ICARDA

Science for resilient livelihoods in dry areas

Guide for rangeland inventorying, monitoring and assessment of arid and semi-arid rangeland ecosystems

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RESEARCH PROGRAM ON Livestock

Contents

List of Figures

List of Tables

1. Introduction

Rangelands occupy approximately 54% of the global terrestrial surface and support more than 200 million households and 50% of the world's livestock (ILRI et al., 2021, MA, 2005; Galvin et al., 2008; Nicholson, 2011), maintain 35% of global biodiversity hotspots, and provide a habitat for 28% of all endangered species (Mittermeier et al., 2011; Oliver, 2017).

Rangelands have economic importance worldwide for livestock production as they are a less expensive source of fodder than other sources due to the vast areas they cover. Rangelands provide nutritious feed for livestock, natural habitats for wildlife, a source of herbal medicines, and are the main area for pastoral herds such as sheep, goats, camels, and cows. Rangelands have great potential for carbon sequestration (Lal, 2004) and play a vital role in storing up to one-third of global carbon reserves (Campbell et al., 2008).

Rangeland specialists have offered several definitions, they agree to consider rangelands as uncultivated lands capable of providing environmental habitats for domestic livestock, wild animals and wild plants (du Toit et al., 2010). They include savannas, grasslands, shrublands, tundras, deserts, alpine meadows marshes, meadows and some woodland ecosystems are dominated by trees, shrubs, grasses, and forbs (Lund, 2007).

More than 80% of rangelands are located in arid and semi-arid areas. These rangelands are more prone to degradation, and when degradation happens, it often creates desert-like conditions with poor productivity and diversity. Rangeland degradation results from different abiotic and biotic factors that need to be addressed through urgent interventions for effective management. Appropriate rangeland management includes careful assessment and inventorying of available resources based on key indicators.

2. Causes of rangeland degradation

Degradation of rangelands can generally be described as a reduction in land productivity closely related to declines in native vegetation cover and soil erosion. Rangeland degradation results from complex phenomenon in time and space and is often caused by multiple forces.

1. Continuous grazing and overstocking cause tremendous land degradation (Figures 1 & 2).
2. Failure to follow traditional grazing procedures which have proven successful over many generations.
3. Agricultural expansion at the expense of rangelands (crop and olive tree planting) (Figure 3 & 4).
4. Harvesting fuelwood (Figure 5).
5. Climate variability and climate change leading to prolonged drought and uneven rainfall distribution

6. Rangelands are often used for extraction of fossil fuels and sand quarries (Figures 6 and 7).

***Figure 1**. Desertification from overgrazing continues to this day.*

***Figure 2.** Advancing desertification, a major concern for humans.*

***Figure 3.** Expansion of cereal cultivation in arid rangeland.*

***Figure 4.** Planting olive trees in arid rangeland.*

***Figure 5**. Harvesting of fuel wood from rangelands*

***Figure 6.** Rangeland disturbance associated with oil and gas resource production*

***Figure 7.** Exploitation of sand quarries*

3. Indicators of rangeland degradation

About 13% of rangelands in the drylands are already degraded, a process greatly exacerbated by climate change (Davis, 2017). The most important indicators of rangelands degradation are:

- Increase in invasive plants (poisonous and unpalatable; Figure 8)
- Loss of palatable species
- Decrease of vegetation cover (Figure 9)
- Decrease the abundance of shrubs (Figure 10)
- Loss of plant diversity
- Increase the richness of therophytes (therophytisation)
- Widening gap between forage production and livestock feed requirements.
- Decline of wild animals and birds living in the natural habitats of rangelands.
- Topsoil loosening due to the destruction of vegetative cover.
- Loss of soil nutrients through erosion resulted from soil exposure.
- Decreased seed stock in the soil.
- Increasing stony surface and rocky outcrops.
- Increased surface soil erosion and sand accumulation (Figure 11).
- Decreased efficiency in rangelands and land-use transformation into urban or agricultural areas.
- Greater risk of desertification (Figure 12).
- Conflicts over water and rangeland resources.

Figure 8. *Unpalatable and toxic species encroach large areas of rangelands, replacing existing natural vegetation and reducing native shrubs.*

Figure 9. *Decrease of vegetation cover and increasing stone surface and rocky outcrops.*

Figure 10. *Changes in plant morphology and soil depth due to overgrazing and soil erosion.*

Figure 11. Severely degraded rangeland by water erosion as result of loss of protective vegetation.

Figure 12. *Rangeland exposed to sand drift and dust storms as result of loss of protective vegetation.*

4. Rangeland management

Rangeland management is a science that focuses on preservation and sustainable management of natural resources for the benefit of the population and future generations (SRM, 2016). Rangeland management is unique from other agricultural activities in that it deals with the balance between plants and animals rather than a focus on one or the other.

Rangeland management integrates concepts, principles, and management practices that apply to various and livestock grazing to ensure the sustainability and improvement of forage and livestock productivity. Rangelands are sustainable if they are properly managed and require less effort and cost compared to maintaining forage cropping systems. Rangelands management builds on the following basic concepts:

- Rangelands are a natural renewable resource (Batabya and Godfrey, 2001)
- Rangelands are the largest low-cost and most diverse land sources of forage for livestock compared to other fodder crop lands (Ismail et al., 2014)
- Rangeland restoration is based on natural characteristics such as soil, topography and climate (Jamsranjav et al., 2012)
- People benefit from a wide range of services provided by rangelands (Sala et al., 2017).

5. Methods of assessing rangelands

There are numerous indicators used for monitoring and assessing rangelands such as:

- Species dominance, abundance, and frequency
    - palatable species,
    - invasive plants
- vegetation cover, density, biomass, forage production, and plant diversity.
- Soil characteristics (soil surface, depth, texture, fertility)
- The above indicators will determine rangeland condition

5.1. Data collection equipment

The ability to identify plant species is essential. Sampling procedures are related to the data needed and the degree of precision necessary. To achieve this goal, some basic tools for rangelands data collection are needed in general, these tools are simple and inexpensive (Figure 13).

- Datasheets to record quantitative direct measurements: established a protocol for data recording on data sheets with clear markings in the appropriate boxes. Calculations can be done after the fieldwork is completed.
- Bags to collect field samples: The storage method depends on how long you are in the field. Plastic bags are acceptable for storing specimens for a few hours, but if they have a high moisture content as in fresh leaves and flowers, mold may develop quickly. Paper bags are more effective as long as they are kept cool. Dry leaves from arid and desert regions can be stored in paper bags without cooling. Long trips of weeks rather than days may require pressing or drying the samples.
- Quadrate and rectangles frames (1 m^2 or 0.5 m^2) for counting annual density and biomass sampling: The square sampling frame should be lightweight and easily carried in the field. It can be made of metal, wood, or PVC pipe.
- 50-meter retractable measuring tape.
- A metal pin about 1 meter long sharpened to a point.
- Metal stakes to tighten the measuring tape.
- Hammer to insert stakes into the ground.
- Clippers to harvest aboveground biomass inside the framing square.
- Balance for weighing fresh samples.
- Digital camera: Whenever possible, take photos to document vegetation changes. A high-resolution digital camera is recommended.
- Global Positioning System: GPS is used to locate plant communities or a particular plant. GPS data can be overlaid on Google Earth image to assess the geolocation accuracy.
- Pens, pencils, clipboards.

