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ECOL462:

Landscape Ecology and Planning

Course Teacher

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Pondicherry University, India

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Content

Pondicherry University, India

1. General Information

Course Code : ECOL - 462

Course Title : Landscape Ecology and Planning

Number of Credits : 3.0 ECTS

Course duration : 18 Weeks

Level : Postgraduate

Course Teacher : Dr. Subhankar Chatterjee

Prerequisite : Required courses (or equivalents): No prerequisite courses are required although a basic understanding of ecology and environmental sciences (high school/graduate level) will be an added advantage. Strong English language skill (verbal and writing) is essential. Supplementary reading and writing courses may be advisable for students with English as a second language. Basic computer operation (Windows/Mac) knowledge is necessary for lab-related activities.

2. Course description

Ecology is a broad scientific discipline that focuses on interactions, most typically involving organisms. Landscape ecology is the study of the causes of environmental patterns and the consequences of spatial heterogeneity and patterns on ecological processes. Landscape ecology provides concepts, theories, and methods that emphasize the importance of spatial patterning on the dynamics of interacting ecosystems, how to characterize the patterning, and how it might change through time. In studying landscape ecology, one will understand the dominant themes of the field, familiarize with its current research trends, and explore applications of the landscape approach. The course should be useful to students in ecology and natural resources as well as conservation biology, landscape architecture, geography, land use planning, and other related fields. As a discipline, it provides us with a new way of viewing and investigating ecological systems. Diverse aspects of spatial patterning, its causes, development, and importance for ecological processes will be taught in this course so that students can independently apply the knowledge of landscape ecology for both management and conservation purposes.

3. Course goals

The main course objective is to make the students in-depth understanding of the concepts and salient features of Landscape ecology. Students will get an overview of the field along with current concepts, methods, and applications of landscape ecology. With hands-on training on quantitative tools of landscape ecology, field-related projects and reading writing assignments will enable students to develop or apply these tools and concepts in their studies and/or research.

4. Course outcome

By the end of the course, successful students will:

1. Understand the current concepts of landscape ecology and the scale, scaling techniques, and spatial patterns.

2. Explain how ecological systems are dynamic in space and time

3. Infer the abiotic and biotic processes that structure landscape mosaics and patterns of biodiversity at multiple spatial scales;

4. Explain the basis of spatial pattern analysis using continuous and categorical spatial data;

5. Use standard software packages and the tools specific to landscape ecology, run and interpret the results of simple landscape models to answer questions about heterogeneity, scale, and ecosystem dynamics.

6. Review the theory, methodology, and application of landscape ecology to contemporary issues in conservation biology and resource management;

7. Conduct independent research in landscape ecology, including proposal writing, implementation, oral/poster presentation, and written manuscripts/popular articles.

5. Course structure

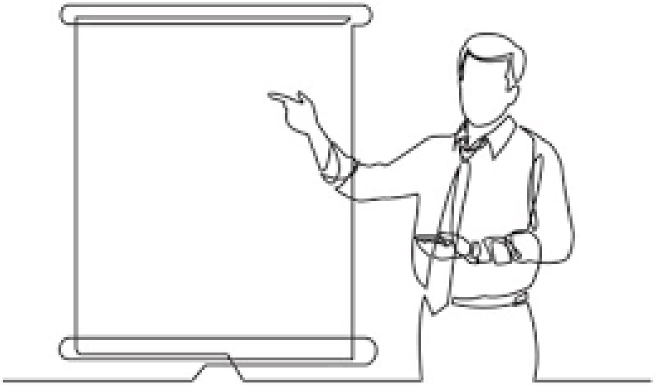
5.a. Course Content

Week -1	Introduction of the course: General overview of Landscape ecology and planning
	Scope of landscape ecology: Definitions and Scale
	Land and Landscape processes
Week -2	Hierarchy: ecosystems to land units;
	Ecological principles at work with Landscapes
	Lab 1: Creating landscape pattern
Week -3	From Ecosystem ecology to Landscape Ecology
	Exam-1 (UNIT-I)
Week-4	Spatial Heterogeneity and Landscape
	History of Landscape Ecology
Week-5	Concept of Scale and technological advances;
	Patch – Corridor – Matrix model
	Lab 2: Using neutral landscape models
Week-6	Disturbance, remnant, environmental, and introduced patches.
	Exam-2 (UNIT-II)
Week-7	**Assignment submission and presentation**
Week-8	Patches as Islands – Patch Size and Edge effect
	Habitat Fragmentation and Nonnative Species; Metapopulation Dynamics and Appropriate Management
Week-9	Understanding Landscape Structure Using Landscape Metrics – Composition, Shape, Configuration
	Lab 3: Understanding landscape metrics
	Lab 4: Understanding landscape metrics continued
Week-10	Spatial statistics – spatial independence, spatial structure, and spatial interpolation
	Lab 5: Scale detection using spatial stats
	Exam-3 (UNIT-III)
Week-11	Land Use/Cover Change; Ecosystem and biodiversity impacts

	Organisms and landscape pattern; Ecosystems processes on landscapes
	Lab 6: Spatial dynamics of ecosystem processes
Week-12	Inventory and Tools for wasteland assessment and evaluation
	Land Reclamation and Restoration
	Natural hazard mitigation/erosion
Week-13	Concept of ecological land degradation – desertification, deforestation, waterlogging, salinization, and soil erosion
	Exam-4 (UNIT-IV)
Week-14	**Assignment submission and presentation**
Week-15	Landscape ecology Practices in Planning: Landscape Connectivity and Urban Networks – Parks, greenbelts, and greenways/green infrastructure
	Lab 7: Assessing multi-scale landscape connectivity
Week-16	Designing Landscapes and Urban Sustainability.
Week-17	Field Report – Participatory Sketch Mapping of Landscape Features
	Exam-5 (UNIT-V)
Week-18	**Assignment submission and presentation**

5. Course structure

5.b. Mode of delivery



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In class lectures

On-line Tutorials

Google Classroom

Interactive and self-reflective methods of teaching and learning will be followed. A lecture followed by a student-led discussion and hands-on computational exercises on quantitative methods that are used in landscape ecology will be included. Exercise-based (continues internal assessment), student-directed learning approach will be followed where research based teaching-learning and application of theory into practical problem solving will be given priority.

5. Course structure

5.c. Lectures and in-class discussion

Students will be able to

(i) understand the current concepts of landscape ecology scale, scaling techniques, and spatial pattern;

(ii) explain how ecological systems are dynamic in space and time;

(iii) infer the abiotic and biotic processes that structure landscape mosaics and patterns of biodiversity at multiple spatial scales;

(iv) explain the basis of spatial pattern analysis using continuous and categorical spatial data.

5.d. Lab work and in-class participation

Students will be able to use standard software packages and the tools specific to landscape ecology, run and interpret the results of simple landscape models to answer questions about heterogeneity, scale, and ecosystem dynamics

5.e. Reading assignments and discussion of assigned papers(All the students are expected to have read the assignment before class and given thought to the paper'scontent and context).

Review the theory, methodology, and application of landscape ecology to contemporary issues in conservation biology and resource management.

6. Course Assessment

Type of assessment	**Percentage of Marks**
Continuous internal assessment	10
Progress assessment	10
Project completion and presentation	20
Final assessment	60
Total	**100**

7. References

1. Turner MG Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature.
2. Lopez, RD, Frohn, RC, 2017. Remote Sensing for Landscape Ecology: New Metric Indicators CRC Press; 2 edition
3. Forman RTT, and M Godron.1986. Landscape ecology. Wiley, New York.
4. Risser PG, JR Karr, and RTT Forman.1984. Landscape ecology: directions and approaches. Special Publ. No. 2, I11. Natural Hist. Surv., Champaign.
5. Turner MG.1989. Landscape ecology: the effect of pattern on process. Ann. Rev. Ecol. Syst. 20:171-197.
6. Turner MG.2005. Landscape ecology: what is the state of the science? Annu. Rev. Ecol. Evol. Syst. 36:319-44.
7. Forman RTT.1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press, Cambridge, England.

