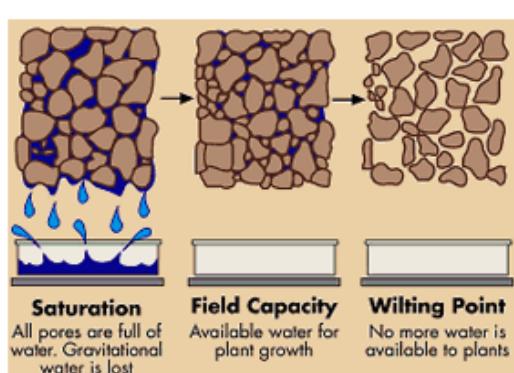
Volumetric soil moisture (in m³/m³): $\theta = \frac{M_w - M_d}{V}$

Where θ is the volumetric soil moisture

Bulk density of soil (in g/cm³): $B = \frac{M_d}{V}$

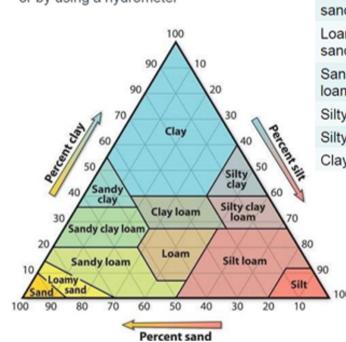
Where B is the bulk density

Soil carbon content (in g/cm³): $C_{soildensity} = B(\%C)$; %C = 2%



Soil texture triangle

Texture can be determined by hand texturing or by using a hydrometer



Textural class	Bulk density (g cm ⁻³)	Available water capacity
Coarse sand	1.65	0.25-0.75
Loamy sand	1.6	1.10-1.20
Sandy loam	1.55	1.25-2.00
Silty loam	1.5	2.00-2.50
Silty clay	1.45	1.50-1.70
Clay	1.35	1.20-1.50

Bulk density considers both the solids and the pore space

Soil measurement at Firbush:

At each side point (N, S, W, E), measure:

- Soil temperature (mercury thermometer)
- Soil depth (soil depth probe)
- Soil moisture (soil moisture probe)
- GPS location

At the centre point, determine the horizons of the soil and volume:

- The core (of known diameter and height) is hammered into the soil surface
- Subtract the height of the soil from it for h, then remove the soil into a tray and weigh it (wet mass)
- Save the sample to be oven dried at Kings

Microclimate

A measurement on a small spatial and temporal scale (the definition varies on the size/scale of the study - e.g., within a forest or within a tree). Change can be monitored through monitoring microclimates

Microclimatic variables:

- Temperature (chemical reaction rates, concentration values, metabolism)
- Humidity and precipitation (water content, VPD)
 - Ambient vapour pressure (AVP) → air water content, in kPa
 - Saturation vapour pressure (SVP) → maximum air water content, in kPa
 - $\frac{AVP}{SVP} = \text{relative humidity (0 - 100\%)}$
 - The dew point is at $SVP = AVP$
 - Warmer air holds more water (with global warming, the atmosphere will hold more water)

- Wind and pressure
 - Wind speed and direction (northerly → from N to S)
 - Wind speed is measured with an anemometer → gives a point-measurement (one point in space and time). To increase the accuracy,
 - Increase replicates or
 - Use data-loggers (with sensor, processor, and memory storage → these may have to be charged and replaced (depending on study time frame), so consider that as well) to give a time-series of data (useful for monitoring seasonal changes)
 - Affects seed/pollen dispersal and pollution
- Light and radiation (photosynthesis rates)
 - The intensity, measured on the electromagnetic (EM) spectrum → e.g., the photosynthetically active radiation (PAR) is between 400 and 700 nm

Dataloggers are electronic devices that record the outputs of the attached sensors over time (can be used for soil temperature, humidity, wind speed, precipitation etc) → they produce large data sets (recordings every minute with 30-minute averages also recorded)

The microclimate at Firbush:

- Less temperature variation (due to the high specific heat capacity of water)
- Forest and vegetation cover of the area (evapotranspiration rates between different vegetation types and between vegetation and water → the shading by the vegetation (and general aspect) will affect the soil temperature as well)
- The changes in relief (coupled with vegetation) will change the air circulation patterns, creating other, smaller microclimates
- The topography of the area (temperature and wind speed change with altitude)

Aquatic systems:

Stream flow and discharge:

River flow data are used for many purposes, including assessment of extreme hydrological events (floods and low flows), catchment management, and assessment of water resources for drinking water supply, irrigation and ecological/environmental assessments and management, etc.

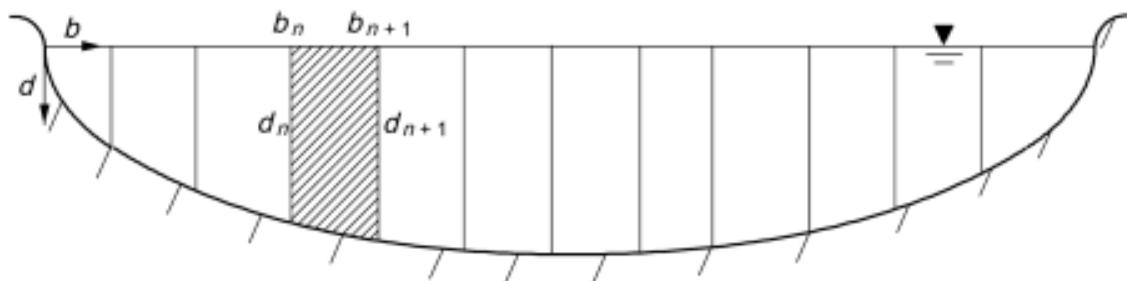
Streams with different hydrological characteristics will support different species or life stages of the same species both within and around the stream (e.g., fish tend to congregate in areas with high dissolved oxygen (DO) content). Likewise, the ecology of an area will influence the hydrology of a stream.

Flow velocity (V ; m/s) is the actual speed of water in the stream whereas **stream discharge** (D ; m^3/s or l/s) is the volume of flow passing a point over a given time interval. Usually flow velocity is given in metres per second ($m\ s^{-1}$) and discharge in cubic metres per second ($m^3\ s^{-1}$) or litres per second ($l\ s^{-1}$). The two measurements are related:

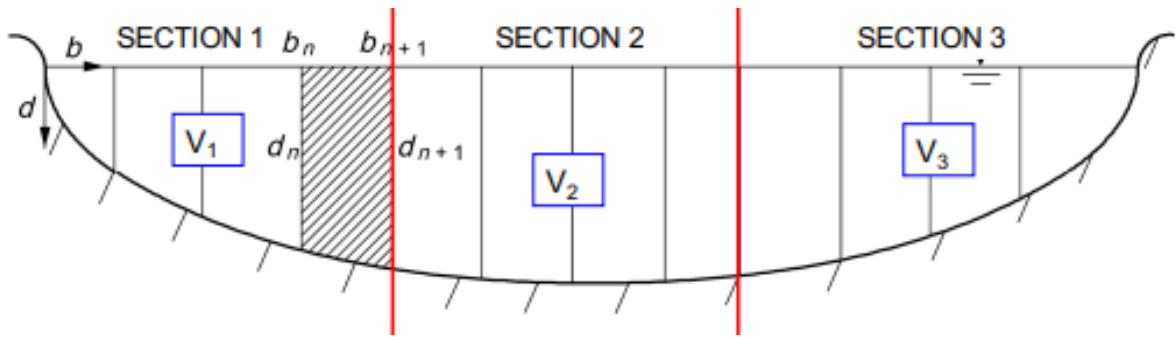
$$D = V A \text{ where } D \text{ is the discharge rate } (m^3/s), V \text{ is the velocity } (m/s), \text{ and } A \text{ is the area } (m^2)$$

There exist a variety of techniques to measure discharge, area, and velocity and the exact method chosen depends on resources of time and money, the nature of the river channel, and the purpose for which the discharge data are required. Here we employ the British Standard Method:

- Where water depth and velocity are measured at all verticals across the profile (VA calculated for each subsection and a mean calculated for the river)
- There should be ≥ 22 verticals for a channel that is >5 m wide.



- The same method can be simplified if working under time constraints (lower number of verticals and velocity only measured at the middle of each section)



Area (A):

Measure the width of the river and find the centre point, then find two (or more) centre points of each half (1/4 way from each side).

