Measuring Biodiversity

- **Genetic Diversity**
- **Species Diversity**
- **Taxonomic Diversity**
- **Surveys**
- **Patterns in Time**
- **Patterns in Space**

At any level, diversity has at least two components…

- How many different types of things are present
  - Elephant, rhino and lion **is less diverse** than
  - Elephant, rhino, lion, leopard and buffalo
- How evenly they are represented
  - 1000 elephants and 1 lion **is less diverse** than
  - 500 elephants and 500 lions

'Academic' ways of measuring biodiversity

Species level

- Richness: Total number of species in an area (α diversity)
- Species turnover along a gradient (β diversity)

Ecosystem level

- Number of different habitats or ecosystems (γ diversity)

Genetic level

- Genetic homology
- Cladistic distance

'Policy' ways of measuring biodiversity

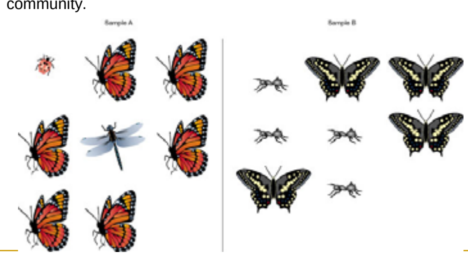
- **'Extinction based' (IUCN)**
  - Threatened species (Red Data Books)
- **'Area based' (Millennium goals)**
  - Area under protection
  - Area of a key habitat (eg Forest cover)
- **'Richness based'**
  - Indicator groups or species eg CI Rapid Biodiversity Assessment
- **Complementarity –based**
  - Various conservation optimisation tools
- Various **spatial representations**
  - Hotspots, last wild places

Methods to Measure Biodiversity

- **Species Richness**
- **Species Evenness**
- **Disparity**
- **Species Rarity**
- **Genetic Variability**.

Measuring Biodiversity…

- **<u>Species Richness</u>**; the total number of given species in a quantified area.
- **<u>Species Evenness</u>**; the degree to which the number of individual organisms are evenly divided between different species of the community.



Measuring Biodiversity…

- **Disparity**; measures the phenotypic differences among species resulting from the differences genes within a population.
- **Species Rarity**; the rarity of individual organisms within a quantified area.

http://www.rit.edu/~rhrsbi/GalapagosPages/DarwinFinch.html

Measuring diversity

How do ecologists measure diversity?

Richness = the number of species in a community

Simple to understand, but does not take into account differences in relative abundance

Disparities in relative abundance affect diversity estimates in two ways:

(1) total number of species in a sample will depend on sample size

this makes it tough to compare species counts for two areas that have been sampled with different degrees of effort

(2) individual species probably should not contribute equally to diversity

the functional importance of a species in a community will often be related to its abundance

Measuring diversity

Two indices of diversity that incorporate relative abundance are Simpson's index (D) and the Shannon-Wiener index (H):

D = Simpson's index = $1/\Sigma p_i^2$

p_i = the proportion of each species in the total sample

Simpson's index, D, varies from 1 to S, the number of species in a sample:

larger values of D indicate greater diversity

when all species have equal abundances, $D = S$

when species have unequal abundances, $D < S$

Rare species contribute less to D than do common ones.

Measuring diversity

The Shannon-Wiener index (H):

H = Shannon-Wiener index = $- \Sigma p_i \log_e p_i$

p_i = the proportion of each species in the total sample

Like D, H increases with increasing species number.

Like D, H places less value on rare species compared to common species.

Expressing Shannon-Wiener as e^H scales the index to the number of species, making it more comparable to Simpson's.

Measuring diversity

Richness estimates from samples of unequal size can not be validly compared:

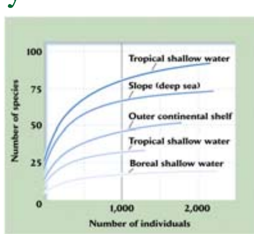
rarefaction allows for such comparisons,

a statistical procedure in which equal-sized sub-samples are drawn at random from the total sample:

this portrays relationship of richness to sample size

By curve fitting, one can estimate the total number of species from a sample.