LANDSCAPE ECOLOGY AND PLANNING

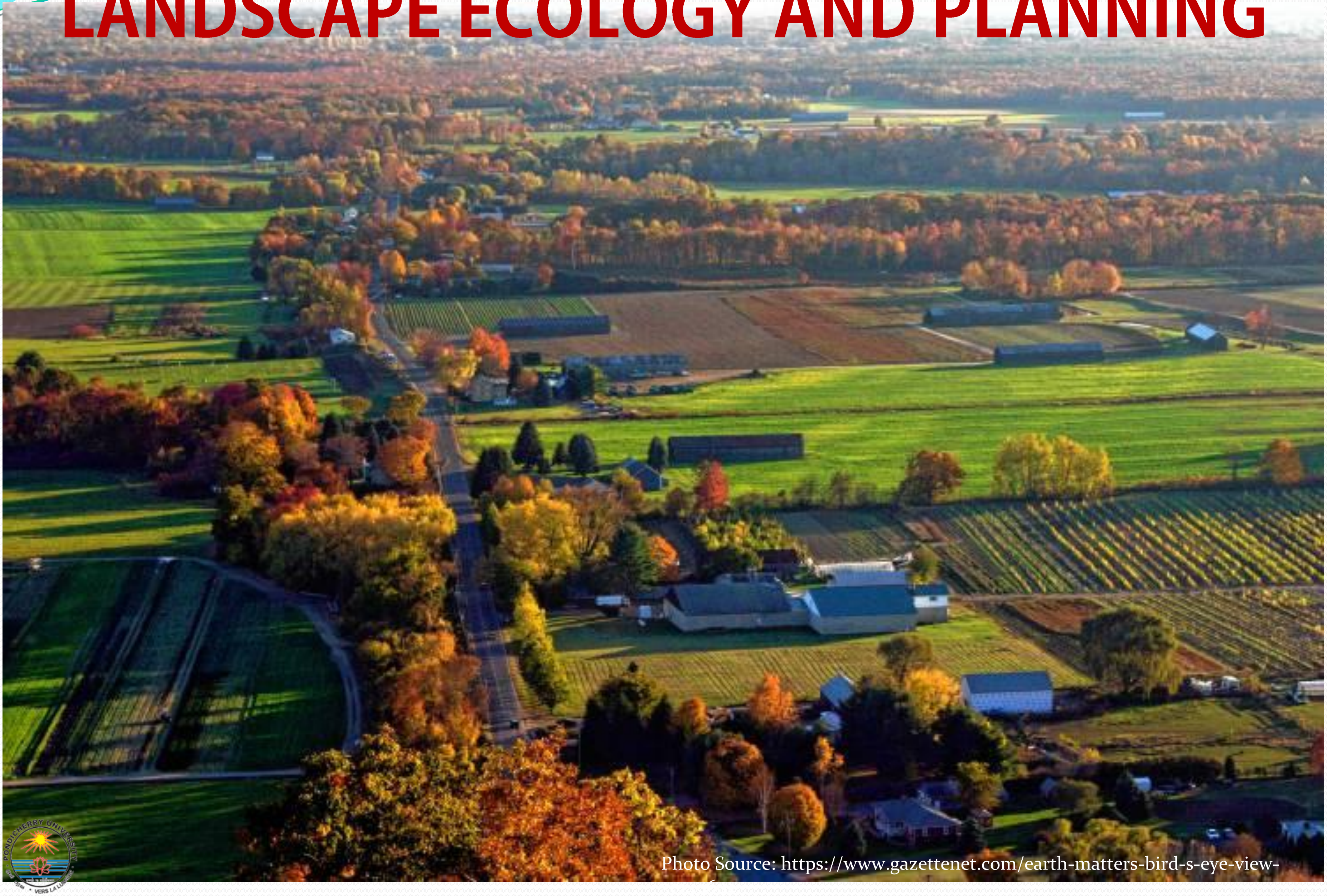

Photo Source: https://www.gazettenet.com/earth-matters-bird-s-eye-view-

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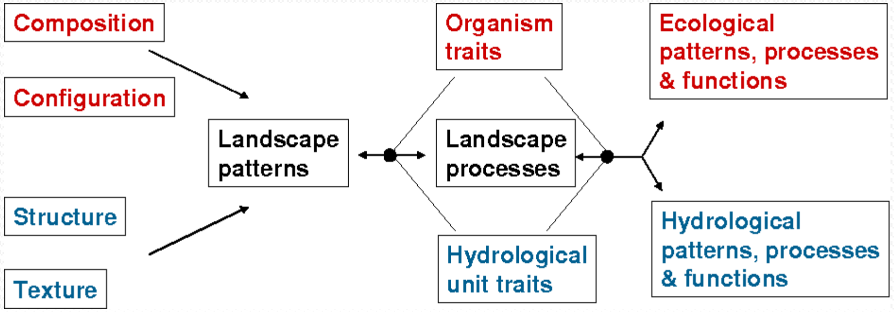
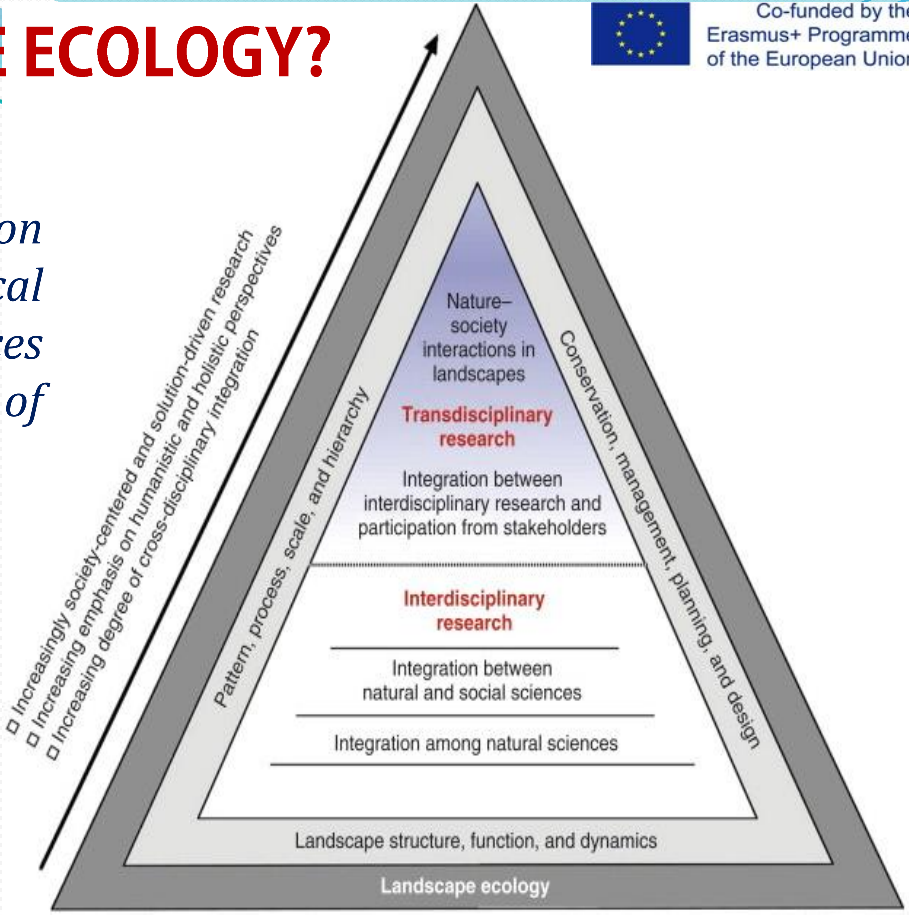
What is LANDSCAPE ECOLOGY?

Landscape ecology emphasizes the interaction between spatial pattern and ecological process—that is, the causes and consequences of spatial heterogeneity across a range of scales.



Composition
Configuration
Structure
Texture
Landscape patterns
Organism traits
Landscape processes
Hydrological unit traits
Ecological patterns, processes & functions
Hydrological patterns, processes & functions

DOI:10.5194/HESS-10-967-2006



Nature–society interactions in landscapes
Transdisciplinary research
Integration between interdisciplinary research and participation from stakeholders
Interdisciplinary research
Integration between natural and social sciences
Integration among natural sciences
Landscape structure, function, and dynamics
Pattern, process, scale, and hierarchy
Conservation, management, planning, and design
Landscape ecology
☐ Increasingly society-centered and solution-driven research
☐ Increasing emphasis on humanistic and holistic perspectives
☐ Increasing degree of cross-disciplinary integration

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/landscape-ecology

- *Landscape ecology explicitly addresses the importance of spatial configuration for ecological processes*. Not only is landscape ecology concerned with how much there is of a particular component, it also considers how it is arranged.

