



Sampling methods in ecology

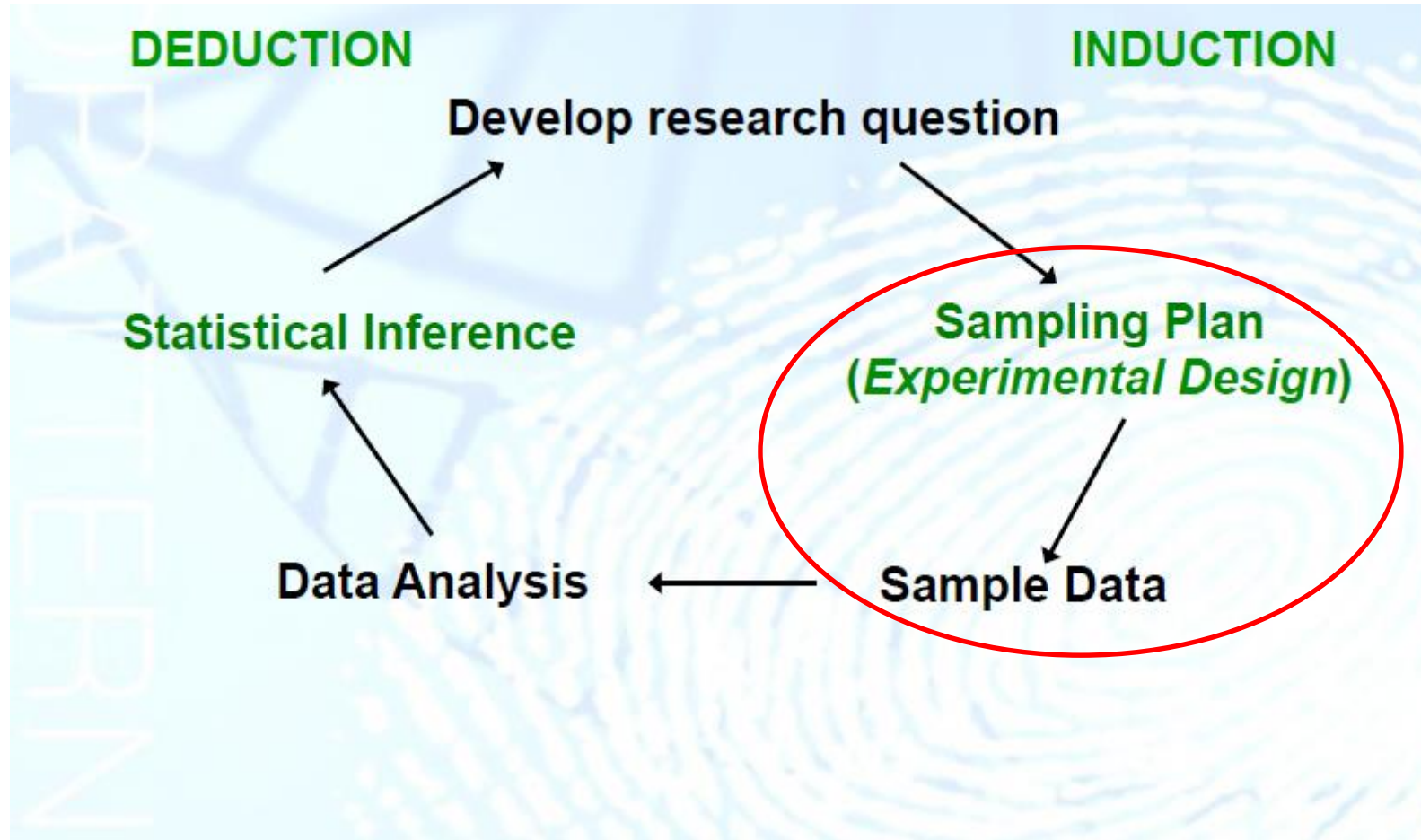
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Questions addressed in the lesson

1. What is a sampling?
2. What is the population of interest and why is it important to have an appropriate sampling unit?
3. What is an appropriate sampling unit size and shape?
4. How should sampling units be positioned?
5. Should sampling units be permanent or temporary?
6. How many sampling units should be sampled?

The research cycle



The research cycle

1. Recognition and choice of the hypothesis to be tested
2. Choice of factors, levels and so on
3. Selection response variable
4. Choice of design
5. Conducting experiment/observations
6. Statistical inference
7. Drawing conclusion and recommendations

Study design

Two major types of studies:

1. **Observational:** investigators observe subjects and measure variables of interest without assigning treatments to the subjects. The treatment that each subject receives is determined beyond the control of the investigator.
2. **Experimental:** investigators apply treatments to experimental units (people, animals, plots of land, etc.) and then proceed to observe the effect of the treatments on the experimental units.

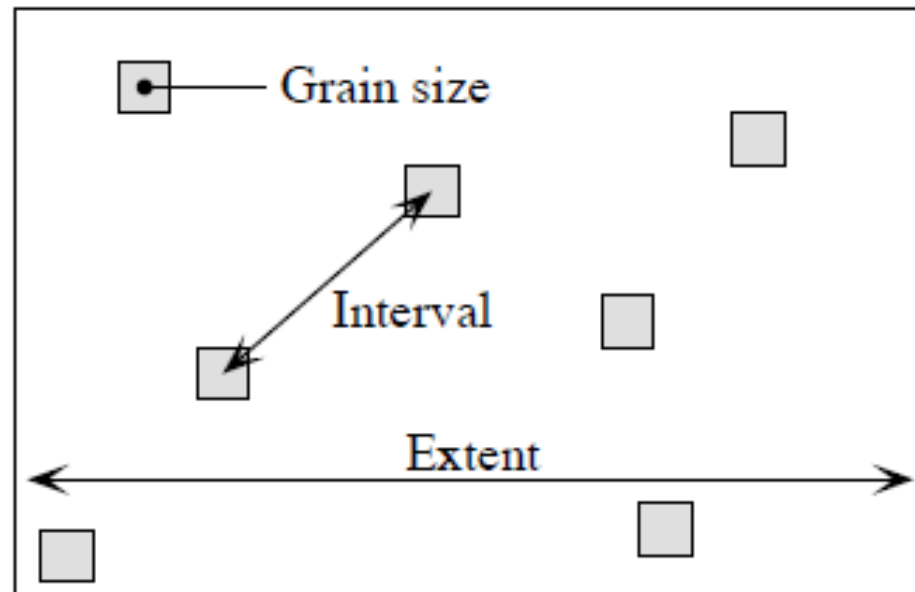


Key concepts

Grain size: is the size of the elementary sampling units. It may be expressed as the diameter, surface or volume of matter supporting the measurements.

Sampling interval: is the average distance between neighbouring sampling units.

