Modelling species-habitat relationships across scales for nature conservation
Day 1 – Counting living things

Dr. Elina Takola

Chapter 1: Welcome

Quizz of species identification

Chapter 2: From Aristotle to Humboldt

Aristotle (384 - 322 BCE)

- distinguished different groups of organisms based on their physiology, morphology and way of life.
- associated morphological characteristics with feeding strategies and the distinct habitats in which the animals live
- fish with gills vs other aquatic species (hippos, crocodiles, seals, sea turtles)

Theophrastus (371–287 BCE)

- successor of Aristotle
- studied the relationship between plants and their environment
- noted that plants were bound to their habitat and thrived best in a “favorable place” and “mutation according to place”
- studied soil, moisture, temperature, wind, and exposure
- was interested in the effect plants had on each other
    - noted that olives, myrtles and pines thrived when growing together but that the almond tree was a “bad neighbor”

And since then…

- Ancient Roman times: animal classification between animals with blood (vertebrates) and those without (invertebrates) &
  based on the type of "soul" they possessed
    - Rational, sensitive, and vegetable “souls”
    - Midieval times (~500–1500 AD): religious (theological) approach

- In 17th century bugs were considered to be “born of mud” and “beasts of the devil.”
- Carolus Linnaeus (1749, *Oeconomia Naturae*): essay which focused on the balance of nature and the environments in which various natural communities exist.
- Jean-Baptiste Lamarck (1809, *Philosophie zoologique, Zoological Philosophy*): fossils represent the early stages of species that evolved into different, still-living species
    - In order to refute this claim, geologist Charles Lyell mastered the science of biogeography and used it to argue that species do become extinct and that competition from other species seems to be the main cause.

November 28, 1660

- Twelve men of science establish a 'College for the Promoting of Physico-Mathematical, Experimental Learning' at Gresham College, London.

The Philosophical Transactions (March 6, 1665)

Henry Oldenburg, the Secretary of the Society, publishes the first edition of the world's first scientific periodical.

Alexander von Humboldt (1769-1859)

- Pioneered modern physical geography and biogeography.
- Extensive expeditions in Latin America; comprehensive data collection.
- Emphasized the unity of nature and environmental relationships.
- Climatology and Ecology
- Multidisciplinary Approach (combined geology, botany, zoology, and meteorology in research)
- Inspired figures like Darwin; shaped scientific methods and natural history.

Charles Darwin (1809-1882)

- Developed the Theory of Evolution by Natural Selection
    - Organisms with advantageous traits survive and reproduce
- Authored *On the Origin of Species* (1859)
    - Revolutionized biology; challenged fixed-species view
- Voyage on Beagle (1831–1836)
    - Collected data globally (Galápagos finches)
- Other Notable Works
    - *The Descent of Man* (1871) – human evolution
    - *The Expression of Emotions in Man and Animals* (1872)

Ernst Haeckel (1834-1919)

- **Phylogenetic Trees**: Early evolutionary trees; visualized descent and common ancestry
- **Biogenetic Law**: "Ontogeny recapitulates phylogeny"; embryology linked to evolution
- Coined "ecology," "phylogeny," "protist"; advanced taxonomy
- Scientific Illustration: *Art Forms in Nature*; detailed morphology, uniting science and art.

Indigenous knowledge

- Land managers in Australia have adopted many of the **fire-control** practices of the **aborigines**
- Indigenous stories in northern Australia: birds actually starting fires by dropping a burning branch in unburned places.
    - Researchers watched and documented this behaviour
    - **Milpa** (traditional farming system of the Indigenous Maya & Aztecs): a sustainable agricultural model that involves rotating agricultural plots usually with corn, beans, squash and other vegetables within a forested area
    - Polycultures + natural forest regeneration in previously cultivated plots → “forest gardens” with high biodiversity and soil fertility
    - Indian farmers have used seeds from the neem tree *Azadirachta indica* as a natural insecticide to protect crops and stored grain

Hildegard von Bingen (DE) (1098–1179)

- Nun, writer, composer, philosopher, and visionary
- Authored Physica and Causae et Curae, early works on natural history and medicine
- Emphasized the interconnectedness of nature, health, and spirituality