- *Landscape ecology often focuses upon spatial extents that are much larger than those traditionally studied in ecology.*

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What is LANDSCAPE ECOLOGY?

❖The term “landscape ecology” was introduced by the German biogeographer Carl Troll (1939), arising from the European traditions of regional geography and vegetation science and motivated particularly by the novel perspective offered by aerial photography.

❖Landscape ecology focuses on (1) the spatial relationships among landscape elements, or ecosystems, (2) the flows of energy, mineral nutrients, and species among the elements, and (3) the ecological dynamics of the landscape mosaic through time (Forman 1983).

❖Landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscape, influences of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity (Risser et al. 1984).

❖Landscape ecology is sometimes considered to be an interdisciplinary science dealing with the interrelation between human society and its living space—its open and built-up landscapes (Naveh and Lieberman 1984).

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Is landscape ecology a sub discipline of ecology?

Many Scientist Many theories……………………

Many ecologists do consider landscape ecology as a branch of ecology

Risser et al. contemplated three ways in which landscape ecology may be viewed: as an intersection of many disciplines, as a separate discipline, or as a branch of ecology. They concluded that only the first option was “intellectually and practically the most persuasive.

Zonneveld indicated that landscape ecology is not part of biological sciences, but a branch of geography.

A major forcing function of landscapes is the activity of mankind, especially associated cultural, economic, and political phenomena. . . . Landscape ecology is not a distinct discipline or simply a branch of ecology, but rather is the synthetic intersection of many related disciplines that focus on the spatial-temporal pattern of the landscape” [Risser et al. 1984]

Definitions of landscape ecology evolved with time

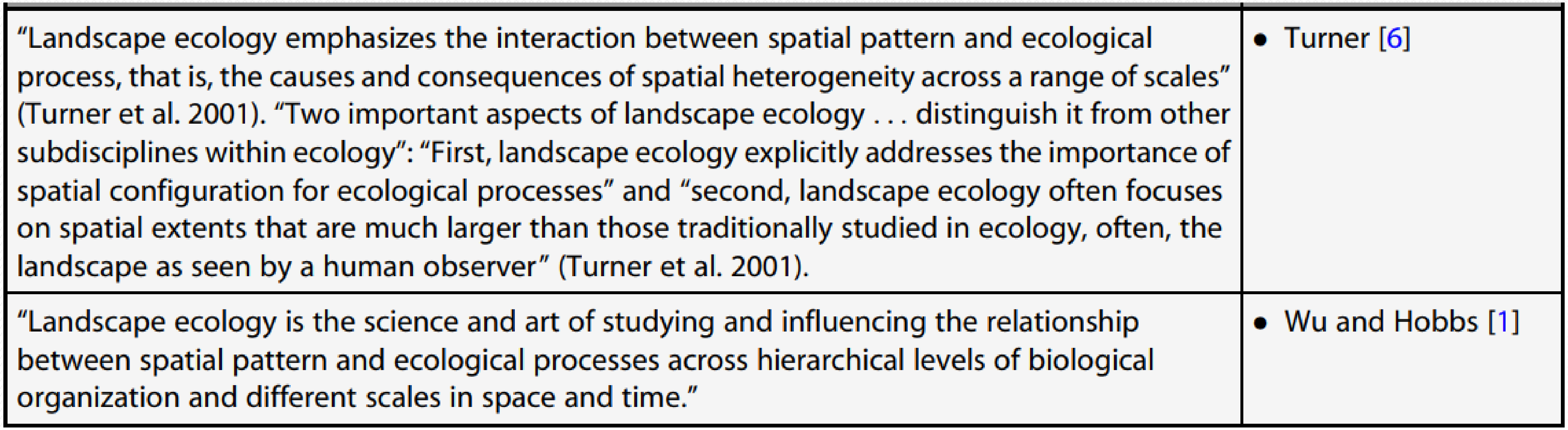
Definition	Source
The German geographer Carl Troll coined the term "landscape ecology" in 1939, and defined it in 1968 as "the study of the main complex causal relationships between the life communities and their environment in a given section of a landscape. These relationships are expressed regionally in a definite distribution pattern (landscape mosaic, landscape pattern) and in a natural regionalization at various orders of magnitude" (Troll 1968; cited in Troll 1971)	• Troll [19] • Troll [20] • Troll [21]
"Landscape ecology is an aspect of geographical study which considers the landscape as a holistic entity, made up of different elements, all influencing each other. This means that land is studied as the 'total character of a region', and not in terms of the separate aspects of its component elements" (Zonneveld 1972)	• Zonneveld [22]
"Landscape ecology is a young branch of modern ecology that deals with the interrelationship between man and his open and built-up landscapes" based on general systems theory, biocybernetics, and ecosystemology (Naveh and Liberman 1984). "Landscapes can be recognized as tangible and heterogeneous but closely interwoven natural and cultural entities of our total living space," and landscape ecology is "a holistic and transdisciplinary science of landscape study, appraisal, history, planning and management, conservation, and restoration" (Naveh and Liberman 1994)	• Naveh and Lieberman [5] • Naveh and Lieberman [23]
"A landscape is a kilometers-wide area where a cluster of interacting stands or ecosystems is repeated in similar form; landscape ecology, thus, studies the structure, function and development of landscapes" (Forman 1981). Landscape structure refers to "the spatial relationships among the distinctive ecosystems;" landscape function refers to "the flows of energy, materials, and species among the component ecosystems;" and landscape change refers to "the alteration in the structure and function of the ecological mosaic over time" (Forman and Godron 1986).	• Forman [11] • Forman [12]

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Definitions of landscape ecology evolved with time

"Landscape ecology focuses explicitly upon spatial pattern. Specifically, landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscapes, influences of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity" (Risser et al. 1984). "Landscape ecology is not a distinct discipline or simply a branch of ecology, but rather is the synthetic intersection of many related disciplines that focus on the spatial-temporal pattern of the landscape" (Risser et al. 1984).	• Risser et al. [24]
"Landscape ecology emphasizes broad spatial scales and the ecological effects of the spatial patterning of ecosystems" (Turner 1989).	• Turner [25]
"Landscape ecology is the study of the reciprocal effects of the spatial pattern on ecological processes," and "concerns spatial dynamics (including fluxes of organisms, materials, and energy) and the ways in which fluxes are controlled within heterogeneous matrices" (Pickett and Cadenasso 1995).	• Pickett and Cadenasso [14]
"Landscape ecology investigates landscape structure and ecological function at a scale that encompasses the ordinary elements of human landscape experience: yards, forests, fields, streams, and streets" (Nassauer 1997).	• Nassauer [26]
Landscape ecology is "ecology that is spatially explicit or locational; it is the study of the structure and dynamics of spatial mosaics and their ecological causes and consequences" and "may apply to any level of an organizational hierarchy, or at any of a great many scales of resolution" (Wiens 1999).	• Wiens [27]

Definitions of landscape ecology evolved with time



"Landscape ecology emphasizes the interaction between spatial pattern and ecological process, that is, the causes and consequences of spatial heterogeneity across a range of scales" (Turner et al. 2001). "Two important aspects of landscape ecology . . . distinguish it from other subdisciplines within ecology": "First, landscape ecology explicitly addresses the importance of spatial configuration for ecological processes" and "second, landscape ecology often focuses on spatial extents that are much larger than those traditionally studied in ecology, often, the landscape as seen by a human observer" (Turner et al. 2001).	• Turner [6]
"Landscape ecology is the science and art of studying and influencing the relationship between spatial pattern and ecological processes across hierarchical levels of biological organization and different scales in space and time."	• Wu and Hobbs [1]

- One line of theory was particularly influential in the development of landscape ecology: island biogeography, the analogy between patches of natural vegetation and oceanic islands.

- The theory has two basic parts: (1) the probability of a species reaching an island is inversely proportional to the distance between the island and the source (mainland or source patch) and directly proportional to island size, and (2) the probability of extinction of a species on the invaded island is a function of island size.

- Efforts in landscape biogeography that assessed population and community responses to fragmented landscapes owe much to this body of theory, although metapopulation models (Hanski 1998) have largely replaced island biogeography models as the theoretical framework within which issues of habitat fragmentation are considered (Baguette and Mennechez 2004).