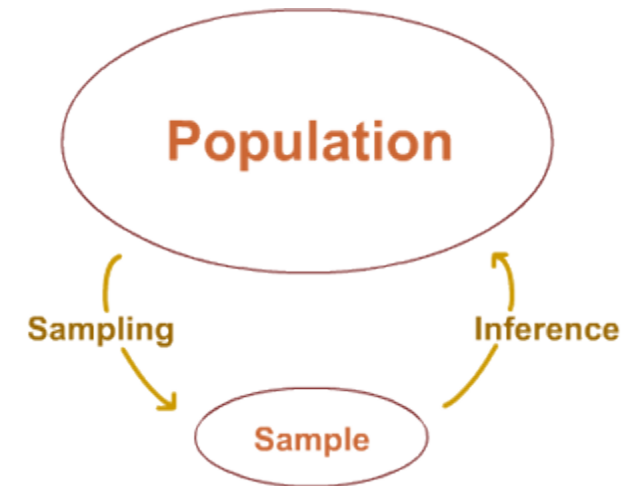
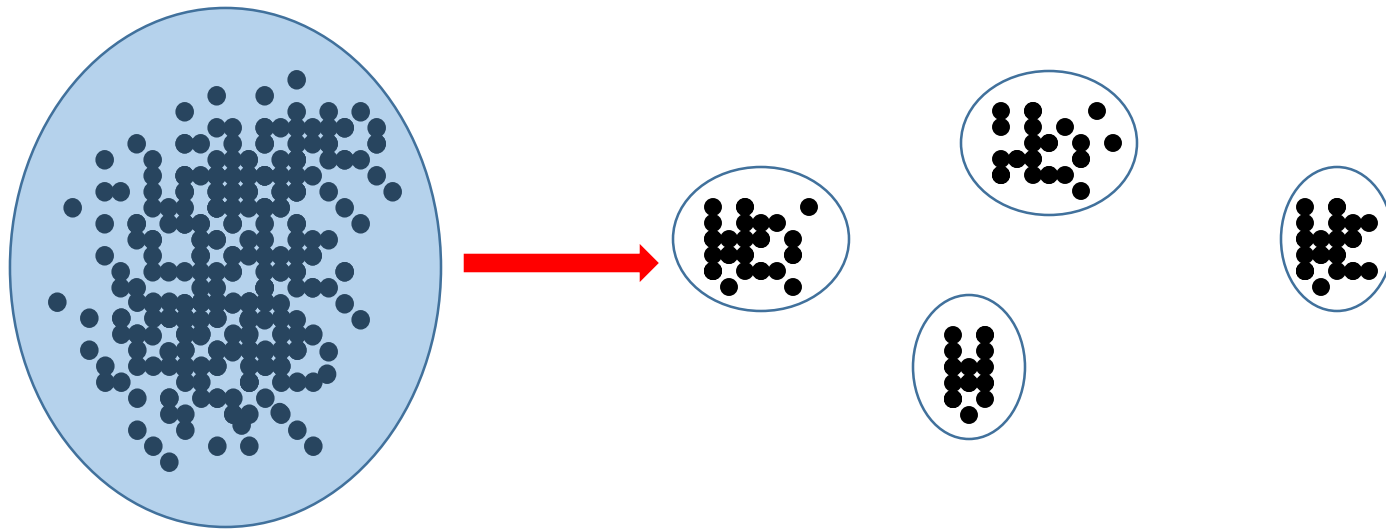
Extent: is the total length, area or volume included in the study.



What is sampling?

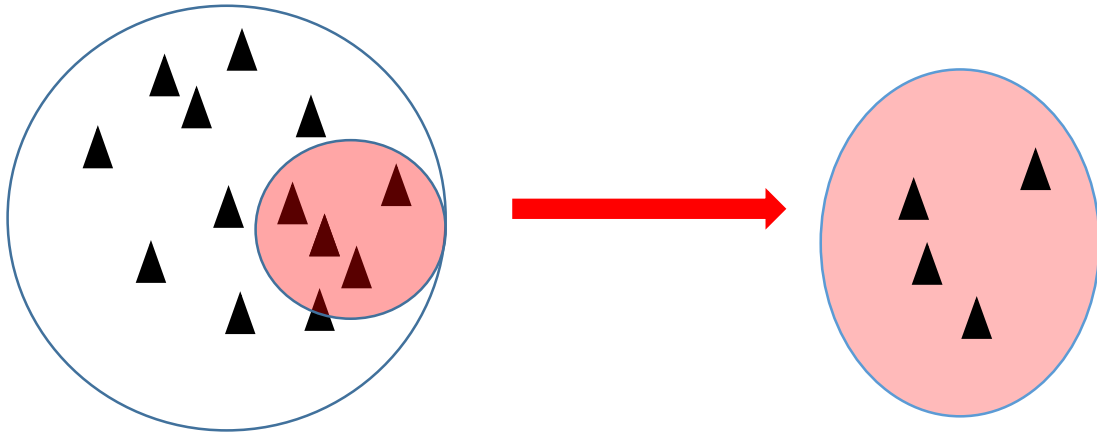
Sampling is that part of statistical practice concerned with the selection of individual observations intended to yield some knowledge about a population of concern.

The aim of the sampling is making inference on the population of interest, this allow us to make generalization including some measures of “goodness of fit”



What is sampling? – Basic concepts

- Random



All the sampling units must have the same probabilities to be sampled!

What is sampling? – Basic concepts

- Replication

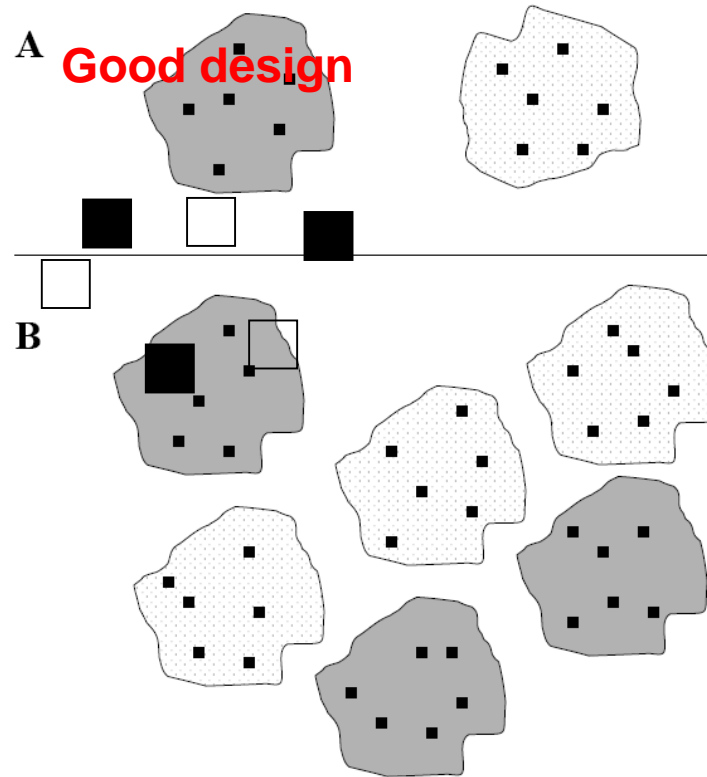
- To make inference I need a correct number of replicates
- Replicates must be **independent** meaning that the position of a sampling unit doesn't influence the position of the others (**not correlated**)

Degrees of Freedom	$\alpha = 0.05$
1	12.71
2	4.30
3	3.18
4	2.78
5	2.57
6	2.45
7	2.36
8	2.31
9	2.26
10	2.23
11	2.20
12	2.18
13	2.16
14	2.14
15	2.13

- Pay attention to **pseudoreplication!**

Pseudoreplication

Pseudoreplication: effect of a factor that is studied using a source of variability not appropriate to study the hypothesis under investigation



Bad design

Fig. 6 - Confusione negli esperimenti di predazione e rimozione del problema.

