BDC334 Class Test 1, 2025 – Model Answers

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Question 1

Species tables list which species are present (and often their abundances) in different locations. **Environmental tables** describe the conditions in those locations (*e.g.*, temperature, habitat type, nutrient levels). Explain clearly and simply why having both types of tables is valuable in ecological research. Describe what **kinds of analyses** and **insights** they make possible, and **what kinds of patterns or relationships** you might discover from them. Write your answer as if you were explaining it to an interested non-scientist with no background in ecology.

[20 marks]

Model Answer (20 marks)

The value of having both **species tables** (sites × species, often with abundances) and **environmental tables** (sites × environmental variables) lies in their ability to take an ecological study from raw description toward explanation and prediction. Separately, species data allow us to document presence, absence, and relative dominance, while environmental data provide measurements of the abiotic and habitat conditions. Brought together, they allow the formal comparison, quantification of diversity, analysis of gradients, and testing of competing theories (more correctly, hypotheses) of community assembly.

Diversity Framework

Species tables allow the computation of classical diversity partitions:

- **Alpha diversity (α)**: the diversity within a single site, summarised with univariate indices such as **species richness**, **Shannon's H′**, **Simpson's D**, and **Pielou's J** for evenness. These indices are sensitive to richness and evenness in different ways, and thus capture different aspects of community structure.
- **Beta diversity (β)**: the **turnover** (and also **nestedness-resultant** beta diversity) of species between sites, often calculated from dissimilarity matrices that compare all pairs of sites. This highlights how composition shifts across environments or distances.
- **Gamma diversity (γ)**: the total diversity across all sites combined, which links the local and between-site scales.

These three forms of diversity measures allow us to move from the question "how diverse is this site?" toward "how does diversity change across space and environment?"

Matrices: Dissimilarity and Distance

The two tables are transformed into pairwise matrices that become the analytical core:

- From the **species table** we compute **dissimilarity matrices** (*e.g.*, **Jaccard**, **Sørensen**, **Bray–Curtis**, etc.). These quantify how composition differs between each pair of sites, based on either presence–absence or abundance.
- From the **environmental table** we compute **distance matrices** (commonly **Euclidean** on **standardised** variables, or other metrics if appropriate). These quantify how dissimilar the abiotic settings are across sites. This parallel structure (*i.e.*, the matrices share the same number of rows, *i.e.*, sites) allows direct comparison of biological and environmental spaces: if sites that are environmentally similar also have similar communities, one infers an environmentally driven structuring (*i.e.*, the niche differentiation model, which is when species are sorted along gradients).

Analytical Patterns and Curves

A set of canonical patterns and statistical tools can be derived once both tables are present:

- **Species Abundance Distributions (SADs)**: show how commonness and rarity are apportioned. They test against theoretical distributions (log-normal, geometric, broken-stick) and allow comparison across sites. Typically, communities are represented by one or two very dominant species, while the rest are less dominant but mostly scarce.
- **Occupancy–Abundance Curves**: reveal the relationship between how widespread a species is across sites and how abundant it is where present, with implications for metapopulation and niche theory.
- **Species–Area Curves**: plot richness as a function of area sampled, derived from cumulative species data across sites. They are fundamental to scaling laws and conservation planning.
- Rarefaction Curves: standardise richness comparisons by sample size, allowing comparison of communities with different sampling efforts.
- **Distance–Decay Curves**: show how species similarity declines as spatial or environmental distance increases, thus quantifying turnover and linking β-diversity to gradients of space or condition.
- **Elevation Gradients**: a variation of environmental gradient analysis, illustrating how richness and composition vary with altitude, often yielding unimodal ("hump-shaped") richness patterns.

These curves provide evidence not only for description but also for discriminating among competing theories.

Insights from Gradients and Discontinuities

Species often respond unimodally to environmental gradients, with each taxon showing an optimum and declining abundance away from it. Across multiple species this yields coherent turnover, observable in distance–decay analyses. Patterns can be continuous (gradual replacement) or discontinuous (sharp faunal breaks at thresholds). Both kinds of structure are central to biogeography.

Linking to Theories

- **Niche theory** predicts strong correspondence between environmental gradients and community composition, because species are filtered by their physiological and ecological tolerances.

- **Neutral theory**, by contrast, downplays environmental filtering and emphasises stochastic processes, dispersal limitation, and demographic drift. Analyses of the degree to which species–environment associations outperform null (randomised) expectations provide tests of these theoretical perspectives. Species–environment matrices thus create the empirical basis for adjudicating between these models of community assembly.

Correlations and Associations

- **Environmental tables** allow computation of **pairwise correlations** among variables (*e.g.*, whether temperature and nutrient concentrations covary), clarifying structure in the abiotic template.
- **Species tables** allow assessment of **associations among taxa** (*e.g.*, co-occurrence analyses), revealing potential interactions or shared habitat preferences.