Maria Sibylla Merian (DE) (1647–1717)

- Studied insect life cycles, especially metamorphosis, through detailed observations
- Scientific illustrations
- Traveled to South America (Suriname) to document tropical insects and plants firsthand
- Advanced understanding of insect-plant relationships and early ecological interactions

Mary Anning (UK) (1799–1847)

- Fossil discoverer
- Contributed to early understanding of prehistoric life and extinction
- Self-taught scientist
- Recognized posthumously for shaping fossil science despite initial gender and class biases

Ben Cao Gang Mu 《本草纲目》

(Compendium of Materia Medica)

- the most complete and comprehensive medical book ever written in the history of traditional Chinese medicine
- compiled and written by Li Shi-zhen (1518~1593), a medical expert of the Ming Dynasty
- Comprehensive catalogue of natural substances, detailed descriptions of flora and fauna, integration of Ecology and Medicine (empirical study of nature)

Meanwhile…

- Han Dynasty (206 BCE–220 CE), Chinese agricultural manuals documented sophisticated irrigation, soil management, and crop diversity practices reflecting ecological principles.
- African pastoralists and agriculturalists developed rotational grazing, fallow systems, and agroforestry suited to local climates and biodiversity.
- “Sacred areas”
- Islamic Golden Age (circa 8th to 14th century): systematic study of nature → groundbreaking contributions to botany, zoology, medicine, astronomy, and chemistry (later passed on to Europe and integrated into the Renaissance)
    - Arabic translations of Greek texts, especially from figures like Aristotle, Galen, and Hippocrates, were the foundation for later studies in medicine, botany, and zoology.
- Al-Jahiz (9th century)
    - Introduced concepts related to natural selection and ecological interactions centuries before Darwin
    - Book of Animals (Kitab al-Hayawan) explores the relationships between organisms and their environment
- Female leading figures: Rufayda al-Aslamia (medicine), Maryam al-Ijliya (astronomy), and Fatima al-Fihri (founded the University of Al-Qarawiyyin, located in Fez in Morocco)

* On 30 May 1667, aristocrat Margaret Cavendish, Duchess of Newcastle, became the first woman to attend a meeting of the Royal Society, accompanied by her female attendants. This was very unusual in what was then a male-dominated Society, and it would be centuries before women next attended meetings.

Chapter 3: Biodiversity; definitions & measures

What is life?

- "Life is a self-sufficient chemical system far from equilibrium, capable of processing, transforming and accumulating **information** acquired from the environment" (Vitas M, Dobovišek A (2019) Towards a general definition of life. Orig Life Evol Biosph 49:77–88)
- NASA: "Life is a self-sustaining chemical system capable of Darwinian evolution"
- J. Gómez-Márquez: "In my opinion, living organisms share seven traits: organic nature, high degree of organization, pre-programming, interaction (or collaboration), adaptation, reproduction and evolution, the last two being facultative as they are not present in all living beings."

What is biodiversity?

- Many definitions of biodiversity:
    - Some consider it to be synonymous with species richness (Marc and Canard, 1997, Heywood, 1998), others see it as species diversity (Bond and Chase, 2002), whereas many propound a much broader definition such as the 'full variety of life on Earth' (Takacs, 1996).
- Article 2 of the CBD defines biological diversity as
    - *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems"* (https://www.cbd.int/convention/articles/?a=cbd-02).
- The latest consensus definition of biodiversity in the intergovernmental space, building heavily on that by the CBD, has been established by the IPBES.
    - "The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems" (https://ipbes.net/glossary/biodiversity).
- Traditionally, ecologists have been concerned with the concept of ecological diversity. Species diversity is the most commonly used representation of ecological diversity, but it is not the only measure. Niche width and habitat diversity are also key components of ecological diversity. Niche width describes the availability of resources to an organism (or taxon) over spatial and temporal scales.

How do we measure biodiversity?