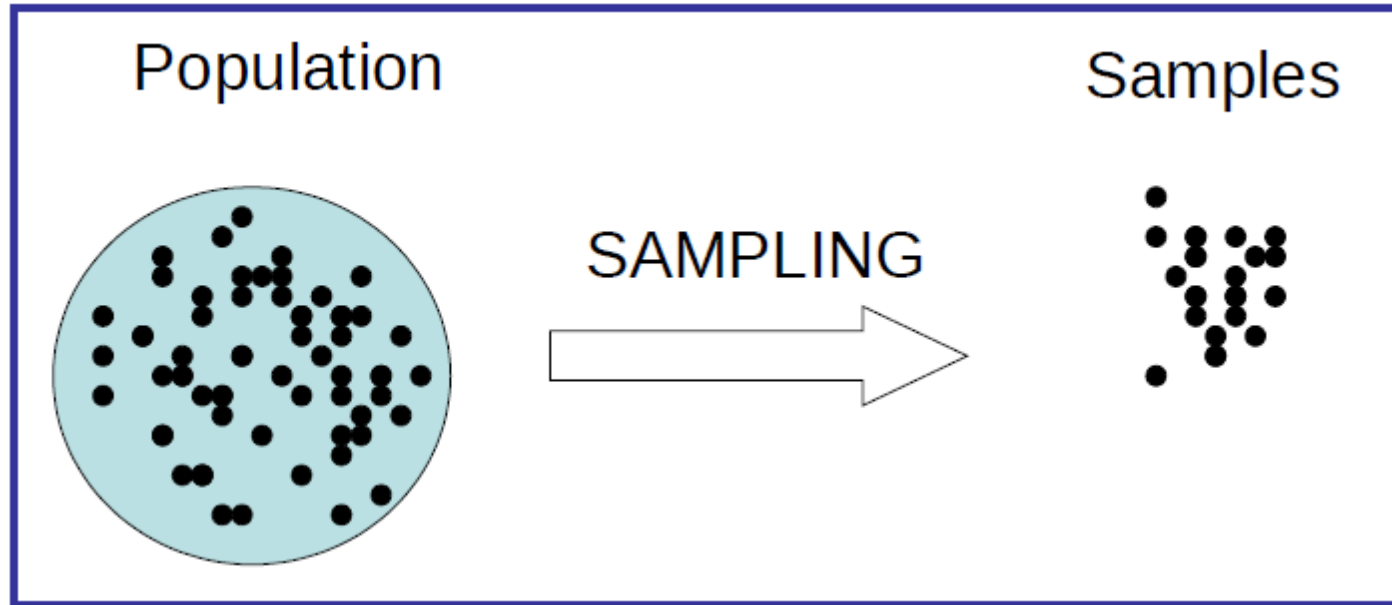
- Predatore presente;
- Predatore rimosso.

(A) Rappresentazione schematica di un esperimento fuso. Il predatore viene rimosso da una singola area mentre viene lasciato a densità naturale in un'altra area. L'abbondanza della preda è valutata in unità di campionamento replicate all'interno di ciascun'area. Questo disegno confonde l'effetto del predatore con la variabilità intrinseca tra area ed area.

(B) Esperimento corretto. Vi sono più aree replicate per ciascun livello del fattore predatore e più unità di campionamento in ciascun'area. La replicazione delle aree permette di separare l'effetto area dall'effetto del predatore. Si veda il testo per ulteriori dettagli.

What is the population of interest?

- Target vs. sampled population



Sampling vs. Non-sampling errors?

In any study errors should be minimized

Sampling errors and bias

Induced from your sampling design, result from chance (**random sampling error**) or when the selection of individuals, groups or data for analysis in such a way that proper randomization is not achieved, thereby ensuring that the sample obtained is not representative of the population intended to be analyzed (**selection bias**).

Non-sampling errors

These errors are associated with human, rather than chance, mistakes:

- 1) Using biased selection rules, such as selecting "representative samples" by subjectively locating sampling units, or by substituting sampling units that are "easier" to measure
- 2) Using vegetation measurement or counting techniques within sampling units in which attributes cannot be accurately counted or measured
- 3) Inconsistent field sampling effort
- 4) Transcription and recording errors
- 5) Incorrect or inconsistent species identification

What is an appropriate sampling unit size and shape?

- The type of sampling unit you select depends on the vegetation attribute you are measuring, the most common are density, cover, frequency, and biomass. Attributes related to individual plants (e.g. height, number of flowers per plant) are also often of interest.
- The most efficient design is usually the one that yields the highest statistical precision (smallest standard error and narrowest confidence interval around the mean) for either a given area sampled or a given total amount of time or money.

Main types of sampling units

Individuals: Individuals are the sampling units for attributes such as plant height, number of flowers per plant, or cover if the cover measurements are made on individual plants (e.g., tree stem diameters, bunchgrass basal area measurements).

Object parts: Fruits might be the sampling units if the attribute is the number of seeds per fruit or the percentage of fruits containing some seed herbivore. Or, you may be interested in estimating the number of flowers per inflorescence, in which case the inflorescence is the sampling unit.

Quadrats (plots): Sampling unit of constant size. Most estimates of density, frequency, or biomass require the use of quadrats, which represent the sampling units. Quadrats can also be the sampling units for cover measurements if visual estimates of cover are made within quadrats.

Lines (transects): When cover is measured using the line-intercept method, the line is the sampling unit. Lines can also serve as sampling units when points (for cover) or quadrats (for cover, density, or frequency) are positioned along lines and the points or quadrats are not far enough apart to be themselves considered the sampling units (because they are not independent of one another).

Point frames or point quadrats: When cover is measured using point frames or point quadrats and these frames or quadrats are randomly positioned, then the point frames or point quadrats are the sampling units. Point frames are not recommended because they are inefficient for measuring cover in most vegetation types.