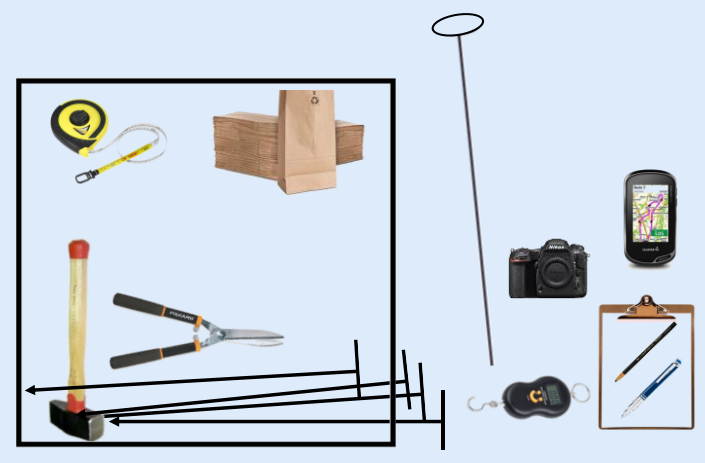

Figure 13. *Simple tools needed to rangeland assessment and monitoring.*

5.2. Site description

Before taking measurements, detailed properties of site and vegetation communities to be studied must be identified (Sheley et al., 2011). An ecological site description includes:

- Coordinates of the target site, plot locations and transect starting points (where required) using GPS should be recorded. Elevation above mean sea level may also be identified.
- Vegetation communities are distinguished by the dominant species.
- Soil type: Rangeland soils are extremely diverse (sandy, silty, loamy, clay loam, limestone and sand dunes).
- Geomorphology: Refers to the nature of the terrain (plains, hills, mountains, wadis, etc.).
- Slope: is usually expressed in percent or degrees.
- Climate: is the average weather for the region (humid, semi-arid, arid, desert, etc.).
- The average amount of rainfall in the area.
- Tenure systems (private, communal, public, protected, etc.).
- Current state: Natural reserve (park), rested (age of resting, implemented strategies, who supported the project), rotational grazing, continuously grazed, etc.).
- Grazing patterns: stable grazing systems, seasonal, transhumant grazing, etc.).
- Number of the main types of livestock (sheep, goats, camels or a mixed herd).
- Distribution of water points.

5.3. Methods for rangelands assessment

5.3.1. Traditional methods

Method	Description	Design
Line-point intercept technique	Three 50-meter transects should be established in each site. drive a pin into the ground every 50 cm along the transect. At each of the 100 points on the line of each transect, record the plant species and type of ground (stone, wind veil, crust, or litter). Intersecting transect plots can be in spoke or parallel design.	Spoke design  Parallel design 
Quadrats for density counting	A quadrat (1 m^2) is used most often to measure the density of annual species. A rectangular frame (50 m^2) is used most often to measure the density of perennial species. Rectangles developed to measure the density of perennial species are usually aligned with the line intercept. Treatments should be replicated.	- Square quadrat (1 m^2) to measure the density of annual species - Rectangular frames (50 m^2) to measure the density of perennial species

Square quadrats to measure annual biomass using the harvest method	When estimating annual biomass per quadrat, all annuals plant material within the boundaries of the quadrat must be clipped, even if the plant is rooted outside the quadrat. Do not harvest plants parts outside the quadrats, even if the plant is rooted within the quadrat. To get particular precision estimates of effect size, treatments should be replicated at least five times	- Square quadrat (1 m^2) to estimate the biomass of annual species
Non-destructive perennial aboveground biomass estimation	Take one branch from each medium-sized perennial species. This reference branch will be weighed and used as a reference branch or experimental unit for sampling. Estimate the number of branches of each plant based on the reference branch. Determine the total biomass of each shrub by multiplying the number of branches by the weight of the reference branch after drying and then multiplying by the density.	 - Medium plant  - Reference branch

5.3.2. New technology to monitor and assess rangelands

Traditional procedures to assess vegetations cover include visual estimates in quadrats and at point intercepts. These methods have been used for decades in rangeland monitoring. However, with the recent advances in geoinformatics, new techniques for assessing and monitoring vegetation cover are becoming more widely used. For example, high-resolution digital cameras offer a fast, affordable and reliable way of measuring several key vegetation characteristics (Louhaichi et al., 2018a). These new cover estimation technologies can provide a large amount of spatial and temporal data that can be used for understanding changes to vegetation over time.

DVCT is more efficient, less subjective, repeatable and allows for derivation of additional metrics. The recorded color intensity of each pixel can be read by VegMeasure to create meaningful classes, such as bareground, litter, vegetation and other categories of interest. The software allows for the extraction of hue, calibration of thresholds, classification of K-means and setting brightness and green leaf algorithms. Large scale maps may be created with greater ease and repeat monitoring tracks temporal changes in vegetation.

5.3.2.1. Field image acquisition

Field based images can be taken using a digital camera with built in GPS and mounted on a stand (monopod) (Figure 14). Images can be batch processed quickly and classes determined to measure the percentage vegetation cover.

Figure 14. Camera equipment (a) and demonstration of image acquisition in the field.

Follow these steps to ensure standardization of image acquisition:

- To save time, use a standard camera setup that accurately tracks the date, time, and the location
- It is recommended to set your camera to the highest resolution possible.
- Adjust camera height and keep the height constant throughout the sampling period (record the height of the camera above the ground).

- Eliminate shadow so images can be processed without additional noise.
- Try to keep the same orientation of the camera.
- Do not zoom in or out (keep default).
- Make sure the camera GPS recording feature is on.
- When moving from one location to another, try to keep the camera upright to maintain continuous connection of the GPS in the camera with the satellites.
- The number of images taken per site will depend on the extend and homogeneity of the target area.

5.3.2.2. Image processing

Digital vegetation charting technique (DVCT) employs an automated classification of digital images using VegMeasure® software. This is a non-commercial software package that performs image processing to estimate vegetative ground cover in a non-destructive manner (Louhaichi et al., 2010). Similar to quadrat sampling, DVCT estimates vegetation cover to determine the resource status of the target area.

After transferring the images to your local drive, follow the following steps to perform image processing and estimate ground cover:

- Run the software and specify the input photos folder that needs processing.
- The software has various algorithms and image processing techniques which contain supervised and unsupervised methods.
- Supervised classification (Figure 15) allows for greater customization in the images, ranges, values and categories allowing for cross comparison of values over time.
- The category color can be changed to be reflected in proceeded output picture.
- Any color in the original image can be selected and added as an interest category and all pixels having similar RGB values will be classified as part of this category (Figure 16).
- When all the colors in the selected image are added to their categories, the program can process multiple selected images.
- Afterward, file with the original image name along with the classification values for each category will be generated and the data can be obtained.

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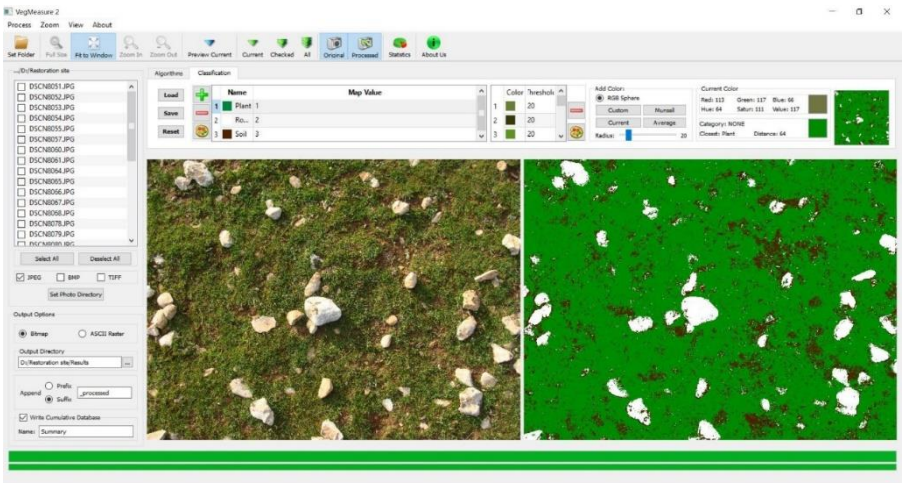


Figure 15. The classification method of image processing using VegMeasure software.