- Some authors (e.g., Haila 2002) suggested that island biogeography acted as an “intellectual attractor” that constrained thinking about habitat fragments.

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Definition of commonly used terms in landscape ecology (adapted and expanded from Forman 1995)

Term	Definition
Composition	What and how much is present of each habitat or cover type
Configuration	A specific arrangement of spatial elements; often used synonymously with spatial structure or patch structure
Connectivity	The spatial continuity of a habitat or cover type across a landscape
Corridor	A relatively narrow strip of a particular type that differs from the areas adjacent on both sides
Cover type	Category within a classification scheme defined by the user that distinguishes among the different habitats, ecosystems, or vegetation types on a landscape
Edge	The portion of an ecosystem or cover type near its perimeter, and within which environmental conditions may differ from interior locations in the ecosystem; also used as a measure of the length of adjacency between cover types on a landscape
Fragmentation	The breaking up of a habitat or cover type into smaller, disconnected parcels; often associated with, but not equivalent to, habitat loss
Heterogeneity	The quality or state of consisting of dissimilar elements, as with mixed habitats or cover types occurring on a landscape; opposite of homogeneity, in which elements are the same
Landscape	An area that is spatially heterogeneous in at least one factor of interest
Matrix	The background cover type(s) in a landscape, characterized by extensive cover and high connectivity; not all landscapes have a definable matrix
Patch	A surface area that differs from its surroundings in nature or appearance
Scale	Spatial or temporal dimension of an object or process, characterized by both grain and extent

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Hierarchy

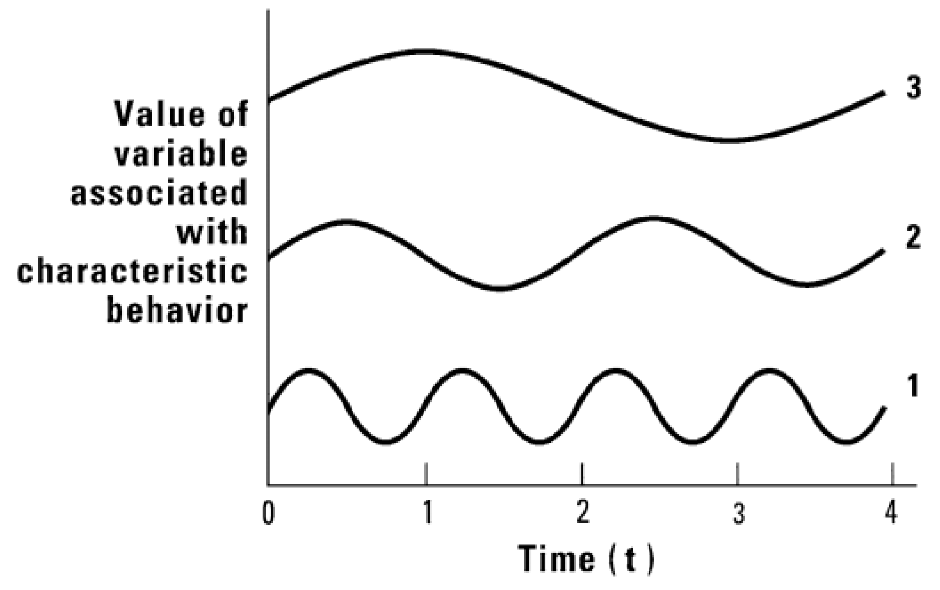
❖A <u>hierarchy</u> is defined as a system of interconnections wherein the higher levels constrain the lower levels to various degrees, depending on time constraints of the behavior.

❖Hierarchy theory is concerned with the ecological consequences of levels of organization in ecological systems (O'Neill et al. 1986). In the simplest series (cell, organism, population, community), each level is composed of subsystems (e.g., the next lower level for organisms are cells) and is constrained by the level above it (populations constrain organisms).

❖Ecological organizations do show hierarchical structure (Rowe 1961), with emergent properties that affect ecological processes at a variety of scales.

❖At every level in a hierarchy there are elements, called holons, which include both wholes and parts.

Within a hierarchical system, the levels are distinguished by differences in the rates, or frequencies, of their characteristic processes (Below Fig). Holons have characteristic rates of behavior, and these rates place them at certain levels in the hierarchy of holons.



Value of variables associated with a level of an ecological hierarchy as they change through time. The *top line* (*line 3*) is a slow variable, one that would serve as a constraint to the lower levels; this may change so slowly that it is perceived as a constant by an observer. The *middle line* (*line 2*) might be the scale at which an observer measures change in the system. The *lower line* (*line 1*) is a fast variable, one that might change so quickly that it could be perceived as a constant. Redrawn from Allen and Starr (1982:12)

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

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❖For example, an individual organism, as a holon, can interact with other individual organisms because both operate at the same space–time scale. But, an individual organism cannot interact with a biome—they are orders of magnitude different in scale.

❖To the individual organism, the biome is a relatively constant background or context within which it operates. Thus, temporal scales serve as important criteria for identifying levels within a hierarchy, and there are different scales of space and time over which controls operate.

❖An important concept from hierarchy theory is the importance of considering at least three hierarchical levels in any study (Below Fig.). The focal level or level of interest is identified as a function of the question or objective of the study.

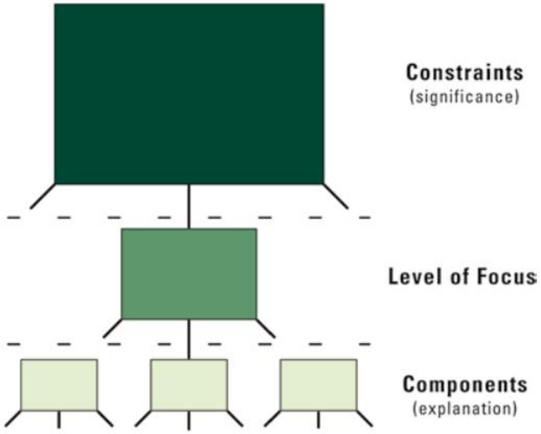


Illustration of the three levels in a hierarchy. Upper levels constrain the focal level and provide significance; lower levels provide details required to explain response of focal level. Adapted from O'Neill et al. (1986).

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

❖For answering the question, “What is the effect of insect herbivory on tree growth rate” would require focusing upon individual trees, whereas, “What is the effect of insect herbivory on the distribution of live and dead trees across the landscape?” would require focusing on the forest as a whole.

❖Two additional levels then must be considered. The level above the focal level constrains and controls the lower levels, providing context for the focal level. The level below the focal level provides the details needed to explain the behavior observed at the focal level.

❖Although the variables that influence a process may or may not change with scale, a shift in the relative importance of the variables or the perceived direction of a relationship often occurs when spatial or temporal scales are changed.

❖For example, predicting the rate of decomposition of plant material at a very local scale requires detailed knowledge of the microclimate, variability in the environment, and characteristics of the litter such as its lignin content; however, effectively predicting rates of decomposition at regional to global scales can be done based solely on temperature and precipitation (Meentemeyer 1984).

- Hierarchy theory suggests that multiple scales of pattern will exist in landscapes because of *the multiple scales* at which processes are acting. Consider the processes that may give rise to pattern in a hypothetical forest landscape.

- Over broad scales of space and time, geomorphological processes result in distributions of substrate and soil that influence what tree species might occur at what positions. Within the forest that develops, the pattern and frequency of large disturbances such as fire or pathogen epidemics may generate a coarse-grained pattern of different successional stages across the landscape.

- Hierarchy theory also tells us that attention should be focused directly on the scales at which phenomena of interest occur; there is no single correct scale for studying landscapes or any other ecological system; and that if we change the scales, the relevant processes or even the direction of relationships that we observe may well change.

- The scale of interest must be dictated by the question or phenomenon of interest. Finer-scale processes may be viewed as the details required to “explain” the phenomena at the focal scale while broader-scale patterns are the “constraints” that limit the potential range of rate processes.

Ecosystem Ecology to Landscape Ecology

❖From a theoretical viewpoint, ecosystem and landscape ecology differ since they deal with ecological topics having very different spatial and temporal scales.

❖From a practical standpoint, they deal with dissimilar purposes emerging both from unlike research scales and different approaches, as the interest of landscape ecology is mainly focused on the whole ecological mosaic rather than on single components, (assuming an “horizontal” ecological perspective).