Attributes measured using quadrats

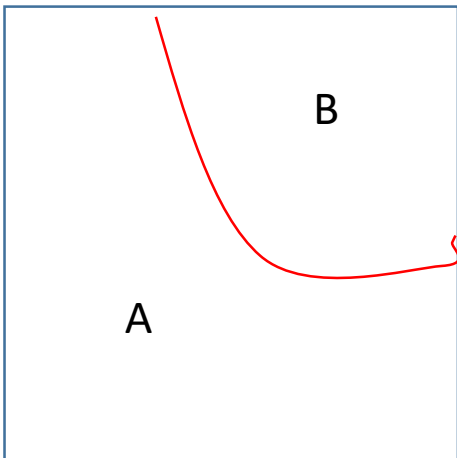
Quadrats are required for estimating several vegetation attributes including:

Density - for counting the number of objects within the unit area of the quadrat.

Biomass - achieved by "clipping" all the material of a given type (e.g., grass, shrub or forb) or species within a quadrat.

Cover - often accomplished by estimating the area of a quadrat that is covered by a plant's canopy.

Frequency - the proportion of quadrats in which a species occurs is called frequency, thus quadrats are required to estimate plant frequency.

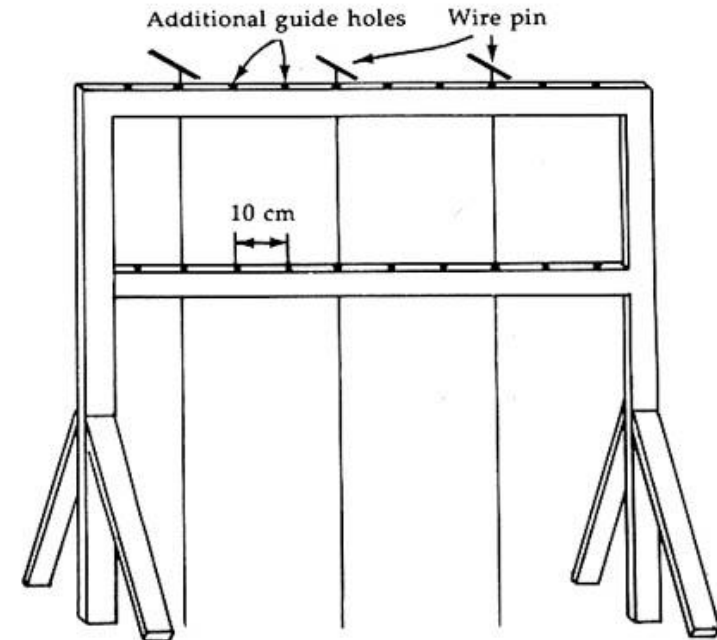


Point sampling methods to measure cover

Point frame

The frame is set up over the vegetation and the needles are lowered down through the plant canopy.

- Every time the point of a needle touches a plant, a “hit” is recorded with the species name.
- The needle can make several hits before it eventually touches the ground surface.
- % cover of species A = (No. of hits that intercept species A) / (No. of points)
- This is the only point sampling method that can give an accurate estimate of absolute cover of each species in multistratose vegetation, and hence an estimate of total leaf area for each species.
- It is, however, a very time consuming method.

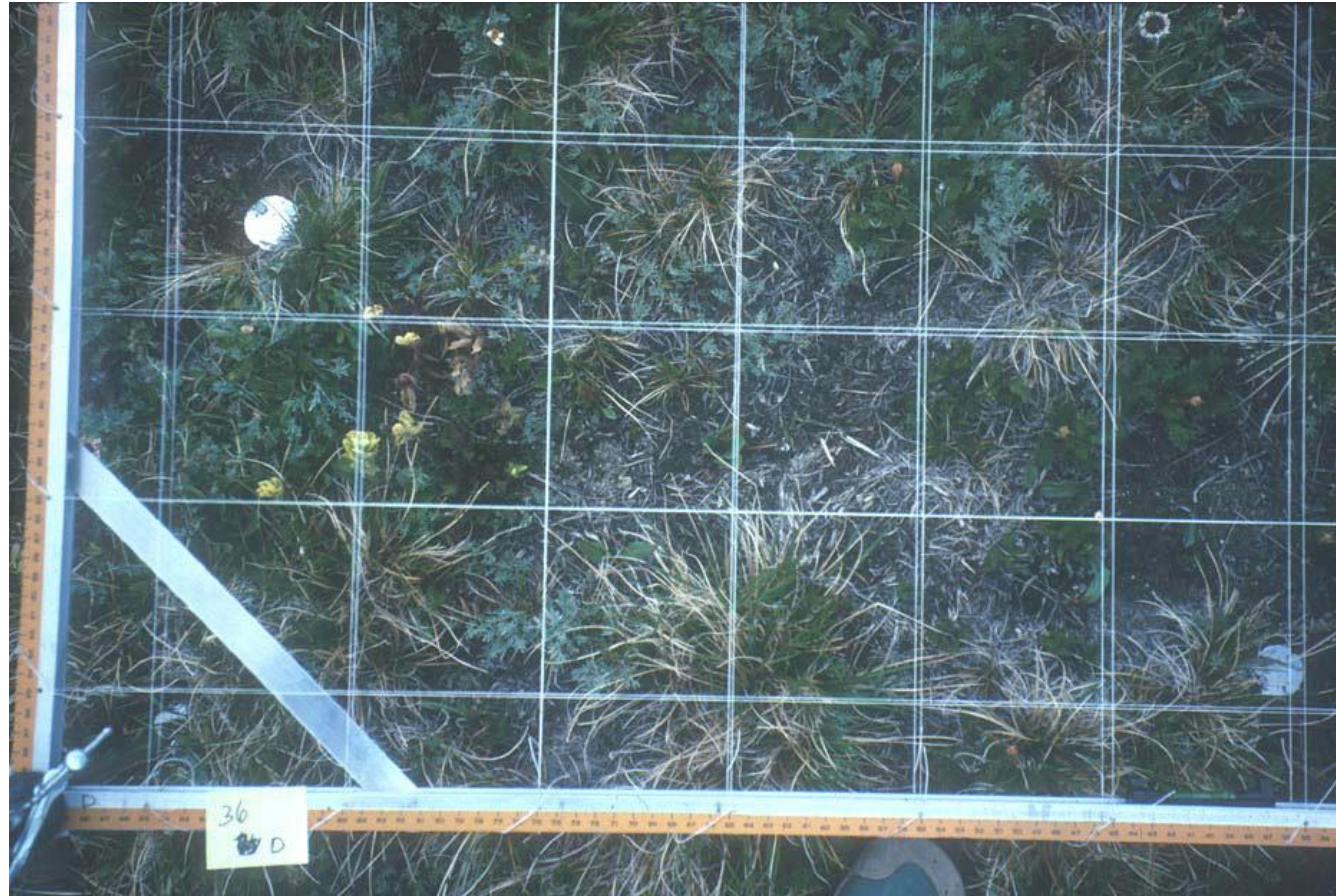


Point sampling methods to measure cover

Point quadrat

This device is very useful for low-growing graminoid or dwarf shrub vegetation.