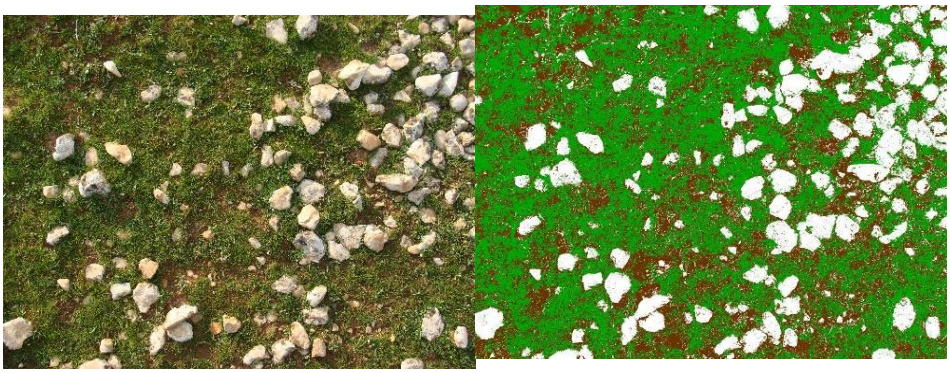


Figure 16. *Original (left) and processed (right) images using VegMeasure software to estimate ground cover in grassland site*

For more information, please refer to VegMeasure manuals.

- Volume 1: Field Manual and VegMeasure (Louhaichi et al., 2018 b)
- Volume 2: Image Processing Manual. (Louhaichi et al., 2018 c).

5.4. Indicators for qualitative and quantitative assessment

Key indicators used in rangeland monitoring

Indicator	Description
Vegetation cover (%)	The percentage of ground covered with vegetation when looking at the ground from above.
Density (plants/unit area)	The number of individual plants per unit area (for example plants/m^2 or plants/ha).
Frequency (%)	The number of times a species is present in the total number of sampled points. It is used to express the degree of species distribution uniformity on the ground. .
Biomass (kg DM/m^2 or kg DM/ha)	The total weight of plant material within a given area. Measurement of biomass in terms of dry matter weight is more accurate because the fresh weight may vary according to season.
Forage production (kg DM/m^2 or kg DM/ha)	The weight of all vegetative parts of forage produced within a designated period of time in a given area. Production may be expressed as green or dry matter weight.
Pastoral value (FU)	The pastoral value of rangeland is defined as that portion of a unit of forage that contributes directly to livestock maintenance. Pastoral value is usually described in fodder units (FU) and is expressed as a decimal fraction of a kilogram of dry matter (FU/kg DM).
Carrying capacity	The maximum stocking rate possible that is consistent with maintaining or improving vegetation or related resources. The carrying capacity of a rangeland determines how many animals can be supported by the annual biomass production without causing harm to the rangeland.
Species richness	The total number of all species recorded in each area.
Botanical composition	List of all species recorded in each area.

5.4.1. Frequency and vegetation cover

Vegetation cover is the relative area covered by single plants, a group of individuals of a single species, or all species of plant community. It is expressed as a percentage of the total area of the plant community. For example, a percentage of 100% means that the ground surface is completely covered by vegetation, 80% means that 20% of the soil surface is not covered by vegetation and 0% means that the ground has vegetation.

Vegetation cover is estimated by the point intercept method. A metal pin or stake is inserted vertically next to the measuring tape at 50 cm intervals (100 points). The intersection at each point is recorded (vegetation, litter, stone, crust, wind veil; Figure 17). It is essential to replicate the sampling method by recording measurements from at least three transects laid out in either the spoke or parallel design. The layout of transects may vary depending on landscape-scale. Parallel transects must be evenly spaced.

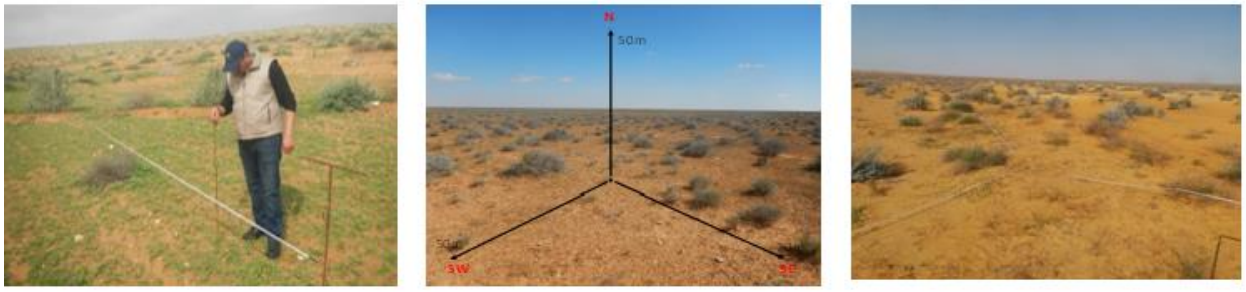


Figure 17. *Demonstrations illustrating the layout of transects used in point intercept method.*

In the spoke design, all transects start from a fixed point and radiate outwards at angles of 120 degrees (Figure 17). All vegetation and soil surface data (Figures 18 and 19) are noted regularly on standardized datasheets. Use one datasheet for each line with scoring 100 points) (Figure 21). Frequency is the proportion or percentage of points that contain a species of interest. Frequency is used to monitor a particular location over time and compare different sites, such as the entry of unwanted exotic plants.

Point falling on vegetation

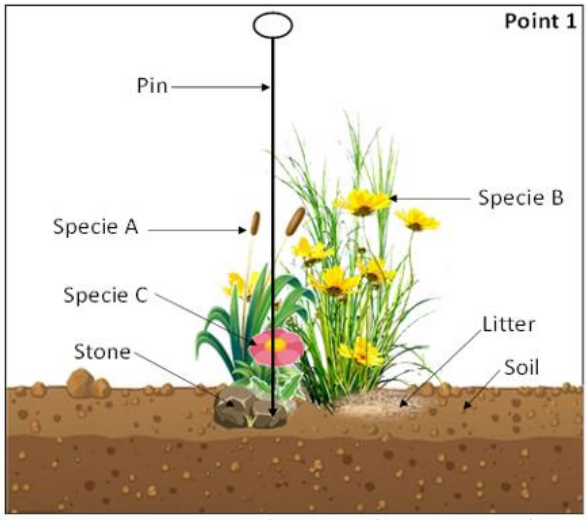
Point falling on stones

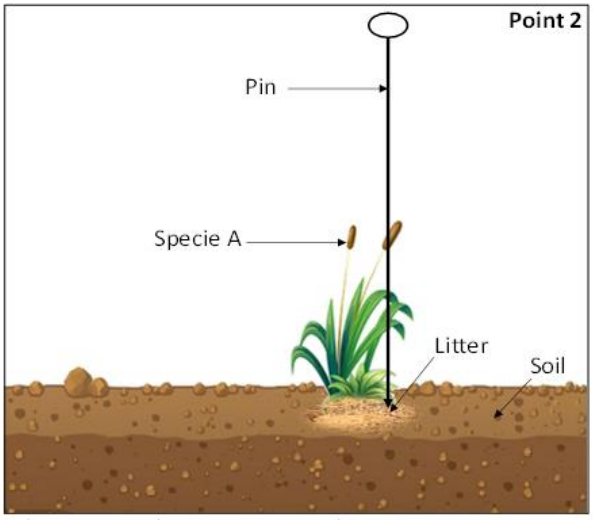
Point falling on soils crust

Point falling on litter

Point falling on wind veil

Figure 18. *The main elements covering soil surface*





Point	Specie A	Specie B	Specie C	Soil surface
1	x	x	x	Stone
2	x			Litter
3				
etc.				