Area is calculated assuming each section is a trapezoid: $A = \left(\frac{D_1+D_2}{2} + \frac{D_2+D_3}{2}\right)x$
where x is the distance between D_1D_2 and/or D_2D_3

$$A = \left(\frac{D_1+D_2}{2} + \frac{D_2+D_3}{2}\right)x = \left(\frac{21+36}{2} + \frac{36+21}{2}\right)0.75 = 4275 \text{ cm}^2 = \mathbf{0.4275 m}^2$$

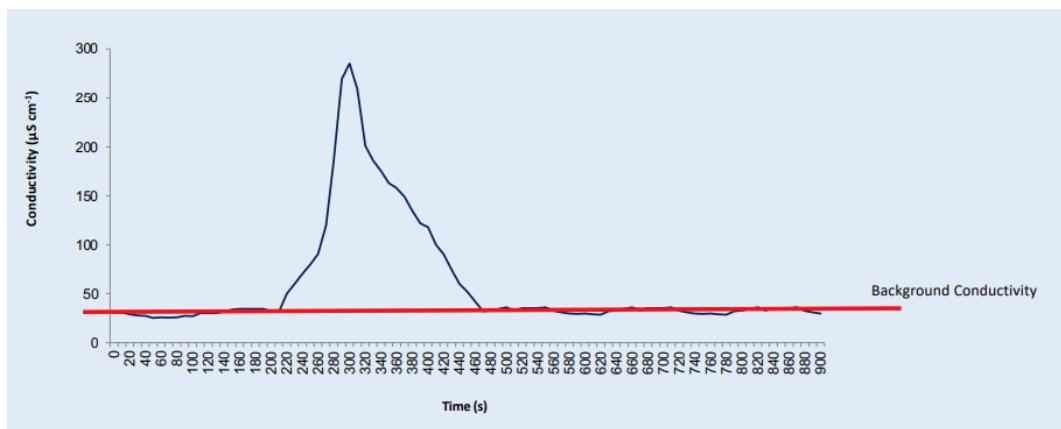
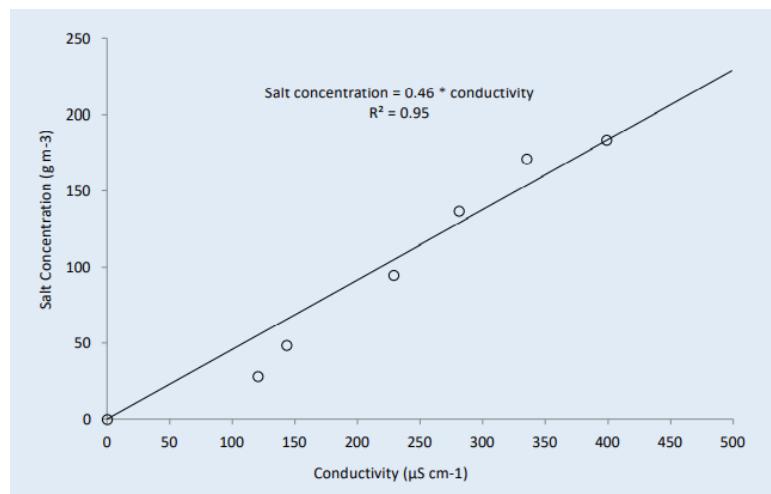
Velocity (V) can be measured using two methods:

1. Flowmeter:

- Either mechanic or electromagnetic (more reliable)
 - The electromagnetic flowmeter measured the electromotive force (EMF) that results from a conductor (water) moving through the field
- Place the meter 40% of the depth (from the bottom; so that the measurement is unaffected by wind or river channel topography) into the river at any one point (X_1, D_2, X_3) and read the numbers off the reader
 - The meter provides the mean flow (m/s) with its standard deviation: mean flow at D_2 : **0.021 m/s** and SD = 0.006 m/s
 - We didn't measure the velocity at X_1 and X_3 because the water created eddies and the velocity was negative (clearly unrealistic):

2. Dilution gauging:

- Using a conservative tracer (one that will not stay in the water or bond to anything in the environment, e.g., salt)
 - Tracers can be salts, dyes, or radioisotopes
 - A conductivity meter is used to measure the change in electric conductance over time (in Siemens, S)
 - The flow is calculated by measuring the dilution of the traces where is thoroughly mixed with the water (with a conductivity meter)
 - Ideal for turbulent streams with steep gradients



The concentration is the area under the curve

$$Area = \int_{t_1}^{t_2} (C_{measured} - C_{background}) dt$$

- To measure velocity using dilution gauging:
 - Dissolve 250g of salt into a bucket of water
 - Take the baseline river conductivity level before tracer is added; 82 S
 - Drop the salt water (salt slug) into the river: the mixing length should be about 20 times the average channel width; 30m upstream here
 - Take conductivity readings every 10s until the level returns to the baseline (this meter corrected for temperature)

The discharge (D) in Firbush stream:

$$D = VA$$

$$D = 0.021 \text{ m/s} * 0.4275 \text{ m}^2 = 0.00898 \text{ m}^3/\text{s} \rightarrow \text{very slow}$$

- The slow speed of the river coupled with the small width of the river allows us to conclude that the discharge rate of this river into Loch Tay is slow

Lake water properties

Loch Tay is a long narrow freshwater loch occupying the excavation of a glacial rock basin. It is ~ 23 km long, typically ~ 1-2 km wide and over 150 m deep in some parts. The catchment area of Loch Tay is 576 km². It is the sixth largest loch in Scotland by area.

Aquatic ecosystems like Loch Tay are composed of biotic communities and abiotic environmental factors (e.g., temperature, pH), which form a self-regulating and self-sustaining unit. It is important that scientists monitor aquatic ecosystems regularly to ensure that acceptable levels of water quality are maintained by measuring dissolved oxygen and transparency (which determine the extent and kinds of organic life in the water body).

Lakes can be classified into **three trophic levels**:

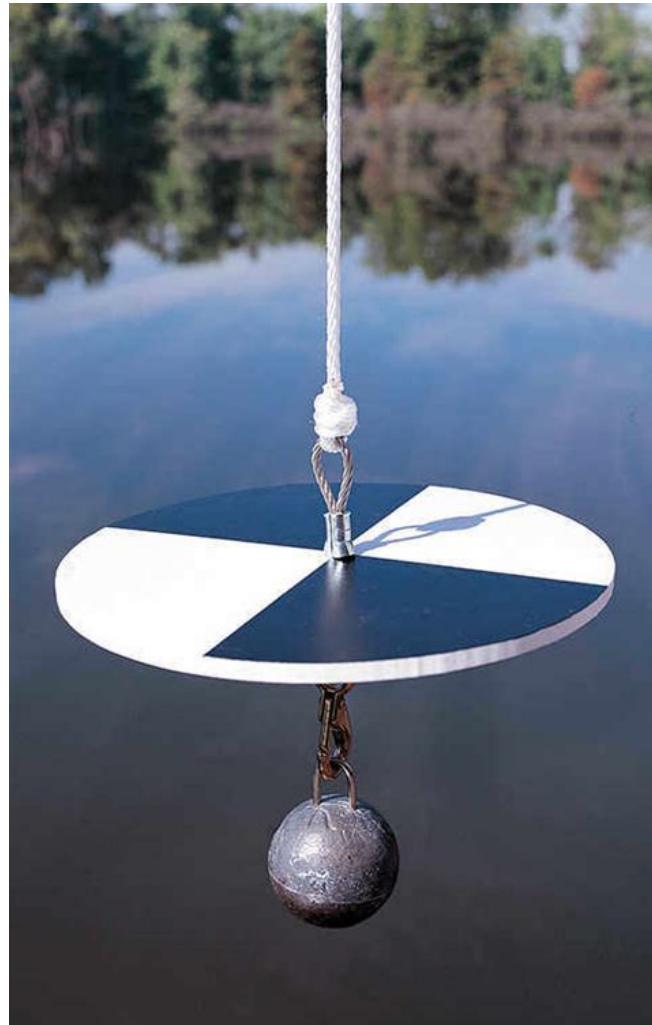
Oligotrophic

Algal blooms occur when the number of algae in a lake or river increase exponentially. May occur when available nutrients increase faster than macrophytes (aquatic plants) can absorb them. If the grazing by zooplankton increases, algae will be reduced.