These internal structures enrich the interpretability of cross-table comparisons.

Question 2

Imagine you are studying a clear biogeographic break in species composition across a region in South Africa.

a) Define this region and explain aspects such as its spatial extent, landscape features, and ecological properties.

b) Describe how you would use the concepts of α, β, and γ diversity to quantify changes in community structure along this gradient. Define each diversity level in the context of your chosen system.

c) Explain how principles such as distance decay and species' unimodal responses to environmental variables could lead to high species turnover (β diversity) across the gradient.

[30 marks]

Model Answer 1 (30 marks) — Marine example

a) Study region, spatial extent, landscape features, ecological properties

A well-known South African **marine biogeographic break** occurs across the **south coast transition between the warm Agulhas system and the cool-temperate Benguela system**. This region is called the Benguela-Agulhas Transition Zone (B-ATZ) according to Smit et al. (2017). I would delineate a coastal/offshore belt from **Mossel Bay to Sea Point (~450 km of coastline)**, extending **inshore reefs and kelp/rocky shores out to the shelf (~50–100 km offshore, to ~200 m depth)**.

Why this is a clear break

- **Physical oceanography:** Strong shift from **warm, oligotrophic Agulhas water with fast alongshore flow** to **cooler, nutrient-rich Benguela waters influenced by upwelling**.
- **Habitat template:** Mix of **rocky shores, kelp forests (westwards), sandy embayments, reefs**, and **estuaries**; exposure and substratum type vary predictably with headlands/bays.
- **Ecological signal:** Turnover in **macroalgae (*e.g.*, kelps westwards), reef fish, invertebrates**,

and **plankton**; changes in **functional composition** (*e.g.*, filter-feeders and cold-temperate macroalgae increase westwards; warm-affiliated taxa increase eastwards).

Sampling frame
- Divide the coast into **20–30 km coastal cells** with **replicate intertidal and subtidal sites** per cell.
- Within each site, survey **standard quadrats/transects** for macroalgae/invertebrates and **underwater visual census/BRUV** for reef fish.
- Build **species tables (sites × species, abundance/cover)** and **environmental tables (sites × variables)** with **SST, chlorophyll-*a* (proxy for productivity), upwelling indices, wave exposure, substrate, salinity, and coastal orientation**. Standardise environmental variables prior to analysis.

b) Using α, β and γ diversity to quantify change along the gradient
Definitions in this system
- **α-diversity (local):** Diversity **within a site** (*e.g.*, richness and Shannon/Simpson based on quadrats/transects).
- **γ-diversity (regional):** The **total species pool across the whole transition zone** (Agulhas–Benguela transect). Optionally compute γ separately for the **eastern (Agulhas)** and **western (Benguela)** blocks.
- **β-diversity (between sites): Compositional change among sites** alongshore. Compute **Jaccard** (presence–absence) and **Bray–Curtis** (abundance/cover) dissimilarities.

Workflow (BDC334 approaches)
1. **Compute α** for each site; plot **α *vs.* longitude/coastline distance** to test for within- *vs.* across-province differences.
2. **Compute γ** for the full transect and for each biogeographic block to show how the transition contributes to regional pools.
3. **Quantify β** in two ways:

- **Serial β** between **adjacent coastal cells** ($\beta_{i,i+1}$) to locate where **turnover peaks** (the break).
- **All-pair β** among sites; visualise with **ordination (*e.g.*, NMDS/PCoA on Bray–Curtis)** and **clustering** to recover two assemblage groups with a narrow mixing zone.

4. **Partition β** into **turnover *vs.* nestedness** to evaluate **species replacement** (expected at a boundary) versus simple richness gradients.
5. **Relate composition to environment:** Regress **community dissimilarity** against **environmental distance** (standardised SST, chl-a, exposure, substrate) and **geographic distance** to separate environmental filtering from pure space.

c) Distance decay and unimodal responses leading to high β
- **Distance–decay of similarity:** Alongshore **similarity declines with coastal distance** as water masses, exposure, and substrata co-vary. Expect a **steeper decay slope across headlands/upwelling nodes** and at the Agulhas–Benguela interface, signalling **heightened β-diversity**.

- **Unimodal species responses:** Most taxa exhibit **optima** along **SST, productivity (chl-a), exposure, and substrate** gradients. Warm-affiliated species peak under **higher SST/lower nutrients** (east); cold-temperate species peak under **cooler, nutrient-rich** conditions (west). Superimposed unimodal responses across many species produce **rapid species replacement** over short distances, elevating **β**.
- **Thresholds: Thermal/productivity thresholds** around major headlands or upwelling centres can trigger **abrupt community shifts**, consistent with a **biogeographic break** rather than a gradual fade.