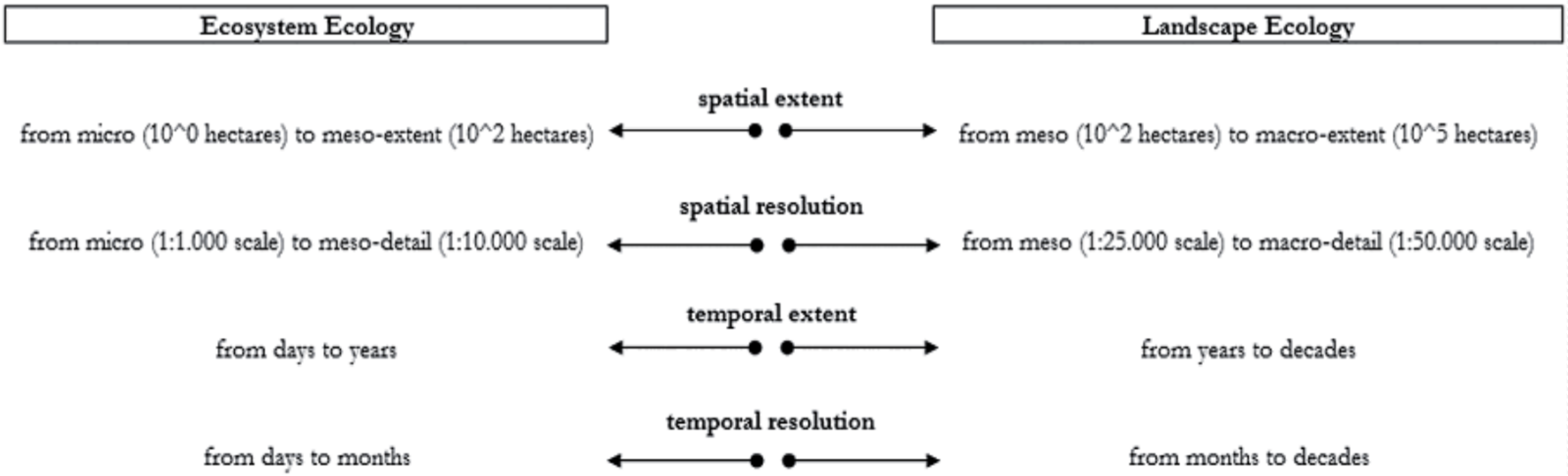
❖A global ecological perspective replaces the “inside-outside” metaphor shared by ecosystem ecology and is substituted by the contextual view proposed by landscape ecology; no internal or external environments really exist, but a mosaic of systems separated by structural boundaries where the outside of a system is the inside of another.

❖The functioning of the whole system (landscape) becomes predominant with respect to its components (ecosystems); how individual ecosystems work is not of primary importance as their functioning is mainly determined by the surroundings.

Source: I. Ferrari & A. Ferrarini; From Ecosystem to Landscape Ecology: a Progression Calling for a Well-founded Research and Appropriate Disillusions Landscape 2008; Online 6, 1-12 . ***DOI:10.3097/LO.200806***

❖Landscape is revealed as a complex system in which heterogeneity, non-linearity and contingency are the norm. Emergent properties, phase transitions, and threshold behavior characterise the landscapes since they are the outcomes of nonlinear dynamics of spatially heterogeneous ecosystems.

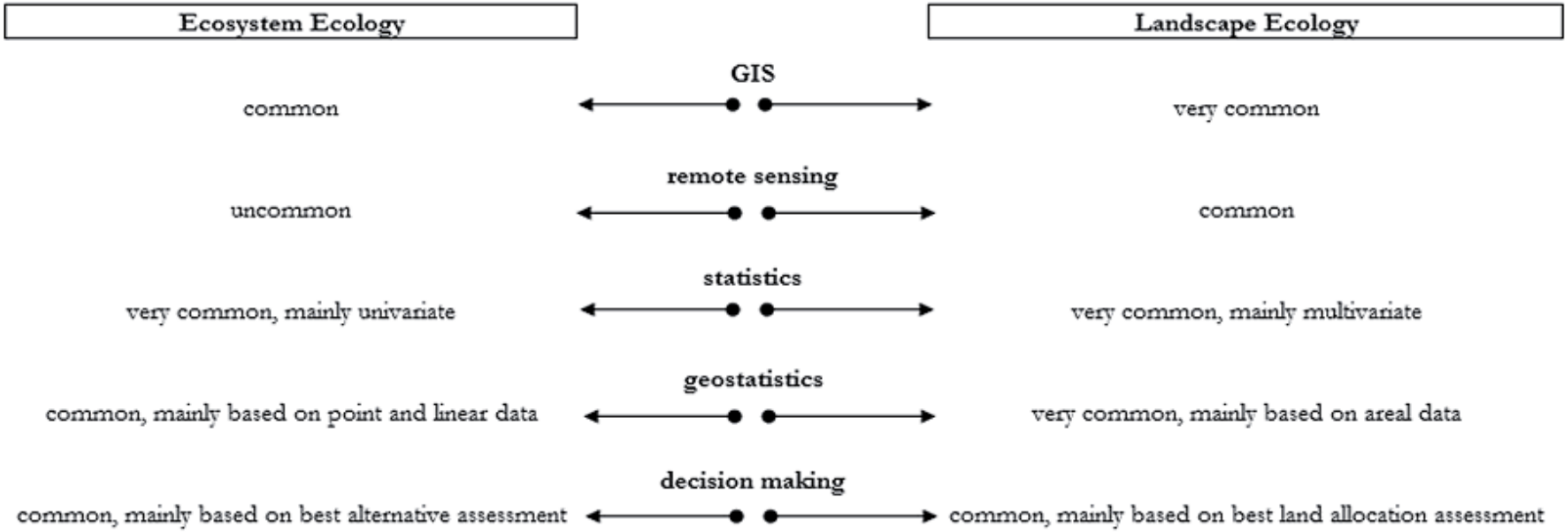
Schematic comparison between ecosystem and landscape ecology along time and space dimensions



Ecosystem Ecology		Landscape Ecology
from micro (10^0 hectares) to meso-extent (10^2 hectares)	spatial extent	from meso (10^2 hectares) to macro-extent (10^5 hectares)
from micro (1:1.000 scale) to meso-detail (1:10.000 scale)	spatial resolution	from meso (1:25.000 scale) to macro-detail (1:50.000 scale)
from days to years	temporal extent	from years to decades
from days to months	temporal resolution	from months to decades

Source: I. Ferrari & A. Ferrarini; From Ecosystem to Landscape Ecology: a Progression Calling for a Well-founded Research and Appropriate Disillusions Landscape 2008; Online 6, 1-12 . ***DOI:10.3097/LO.200806***

Schematic comparison between ecosystem and landscape ecology with respect to methodological issues



Ecosystem Ecology		Landscape Ecology
common	GIS	very common
uncommon	remote sensing	common
very common, mainly univariate	statistics	very common, mainly multivariate
common, mainly based on point and linear data	geostatistics	very common, mainly based on areal data
common, mainly based on best alternative assessment	decision making	common, mainly based on best land allocation assessment

From a methodological point of view, ecosystem and landscape ecology actually show both similarities and divergences (Above Fig). Both disciplines use GIS widely, while remote sensing is much more common in landscape ecology as it gives a synoptic view of large areas of landscape where ecologists rarely visit. Ground truth is thus an essential divergence between ecosystem and landscape ecology, since the former is usually based on *in situ* surveys while the latter makes heavy use of remote information, such as satellite images. *Statistics is common in both disciplines, but ecosystem ecology privileges uni-variate methods, while landscape ecology favours multivariate ones.*

Source: I. Ferrari & A. Ferrarini; From Ecosystem to Landscape Ecology: a Progression Calling for a Well-founded Research and Appropriate Disillusions Landscape 2008; Online 6, 1-12 . ***DOI:10.3097/LO.200806***

History of Landscape Ecology

- One of the most important reasons for understanding landscape history is that we are in a period of rapid global change, and the past can provide us with important insights.

- Paleoecological studies will be useful to discuss the role of climate in the spatial structuring of the biota and the role of prehistoric humans in influencing landscapes.

- The *Holocene Epoch* (approximately the past 10,000 years) is of particular importance for understanding long-term landscape dynamics because it spans the current interglacial period.

- Studies in *environmental history* have also produced tremendous insights into how landscapes develop and change.