- In sampling a point, the intersections between strings in the upper and lower grid are visually aligned so as to avoid the problem of parallax.
- The percent cover for a species in each layer of the canopy is simply the number of hits out of 100.



What shape of quadrat should be selected?

Rectangle

- Generally best for "clumped" vegetation. Often have lower variance than squares or circles.
- Can reduce plot to plot variability in sparsely vegetated communities.
- Easier to estimate % cover than in circles or squares.

Square

- Greater perimeter:area ratio than circles but less than rectangles.
- Most typically used to estimate frequency because presence/absence is easy to estimate.
- Squares are easier to estimate % cover than circles but not as easy as rectangles.

Circle

- Less perimeter (per area) than square or rectangle.
- Often used in clipping because perimeter decisions are difficult to make when clipping.
- Reducing perimeter:area ratio is also good in communities with large sod-forming plants.

Factor to consider when taking samples

Edge effect: The edge of a quadrat is its outer boundary. The more edge a quadrat has, the greater the difficulty in determining whether plants near the edge are in or out of the quadrat. Rectangular quadrats have more edge per unit area than squares or circles.

You can choose between two simple conventions that help to minimize the non-sampling error associated with plants landing right on the edge:

1. count every other plant that lands right on the edge as “in” and every other one as “out”,
2. specify that any plant that lands on the edge of two adjoining sides of the quadrat is considered “in” while any plant landing on the other two adjoining sides is “out.”

You need to be consistent in applying whichever convention you choose!

Factor to consider when taking samples

Objective of study: parameter estimation vs. pattern detection

Table 1. Dichotomous sampling alternatives in plant ecology.

Kenkel et al., 1989

Objective of the study	Number of variables	Nature of sampling universe	Examples
Parameter estimation	Univariate	Discrete Continuous	Tree height, seed production per plant Cover, density, biomass and diversity estimation by plots. Random plant methods for estimating density and cover.
	Multivariate	Discrete Continuous	Estimation of the mean vector of morphological variables. Estimation of the mean vector of cover values.
Pattern analysis	One population Community	Discrete	Random plant methods.
		Continuous	Quadrat-variance methods. Random points methods.
		Discrete	Ordination or classification of discrete entities (islands, lakes, epiphytic assemblages, etc.)
		Continuous	Florula diversity, resemblance, pairwise interspecific correlation. Ordination and classification of plots.

Factor to consider when taking samples

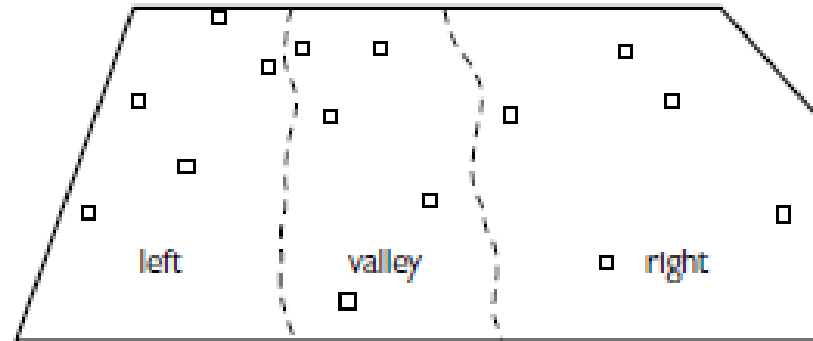
- Travel and setup time vs. searching and counting time
- Spatial distribution of individuals in the population
- Density of target population
- Ease in sampling
- Disturbance effects

How sampling unit should be positioned in the population?

- **Random sampling.** Critical to a valid monitoring study design is that the sample has been drawn randomly from the population of interest.

Preferential sampling, the practice of subjectively selecting sampling units, should be avoided at all costs!

- **Interspersion.** One of the most important considerations in sampling is good interspersion of sampling units throughout the area to be sampled (the target population). The basic goal is to have sampling units well interspersed throughout the area of the target population. The practice of placing all the sampling units, whether they be quadrats or points, along a single or even a few transects should be avoided. Arranging sampling units in this manner results in poor interspersion of sampling units and the sample will not adequately represent the target population. This is true even if the single transect or few transects are randomly located.

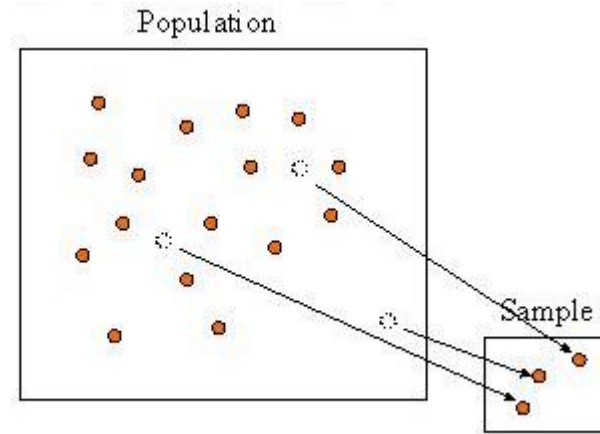


Sampling methods in ecology

1. Simple random sampling
2. Stratified random sampling
3. Systematic sampling
4. Restricted random sampling
5. Cluster sampling
6. Two-stage sampling
7. Double sampling

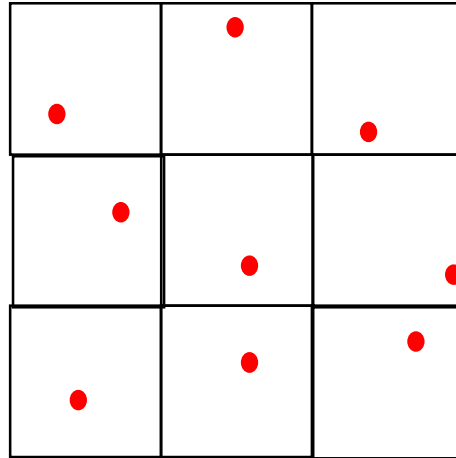
Simple random sampling

- Each combination of a specified number of sampling units has the same probability of being selected
- The selection of any one sampling unit is in no way tied to the selection of any other



Simple random sampling

- Random points
- Grid-cell method



Simple random sampling

Useful in relatively small areas with homogeneous habitat, not too much sampling units.