Or, one can assess differences in diversity from samples of the same size.



Diversity in different sized samples can be compared using rarefaction

Alpha, beta and gamma diversity

Diversity can be measured at a variety of spatial scales.

Local diversity (alpha diversity) is the number of species in a small area of homogeneous habitat.

Size of habitat sampled is arbitrary.

Beta diversity measures turnover in species composition from one habitat to the next *within a region*.

Regional diversity (gamma diversity) is the total number of species observed in all habitats within a barrier-free geographic area.

Gamma diversity = regional species pool

Alpha, beta and gamma diversity

Computation of beta diversity

Beta diversity measured in a number of ways

One measure of **beta diversity** is the number of habitats within a region divided by the average number of habitats occupied per species:

gamma diversity = alpha diversity x beta diversity

e.g., consider the birds of St. Lucia, an island in the West Indies:

9 habitats (grassland, scrub, lowland forest, mangroves, etc.)
alpha diversity = 15.2 species of birds/habitat
each species occupies on average 4.15 of the 9 habitats
beta diversity = 9 habitats/4.15 habitats per species = 2.17
gamma diversity = 15.2 species x 2.17 = 33 species

Species-area relationships

Number of species increases with area sampled.

In 1921 Olaf Arrhenius first formalized the **species-area relationship** as:

$$S = cA^z$$

S = number of species encountered
A = area
c and ***z*** are constants fitted to the data

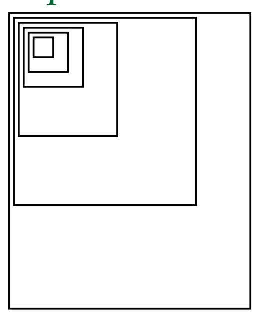
After log transformation, the relationship is linear: $\log S = \log c + z\log A$

Species-area relationships

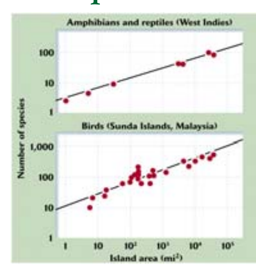
Analyses of many species-area relationships have shown that values of the slope, *z*, fall within the range 0.20 - 0.35.

Are species-area relationships artifacts of larger sample size (more individuals) in larger areas?

Species-area relationships



Species - area relationships first applied to overlapping quadrats of increasing size



Species-area relationships for two archipelagos.

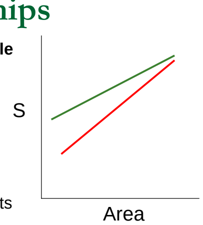
Species-area relationships

Slopes of species-area curves vary in predictable ways:

z-values are lower for regional (continental) areas, higher for islands:

In regional biotas where barriers to movement are not strong, rapidmovement of individuals prevents local extinction within small areas.

Small areas within continents have a higher fraction of gamma diversity compared to that on islands.



Keeping Track….

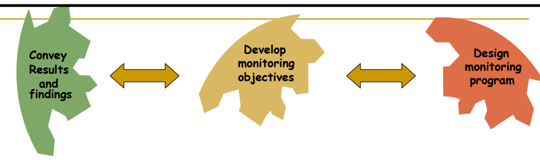
Ecological monitoring is a primary source of information regarding the status and trends of biotic and abiotic resources

Monitoring – implies a repeated assessment of status of some quality, attribute, or task within a defined area over a specified time period.

Monitoring should include the planning of data gathering, data gathering itself, data processing, and archiving, analysis, and the dissemination of results.