Water transparency:

Two main measurement strategies:

1. **Secchi disk** (Angelo Secchi, 1865) measures how deep a person can see into the water (a mean of two measurements → lowering the disk and raising it back up)
 - Source of bias:
 - Time of day (best to do it between 10am and 2pm)
 - Viewer eyesight
 - Sunlight (have the Sun to your back → less reflection)
 - Photic → with light; aphotic → without light (below Secchi depth)



- Trophic classifications using Secchi depth
 - Eutrophic (0.5 - ~2m)
 - Mesotrophic (~2 - ~4 m)
 - Oligotrophic (~4 - 8< m)
- Above Secchi depth → photic; below Secchi depth → aphotic



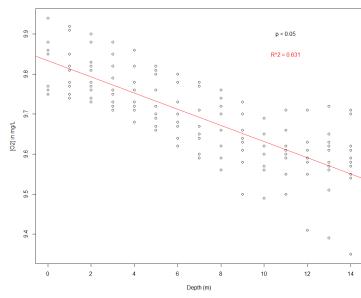
2. Photometer

- More accurate measurement (measures underwater irradiance)

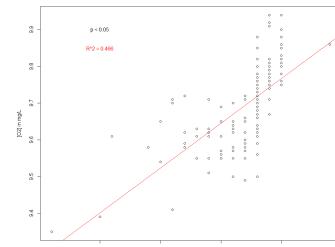
Factors that influence transparency:

- Nutrient levels (e.g., increased inputs from the watershed → leaching from farms)
- Biological activity (e.g., algae, zooplankton, fish, macrophytes)
- Suspended sediment
- Climate
- The natural colour of water (e.g., if influenced by bog waters)
- Turbidity (cloudiness of water or influences from motorboat activity)

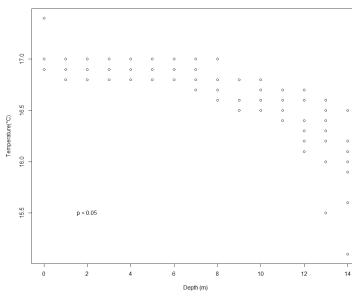
In Firbush: measuring the temperature and dissolved oxygen concentration [DO] (at every meter from the surface until 14m), depth (with a weight on a 30m string), water transparency (with a Secchi disk)



There is a significant relationship between DO and depth

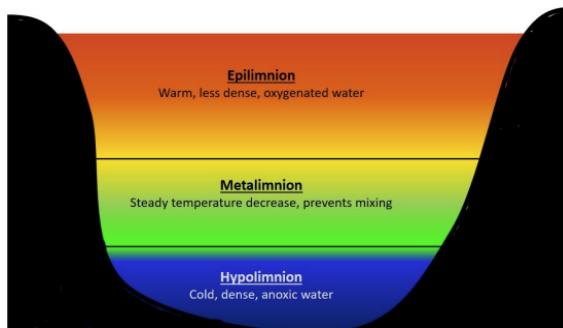


There is a significant relationship between DO and temperature



Relationship between temperature and depth is non-linear but significant

Thermal stratification: a seasonal phenomenon that occurs from late spring to late fall in temperate regions

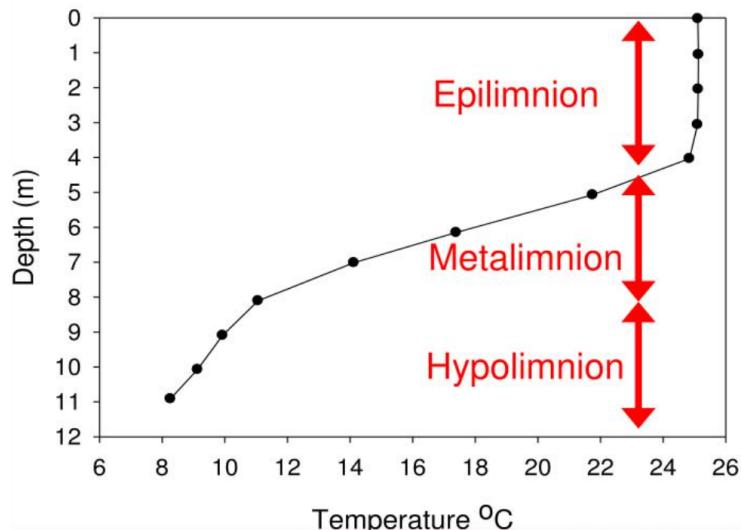


Epilimnion (the upper portion of water; warmer, less dense, oxygenated)

Metalimnion (where the thermocline occurs → steady temperature decrease, prevents mixing)

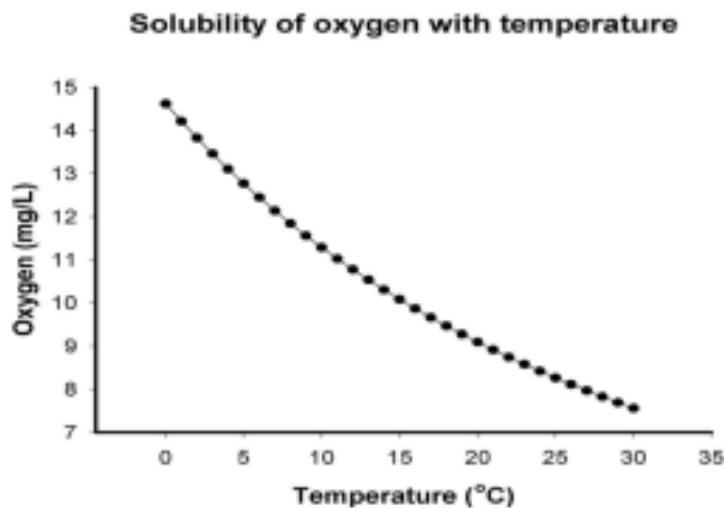
Hypolimnion (the deepest portion of water; colder, denser, anoxic).

Thermocline → a region with the greatest temperature change with depth (>1°C drop per each 1-meter change in depth)



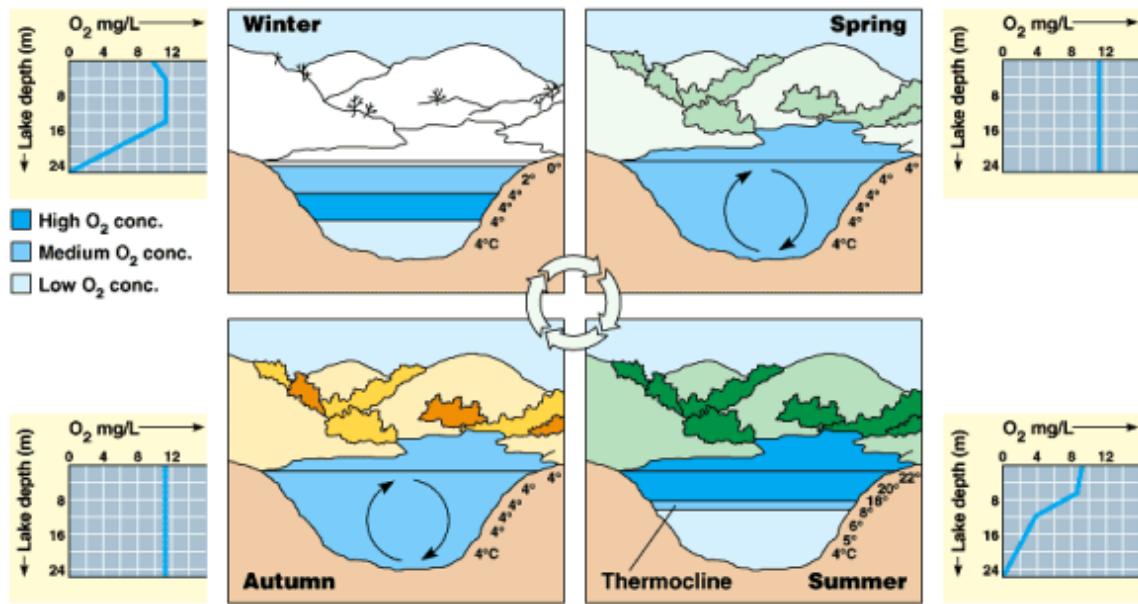
Dissolved oxygen:

Dissolved [O₂] is inversely proportionate to temperature (negative relationship),



Biotic and abiotic processes can sometimes alter this relationship:

- Physical (water movements)
- Biological (photosynthesis, respiration)
- Chemical (dissolved chemicals present)
- Processes that influence the distribution of gasses in aquatic environments
- Seasonal changes:
 - During mixing periods (spring and autumn), [O₂] levels reach equilibrium with the atmosphere
 - As thermal stratification occurs (winter and summer), [O₂] levels decrease until most of the hypolimnion water becomes anoxic



Mixing = circulation of water. Stratification = lack of mixing (development of layers)

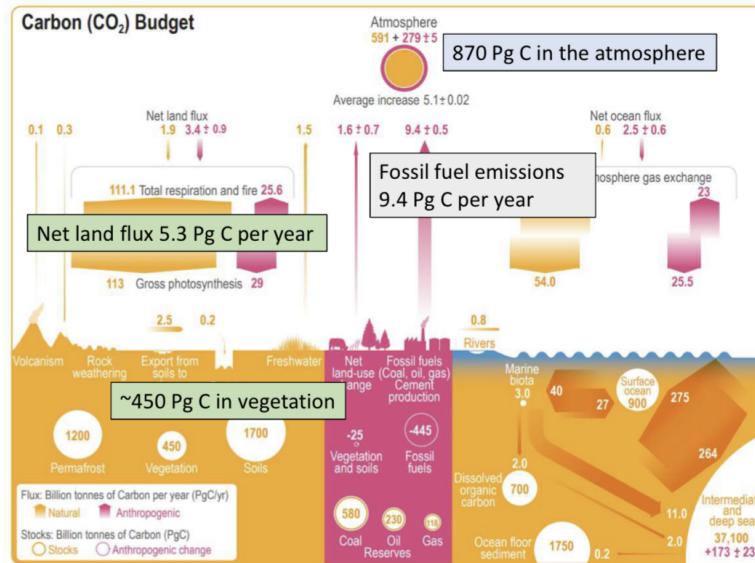
Measurement of O₂ distribution → provides information about the trophic status:

- Mesotrophic or eutrophic lakes have reduced O₂ levels in the hypolimnion → caused by O₂ demand by decaying plankton
- Oligotrophic lakes (low productivity) will show O₂ distribution within a lake will be a function of temperature, usually fairly uniform distributions

Plants and communities:

Above-ground biomass:

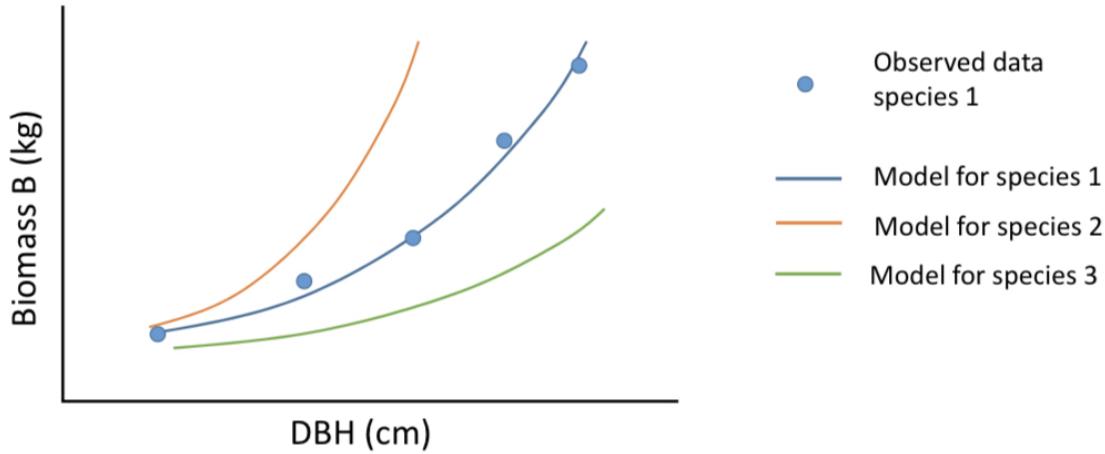
The land carbon sink takes up 50% of all fossil fuel emissions (through vegetation, mostly forests → between 70% and 90% of the land biomass is stored in forests)



Above-ground biomass (ABG) gives insight into soil productivity, ecosystem health, habitat management, carbon stocks/fluxes, ... It is our best estimate (through allometric equations) of C stocks and helps with CO₂ cycle modelling.

Direct measurement of ABG: cut down the tree and weigh it

- Usually required to be able to fit a model to the data (create an allometric equation) → fitting the line creates error:
 - Different species of trees will have different biomass relationships
 - Makes an assumption that the model is applicable for all species
 - The errors can be large (especially at high biomass)
 - Variability (SD) is also large (differences between individual trees of the same species and/or between species)

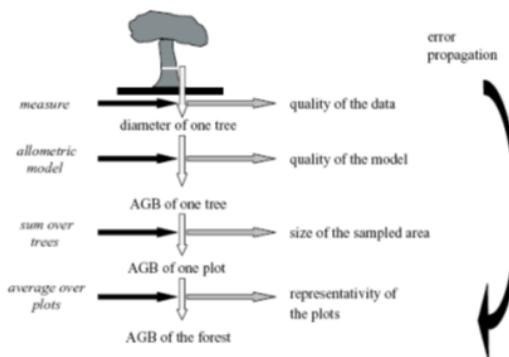


Indirect measurement of AGB: through allometric equations from DBH (at 1.3m) and height (the equations estimate biomass (B) from the stem diameter where biomass is proportionate to the tree diameter)

- This method assumes the tree stem is a cylinder

$$\text{Stem biomass (B, kg)} = \pi R^2 * H * P; \text{ where } R = \text{is the radius (DBH/2; m)}; \\ H \text{ is the height (m), and } P \text{ is the wood density (in kg/m}^3\text{)}$$

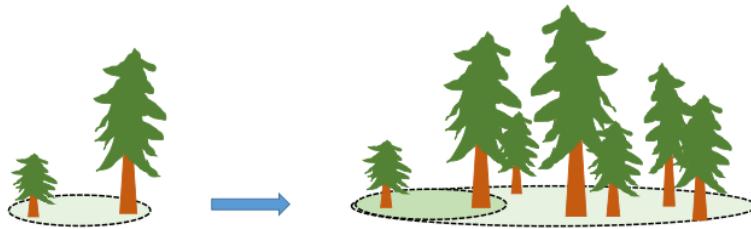
Generally, these are four types of **uncertainty** associated with AGB estimates:



The estimations that lead: $B_{stem} \rightarrow B_{plot} \rightarrow B_{forest}$ propagate error:

1. Error due to tree dimension (equations assume a cylindrical trunk, no forking, no leaning, height errors, etc) and density measurements (how many stems are in your plot (stocking density), how many trees of different sizes are present)
2. Error due to the choice of an allometric equation (different species have different biomass relationships)

3. Sampling uncertainty (in DBH and height measurements, outliers) and
4. Representativeness of small plots across the forest (how representative if your plot of the whole forest - is it too small?)
 - a. Larger plots will likely produce a more normal distribution (larger trees are the greatest source of error → a larger plot can help minimise it)
 - i. However, while a larger plot minimises measurement errors, the equations will still produce bias on their own



DBH can be measured using callipers or DBH tape:

- Assumes a perfectly circular trunk and level ground (accuracy can be added by taking the DBH at two points perpendicular to each other and finding the mean → account for variation in the trunk shape for quality assurance)

Height is measured as the total height regardless of slope (from the ground to the highest point)

1. From trigonometry:
2. With an angle- or distance-based clinometer (always add your eye height!!):
 - The angle-based clinometer gives the tree height as a % of the horizontal distance
 - The distance-based clinometer gives the angle of the elevation
 - Stand either 15 or 20m away (or multiples of 15/20) from the base of the tree
 - You know the distance, the clinometer will give you the angle, then you can calculate the height

Height measurements produce errors:

- Leaning trees (to avoid this, position yourself perpendicular to the direction in which the tree is leaning)
- Being too close to the tree (makes it difficult to see the top of the tree and increases the significance of even small errors)
- Slope (can be accounted for: any slope <5% is negligible; if the slope >5%, then stay on the same contour to negate any slope correction)

The Black Wood of Rannoch:

- 6000–8000-year-old woodland (since the last glaciation)

- In the 1700s, the BWR was subjected to wood removal for timber production → large effect on the entire woodland
- In the 1800s, the Napoleonic wars created a high demand for timber again, increasing extraction
 - To decrease the extraction rate, first attempts at regulation are made:
 - Reduce competition (the native heather competes with tree saplings)
 - Reduce human interference
 - Reduce the effects of razers on natural areas (fenced-off areas)
- The world wars further increased the extraction rate from BWR; canals were even built through it to make it easier to remove the timber)
 - After WW2, the Forestry Commission bought BWR, but by this time the age structure of the forest was very uneven: not enough new trees were growing to maturity → the FC encouraged natural regeneration through fertilisation, removal of grazers, and limiting of timber extraction and forest modification for timber extraction)
- Dominant species now include Scots pine (*Pinus sylvestris*), birch (*Betula pendula*) and rowan (*Sorbus aucuparia*).
 - The understory includes heather (*Calluna vulgaris*), bracken, bryophytes, lichens, blaeberrries, lingonberries, mosses ...