Figure 19. *Example of data collection and completed datasheet using line-point intercept method.*

Specific frequency SF:	SFi is the number of points where a given species is detected during a count along the lines.	$\mathbf{SF}\boldsymbol{i} = \mathbf{n}\boldsymbol{i}$
Centesimal specific frequency: CSF	The CSF is the ratio between the number of points where the taxon is present and the total number of points, all in percentage points, i.e., the centesimal specific frequency (CSF*i*) of taxon *i* is equal to the ratio, expressed as a percentage, of the number of times (n*i*) where the taxon *i* is recorded along the line divided by the total number of points read	$\mathrm{CSF}i\ \% = \frac{\mathrm{n}i\ \mathrm{x}\ 100}{\mathrm{N}}$
Specific contribution: SC	The SC*i* of a species *i* defines its participation in plant cover. It is equal to the quotient of the taxon's centesimal specific frequency (CSF*i*) divided by the sum of the centesimal specific frequencies of all the taxa detected along the line (Daget & Poissonet, 1971)	$\mathrm{SC}i\% = \frac{\mathrm{CSF}i\ \mathrm{x}\ 100}{\sum \mathrm{CSF}i}$ $\mathrm{SC}i\% = \frac{\mathrm{n}i}{\sum \mathrm{n}i}$
Total plant cover: TC	The TC is the ratio in % between the number of points where at least one taxon was found, and the total number of points read.	$\mathrm{TC} = \frac{\mathrm{n}}{\mathrm{N}}$
Total plant cover is less than or equal to 100% **When only one species is found at each point along the line, the sum of centesimal specific frequency is equivalent to the total plant cover**. **Centesimal frequency or relative cover is the cover of a particular species**.		

LINE-POINT INTERCEPT DATASHEET

Location: *Cheneni-Tataouine* Date: *12/03/2019* Line long: *50 m*

Line: *1* Observator: *Mouldi Gamoun* Spacing Interval: *50 cm*

Point	Species							Soil surface	Point	Species							Soil surface
	A	B	C	D	E	F	G			A	B	C	D	E	F	G	
1	X	X	X					Stone	51	X							Stone
2	X							Litter	52			X					Litter
3				X				Crust	53					X			Litter
4						X		Litter	54							X	Stone
5	X					X		Stone	55							X	Litter
6				X			X	Crust	56				X			X	Stone
7								Stone	57	X							Litter
8				X		X		Litter	58			X					Stone
9		X						Litter	59						X		Stone
10						X		Wind veil	60				X				Stone
11				X				Stone	61					X			Litter
12							X	Wind veil	62		X						Stone
13				X			X	Litter	63				X				Stone
14			X		X			Wind veil	64								Litter
15								Litter	65			X		X			Stone
16	X							Litter	66							X	Litter
17						X		Wind veil	67	X							Stone
18				X				Litter	68	X							Crust
19								Stone	69		X						Wind veil
20							X	Litter	70					X			Stone
21			X					Litter	71							X	Crust
22						X		Wind veil	72								Crust
23								Crust	73			X				X	Wind veil
24					X			Wind veil	74								Litter
25			X					Litter	75				X				Wind veil
26								Wind veil	76			X					Stone
27						X		Litter	77								Wind veil
28				X				Litter	78								Wind veil
29			X		X			Crust	79					X			Litter
30		X		X				Crust	80								Litter
31								Stone	81								Crust
32							X	Wind veil	82								Wind veil
33				X				Wind veil	83					X			Litter
34		X						Wind veil	84								Stone
35	X							Stone	85							X	Crust
36			X				X	Litter	86								Wind veil
37				X				Wind veil	87		X						Wind veil
38					X			Wind veil	88							X	Crust
39			X					Stone	89								Wind veil
40					X			Litter	90								Crust
41								Wind veil	91							X	Stone
42					X			Wind veil	92		X			X			Litter
43								Litter	93								Wind veil
44								Wind veil	94	X							Stone
45							X	Stone	95								Litter
46						X		Litter	96								Litter
47			X					Wind veil	97					X			Litter
48	X							Stone	98								Wind veil
49					X			Crust	99								Stone
50		X						Crust	100				X				Litter

Parameters	Species							Total
	A	B	C	D	E	F	G	
SF	11	9	13	15	15	9	16	88
CSF (%)	11	9	13	15	15	9	16	88
SC (%)	12.5	10.23	14.77	17.05	17.05	10.23	18.18	100
TC (%)	= number of point where vegetation is found = **Σ** SF – number of repeated point when more than species was recorded = 88 – 14 = 74%							74
Stone (%)	26							
Litter (%)	33							
Crust (%)	14							
Wind veil (%)	27							

Figure 20. *Example of processing and frequency calculations of vegetation cover.*

5.4.2. Density

Density is the number of individuals of each species per surface unit (m² or ha). Density provides a good ecological indicator of grazing intensity. As grazing pressure increases, the density of palatable species decreases, and the density of unpalatable species increases. When counting the number of annual plants, the count is made on a 1 m² quadrat (Figure 22). For perennial plants, the count is usually taken in a rectangle 50 m^2 aligned with the line intercept used to cover measurement (Figure 23). The number of replications needed is determined by the homogeneity of the area. As the homogeneity of plant community increases, it is necessary to increase the number of observations. In arid areas, five observations for annual species and three observations for perennial species are usually used.

Figure 21. Frame of 1 m2 for annual plants density.