Monitoring Framework

- Applies to all natural resource monitoring
- Monitoring pieces must be designed and implemented to fit together
- View as information system
- Monitoring requires consistent framework



- Initially objectives are stated in common sense statements – challenge is to transform them into quantitative questions
- Statistical perspective is key
  - Know whether a monitoring design can answer the question
  - Know when the question is not precise enough – multiple interpretations

Identify Monitoring Objectives

- Objectives determine the monitoring design
  - Precise statements are required
  - Objectives must be prioritized
  - Objectives compete for samples
- Statistical perspective helps identify
  - Target population
  - Subpopulations that require estimates
  - Elements of target population
  - Potential sample frames
  - Variables to be measured
  - Impact of precision required

Monitoring Objectives

Monitoring programs must clearly state program objectives prior to design and implementation

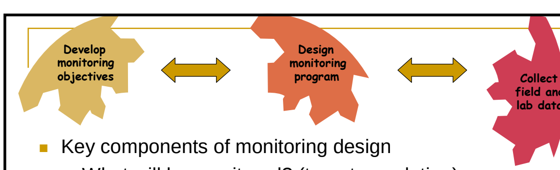
Determine variability and long-term trends in climate for all PACN parks through monthly and annual summaries of descriptive statistics for selected weather parameters, including air temperature, precipitation, cloud cover, and wind speed and direction.

Determine the areal extent, distribution and abundance of selected non-native invasive plants in PACN parks at 5 year intervals.

Determine annual variation in recruitment and mortality for selected populations of long-lived perennial plant species of special management interest.

Attributes of a good objective

- The desired levels of **precision.**
- The desired (or anticipated) power to detect change.
- The estimated level of change (**trigger point**) that would result in management modifications.
- The **scope of inference.** The **spatial** and **temporal scales** over which the inventory or monitoring results are to be applied should be identified.



- Key components of monitoring design
  - What will be monitored? (target population)
  - What will be measured? (variables or indicators)
  - When and how frequently will the measurements be taken? (temporal design)
  - Where will the measurements be taken? (site selection)
- Statistical perspective
  - Sample frame and target population
  - Survey design

Monitoring Indicators

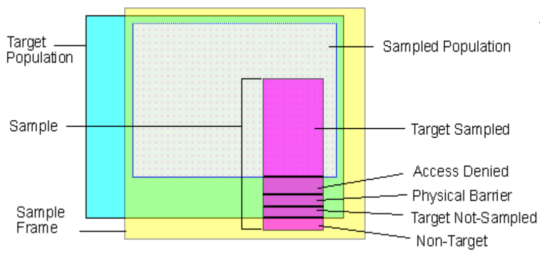
- Population measures are derived from the following types of data:
  - Detection of unmarked individuals or associated signs (e.g., tracks, scat, hair).
  - Detection and location of marked individuals.
  - Counts of marked or unmarked individuals.
  - Reproductive parameters.
  - Genetic data.

  Community measures are derived from detections or counts of individuals within species or species groups.

What is a Target Population?

- Target population denotes the ecological resource for which information is wanted
- Requires a clear, precise definition
  - Must be understandable to users
  - Field crews must be able to determine if a particular site is in the target population
- More difficult to define than most expect.
- Includes definition of what the elements are that make up the target population

Target Population, Sample Frame, Sampled Population



Ideally, cyan, yellow, gray squares would overlap completely

Survey Design & Response Design

- Survey design is process of selecting sites at which a response will be determined
  - Which sites will be visited (spatial component)
  - Which monitoring season will sites be visited (temporal component, panel design)

Definition of sampling

Procedure by which some members of a given population are selected as representatives of the entire population

Definition of sampling terms

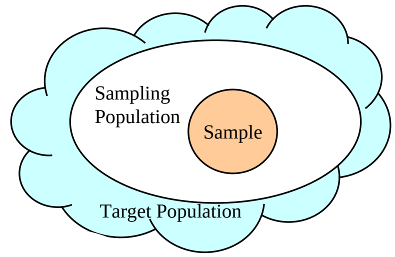
- Sampling unit
  - Subject under observation on which information is collected
- Sampling fraction
  - Ratio between the sample size and the population size
- Sampling frame
  - Any list of all the sampling units in the population
- Sampling scheme
  - Method of selecting sampling units from sampling frame

Why do we use samples ?

