Course 2.1.1: Basics of Ecosystem Analysis

Hierarchy Theory

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Introduction

What is hierarchy theory?

• A theory of system organization (King 1997)

  System: A collection of objects joined in a constitutive relationship of interactions that forms a whole

• Originally designed to understand middle – number systems (Allen & Starr 1982)

And what are hierarchical systems?

• A system organized as a system of systems within systems (King 1997)

• A system composed of subsystems nested within other subsystems

  Nestedness: An important attribute of hierarchies
Introduction

**Middle–number systems - (hmm...?)**

- Have too many components to describe each with its own equation...
- ... and too few components to obtain reliable mean properties by averaging
- Includes most of biology!
- Systems and phenomena that are idiosyncratic and difficult to understand and predict
Introduction

Two (luckily…) kinds of hierarchies

1a. Costitutive:
   Units at each level are physical parts of the units at next higher level

1b. Cumulative constitutive hierarchies

2. Aggregative:
   Units are physical entities organized into collections, but they are physically independent and remain so
Examples of Hierarchies in Biology

The Somatic Hierarchy (Eldredge 1985)

- Subatomic particle / atom / molecule / organelle / cell / tissue / organ / organ system / individual organism
- Unicellular organisms have no levels between the cell level and the organism level
- Note that the hierarchy stops at the organism level and does not proceed to the population level!
- This is a constitutive hierarchy
Examples of Hierarchies in Biology

The Ecological Hierarchy

- Individual organism / population / community
- This is an aggregative hierarchy
- Should not be combined with the constitutive somatic hierarchy!

The Genetic Hierarchy

- Nucleotide bases / chromosomes / genome / gene pool / collection of gene pools
- This is a mixed hierarchy with both systems
- Should not be combined with the constitutive somatic hierarchy
Examples of Hierarchies in Biology
Examples of Hierarchies in Biology

And finally the most interesting…

The Ecosystem Hierarchy

- Ecosystem / Ecoregion Provinces / Ecoregion Divisions / Ecoregion Domains / Biosphere

- This is a land-based constitutive hierarchy
- Ecosystem is a dual organization determined by:
  1. Structural constraints on organisms &
  2. Functional constraints on processes
The Ecosystem Hierarchy

- Ecosystem can be conceptualized as a nested spatial hierarchy (holarchy) of geographic units (holons) all embedded within the biosphere.
- Ecosystem has structure and function. Each level of the ecosystem hierarchy displays emergent properties.
- Their geography is sufficiently homogenous to be ecologically consistent, e.g., a watershed.
Examples of Hierarchies in Biology

The Ecosystem Hierarchy

• At the base of an ecosystem’s hierarchy are individual organisms

• These make up species which in turn make up the assemblage of species found in the ecosystem (ecological community)

• There are also aggregations of ecosystems, with the largest aggregation of all being all of the ecosystems found on a planet
Examples of Hierarchies in Biology

**Holons**

- Self-organising entities of interest
- Watershed, or perhaps a community, or the home range of a species, etc.
- A delineation is required
- Key relationships between holons must be established
- The context of the holon must be explored
Hierarchy structure
Hierarchy structure

L
L
L

L+1

L
L
L

L+1

L
L
L
Hierarchy structure
So (as we’ve seen)

- Hierarchies have a triodic structure:
  - focal level (L), higher (L+1) & lower (L-1)
  - Fully ordered, ranked, nested

- Each level is made up of units
Hierarchical Theory & Geographic Representation

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Hierarchical Theory & Geographic Representation

„Hierarchical theory can provide conceptual and logical frameworks to organize GIS data based on the underline processes and their relationships, to enhance the levels of spatial and temporal information that can be extracted from a GIS database, and furthermore, to offer a theoretical foundations for the design of GIS representations.”

May Yuan
Hierarchical Theory & Geographic Representation

“Hierarchical theory is a theory that applies hierarchy to organize concepts and interpret ecological complexity”

Ahl & Allen (1996)

“Any complex system in the world must be hierarchical, or otherwise we would have no way to acquire it.”

Simon (1973)
Hierarchy Processes

Spatial patterns produced through time ($t$) by hierarchy processes

$t = 0$  $t = 1$  $t = 2$  $t = 3$

Source
Hierarchy Processes

• These occur when interaction between regions is controlled by the position of each region in a structural dependence based upon level in a „hierarchy”

• How such systems generate not only central place, but also shopping trip and other interactive phenomena (Ravenstein <1885>, Berry <1962>)

• How some stages of the measles diffusion process in Southern England are controlled by hierarchy effects
A Summary of The Principles of Hierarchy Theory

Timothy F. H. Allen
Professor of Botany
and Environmental Studies
Ph.D. (1968)
University College of North Wales,
University of Wales
A Summary of The Principles of Hierarchy Theory

Robert V. O'Neill

Pioneer researcher in ecosystem theory, ecological modeling, error analysis, hierarchy theory, and landscape ecology and the development of basic applications in risk assessment and regional environmental analysis.
A Short Annotated Bibliography of Hierarchy Theory


A Short Annotated Bibliography of Hierarchy Theory


Thank you for your attention!