Quantifying the AGB of BWR:

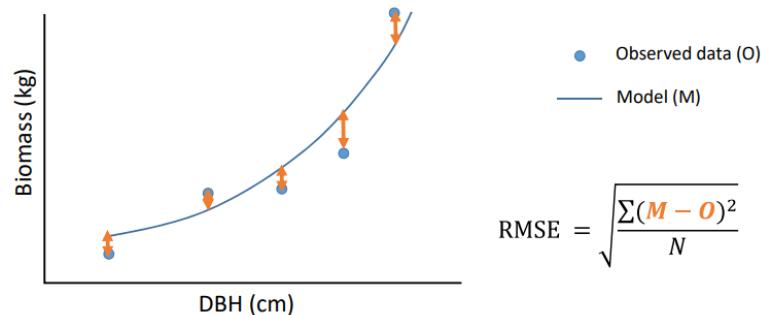
- Each team splits into two (yellow and purple), with one team taking two plots south of the path and the other two plots north of the path
 - 4 circular plots per team, 16 plots total
 - Place a pole in the centre of a circular plot (25.24 m radius: area = 0.2ha)
 - North Plot 1: NN56485 55708
 - North Plot 2: NN56485 55708
 - South Plot 1: N56° 40' 11.8"; N 004° 20' 35.3"
 - Conditions on the day: Drizzle/cloudy, 16C
 - Time: 11.00 - 14.30

- Measurements:
 - Height (with both types of clinometers)
 - DBH (with DBH tape) → only trees with DBH > 5cm
 - Species
 - Status (alive or dead)

The ABG of BWR can be obtained from destructive data and the power function: $B = \alpha D^\beta + \varepsilon$ where B is the biomass, α and β are constants (parameters), D is the DBH, and ε is error

$\text{RMSE} (\text{error}) = \sqrt{\frac{\sum(M-O)^2}{n}}$ where M is the modelled biomass (from equation), O is the observed biomass (from destructive sampling) and n is the sample number.

RMSE determines how good a fit the model is to the data



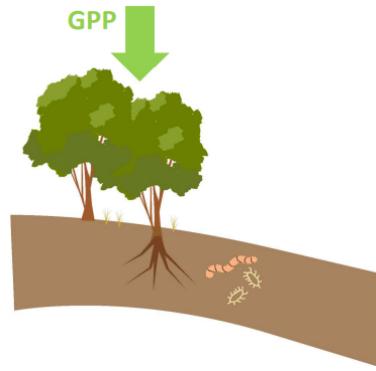
We found the equation from the destructive data: $y = 0.053x^{2.6414}$, $R^2 = 0.9934$ (our model explains 99.34% of the variation within our data) and the RMSE 59.24699 kg (how inaccurate the model is per average tree)

Then you can apply this equation to your estimation data - plug in your DBH for x and find biomass (y); always consider the possible errors (e.g., our plots were 0.2ha and biomass is measured in weight/ha → convert to a full ha before presenting the results)

Primary productivity:

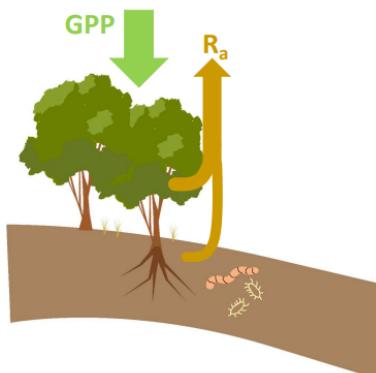
Energy enters terrestrial ecosystems through **GPP** (gross primary productivity) and is stored and

accumulated as carbon (GPP is a flux; in tonnes C/ha/year or Kg/m/year)

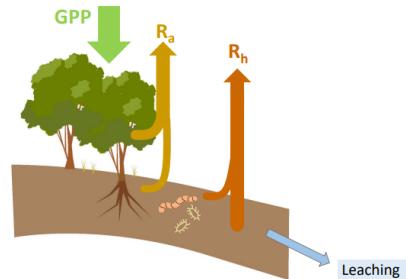


$$NPP = GPP - R_a; \text{ where } R_a \text{ is the autotrophic respiration}$$

NPP is the energy a plant has left after respiring (the amount of carbon fixed into biomass) = leaf production + stem growth + root growth + root exudation, allocation to mycorrhizas, volatile secondary metabolites, ...



$$NEP = GPP - (R_a + R_h + R_L); \text{ where } R_h \text{ is the respiration by heterotrophs and } R_L \text{ is leaching. NEP represents how much carbon accumulates in the ecosystem and is almost impossible to measure directly due to the many variables (e.g., light intensity, temperature, ...) - some of the variables can be manipulated if needed: We can use an infrared gas analyser (EGM 4):}$$



To compare the NEP between different light conditions:

- Place the cone on soil and start measurement, leave for 2 minutes (one measurement every 5 seconds)
- 5 conditions: full light (no cloth), 1 white shade cloth, 2 white shade cloths, 1 light black shade cloth, full dark (1 very dark shade cloth)
 - Repeat twice for each light condition

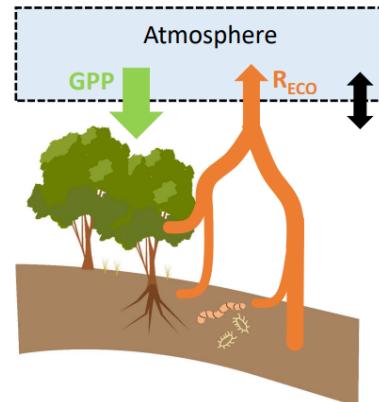
To only measure soil respiration, an EGM4 with a soil respiration chamber can be used → no light inside the chamber (omitting photosynthesis)

It is much easier to measure **NEE** (net ecosystem exchange; in $\mu\text{mol/m}^2/\text{s}$) than NEP:

$$NEE_{atmosphere} = R_{eco} - GPP$$

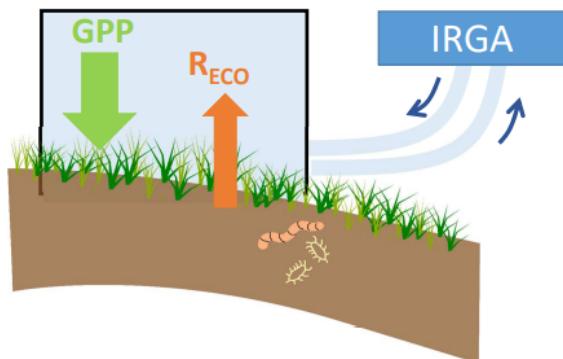
A positive (+) flux = atmosphere gains carbon, ecosystem loses carbon;
A negative (-) flux = atmosphere loses carbon, ecosystem gains carbon

$NEE \sim -NEP$ (roughly equal to -NEP; but NEE only accounts for CO_2 fluctuations)

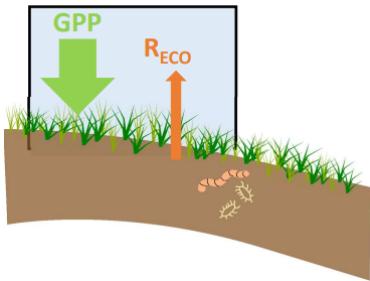


NEE can be measured using an infrared gas analyser (IRGA) that measures CO_2 fluxes of the atmosphere:

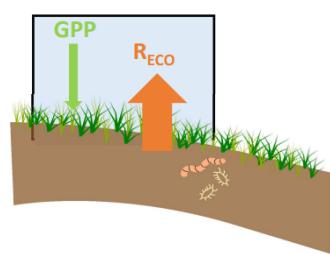
- These chambers work well in short-stature vegetation (e.g., grasses)
- In forests, eddy covariance is used (measured CO_2 concentrations and accounts for the mixing of air - wind speed and turbulence)



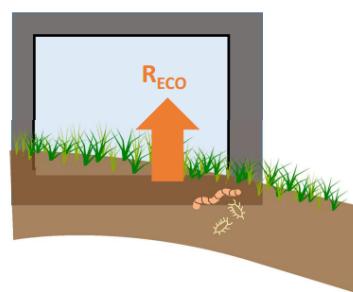
$GPP > R_{eco}$, the atmospheric $[CO_2]$ will decrease (more is taken up than is respired)



$GPP < R_{eco}$, the atmospheric $[CO_2]$ will increase (less is taken up than is respired)



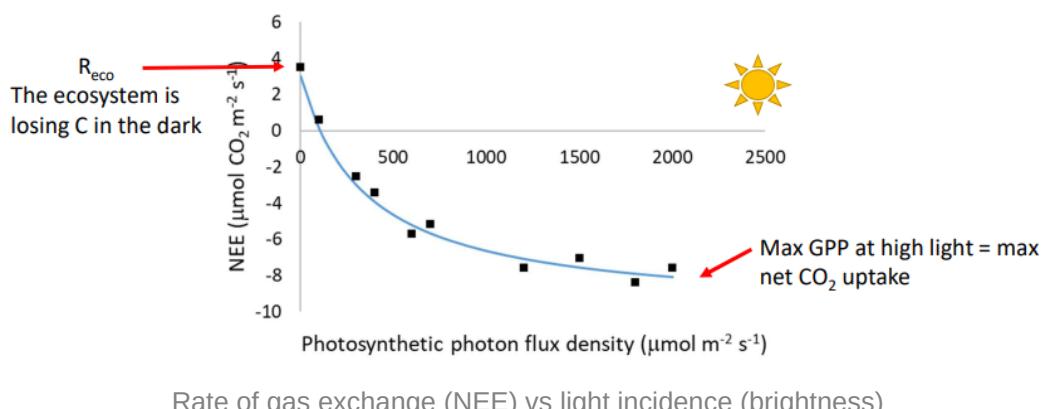
If $GPP = R_{eco}$, then NEE is 0 (the slope of the line = 0)



$$NEE = \frac{\frac{\Delta CO_2}{\Delta t} * p * V}{A}$$

where NEE is the net ecosystem exchange ($\mu\text{mol}/\text{m}^2/\text{s}$), p is the molar density of air ($\sim 41.44 \text{ mol}/\text{m}^3$; varies with temperature and pressure), V is the volume of the chamber (m^3), A is the area of the chamber (m^2) and $\frac{\Delta CO_2}{\Delta t}$ is the slope of the $[CO_2]$ change over time (ppm/s or $\mu\text{mol}/\text{mol}/\text{s}$)