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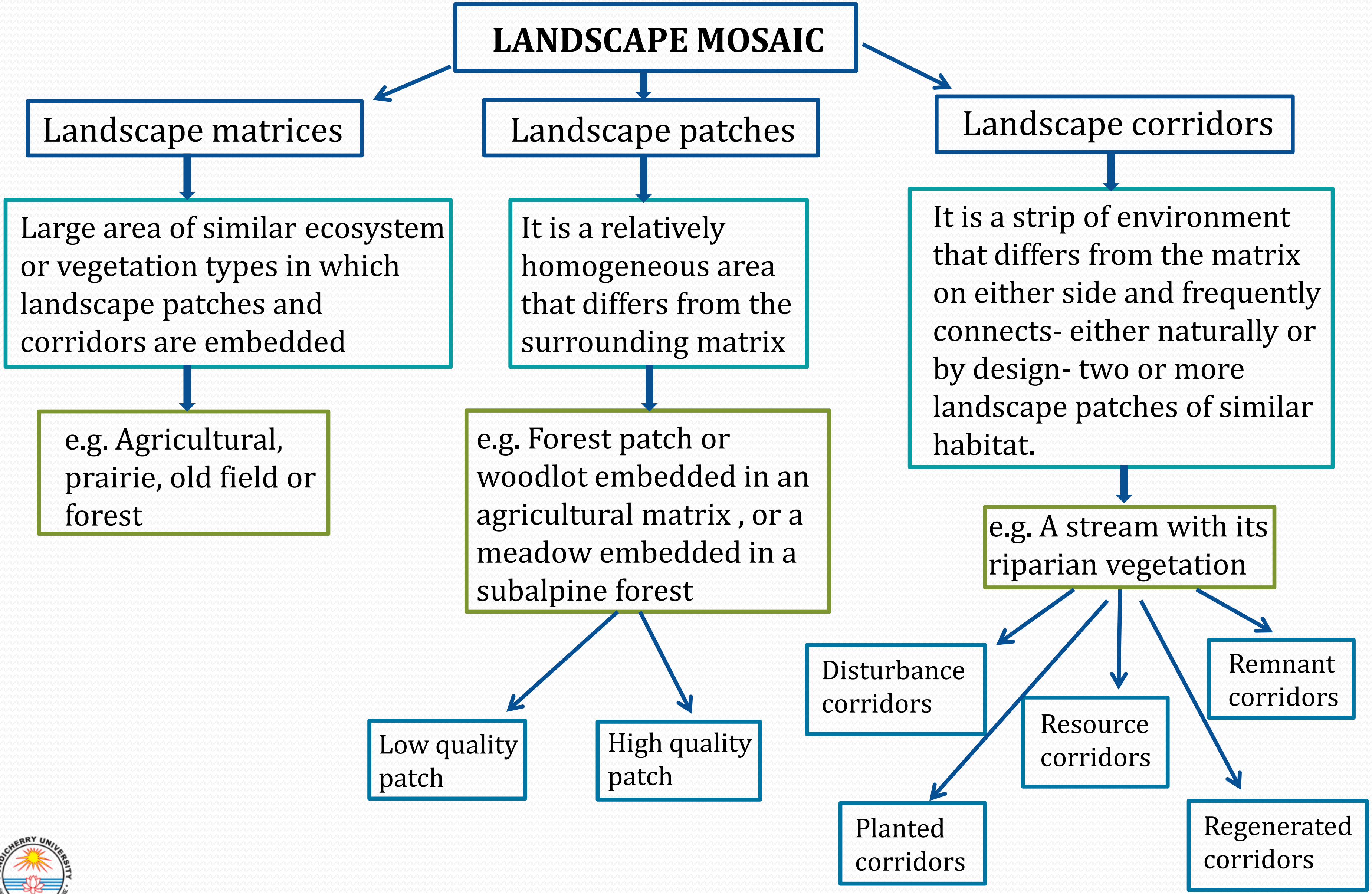
Landscape Elements & Pattern



LANDSCAPE MOSAIC

Landscape matrices

Large area of similar ecosystem or vegetation types in which landscape patches and corridors are embedded

e.g. Agricultural, prairie, old field or forest

Landscape patches

It is a relatively homogeneous area that differs from the surrounding matrix

e.g. Forest patch or woodlot embedded in an agricultural matrix , or a meadow embedded in a subalpine forest

Low quality patch

High quality patch

Landscape corridors

It is a strip of environment that differs from the matrix on either side and frequently connects- either naturally or by design- two or more landscape patches of similar habitat.

e.g. A stream with its riparian vegetation

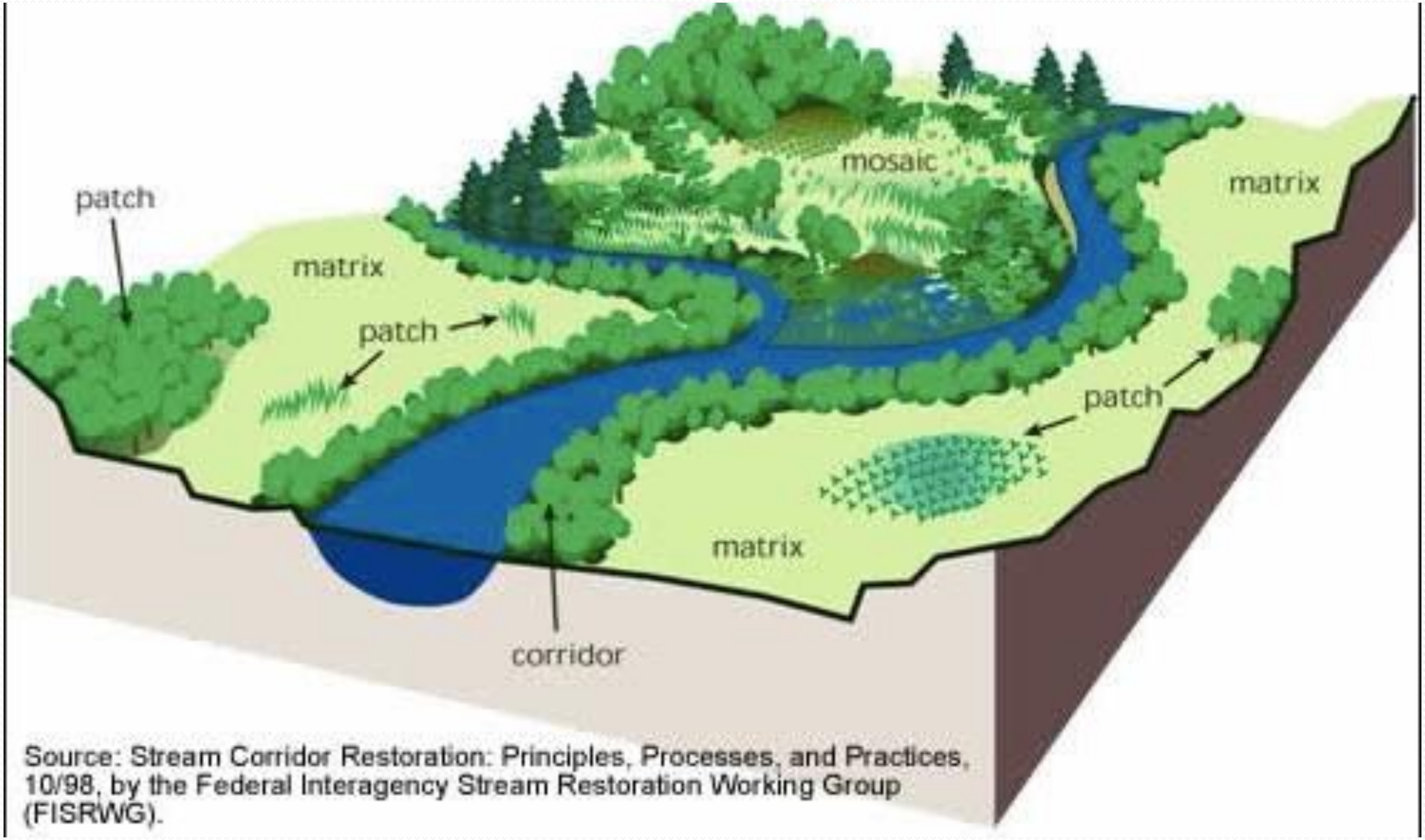
Disturbance corridors

Planted corridors

Resource corridors

Remnant corridors

Regenerated corridors



Source: Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG).