Pros

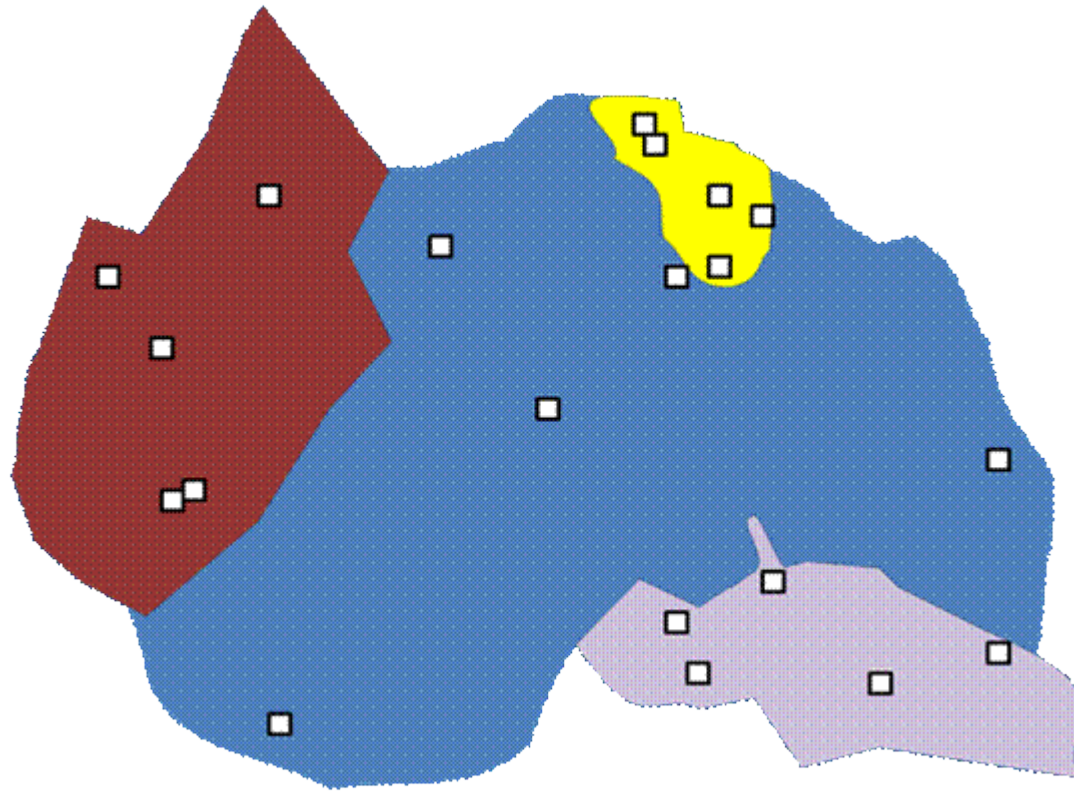
- Simplest kind of random sampling
- The formulas used to calculate means and standard errors are easier

Cons

- By chance, some areas may be left unsampled
- Consider travel time if the area/sample size is large
- If population have clumped distribution, it is better to use others sampling methods

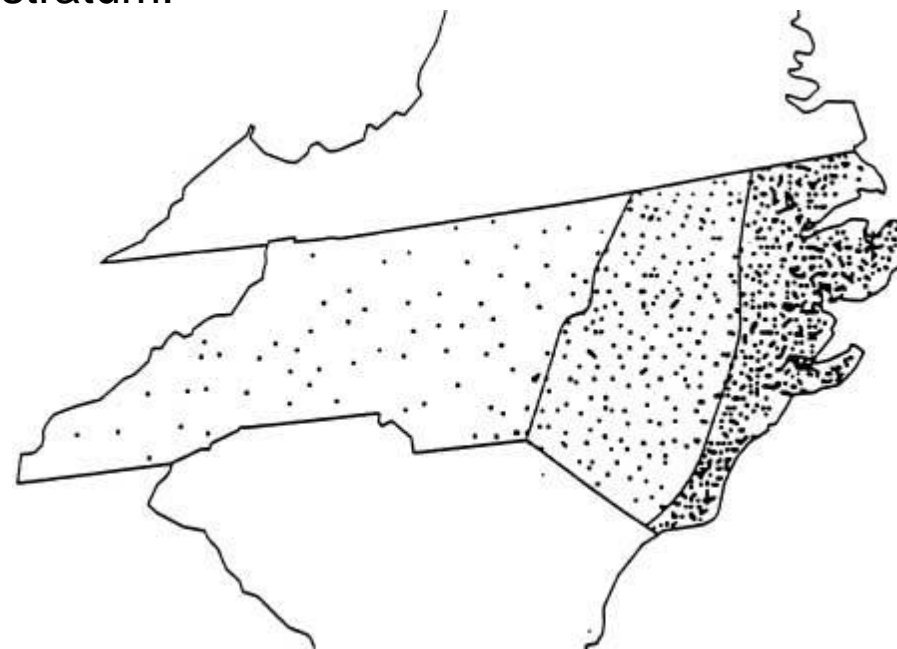
Stratified random sampling

- This method involves dividing the population into two or more subgroups (*strata*) prior to sampling.
- Strata are generally delineated in such a manner that the sampling units within the same stratum are very similar, while the units between strata are very different. Simple random samples are taken within each stratum



Stratified random sampling

- It is very important to **well define the strata**.
- Strata should be defined based on the response of the attribute you are estimating to habitat characteristics that are unlikely to change over time
- If there is no obvious reason for the difference in your area under investigation, you're probably better off using a simple random sampling procedure
- Sampling units do not have to be allocated in equal numbers to each stratum.
 - equally to each stratum;
 - In proportion to the size of each stratum;
 - In proportion to the number of target individuals in each stratum;
 - in proportion to the amount of variability in each stratum.



Stratified random sampling

Useful when the attribute of interest responds very differently to some clearly defined habitat structure. The recommendations within strata are the same of simple random sampling

Pros

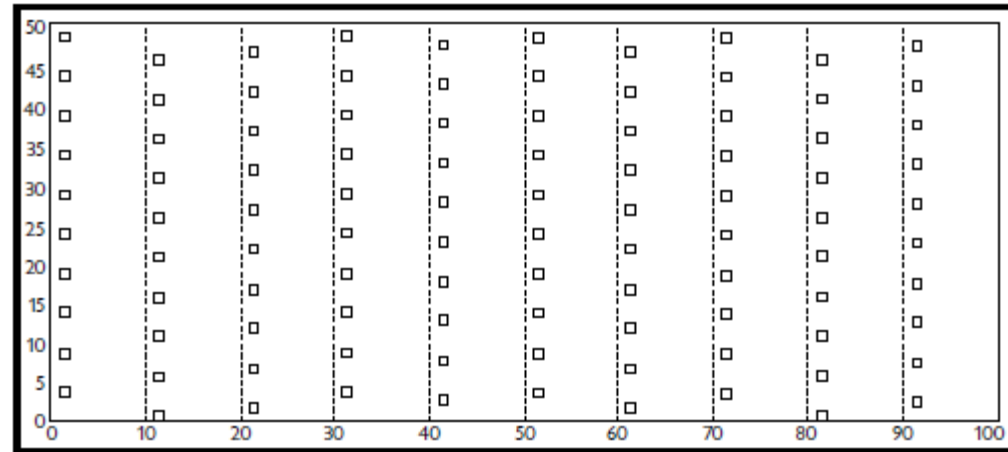
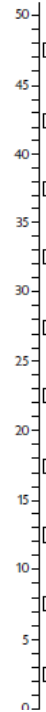
- More efficient in population estimate than simple random sampling if there is a strong variation according to habitat features

Cons

- If geographic area within stratum is large as well as the number of sampling units, it is better to use others sampling methods
- As before, by chance some areas within each stratum may be left unsampled.