Figure 22*. Frame of 50 m^2 for perennials density measurement.*

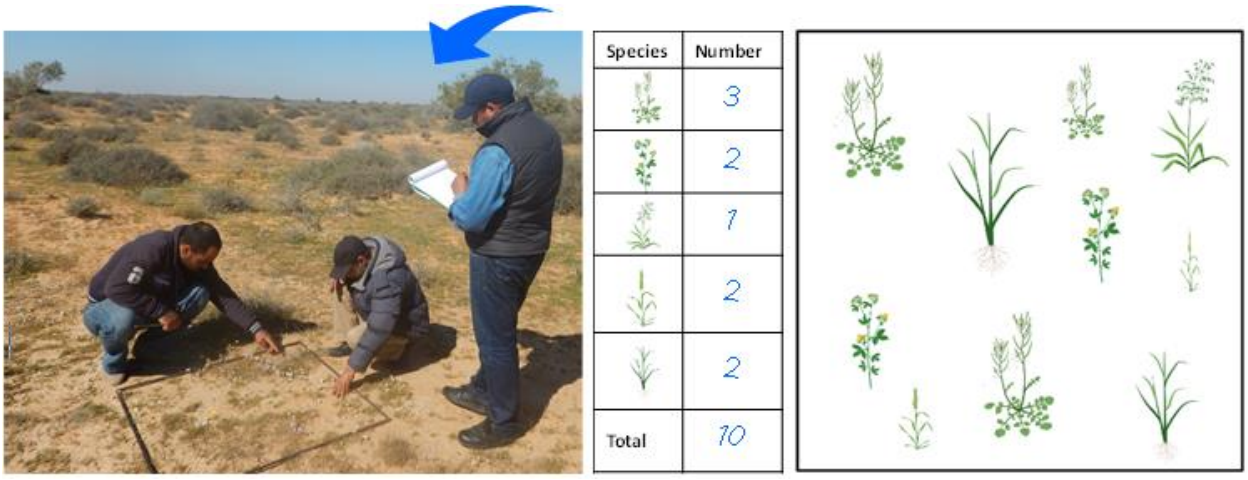


Figure 23. *Measuring the density of annual species using a frame of 1 m x 1 m and counting the number of species rooted inside the frame(left),. Recording numbers in the datasheet(right).*

5.4.3. Aboveground biomass

The most common and simplest method for biomass measurement is to use a quadrat frame for harvesting, drying and weighing the specimens. While simple in principle, biomass measurements are difficult to do in practice, especially for shrubs and trees.

5.4.3.1. Biomass of annual species

Measuring vegetation biomass is best done at the peak growth period. During favorable growth periods, the abundance of annual plants (generally therophytes) is high. To estimate their biomass, to use a 1 m² quadrat (Figures 24, 25). Biomass should be clipped as close to the soil surface as possible. Weigh the harvested biomass with a balance or spring scale, in the field if possible, to get the fresh matter weight. Samples should then be dried for 48 hours at 80°C and weighed again to get the dry matter weight.

***Figure 24**. Clip aboveground biomass rooted inside the frame as close to the soil surface as possible.*

***Figure 25.** Store samples in paper bags, weigh, and mark for determining dry matter content after laboratory drying.*

5.4.3.2. Biomass of perennial species

Biomass harvesting of perennial plants (shrubs and trees) can be harmful to rangeland health and livestock production. Since the measurement of biomass needs a number of replicate samples and some plants are rare or endangered, destructive methods are an issue of concern to researchers. Various non-destructive methods have been developed to conserve ecosystems.
Among the best-known and most accepted methods for measuring the biomass of shrubs and trees is the reference unit method (Figure 26). The quadrats used to determine perennial density are used to estimate total biomass. For details on how to conduct a reference unit measurement, see Annex 1.

Figure 26. *Methods for estimating biomass production of shrubs from biomass production using branch reference, number of branches of each species, and number of shrubs.*

The total biomass of all species represents the overall biomass in a given area (m^2 or ha).

$$BSi = \sum_{i=1}^{n} BRi \ x \ NRi \ x \ Di \qquad \text{Eq. 1}$$

BS_i = Biomass of species$_i$
BR_i = Biomass of reference unit of species$_i$
NR_i = Number of branches equivalent to reference unit in the species$_i$
D_i = Density of species$_i$

$$TB = \sum_{i=1}^{n} BSi \qquad \text{Eq.2}$$

TB = Total biomass

5.4.4. Pastoral value

Rangeland productivity or forage productivity is expressed in fodder units (FU) of useful forage which is calculated from the net primary productivity or the consumable quantity.
For each plant species, a pastoral value. Unfortunately, there are few data on the forage value of shrubs growing in arid and semi-arid rangelands.

If there is data on the pastoral value of perennial shrubs and grasses (FU/kg), keep in mind that one kilogram of dry matter (DM) of annual herbaceous plants provides 0.33 FU (Le Houérou and Hoste, 1977). If there is not enough data, the pastoral value can be estimated using the INRA formula (1978), which is based on vegetation cover and species palatability.

$$PV = 1.5 \sum_{i=1}^{n} SCi \times PIi \times TPC/100 \quad \text{Eq. 3}$$

Where PV is total rangeland production in forage Units (FU)/ha/year, SCi is cover of species i (%), PI*i* is the palatability factor of species *i*, and TPC is total plant cover (%).

5.4.5. Carrying capacity

Carrying capacity is the maximum stocking rate possible which is consistent with maintaining or improving vegetation or related resources. The carrying capacity of rangelands determines how many animals can be supported by the annual forage production without damage the rangeland (Gamoun et al., 2015; Cheng et al., 2017; Meshesha et al., 2019).
It is the ratio of total rangeland production to the annual needs of an animal. Estimating carrying capacity is important in terms of household food security, income and livestock production value chains.

To determine carrying capacity, calculate the total amount of forage production at the end of the growing season divided by the annual need of one animal unit.
To ensure regeneration and forage production in years to come, the rate of … should be included, which varies according to rangeland type.

For example, in the arid rangelands of Tunisia, Gamoun (2012), estimates that to keep the rangeland in a healthy condition, 60% of the available forage should not be grazed.

To prevent overgrazing and rangeland degradation, at least 40% of the standing forage should be left at the beginning of the next rainy season.

The forage unit (FU) is used to calculate the carrying capacity of a rangeland. One feed unit is 1 kg of barley. The feed value of 1 kg of dry matter is approximately 0.33 FU/kg of DM (Le Houérou and Hoste, 1977; Table 1).

$$Carrying\ capacity = forage\ supply \div forage\ demand/head \quad \text{Eq. 4}$$

Table 1. *Forage unit needs for sheep, goats, camels and cows in the Mediterranean Basin according to Le Houérou and Hoste, 1977.*

Animal	Forage unit needs for head per day (FU)	Forage unit for head per year (FU)	Dry matter needs for head per day (kgDM)	Dry matter needs for head per year (kgDM)
Sheep	0.82	300	2.5	900
Goats	0.68	250	2	750
Camel	8.2	3000	25	9000
Cattle	4	1500	12	4500

$$Carrying\ capacity = \frac{Forage\ produced\ (kg\ of\ DM\ per\ ha)\ x\ 60\%}{Daily\ FU\ required/head} = n\ head/days/ha \qquad \text{Eq. 5}$$

Sampling before and after grazing is another method to compare managed-grazed with ungrazed rangelands. This method works well where grazing periods are so short that growth during the grazing period continues is slow or insignificant.

Cages can be used as part of a grazing management strategy (Figure 27). This cage provides a better comparison of grazed, ungrazed and controlled grazing plots. Cages should be placed in multiple locations in the rangeland before grazing, and carefully installed to prevent animals from getting forages inside. At the end of the grazing period, the cages can be removed and the biomass can be estimated . For comparison, the biomass outside the caged should also be measured.

Figure 27. *Example of a cage to prevent grazing and allow growth. Cages should be constructed of sturdy materials since animals will attempt to get at the forage inside.*

5.4.6. Plant diversity

The term, 'plant biodiversity' has several definitions. The common definition refers to the number of species or species richness in a given area. Another index of species diversity is the Shannon-Wiener Diversity index (H') and Evenness.

The Shannon-Wiener index is widely used to assess species diversity across space and time and is defined as:

$$H' = -\sum_{i=1}^{s} pi \; x \; log_2 \, pi = -\sum_{i=1}^{s} (\frac{ni}{N} Log_2 \; \frac{ni}{N}) \qquad \text{Eq. 5}$$

Where H' is the Shannon-Wiener diversity index, pi is the abundance (n/N) of individuals of one particular species found (n) in the plant community divided by the total number of individuals found (N) in the same plant community, Log_2 is the base 2 logarithm.