Important Definitions

Subject	Definition
Landscape pattern:	The composition (diversity and relative abundances) and configuration (shape, size, and spatial arrangement) of landscape elements, including both spatial patchiness and gradients.
Landscape structure:	The composition and spatial arrangement of landscape elements – including patches, corridors, and the matrix.
Landscape dynamics	Temporal changes in the structure and function of a landscape, driven by natural and anthropogenic processes.
Scale:	The spatial or temporal dimension of a phenomenon. In landscape ecology, scale usually refers to grain and extent. Grain is the finest spatial or temporal unit in a data set, within which homogeneity is assumed, whereas extent is the total spatial area or temporal duration of a study. Grain and resolution are two related but distinct concepts. In general, fine-grained analyses require high-resolution data, but high-resolution data, after rescaling or aggregation, can also be used for coarse-grained analyses.
Scaling	The translation of information between or across spatial and temporal scales or organizational levels.
Patch dynamics	A perspective that ecological systems are mosaics of patches, each exhibiting nonequilibrium dynamics and together determining the system-level behavior. Patches can be biotic or abiotic, ranging from a tree gap in a forest or a resource patch in a grassland to a whole ecosystem or a continent.
Pattern analysis	The procedures with which landscape pattern is quantified, primarily, using synoptic indices and spatial statistical methods.
Spatial heterogeneity	The combination of discrete and continuous variations of one or more variables in a landscape, which can be characterized as patchiness, gradients, or a mixture of both. Spatial heterogeneity varies with scale in space and time.

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Models in landscape Ecology

- Models are essential tools in landscape ecology, as they are in many scientific disciplines. Spatial models, in particular, play a prominent role in evaluating the consequences of landscape heterogeneity for ecological dynamics.

- *A model is an abstract representation of a system or process*. Models can be formulated in many different ways. Physical models are material replicas of the object or system under study, but at a reduced size;

- For example, models of ships and airplanes are developed to better understand the forces that act upon them, and architectural models allow the space and structure of a building to be visualized.

- Physical models are used in many branches of engineering, but ecologists also build physical models of streams, ponds, and even whole ecosystems (Perez et al. 1991; Macilwain 1996; Petersen et al. 2003) providing an important bridge between experiments in natural systems and theoretical models (Stewart et al. 2013).

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Why need Models in landscape Ecology

➢Models are useful because they allow us to precisely define the problem, articulate the relevant concepts, and then provide a means of analyzing data and communicating results. Most importantly, models allow us to predict the logical outcomes of how we think a system works and then explore the suite of conditions that vary in time and space.

➢Most models are used to explore the consequences of our assumptions and hypotheses rather than to represent system structure and dynamics definitively. Models should always be regarded as one of the scientific tools for achieving a specific end rather than as goals unto themselves.

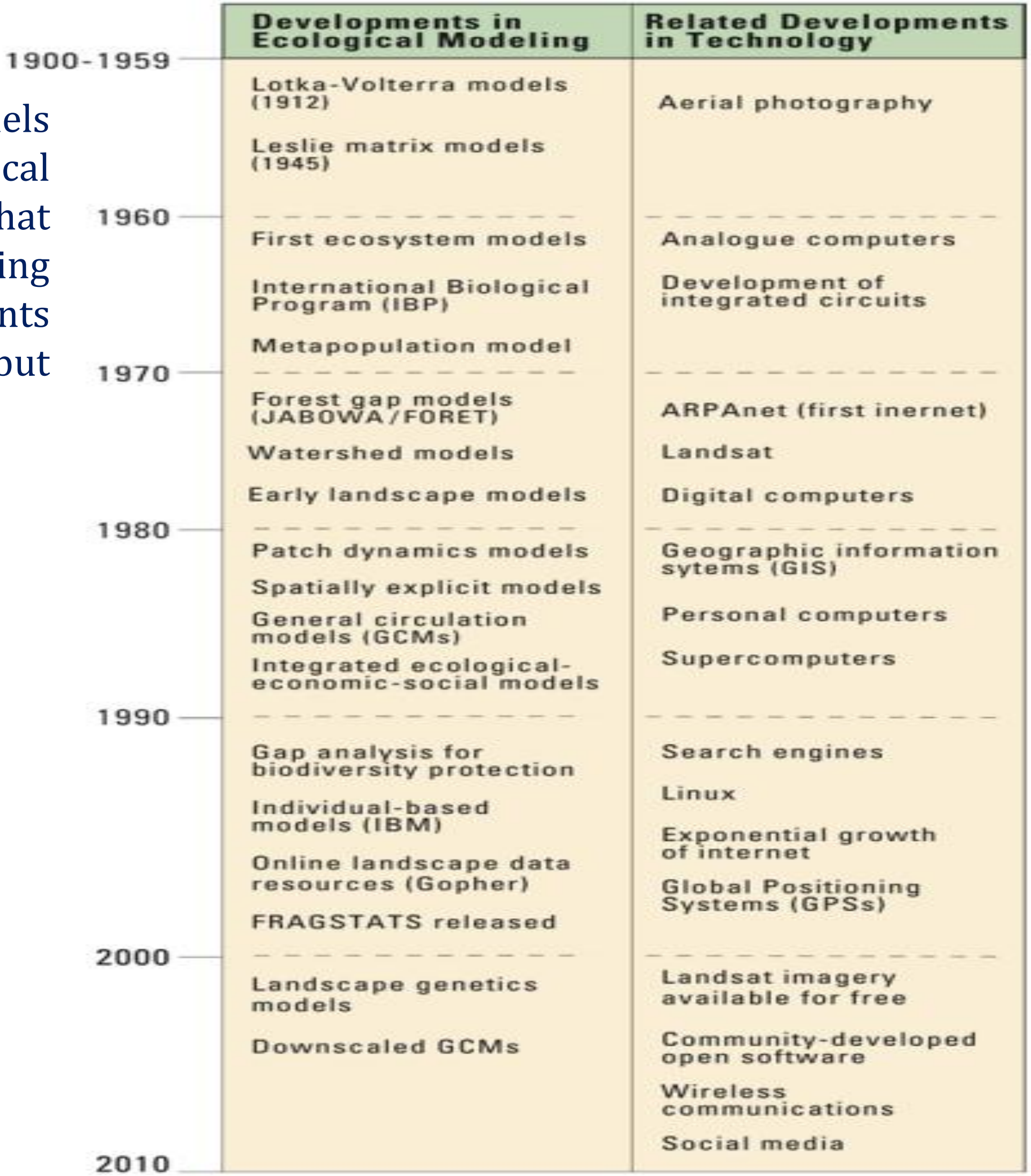
➢When ecologists are faced with answering questions in a large and complex landscape, it is difficult—sometimes impossible—to sample every possible combination of conditions or to conduct experiments at the ideal spatial and temporal scales.

➢Landscape ecologists more commonly use field studies to provide correlative relationships—for example by comparing locations that vary in their degree of land-cover or connectivity of a specific habitat type. Natural disturbances have also been used as "uncontrolled experiments" with their effects expressed in quantitative terms .

➢However, all these approaches are limited in the range of conditions, replication, or control. Under these circumstances, the unique features of each landscape or disturbance event may dominate results. Models can be used to relax empirical constraints, providing a means of systematic comparison across a broad range of conditions, but they do so at the cost of increased levels of unknowns and uncertainties.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Timeline of the development of models in ecology, with important technological and programmatic developments that influenced ecological modelling highlighted in this table. Developments shown are not comprehensive but selected for illustration.