The slope of the NEE graph line gives us the rate of $[CO_2]$ change over time (ppm/s)



Leaf and canopy traits:

Ecosystem processes are determined by the interaction of species traits with their physical environment. Critical trait differences include those related to processes of photosynthesis, respiration, allocation to roots, leaf lifespan, litter quality, among

many others. Groups of species with similar traits are often classified as occupying the same functional type (e.g., C3 grass, evergreen needle leaf trees, planktivorous fish, nitrifying bacteria, or saprophytic fungi).

Understanding the importance of traits, their expression by organisms, and their variation over time is important in managing ecosystems and determining their response to global change. For instance, extinction events, or changes in species richness, will change the trait expression within an ecosystem, with implications for interacting species and ecosystem processes.

A major challenge for ecologists is to identify which traits of organisms have strong effects on ecosystems. The complexity of this challenge is because species interactions govern trait expression.

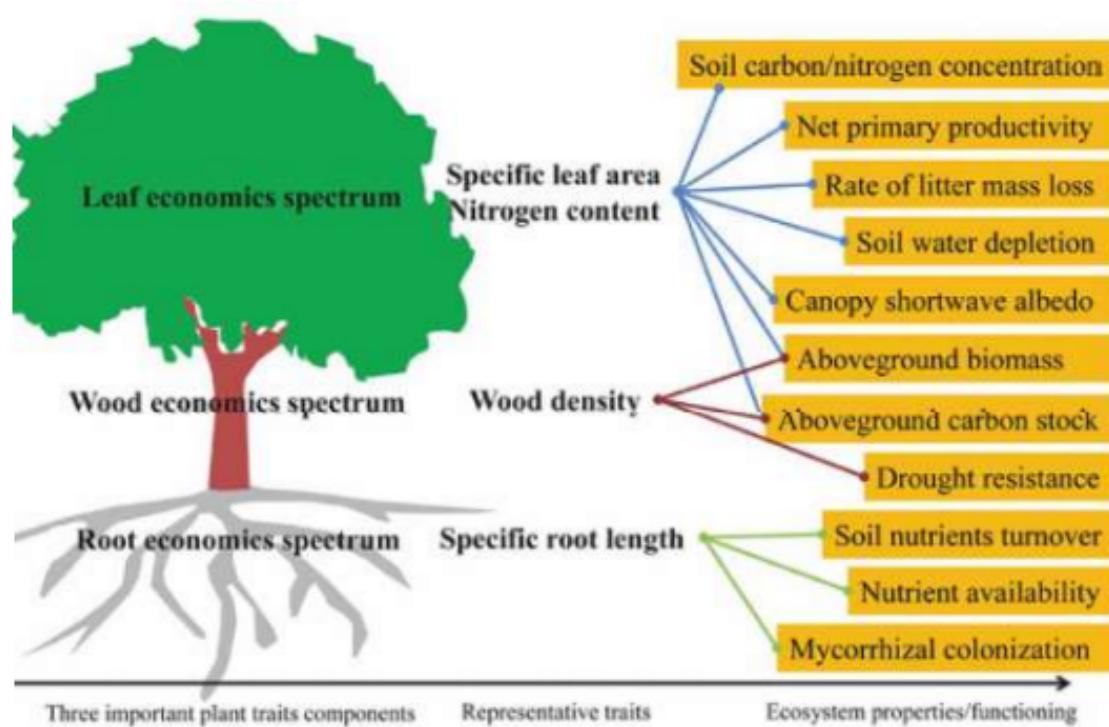
The key traits can be divided into several categories.

1. **Whole plant traits:** growth form, life form, plant height, clonality, spinescence, flammability.
2. **Leaf traits:** specific leaf area (SLA), leaf size, leaf N and P concentration, leaf physical strength, leaf lifespan, leaf phenology, photosynthetic pathway, frost sensitivity

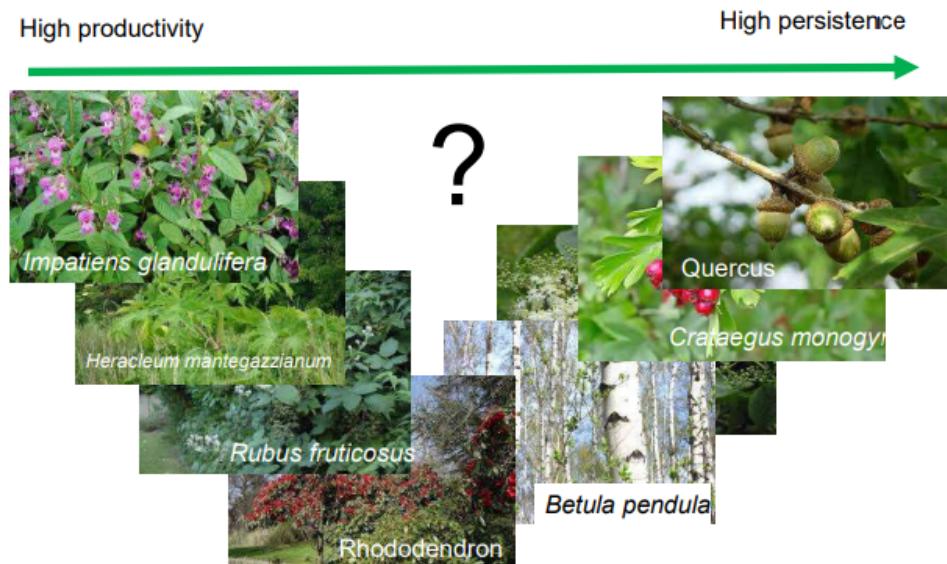
Note that “specific” means “per mass”. So specific leaf area means ‘leaf area per mass’ and would have units cm² g⁻¹.

3. **Stem traits:** stem specific density, twig dry matter content, bark thickness
4. **Belowground traits:** specific root length and fine root diameter, rooting depth, nutrient uptake strategy (N fixer, type of mycorrhizal symbiont, carnivorous etc)
5. **Regenerative traits:** dispersal mode, seed/pollen shape and size, seed mass, resprouting capacity

Traits are often correlated. For instance, SLA is inversely correlated with leaf life span, i.e., thinner leaves (high SLA) are shorter lived, and often of higher litter quality, than thicker leaves.



Plant traits can also be characterised on the **plant economic spectrum** depending on their ecosystem services, productivity, resilience, persistence, etc:



Invasive species tend to have high productivity rates, whereas native species tend to invest more into stabilising life traits (they have different growth and biomass allocation strategies)

Leaf traits include leaf life span, allocation of resources, root density/weight, biomass, dry matter content, photosynthetic capacity, water content, C/N ratio, N content, stomatal conductance, hydraulic conductivity, dark respiration, water-use efficiency, hardiness, specific leaf area...

- Leaf traits represent a realised ecological trade-off and strongly affect plant growth and nutrient cycles.
- The traits may be used in defining an ecosystem or determining its function (e.g., the thicker bark of dry forest trees compared to trees from savannas or spiny leaf traits as a response to herbivory).
- Allow us to understand ecosystem services (e.g., photosynthesis or respiration) and aid in managing/monitoring of said processes.
- May be specific to a leaf or a whole plant

SLA (specific leaf area) is the ratio of leaf area/mass and varies interspecifically.