Old school vs New school

Measures of diversity

Whittaker (1972) Evolution and measurement of species diversity. Taxon 21 (2/3): 213-251. https://www.jstor.org/stable/1218190

Two components are necessary for describing diversity:

Specific Richness (S) = The measurement of the number of species present in a location/studied system

- The more species present, the richer the sample
- Gives equal weight to species which have many/few individuals

Evenness (equitability) = Relative population of each species

- Species represented by many individuals or by few ones do not give the same contribution
- Evenness index is independent of Richness!!

α (alpha) diversity

- Defined as species richness within a single plant community or habitat.
- Represents the average number of species in a given local unit.
- Used to study how species coexist under similar environmental conditions.
- Reflects intra-site diversity (within-habitat).
- Related to the structure and functioning of a single community type.

How to measure alpha diversity?

Species Richness, Shannon-Wiener Index (Shannon Index), Simpson's Index, Inverse Simpson Index, Berger-Parker Dominance Index, Margalef's Richness Index, Menhinick's Richness Index, Fisher's Alpha, Pielou's Evenness, Faith's Phylogenetic Diversity, Functional Richness, Functional Evenness, Functional Divergence, Hill Numbers, Brillouin Index, McIntosh Index, Rarefaction Index

α (alpha) diversity

Mean number of species per site (local sample)

Shannon's Index (H)

H ∈ [0,1]

Higher values indicate higher diversity and more even distribution

Margalef's Index

H ∈ [0,∞)

Higher values indicate greater species richness

Shannon's Index

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

Where

H = Shannon index

pi = proportion of individuals in ith species

s = number of species in a community

Margalef's Index

$$d = \frac{S-1}{\ln N}$$

where

S = number of species

N = total number of individuals in the sample

β (beta) diversity

- Defined as the extent of change in species composition among communities.
- Measures species turnover between habitats across an environmental gradient or geographic space.
- Emphasizes inter-habitat diversity.
- Illustrates ecological differentiation across a landscape or region.

How to measure beta diversity?

Whittaker's Beta Diversity, Jaccard Index, Sørensen-Dice Index, Bray-Curtis Dissimilarity, Simpson's Beta Diversity, Morisita-Horn Index, Raup-Crick Metric, Horn's Index, Chao-Jaccard Index, Chao-Sørensen Index, Baselga's Partition (Turnover and Nestedness), Nestedness-resultant Dissimilarity, UniFrac (weighted and unweighted), Canberra Distance, Euclidean Distance, Manhattan Distance, Gower Distance, Kulczynski Index, Ochiai Index, Percentage Difference Index, Overlap Coefficient

β (beta) diversity

Bray- Curtis dissimilarity
between two sites j and k is

Abundance-based dissimilarity

0 (identical) to 1 (completely different)

Measures compositional dissimilarity considering species abundances

Sørensen Index

Presence/absence-based similarity

0 (no shared species) to 1 (identical)

Measures community similarity based on shared species

Bray- Curtis dissimilarity

between two sites j and k is

$$BC_{jk} = 1 - \frac{2C_{jk}}{S_j + S_k} = 1 - \frac{2\sum_{i=1}^{p} min(N_{ij}, N_{ik})}{\sum_{i=1}^{p}(N_{ij} + N_{ik})}$$

where
N_{ij} = number of specimens of species i at site j
N_{ik} = number of specimens of species i at site k
p = total number of species in the samples

Sørensen Index

$$SI = (2 * EC)/(E1 + E2)$$

where
EC = total number of elements in common between the sets
E1 = number of elements in set 1
E2 = number of elements in set 2

γ (gamma) diversity

- total species diversity in a landscape or region
- Influenced by broad-scale factors like geology, climate, and evolutionary history
- Forms the basis for comparing large ecosystems or biogeographic zones

How to measure gamma diversity?

Species Richness (Total Species Count), Whittaker's Gamma Diversity, Fisher's Alpha (regional scale), Rarefaction Curves (regional), Chao1 and Chao2 (estimators of total species richness), ACE (Abundance-based Coverage Estimator), Jackknife Estimators, Bootstrap Estimators, Hill Numbers (at regional scale), Faith's Phylogenetic Diversity (regional), Functional Diversity Metrics (regional scale), Gamma Diversity Partitioning (additive and multiplicative)