The Shannon-Wiener index varies from 1.5 to 3.5 and rarely exceeds 4 or 5.

Evenness is a measure of community homogeneity in terms of the abundant species.

A plant community is considered even and has high evenness when all species are equally common. Evenness shows the individual distributions among the different species. When individuals are distributed more evenly, sustainability and stability are important, and biodiversity is accordingly higher. The relative proportion of dominant species can be measured by E (evenness or regularity), which is estimated as the ratio of the Shannon-Wiener diversity index to the highest possible diversity for that sample calculated by log_2(richness):

$$E = \frac{H\prime}{H_{max}} = \frac{H\prime}{log_2 \, S} \qquad \text{Eq. 6}$$

Where S is the species richness that is the number of different species in a particular plant community.

Example:

The diversity of a plant community has two components, i) species richness (the number of different species in a community; and ii) the relative abundance of the different species.

Example: Consider two rangelands plant communities (Figure 28), each with 100 individual plants representing five species (A, B, C, D and E) as follows:

Plant community 1: 20A, 20B, 20C, 20D, 20E
Plant community 2: 12A, 12B, 60C, 8D, 8E

The two communities have the same species richness because each contains five species, but they differ significantly in their relative abundance.

In plant community 1, there are five plants species, but the only abundant species is C, which is in plant community 2. Most observers assume that community 1 is more diverse than community 2. The commonly used index of diversity is the Shannon diversity index (H') based on species richness and relative abundance.

$$H' = -\sum_{i=1}^{s} pi \; x \; log_2 \; pi \qquad \text{Eq. 7}$$

$$H' = -(piA \; log_2 piA + piB \;\; log_2 piB + piC \;\; log_2 piC + piD \;\; log_2 piD + piE \;\; log_2 piE)$$

Where A, B, C, D and E are the five species in the two communities, p is the relative abundance of each species, and log_2 is the base 2 logarithm. The higher the value of H', the higher the plant community diversity.

To calculate the Shannon diversity index of the two example communities in Figure 29.

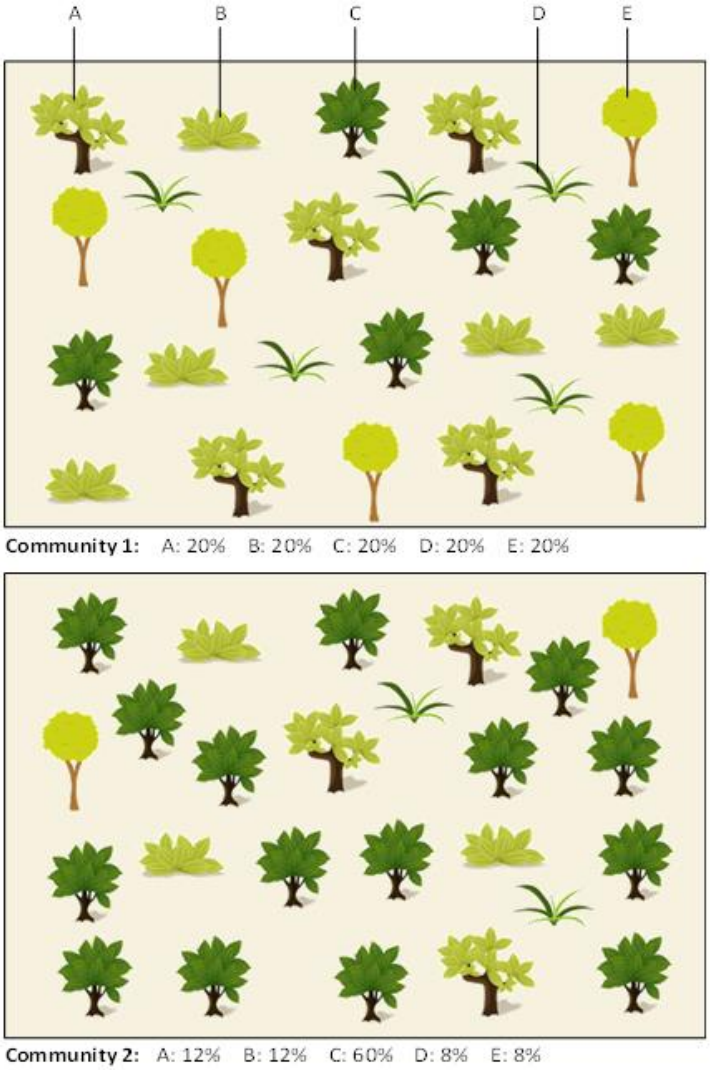


Figure 28. *Two plant communities with different Shannon Indices. Top: community 1; bottom: community 2.*

For community 1, for each species p=0.2, therefore:

$$H' = -5(0.2\ x\ log_2 0.2) = 2.321 \quad \text{Eq. 8}$$

For community 2, for species A and B p=0.12, for species D and E p=0.08, and for species C p=0.6, therefore: $H' = -[2\ (0.12\ x\ log_2 0.12) + 2\ (0.08\ x\ log_2 0.08) + (0.6\ x\ log_2 0.6)] = 1.759$

We can now create a table of species richness, Shannon diversity (H') and evenness (E) for the two plants communities (Table A2).

Table 2. *Calculating H' and evenness.*

Community	Species	Individuals	pi	log_2pi	pi log_2pi	Richness	H'	Evenness
1	A	20	0.2	-2.322	-0.464	5	2.321	0.999
	B	20	0.2	-2.322	-0.464			
	C	20	0.2	-2.322	-0.464			
	D	20	0.2	-2.322	-0.464			
	E	20	0.2	-2.322	-0.464			
2	A	12	0.12	-3.059	-0.367	5	1.759	0.757
	B	12	0.12	-3.059	-0.367			
	C	60	0.6	-0.737	-0.442			
	D	8	0.08	-3.644	-0.292			
	E	8	0.08	-3.644	-0.292			

Other diversity indices presented by Hill (1973) are easier to interpret ecologically. Hill unified diversity numbers into a series of three indices, N_0, N_1, and N_2:

N_0 = S = total number of species present in a sample, and N_1 is the number of abundant species.

$$N_1 = e^{\text{Shannon–Wiener}} = e^{H'} = e^{-\sum_{i=1}^{s}(p_i \times \text{Log}_2 p_i)} = e^{-\sum_{i=1}^{s}(\frac{ni}{N}\text{Log}_2 \frac{ni}{N})} \quad \text{Eq. 9}$$

$$H' = -\sum_{i=1}^{s}(p_i \times \log_2 p_i) = -\sum_{i=1}^{s}(\frac{ni}{N}\text{Log}_2\ \frac{ni}{N}) \quad \text{Eq. 10}$$

where p is the proportion (n/N) of each species recorded in the plant community.

$$N_2 = \frac{1}{\lambda} = \frac{1}{\sum_{i=1}^{s} pi^2} \quad \text{Eq. 11}$$

N_2 is the inverse Simpson Diversity Index equal to the number of very abundant species, with $N_0 \geq N_2$.

It has been shown that N_2 is less sensitive to sampling than N_0 because the importance of rare species decreases with increasing N_2.