- The prime factor determining interspecific variation in relative growth rate
$$SLA = \frac{A}{M_L}$$
 where A is the area of a given leaf or all leaves and M_L is the dry mass of the leaf/leaves. SLA is reported in m^2/kg or mm^2/mg .
- It can be measured with ImageJ (calculate area of flattened leaves from an included scale)
 - Always try and collect a range of leaf samples (across different heights in the canopy and illuminations) to get a representative mean leaf area value
- The wet mass of the leaves can be weighed in the field (inaccurate scale); and the dry mass can be weighed at Kings after drying
 - In the oven for 72 hours at 60C.
- From Firbush data:
 - SLA varies interspecifically
 - Ranges between 10 and 50 m^2/kg
 - Himalayan balsam had the highest mean SLA → 41 m^2/kg ,
 - Then Giant hogweed, hawthorn, bramble, elder, birch, rhododendron
 - Oak had the highest mean SLA → 12 m^2/kg

- High SLA reflects fast growth rates and short lifespan (typical of the invasive species)
- Lower SLA reflects other allocation of biomass (typical of trees and shrubs)
- Hawthorn so high up is surprising, as is rhododendron so low (shrub, but is invasive and fast growing)

LMA (leaf mass per area) is the ratio of leaf mass/area

$LMA = \frac{M_L}{A}$ where A is the area of a given leaf or all leaves and M_L is the dry mass of the leaf/leaves. LMA is reported in g/m².

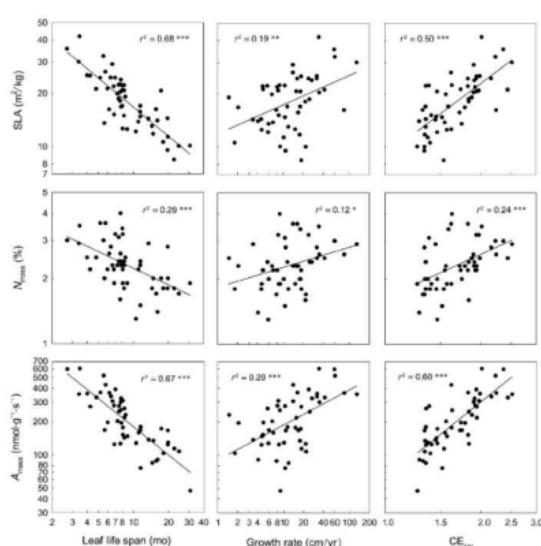


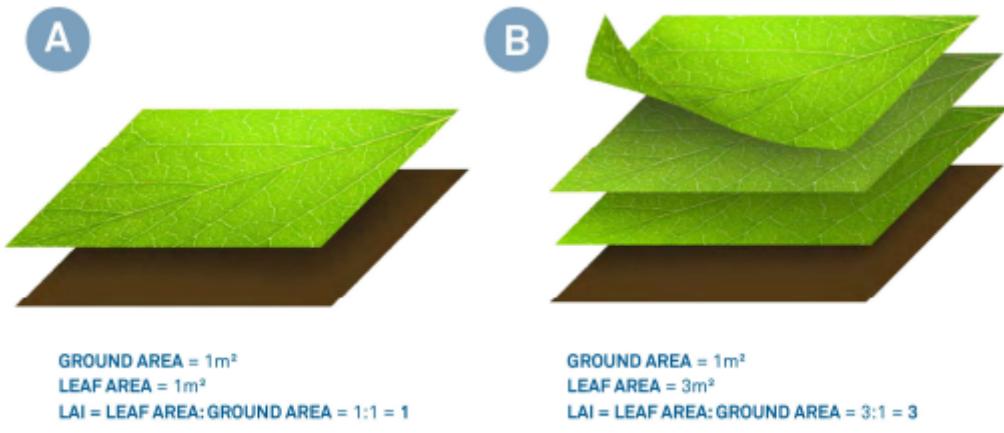
FIG. 1. Relationships between leaf traits and leaf life span (left panels), sapling height growth rate (middle panels), and juvenile crown exposure (CE_{pvw}; right panels) of 53 rain forest tree species. Measurements from top to bottom are: specific leaf area (SLA), nitrogen per unit mass (N_{min}), mass-based photosynthesis (A_{max}), stomatal conductance (g), and photosynthetic water use efficiency (WUE). Continuous lines indicate significant regressions; the broken line indicates a non-significant regression. Coefficients of determination and significance levels are given: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; NS, $P > 0.05$. Note the log-log scale.

Normal Range	SLA		LMA		
		low	high	low	high
Herbaceous species	Aquatic plants	15	210	4	65
	Ferns	10	45	20	95
	Forbs	8	35	25	130
	Grasses	4	30	35	225
	Succulents	2	12	85	510
Woody species	Deciduous shrubs	9	27	35	110
	Deciduous woody species	8	25	40	120
	Evergreen shrubs	2	15	65	380
	Evergreen Angiosperm trees	8	23	40	120
	Evergreen Gymnosperm trees	2	11	90	470

Poorter and Bongers (2006)

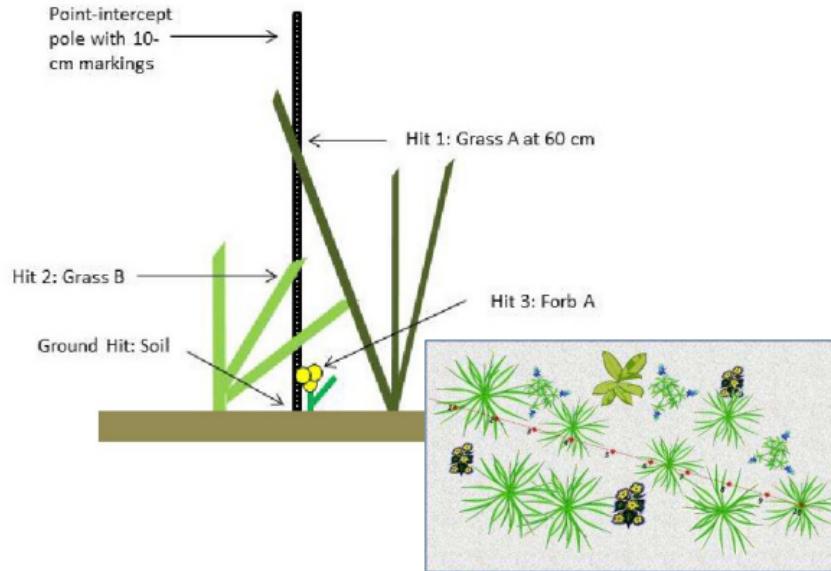
Canopy traits: a canopy is the aggregate of all crowns in a stand of vegetation that represents an important habitat for animals and plants, regulates the surrounding climate, and its traits drive forest productivity (Reich, 2012)

LAI (leaf area index) is the measure of light interception of a canopy (and is often more than 1 because leaves overlap and lay at various angles in the canopy) and represents the total area of leaves above a certain ground (Watson, 1947).



$LAI = \frac{A_{leaf}}{A_{ground}}$; expressed in m² leaf area/m² ground area;

- LAI can also be used to measure plant biomass
- Season is important for LAI measurements (e.g., deciduous forests in winter) as is species, water and nutrient availability, disease, management practices, herbivore density, ...
- Can be measured using 4 methods:
 1. Direct harvest (direct)
 - a. Harvest everything within a plot and then measure the one-sided leaf area of all vegetation
 - b. Time-consuming, destructive
 - c. Used in grasslands and shrublands due to challenges in harvesting tree leaves
 2. Point-intercept (direct)
 - a. Count how many leaves touch a vertically inserted pole
 - b. Time-consuming



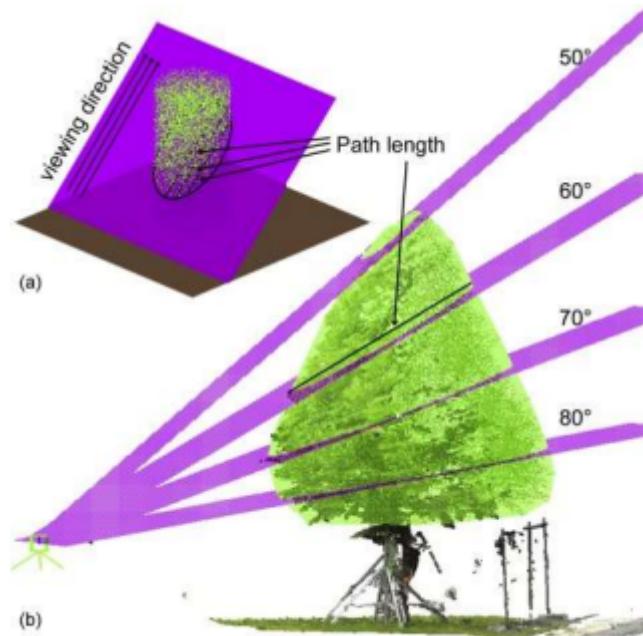
3. Lidar (indirect)

- a. Counts back spatter of light
- b. Can be done with scanners, drones, satellites (creates large datasets over larger areas)
- c. Difficult to obtain under-canopy information due to the reflection of the laser by the leaves