Systematic sampling

- Often used when the area being studied is varied, not very large, or when time is available
- Samples are taken at fixed intervals
- Systematic samples are usually taken along a transect line marked by a tape measure
- The starting point for the regular placement is selected randomly



Consider spacing among quadrats to fulfill independence!

Systematic sampling

- Several factors can affect sampling spacing such as:
 - The average size of gaps (especially in forests),
 - The average size of individual plants
 - The size of areas of clones
 - The size and distribution of microsites
- In general, sampling units should be far enough apart that they do not fall into the same microsite, gap, or clone. This, however, is scale dependent.
- ***Probably the best way to determine spacing of sampling units along transects is to consider the degree of interspersion of your design***

Systematic sampling

Line transect: A measured line is laid across the area in the direction of the environmental gradient. The species touching the line can be recorded along the whole length of the line (continuous sampling) or at specific points along the line (systematic sampling)


Belt transect: Similar to line transect but widens the sampling area– Transect line is laid out– Samples are taken by determining abundance or % cover in an area that is a defined distance from the line. Samples can be taken all the way along the line, at specific intervals or even randomly



Systematic sampling

Useful for any sampling situations, as long as the first **the first sampling unit is selected randomly** and sampling units can be considered **independent (spaced enough)**.

Pros

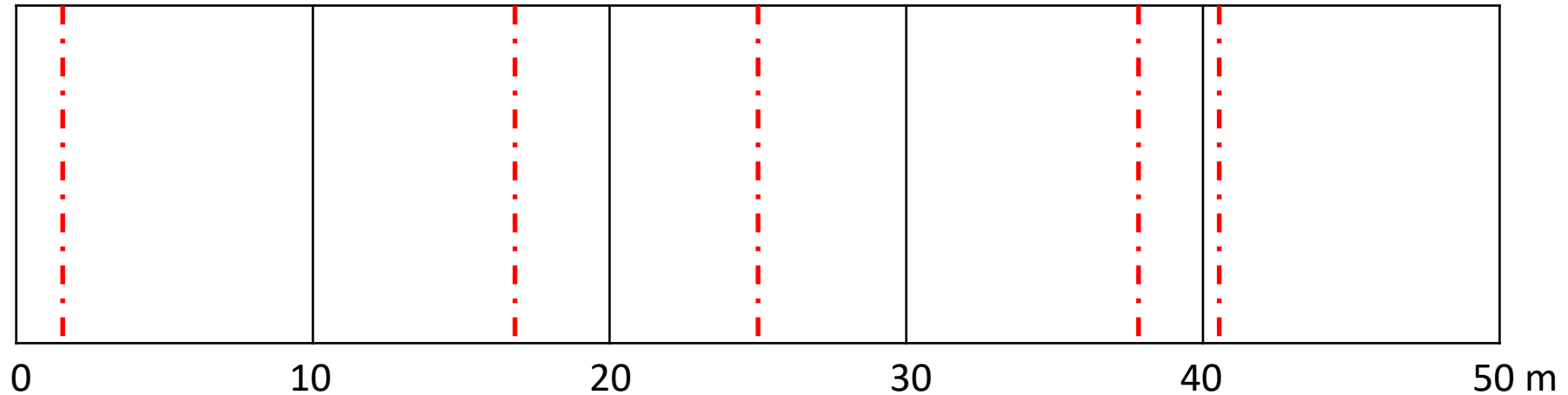
- If the conditions above are respected, this is the best sampling method.
- Investigator can sample evenly across a whole area  **Interspersion** is ensured
- Data gathered can be considered uniform

Cons

- If the number of samples is less than 25-30, the results can be questionable
- It is undesirable if the pattern of the sampling units intersects some pattern in the environment

Restricted random sampling

You determine the number of sampling units, n , you will need to meet your monitoring objective, then divide your population into n equal-sized segments. Within each of these segments, a single sampling unit is randomly positioned. The sample of n sampling units is then analyzed as if it were a simple random sample.



Restricted random sampling

Should be used only if the number of potential samples $< 25-30$, otherwise use systematic sampling

Pros

- Ensure interspersion
- The formulas used to calculate means and standard errors are easier

Cons

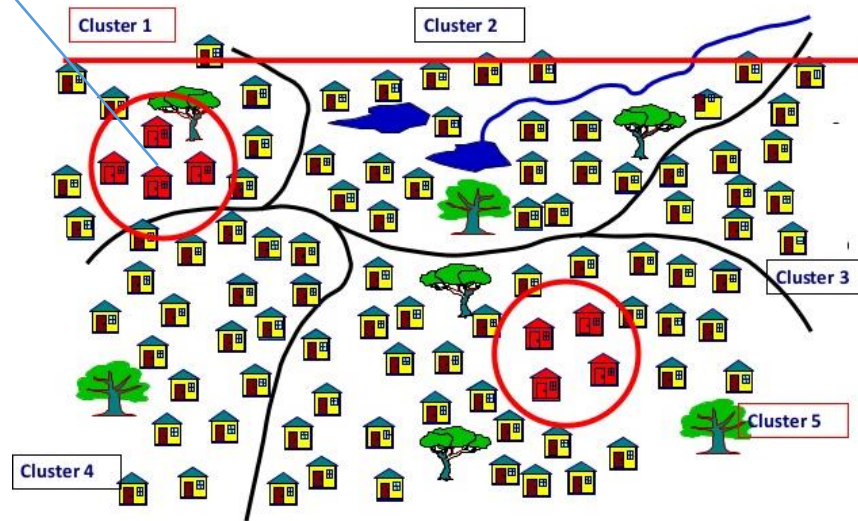
- Not so efficient if samples $> 25-30$
- You can, purely by chance, end up with sampling units positioned side-by-side.

Cluster sampling

Cluster sampling is a method of selecting a sample when it is difficult or impossible to take a random sample of the individual elements of interest.