Evenness is a measure of community homogeneity in terms of the abundant species. A plant community is considered even and has high evenness when all species are equally common. Evenness shows the individuals distributions among the different species. When individuals are distributed more evenly, plant communities are more stable and the biodiversity is higher.

The relative proportion of dominant species can be measured by evenness (or regularity, E_{20}), which is estimated as the ratio of very abundant taxa relative to the total number of taxa in a sample using $E_{20} = N_2/N_0$. The E_{20}. The Simpson evenness and Hill ratio varies between 0 (one species largely dominates all others) and 1 (all species have the same frequency) and is not correlated with species richness:

$$E_{20} = \frac{N_2}{N_0} = \frac{1/\lambda}{N_0} = \frac{1/\sum_{i=1}^{s} pi^2}{N_0} \qquad \text{Eq. 12}$$

Table 3. *Indices of Diversity and Evenness*

Index	Equation	Description
Diversity		
Shannon	$H' = -\sum_{i=1}^{s}(p_i \times \log_2 p_i)$	pi (ni/N) is the proportional abundance of each species. Log is the logarithm (base 2).
Hill	$N_1 = e^{\text{Shannon–Wiener}} = e^{H'}$	H' is Shannon diversity index based on the log (base 2).
	$N_2 = \frac{1}{\lambda} = \frac{1}{\sum_{i=1}^{s} pi^2}$	λ is Simpson diversity.
Evenness		
Shannon	$E = \frac{H'}{H_{max}} = \frac{H'}{log_2 S}$	S is species richness.
Hill	$E_{20} = \frac{N_2}{N_0}$	N_2 is Simpson Diversity Index, N_0 total number of species present in a sample.

5.5. Statistical analysis

Rangelands are a valuable global natural resource, and their management requires an understanding of plant identification (taxonomy), botany, ecology, physiology. Rangeland science is related to bioclimatology, soil science, geology, hydrology, animal science, sociology, economy, modelling and statistics.

A knowledge of statistics is needed to meaningfully assess rangelands and achieve the desired goals. Reliable and valid results depend on rigorous methods of sampling, measurements, data entry and statistical analysis.

Example using SPSS

There are two ways to enter data into SPSS, i) typing the data directly into SPSS, ii) enter the data into Excel then import the Excel file into SPSS.

Steps in one-factor ANOVA

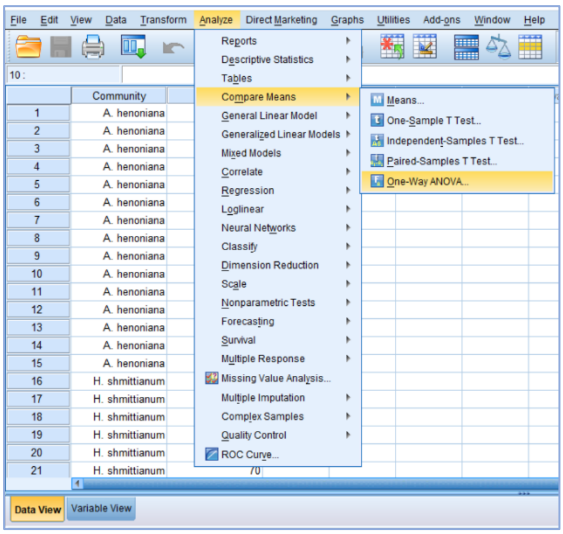
The one-way analysis (ANOVA) is usually used to compare the means of two or more groups that vary on a single independent variable and to determine whether there are any statistically significant differences between the means of two or more independent groups.

Example: comparing four plant communities (*Anthyllis henoniana, Haloxylon schmittianum, Stipagrostis pungens* and *Retama raetam*) to see if there are any differences in vegetation cover and if the vegetation type affects the variation of vegetation cover. Fifteen samples are taken in each plant community.

- The dependent variable can be different indicators, such as vegetation cover, height of plant, number of species, biomass, pastoral value, density and diversity.
- The independent variable is not affected by any other variable in the experiment. Common examples of independent variables in rangeland ecology are the age of protection, season, soil type, vegetation type, and technique of restoration.

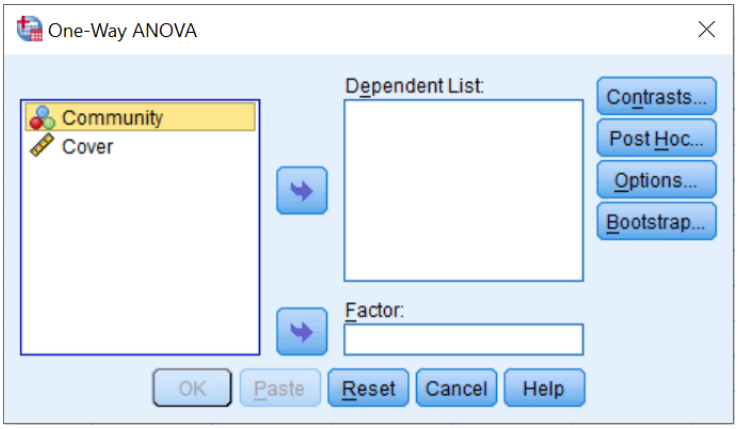
Steps to running ANOVA using SPSS

On the top menu of the SPSS software, **Analyze** > **Compare Means** > **One-Way ANOVA**

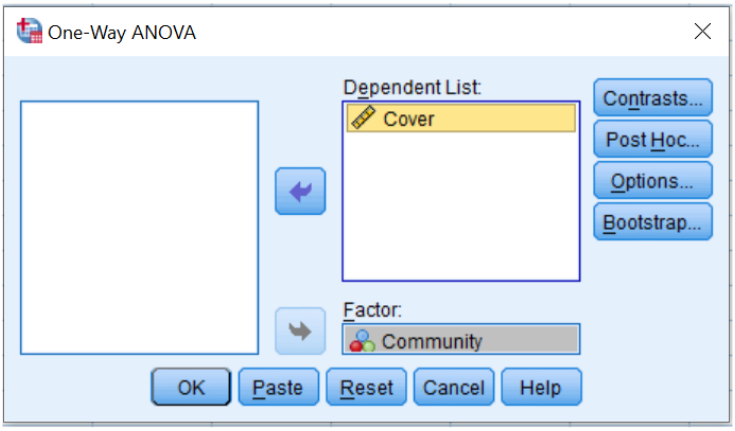


Click on the One-Way ANOVA.