Model Answer 2 (30 marks) — Terrestrial example

a) Study region, spatial extent, landscape features, ecological properties

A clear **terrestrial biogeographic break** occurs across the **Mpumalanga/Limpopo Drakensberg Escarpment**, where **Highveld grassland** on the cool, fire- and frost-prone plateau transitions downslope into **Lowveld savanna**—warmer, more seasonal, and increasingly woody. I would delineate a **~150–250 km transect** (*e.g.*, Long Tom Pass north to Blyde River Canyon) spanning **~1,500 m elevation** (≈2,000 m a.s.l. to ≈500 m a.s.l.).

Key features

- **Spatial frame:** Partition the slope into **10–20 km bands**; within each band place **replicate vegetation plots** (*e.g.*, 20×20 m for woody plants; nested subplots for herbs/graminoids) on comparable aspects/slope positions.
- **Landscape & substrates:** Dissected topography; quartzitic/basaltic formations; **shallow acidic upland soils** *vs.* **deeper colluvial soils** downslope.
- **Ecological template:** Strong gradients in **temperature minima/frost**, **water balance**, **fire regime** (shorter return intervals on the plateau), and **woody cover**. Communities shift from largely treeless **grassland** to **savanna** with *Vachellia/Senegalia, Combretum, Sclerocarya.*

Build **species tables (plots × species; cover/abundance/presence)** and **environmental tables (plots × standardised variables: elevation, frost days, rainfall, soil texture/chemistry, fire-return interval)**.

b) Using α, β and γ diversity to quantify change along the gradient

Definitions in this system

- **α-diversity (local): Within-plot** richness and Shannon/Simpson (plus evenness) to capture dominance structure (*e.g.*, grass dominance *vs.* mixed understory).
- **γ-diversity (regional): All species across the entire escarpment transect**, with γ also computed for the **two zones** (plateau *vs.* lowveld) to compare regional pools.
- **β-diversity (between sites): Turnover among plots/bands** along the slope using **Jaccard** and **Bray–Curtis**; where possible, **partition β into turnover *vs.* nestedness**.

Workflow (BDC334 approaches)

1. **Compute α** per plot/band; plot **α *vs.* elevation or along-slope distance** to reveal local richness patterns.

2. **Compute γ** (full transect and zone-specific) to show how the transition contributes to regional diversity.
3. **Serial β** between **adjacent bands** pinpoints **where turnover peaks** (the break), while **all-pair β** plus **ordination/clustering** tests for two coherent assemblages with a narrow ecotone.
4. **Partition β** to show that the boundary is dominated by **species replacement** rather than nested loss/gain.
5. **Relate composition to environment:** Regress **community dissimilarity** against **environmental distance** from the standardised environmental table and against **geographic distance** to quantify environmental filtering *vs.* space.

c) Distance decay and unimodal responses leading to high β

- **Distance–decay of similarity:** Along the escarpment, **similarity declines with along-transect distance** because **frost regime, temperature minima, soil depth/fertility, and fire** co-vary with distance. Expect a **steeper decay across the break** than within either zone, indicating **heightened β**.
- **Unimodal responses:** Species show **single optima** along key drivers:
  - **Frost/temperature minima:** Frost-sensitive woody species peak downslope; frost-tolerant grasses/forbs peak upslope.
  - **Fire regime:** Fire-avoiding or resprouting woody species peak where **fire intervals lengthen**; fire-tolerant graminoids peak with **frequent fires**.
  - **Soils/water balance:** Taxa tied to **deeper, mesic soils** peak downslope; **shallow, rocky soils** favour different upland assemblages.

    Superimposed unimodal curves across many species create **rapid replacement** over short spatial spans, generating **high β-diversity** at the escarpment boundary.
- **Thresholds:** Crossing **frost lines, fire-regime shifts, or soil transitions** can produce **abrupt community changes**, consistent with a **biogeographic break**.

Indicative marking guide (both versions; 30 marks each)

- **(a) Region & properties (10 marks):** clear boundary and extent; key environmental/physical gradients; defensible sampling frame.
- **(b) α/β/γ framework (12 marks):** correct, contextual definitions; appropriate indices; serial *vs.* all-pair β; β-partitioning; coherent analysis workflow linking species and environment.
- **(c) Mechanisms (8 marks):** sound distance–decay reasoning; mechanistic unimodal responses tied to named variables; explicit link back to high β at the break.

Bibliography

Smit AJ, Bolton JJ, Anderson RJ (2017) Seaweeds in two oceans: beta-diversity. Frontiers in Marine Science 4:404.