4. Gap fraction (indirect)

- a. Used in forests where direct harvest is difficult/impossible
- b. Measures the amount of clear sky that is visible under the canopy with
 - i. A fisheye lense or
 - ii. LAI 2000 → calculates LAI automatically and collects metadata using $PAR_t = PAR_i^{-kz}$
 1. Press log, then calibrate in the open air (with the button on holding stick)
 - a. Will return the LAI and SD
 2. Face the canopy (back to the sun)
 - a. Don't sample on really sunny days
 3. Benefits of the LAI

- a. Compares the below and above-canopy conditions to reduce errors (more accurate than using fisheye lenses)
4. Issues with the LAI
- a. Measures the plant area index (not leaf area index; includes stems)
 - i. Winter measurements in deciduous systems can be used to correct for stem area
 - b. The instrument doesn't function well if the canopy is sunlit (so the foliage is brighter than the sky) → measure on cloudy days or at dawn/dusk
 - c. Obtaining above-canopy readings may be difficult in forests → this measurement should be taken in an open area
 - d. May not fit under the canopy in short-stature vegetation (think grasses and herbs)



- From Firbush data:
 - LAI varies between functional groups (grassland/trees) → m^2/m^2 (so no unit)
 - Ranges between 0 and 9

- Point-intercept vs LAI-2000
 - Point-intercept → grass has higher LAI (7) than trees (3.6)
 - LAI-2000 → grass has lower LAI (3.8) than trees (4.6)
- Use a two-factor ANOVA to compare the effect of vegetation and measurement type on LAI

Spatial autocorrelation

Ben Lawers National Nature reserve:

- 10th highest Munro at 1214m
- Encompasses 4500ha
- Rich in wildlife: red deer, ravens, skylarks, black grouse, arctic-alpine plants...
- While most Scottish mountains are igneous (with acidic soils), Ben Lawers is metamorphic (Ben Lawers mica schist, more nutrient-rich soils).
 - The rock also breaks up easier to form more niches, creating unique habitats
- Ben Lawers is home to a range of arctic-alpine plants (e.g., mountain sandwort, snow pearlwort, drooping saxifrage, ...) that are adapted for harsh winters and long snow lie (chinophiles → snow-tolerant plants)
 - Has the most celebrated collection of rare arctic-alpine plants in Britain, as well as over 600 types of lichen
 - The best site in Scotland to see arctic-alpine plants
 - With climate change, these plants are declining in numbers as less snow-tolerant species are out competing it



Gentiana nivalis



Saxifraga oppositifolia

- The area has naturally positioned/appeared (rowan and willow) and introduced (heather, birch, alder) vegetation, which are all affected by disturbance:
 - Plants like willowherb, fireweed, and coltsfoot all appear near paths/roads → were brought in by walkers, cars, etc.
 - Grazing by sheep limits natural regeneration of tree saplings and reduces growth (heather is especially vulnerable to grazing)
- The Scottish National Trust owns the land, but not the grazing rights of the whole area (sheep are allowed to graze most of the areas
 - Where they do own the grazing rights, the areas are fenced off and grazers can be further managed through culling (e.g., roe and red deer)
 - The goal of such management is to allow natural regeneration through the exclusion of grazers
 - The trust also encourages the breaking up of the soil by cattle and makes use of the topography (which naturally limits grazing)
 - The area is also rich in peat, which the trust works to restore and maintain in order to raise the water table, increase Sphagnum numbers, and maintain it as a significant C sink



Chelaria sedoides



Salix herbacea

Designated Special Area of Conservation (SAC)

Two key issues of the Ben Lawers park:

- Overgrazing (ground stability is reduced, erosion is increased, peat becomes exposed; can lead to ecosystem collapse). To manage the effects of overgrazing, the National Trust works to:
 - Re-profile the hags (exposed peat) and

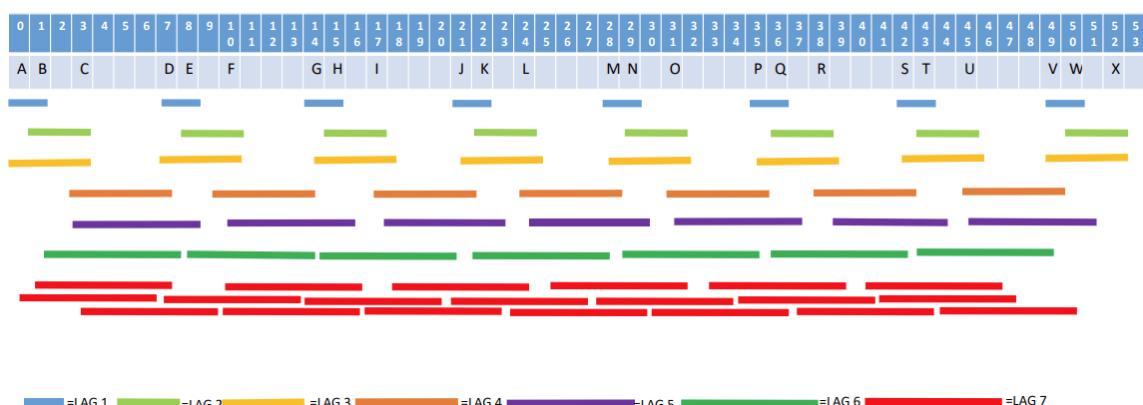
- Restore vegetation (active planting, transplants from other sites, exclosures
→ keeping grazers out of the areas)
- Path erosion - to manage the effects, the National Trust:
 - Created a footpath network (increase drainage, add signage) and
 - Revegetates areas of erosion scars

Monitoring strategies:

- Using remote sensing to observe any changes in vegetation changes
- Tagging animals

The natural variety of landscape in the area comes with changes in vegetation (as well as by land use, topography, and cover). Cyclic sampling is used in surveys and monitoring as it is useful in detecting any **spatial autocorrelation** (the idea that two nearby plots are more similar than two further plots). It captures the probability of similarity by asking:

- How should continuous variables be sampled?
 - Spatial autocorrelation measured the correlation of a variable with itself at various distances (e.g., soil depth, ABG, etc. over a wide area)
- What are the intrinsic scales of variation in a landscape - how far apart are the plots?
- Spatial continuity is common → two plots that are close to each other are more likely to be similar than two plots that are far away from each other



Allows for repeated measurement of variance across different distances (lags)

How do you decide on the sampling method?

1. Define the space of the study (e.g., Ben Lawers, Europe, Loch Tay, ...)
2. Decide how accurate you need to be (e.g., what is the scope/scale of the study?)
3. Define the timing of the study (e.g., sampling pollinators is seasonal)
4. Define the strata (which should be based on the size and characteristics of the space defined in 1. → can be along a gradient such as elevation or altitude)
5. Define the number of replicates (the higher the number of replicates, the higher the precision → consider any constraints and efficiency, but aim for 5% of standard error)
6. Define the sampling unit (e.g., single leaf, population, community, plot size, ...)
7. Decide on a sampling pattern:
 - a. Completely random → might find some spatial autocorrelation
 - b. Structured → might not capture all variability and be biased
 - c. Stratified random → best compromise

Examining the vegetation change with altitude in Ben Lawers:

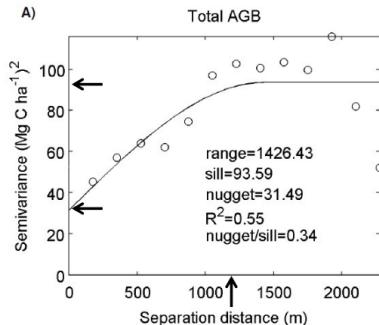
A distance pairing of 1-7 distances allows you to measure all distances without having to sample all plots (cyclic sampling)

Measure all of the below variables along a 50m transect at three altitudes (using cyclic sampling with $1m^2$ plots):

- Species richness (count the number of different species present in each plot)
- Vegetation height (with a meter stick)
- Vegetation functional type (woody, moss, lichen, herb, grass) → stay consistent

- Soil depth (with soil depth probes and a meter stick)
- Soil temperature (with a soil temperature probe)

With the data, you can then produce a **variogram**:



Sill → the point at which maximum variability is reached

Nugget → the variability due to measurement error or finer resolutions (where the model intersects with 0m distance between the plots) → the inherent (natural) variability

As you compare plots that are further apart, the variance increases until the sill (maximum variability)

Range → separation distance at which points are no longer correlated (how far two plots have to be from each other to measure a difference)

Above this distance, the variance will remain stable

The nugget-to-sill ratio indicated the degree of spatial dependence in the data:

- <0.25 = strong spatial dependence → plots are similar
- 0.25 - 0.75 = moderate spatial dependence → plots differ

If the plots don't reach a sill, the plots are all spatially autocorrelated (all subplots come from the same larger plot → no difference with distance because we aren't far enough apart for a difference)

- If they are not spatially autocorrelated, it means they are different because they are far enough apart → then you can find what changes over that distance (e.g., hydrology, topography, etc)