We identify randomly groups of quadrats (clusters)

We then **measure every element** within each of the randomly selected clusters



Cluster sampling

Generally used when interested in individual characteristics (e.g. mean height of rare trees)

Pros

- Less costly to sample collection of elements in a cluster (more cost-effective) than sampling an equal number of elements selected randomly from the population

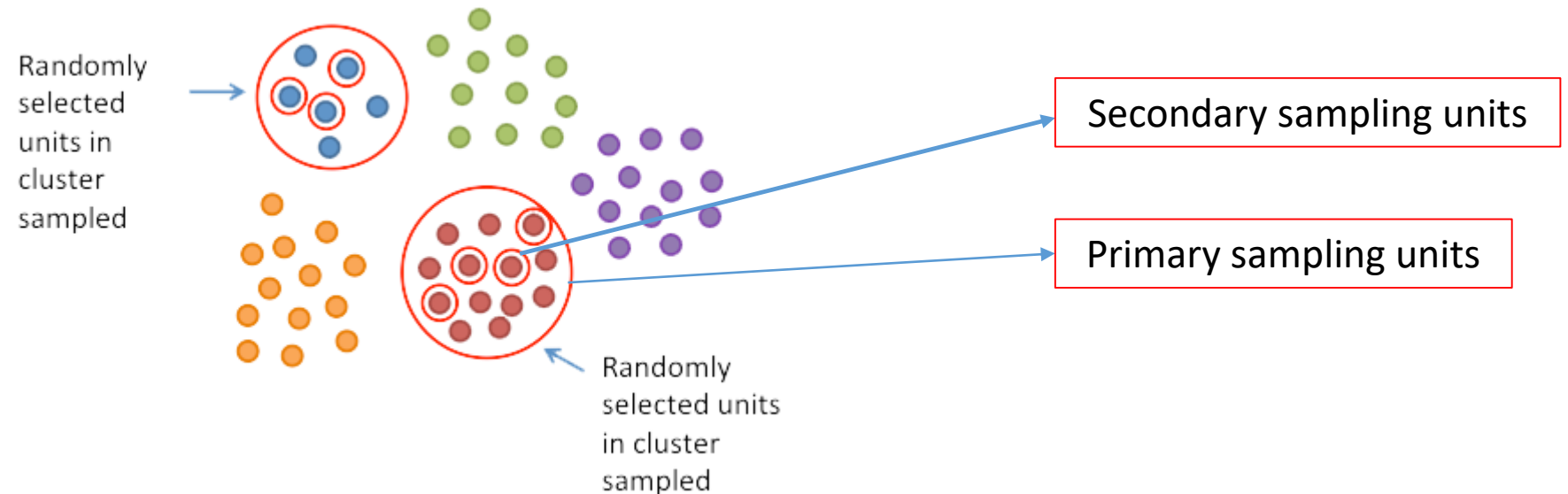
Cons

- Can be time-consuming (you must measure all elements in the cluster)
- If clusters contain a lot of elements, it is more efficient to use two-stage sampling
- Difficulties in determining how many clusters are needed and their sizes

Two-stage sampling

Two-stage sampling is similar to cluster sampling in that we identify groups of elements about which we wish to make inferences.

We then take a **random sample** of these groups



The secondary sampling units can be either a simple random sample of elements or a systematic sample of elements

Two-stage sampling

Similar to cluster sampling in identifying groups; used to estimate values associated with individuals

Pros

- The same of cluster sampling, 2-stage is preferred/more efficient when the number of individuals in each group (quadrat) is large
- Cost effective

Cons

- Standard deviations associated both at primary and secondary sampling units
- If clusters contain a lot of elements, it is more efficient to use two-stage sampling
- Difficulties in determining how many clusters are needed and their sizes

Double sampling

Double sampling, sometimes called two-phase sampling, involves the estimation of two variables.

Because one of these variables, the variable of interest, is difficult or expensive to measure, it is measured in only a relatively small number of sampling units. In order to improve the rather poor precision of the estimate that normally results from a small sample, an auxiliary variable that is much easier to measure and well correlated with the other variable is estimated in a much larger number of sampling units.

Pros

- If the auxiliary variable is relatively quick to measure and is highly correlated with the variable of interest, double sampling is much more efficient and cost effective than directly measuring the variable

Cons

- Some difficulties in data analysis

Should sampling units be permanent or temporary?

When sampling units are temporary, the random sampling procedure is carried out independently at each sampling period.

The principal advantage of using permanent instead of temporary sampling units is

- For many plant species, the statistical tests for detecting change from one time period to the next in permanent sampling units are much more powerful
- Reduction in the number of sampling units that need to be sampled to detect a certain magnitude of change

Permanent sampling unit

Permanent sampling units will be the most advantageous when there is a high degree of correlation between sampling unit values between two time periods

One is the time and cost required to permanently mark the units.

Even when the markers are still in place, they may be difficult to find

Impacts either from investigators or from animals may bias your results

You need at least two years of data

How many sampling units should be sampled?

Adequacy relates to the ability of the observer to evaluate whether the management objective has been achieved. To choose an adequate number of sampling unit consider:

1. Study aims

If you are targeting point-in-time estimates (parameter estimation), you need to specify how precise you want your estimates to be. If you are trying to detect changes in some average value, you need to specify the magnitude of the change you wish to detect

2. Sample size should be based on the amount of variability in actual measurements

You should assess this variability during pilot sampling

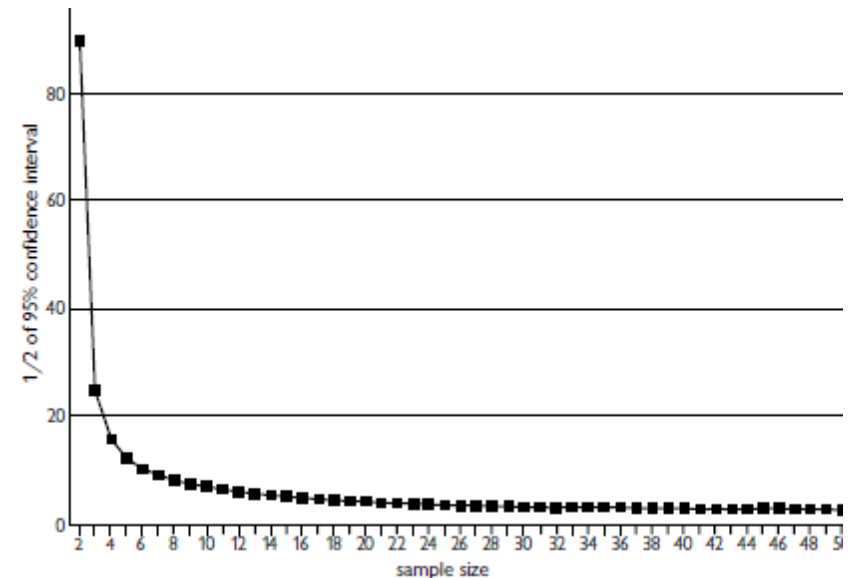
3. Relationship of sample size to precision level

Precision increases with sample size, but not proportionately

4. Use data from similar studies to estimate the standard deviation

5. By professional judgment

6. Using computer programs



Conclusions

- Before starting **set your aims/priorities!**
- Clearer is the question, easier is the sampling, simpler is the statistics to be applied
- If you have blurry and foggy questions and bad design, you will have to apply complex analyses

UP TO YOU

- 1) A biologist want to obtain body weights of male reindeer calves from a herd during the seasonal roundup
- 2) A researcher want to investigate plant diversity in urban environment according to the habitats present in the cities
- 3) *Pinus mugo* is a low shrub found in subalpine fields. Imagine you are interested in the pollination biology of this species and you need to know its overall abundance within your study area, a subalpine field in Julian alps.
- 4) Surveying forest and grassland songbirds with the point count method at stations distributed along a transect line