Get information from large populations

- At minimal cost
- At maximum speed
- At increased accuracy
- Using enhanced tools

Sampling and representativeness



Target Population ➔ Sampling Population ➔ Sample

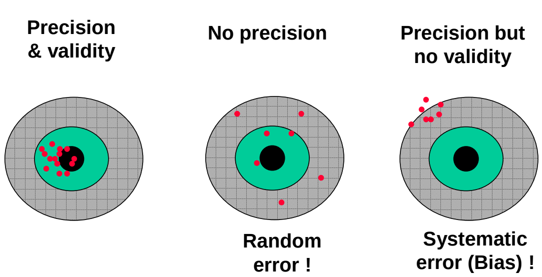
Probability samples

- Random sampling
- Each subject has a known probability of being chosen
- Reduces possibility of selection bias
- Allows application of statistical theory to results

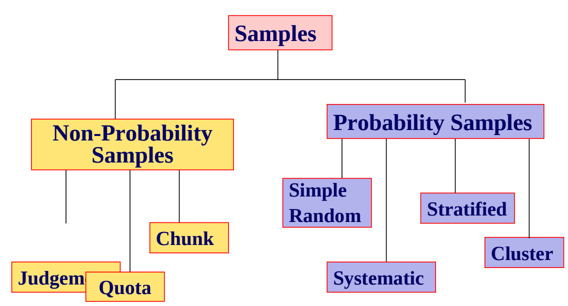
Sampling error

- No sample is the exact mirror image of the population
- Magnitude of error can be measured in probability samples
- Expressed by standard error
  - of mean, proportion, differences, etc
- Function of
  - amount of variability in measuring factor of interest
  - sample size

Quality of an estimate

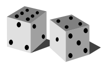


Types of Sampling Methods



Simple Random Samples

- Every individual or item from the frame has an equal chance of being selected
- Selection may be with replacement or without replacement
- Samples obtained from table of random numbers or computer random number generators

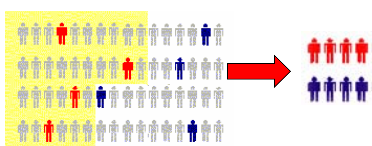


Systematic Samples

- Decide on sample size: n
- Divide frame of N individuals into groups of k individuals: k=n/n
- Randomly select one individual from the 1st group
- Select every k-th individual thereafter

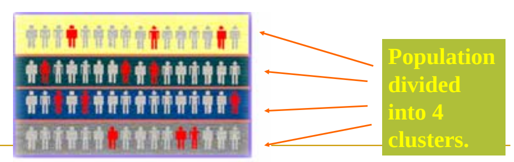
Stratified Samples

- Population divided into two or more groups according to some common characteristic
- Simple random sample selected from each group
- The two or more samples are combined into one



Cluster Samples

- Population divided into several “clusters,” each representative of the population
- Simple random sample selected from each
- The samples are combined into one



Advantages and Disadvantages

- Simple random sample and systematic sample
  - Simple to use
  - May not be a good representation of the population’s underlying characteristics
- Stratified sample
  - Ensures representation of individuals across the entire population
- Cluster sample
  - More cost effective
  - Less efficient (need larger sample to acquire the same level of precision)

Design-Based Population Estimation

- Scientific inference from sample to population
- Minimizes assumptions used in the inference process
- Relies on principles of statistical survey design and analysis
- Natural resource programs who use
  - Forest Inventory & Analysis
  - National Resource Inventory
  - National Wetland Status and Trends Program
  - National Agricultural Statistics Service programs
  - Environmental Monitoring and Assessment Program (EMAP)

Attributes of a good indicator

- Does it measure what it says it does?
- Sensitive, but not oversensitive
- Scale appropriate in time and space
- Feasibility
- Reliability
- Understandable by policymakers

(NRC 2000)