Lecture 1: Introductory Lecture

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ℹ BCB743

This material must be reviewed by BCB743 students in Week 1 of Quantitative Ecology.

1 BDC334: Introduction

1.1 Main Content

1.1.a Professor Smit (Term 3)

- Latitudinal gradients in diversity.
- Interactions of body and population size on diversity and distribution.
- Earth as a system
- The physical nature of environmental drivers of biogeography.
- Global change: the distinction between natural variability and anthropogenically-driven change.
- Overview of the biological responses to global change.
- Basic data collection and analytical methods in biogeography.

1.1.b Professor Boatwright (Term 4)

- Global biogeography: key principles and concepts.
- Continental drift and glaciation.
- Theories of biogeography and biogeographic reconstruction.
- Phylogeography
- Island biogeography theory and its applications for conservation.

1.2 Main Outcomes

On completion of this module the student should be able to:

- Discuss the past, present and projected future patterns of global biogeography.
- Examine the distribution of past floras, faunas and climate with respect to plate tectonics and compare them with current distributions.
- Explain the role that the major environmental drivers play in driving these biogeographical patterns.
- Understand the physical basis underpinning the components of global change.
- Recognise the central importance that humans play in bringing about global change.
- Understand the ecological, physiological and behavioural basis for biogeographical change.
- Contrast the fundamental differences between ecological biogeography and historical biogeography.
- Consider the biogeography of key extant plant and animal lineages.
- Apply the appropriate concepts to collect, analyse and interpret multivariate environmental and ecological data.
- Present their position on the above in discussion or in written format.

2 Overview

In Lecture 2 ("Overview of Ecosystems"), I develop a conceptual framework for macroecology: defining ecosystems, examining natural and anthropogenic gradients (from tropical–polar latitudes to planetary scales), and outlining course logistics and future applications in global change and epidemiology. Building on this, Lecture 3 ("Ecological Gradients") does into the mechanics of environmental gradients (such as temperature, moisture, wave action) across spatial scales, introduces coenoclines and statistical methods, and highlights tools like remote sensing for tracking biodiversity patterns amid climate-driven shifts.

Subsequent sessions shift toward quantitative analyses and unifying theory. Lecture 4 ("Biodiversity Concepts") clarifies alpha, beta, and gamma diversity metrics, such as Shannon, Simpson, and related indices, and explores their application from local plots to regional and global scales. Lecture 5 ("Multivariate Data") treats the foundational mathematical underpinnings of macroecology: similarity/dissimilarity matrices, Euclidean and multidimensional distances, and their implementation in species-by-site matrices. Finally, Lecture 6 ("Unified Ecology") synthesises these ideas and presents current approaches to unified macroecological theory, from microbial sampling and metabolic scaling to species–area relationships, distance-decay, and the application of these principles to forecasting biogeographical change under human-induced environmental shifts.

2.1 Lecture 1. Overview of Ecosystems

This lecture.

2.2 Lecture 2. Overview of Ecosystems

In Lecture Two, "Overview of Ecosystems," ecosystems are characterised as dynamic assemblies whose presence at particular places and times is explained by underlying environmental drivers—gradients in abiotic variables such as temperature, photoperiod and seasonality spanning tropical to polar regions and even local thermal shifts, such as those around Cape Point. I then turn my attention to ecosystem structure and contrasts these natural gradients with anthropogenic impacts that reshape community form and function. In doing so, we explore a selection of terrestrial and marine systems through both lenses. I conclude the lecture by mapping the module's trajectory (from defining biodiversity and deploying similarity-matrix methods to developing unifying macroecological theory) and extends consideration to planetary gradients beyond Earth and future applications in global-change and infectious-disease contexts.