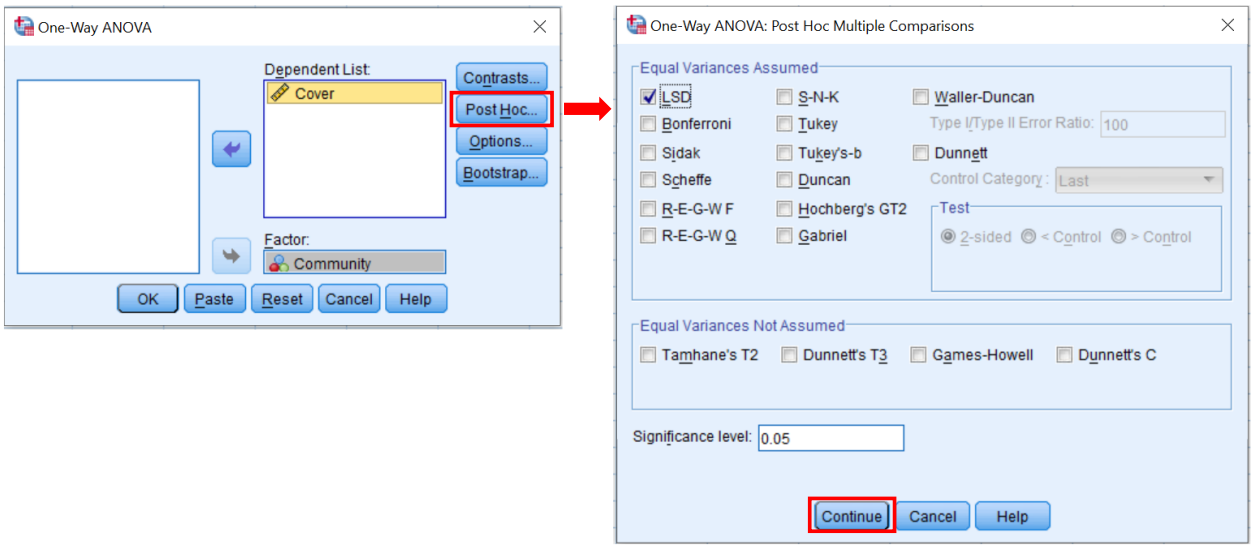
A dialogue box will open.



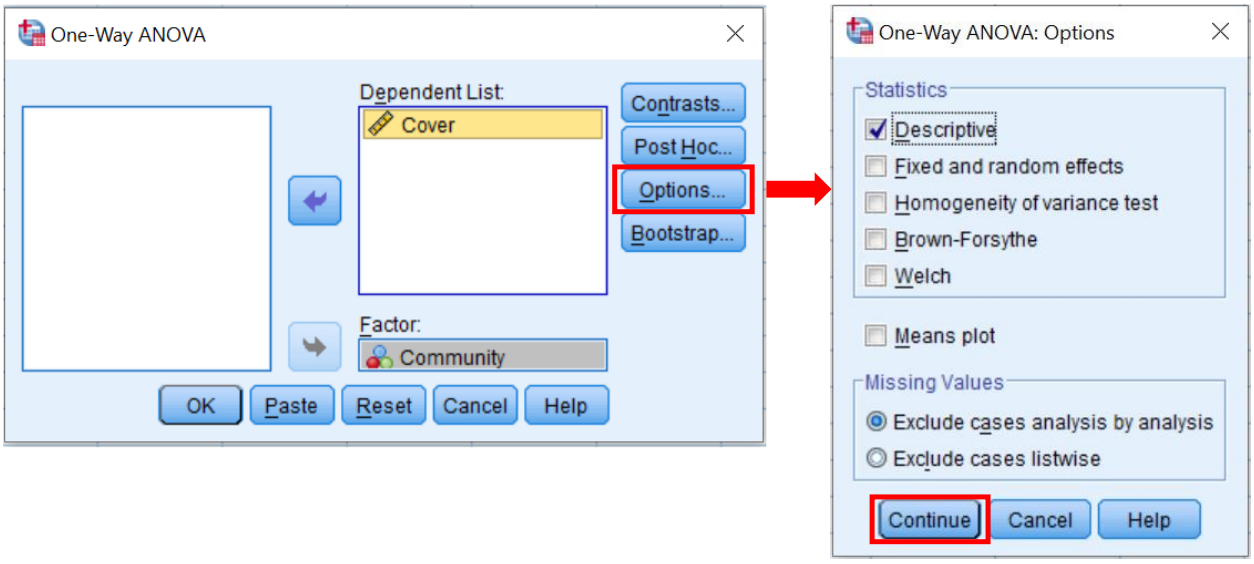
Move the dependent variable, Cover, into the window **Dependent List**, and the independent variable, **Community**, into the window **Factor** using the Right arrow buttons or drag-and-drop the variables into the boxes.



Click on the Post hoc button. This will bring up a new window. Select the LSD checkbox. Click on the Continue button.



Click Options. This will bring up a new window. Select the Descriptive checkbox in the Statistics group, then click Continue.
Click OK to run the ANOVA test.



Output of One-Way ANOVA

The results are presented in the output window of SPSS in three tables:

1. The descriptive table shows the mean, standard deviation and 95% confidence intervals for the dependent variable (in this case, cover) for each separate group (*A. henoniana, H. schmittianum, S. pungens* and *R. raetam)*, as well as when all groups are combined (Total).

Descriptives

Cover

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A. henoniana	15	55.27	12.360	3.191	48.42	62.11	36	79
H. shmittianum	15	69.20	16.402	4.235	60.12	78.28	44	91
S. pungens	15	81.67	9.649	2.491	76.32	87.01	60	97
R. raetam	15	71.07	16.015	4.135	62.20	79.94	46	94
Total	60	69.30	16.516	2.132	65.03	73.57	36	97

The ANOVA table has the outputs of the one-way ANOVA test. The table shows degrees of

ANOVA

Cover

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5295.000	3	1765.000	9.152	.000
Within Groups	10799.600	56	192.850		
Total	16094.600	59			

The mean are significantly different, F (3,56) = 9.152, P = 0.000

freedom (df), the F statistic (F) and the significance value (Sig.). In this example, the significance value is below 0.05, which means a statistically significant difference in the mean cover of the plant communities.

The Multiple Comparisons table shows which plant communities differed from the others. The LSD post hoc test is generally the useful test for conducting post hoc tests on a one-way ANOVA. In the table below, that there is a statistically significant difference in cover between all communities ($p > 0.05$), except between *H. shmittianum* and *R. raetam* where there were no differences ($p = 0.714$).

Multiple Comparisons

Dependent Variable: Cover

LSD

(I) Community	(J) Community	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A. henoniana	H. shmittianum	-13.933*	5.071	.008	-24.09	-3.78
	S. pungens	-26.400*	5.071	.000	-36.56	-16.24
	R. raetam	-15.800*	5.071	.003	-25.96	-5.64
H. shmittianum	A. henoniana	13.933*	5.071	.008	3.78	24.09
	S. pungens	-12.467*	5.071	.017	-22.62	-2.31
	R. raetam	-1.867	5.071	.714	-12.02	8.29
S. pungens	A. henoniana	26.400*	5.071	.000	16.24	36.56
	H. shmittianum	12.467*	5.071	.017	2.31	22.62
	R. raetam	10.600*	5.071	.041	.44	20.76
R. raetam	A. henoniana	15.800*	5.071	.003	5.64	25.96
	H. shmittianum	1.867	5.071	.714	-8.29	12.02
	S. pungens	-10.600*	5.071	.041	-20.76	-.44

*. The mean difference is significant at the 0.05 level.

There was a significant difference in vegetation cover between plant communities as determined by one-way ANOVA ($F(3,56) = 9.152$, $p < 0.05$). Specifically, *A. henoniana* (55.266±3.191), *H. schmittianum* (69.2±4.235), *S. pungens* (81.666±2.491) and *R. raetam* (71.066±4.135) communities were significantly different from each other ($p < 0.001$). Between *H. schmittianum* and *R. raetam* ($p = 0.714$), there was no significant difference.

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Annex 1. How to use the reference unit method to measure the biomass of trees and shrubs.

Clip one tuft or branch of each perennial species as a standard unit. This becomes the reference branch or experimental unit for sampling (Figure 24). Estimate the number of branches per pant. Dry the reference branches at 80 degrees Centigrade or 48 hours to get the dry matter content in kilograms.

Get the total biomass of each species by multiplying the biomass of the reference unit by the estimated number of branches of the individual plant, multiplied into the density of the species.