2.3 Lecture 3. Ecological Gradients

In Lecture Three, I begin by situating macroecology within the study of environmental gradients, and frame our inquiry around how life arranges itself according to shifts in temperature, moisture, and other abiotic drivers across the planet's surface. I then define an environmental gradient as the progressive change in a variable, whether it's the temperature drop from Johannesburg to Cape Town or the rainfall decline from KwaZulu-Natal into the Northern Cape, and show how these gradients dictate where organisms can thrive. Turning to species-level patterns, I illustrate the classic unimodal response in which a species' abundance peaks at its optimal temperature and wanes away from that "sweet spot," and remind us that the same principle applies equally to gradients of humidity, soil nutrients, and beyond. To capture the true complexity of natural systems, I introduce coenoclines, coenoplanes, and coenospaces, which are conceptual tools that overlay multiple gradients into multidimensional maps of species distributions. Alongside these conceptual advances, I weave in lessons from classical quadrat-and-transect sampling methods and from ecophysiology to show how nutrient- and energy-flow processes at organismal levels scale up to community structure. Finally, I place all of this within the broader context of global change: ongoing shifts in climate and biogeochemical cycles will continually reshape these gradient-driven processes and, ultimately, the patterns we observe in biogeography.

2.4 Lecture 4. Biodiversity Concepts

In Lecture Four, I introduce the three "Greek-letter metrics" of biodiversity (alpha, beta, and gamma) explaining that alpha diversity measures richness at the smallest sampling unit, beta diversity captures species turnover among units, and gamma diversity represents the total number of species across an entire study area. I explain that univariate indices such as Shannon's and Simpson's quantify not only species counts but also the relative abundances of those species, then I detail how alpha diversity measured via quadrat sampling (counting species per plot) and introduce dissimilarity indices like Bray–Curtis and Jaccard for pairwise community comparisons. Shifting to beta diversity, I characterise it as "species turnover" to illustrate how it quantifies landscape heterogeneity along environmental gradients and summarise its role in measuring compositional change. Finally, I show how gamma diversity scaled from reserve-wide quadrat totals to global species estimates, and emphasise that researchers must define alpha and gamma scales relative to their study extents, whether local quadrats or continental surveys, before selecting appropriate diversity metrics.

2.5 Lecture 5. Multivariate Data

In Lecture Five, I introduce the multivariate nature of ecological data by describing how we sample eight quadrats ("sites A" through "H") and count species to distinguish abundance data (where zeros indicate absence and positive integers record quantity) from presence–absence data, which simply flags occurrence with ones and zeros. I explain that our goal is to determine how similar these sites are in species composition, whether they share the same taxa or differ in relative abundances, and that similarity can arise from both shared presence and uneven abundance patterns. To quantify these relationships, I introduce distance and dissimilarity matrices, using Euclidean distance for environmental variables and indices such as Bray–Curtis, Sørensen or Jaccard for species-composition data. I then detail the Euclidean formula by extending the Pythagorean theorem to three and n dimensions to calculate environmental distances across any number of variables. I conclude by emphasising that ecological datasets inhabit a space defined by as many dimensions as there are measurements, and that constructing these multivariate distance matrices provides the foundation for all further analyses in the module.

2.6 Lecture 6. Unified Ecology

In Lecture Six, I begin by reviewing foundational papers that drive the ambition of unified macroecology, which is asking whether patterns identified in multicellular organisms also hold for microbial life across scales. I then highlight advances in genetic and computational tools (high-throughput sequencing and big-data analyses) that allow us to treat soil or water samples as ecological quadrats, before unpacking metabolic-scaling laws: the three-quarters power law of multicellular organisms, the linear 1:1 scaling in protists, and the doubling rule in bacteria, each of which reveals physiological underpinnings of ecosystem function. Turning to Shade et al. (2018), I explore the challenges of defining 'individuals' and 'species' in microbes and set out a unified accounting framework that quantitatively links species richness and abundance to spatial scale and sampling effort. The lecture then demonstrates key empirical tools: rank-abundance curves show many rare versus few dominant species, occupancy–abundance relationships illustrate how prevalence rises with local abundance, species–area curves depict the plateau of cumulative richness with additional samples, and distance-decay analyses reveal how community similarity wanes over space. All of these are presented as indispensable analytics for a truly unified macroecological theory.

Bibliography