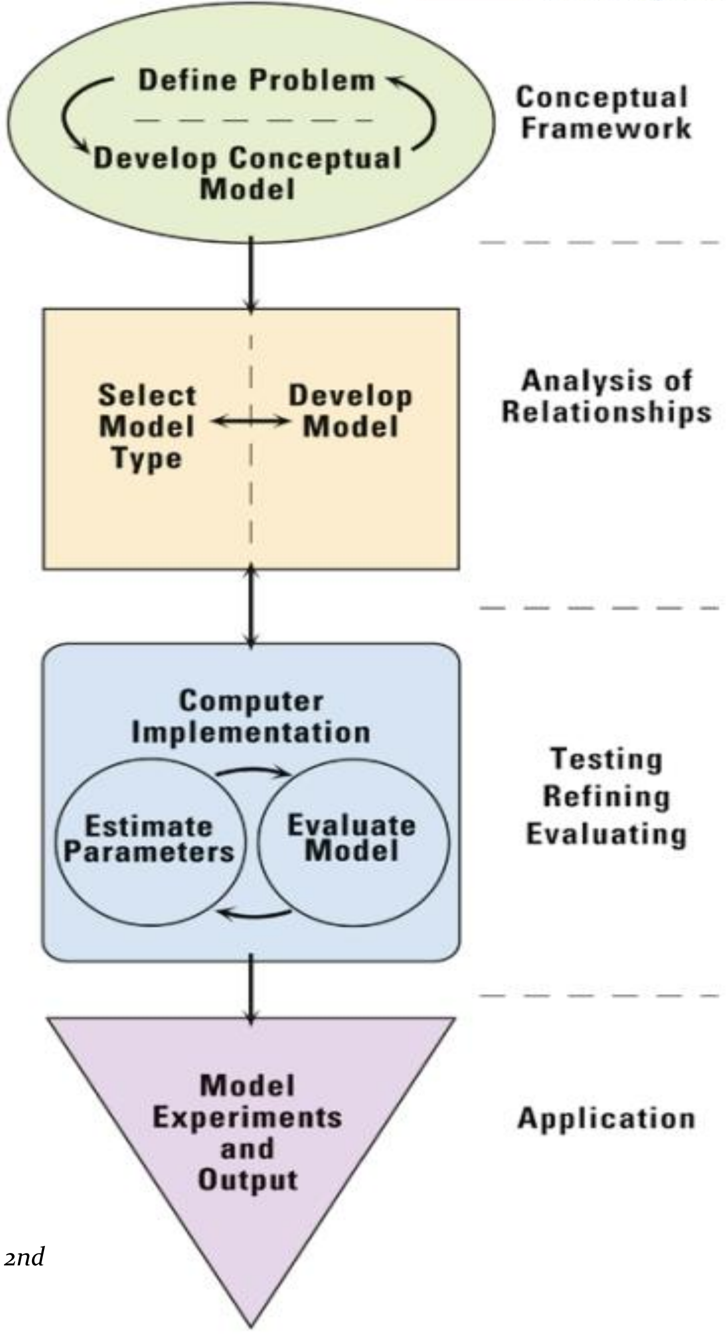


	Developments in Ecological Modeling	Related Developments in Technology
1900-1959	Lotka-Volterra models (1912) Leslie matrix models (1945)	Aerial photography
1960	First ecosystem models International Biological Program (IBP) Metapopulation model	Analogue computers Development of integrated circuits
1970	Forest gap models (JABOWA/FORET) Watershed models Early landscape models	ARPAnet (first inernet) Landsat Digital computers
1980	Patch dynamics models Spatially explicit models General circulation models (GCMs) Integrated ecological-economic-social models	Geographic information sytems (GIS) Personal computers Supercomputers
1990	Gap analysis for biodiversity protection Individual-based models (IBM) Online landscape data resources (Gopher) FRAGSTATS released	Search engines Linux Exponential growth of internet Global Positioning Systems (GPSs)
2000	Landscape genetics models Downscaled GCMs	Landsat imagery available for free Community-developed open software Wireless communications Social media
2010		

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

- Models are characterized in various ways: for example, models may be deterministic or stochastic; analytical or simulation; dynamics or static; and represent time as continuous or discrete.

- A model is spatial when the variables, inputs, or processes have explicit spatial locations represented in the model. A spatial model is only needed when explicit space—what is present and how it is arranged—is an important determinant of the process being studied.



Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Neutral landscape models (*NLM*)

- A simple standard for landscape pattern—and thus the basis for testing differences between landscapes—is a random map which lacks all factors that might organize or structure pattern (Gardner et al. 1987; Gardner and Urban 2007).

- Tests of observed landscapes against replicate random maps reveal the magnitude and significance of differences due to the structure of actual landscapes.

- Therefore, random maps are *neutral landscape models* (*NLM*) against which effects of processes that structure actual landscapes may be tested.

- Studies of NLMs have shown that surprisingly rich patterns can be generated by random processes alone—and their use has shown that actual landscapes may not always be measurably different from these random patterns.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Neutral landscape models (*NLM*)

- A NLM is any model used to generate pattern in the absence of specific processes being studied. Predictions from NLMs are not intended to represent actual landscape patterns, but rather define the expected pattern in the absence of a specific process.

- Comparison of the results of NLMs against actual landscapes provides a standard against which measured departures may be compared. If real landscapes do not depart from a NLM then there may be no need for a more complex model.

- The types of NLMs that may be generated are diverse (see Keitt (2000) for a unified approach to the generation of NLMs). Random maps provide the simplest NLM, but more complex neutral methods including hierarchical random maps and fractal maps have been used to provide insight into the effect of structured patterns of land-cover on ecological dynamics.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Neutral landscape models (*NLM*)

❖Studies utilizing NLMs have been important in the development of theory and the testing of methods for the analysis of landscape patterns.

❖Results of these studies have been helpful for exploring the implications of landscape patterns for ecosystem processes, population dynamics, disturbances, management decisions, and conservation design.

❖Neutral models are particularly useful for testing differences between landscapes when experimental manipulation and/or replication is not feasible and also serve as an economical means for designing expensive empirical studies.

❖NLMs also played an important role in the development of theoretical landscape ecology by identifying critical thresholds in landscape connectivity, and they have been crucial for understanding the behavior of metrics of landscape pattern.

❖NLMs will continue to have a role in landscape studies because of the challenges associated with manipulating spatial patterns in broad-scale empirical studies.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Landscape Pattern

Photo Source: Google.com

Causes of Landscape Pattern

- In a landscape, we look at its *composition* and *spatial* amount, and how these elements are arranged.

- In an agricultural landscape, we may observe forests occurring along streams and on steep ridges, whereas croplands and pastures occupy upland areas of gentler slope. In a fire-dominated boreal forest landscape, we may see expanses of old forest, young forest, and early successional vegetation. In a deciduous forest, we may observe small gaps in an otherwise continuous canopy of trees, and we may detect boundaries between forests dominated by different species of trees.

- In landscapes of small extent (e.g., 100 m by 100 m), we may observe complex patterns of vegetated and unvegetated surfaces.

- Contemporary landscapes result from many causes, including variability in *abiotic conditions,* such as climate, topography, and soils; *biotic interactions*, such as competition, mutualism, herbivory, and predation, that can generate spatial pattern even when environmental conditions are homogenous; *natural disturbances and succession*; and past and present patterns of *human land use*.

- Broad-scale variability in the abiotic environment sets the constraints within which biotic interactions and disturbances act. The environmental template sets the stage, but landscape patterns result from multivariate causes that operate and interact over many scales in time and space.

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Observations of landscape patterns can trigger a number of general questions:

1. How do all these different patterns develop?

2. What is the relative importance of different causes?

3. Do similar patterns emerge from similar processes?

4. How do landscape patterns change through time?

5. What conditions produce gradual vs. abrupt changes in landscape patterns?

6. Can future patterns be predicted?

7. For how long are patterns discernible after the processes creating the patterns have ceased?

- Important information about the causes and changes in landscape patterns comes from the field of *paleoecology*, the study of individuals, populations, and communities of plants and animals that lived in the past and their interactions with changing environments.

- Paleoecology offers a wealth of insight into the long-term development of today's landscapes and has re-established its ties with *biogeography*, which seeks to explain patterns of species distribution.

Key drivers of Landscape Pattern

- Landscape patterns develop on the template established by **climate, landform, and soils**. *Climate* refers to the composite, long term, or generally prevailing weather of a region (Bailey 2009), and climate acts as a strong control on biogeographic patterns through the distribution of energy and water.

- Climate effects are modified by *landform*—the characteristic geomorphic features of the landscape, which result from geologic process producing patterns of physical relief and soil development. Together, climate and landform establish the template upon which the soils and biota of a region develop.

- Already, studies have shown that organisms are rapidly shifting their distributions to higher latitudes and elevations (Chen et al. 2011); disturbance regimes are changing (Westerling et al. 2006); and permafrost, glaciers, and sea ice are melting (e.g., Perovich 2011). Thus, it is important for landscape ecologists to have a general understanding of climate variability and its potential effect on landscapes.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

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Landform effects on ecosystem patterns and processes

➢Landforms range from nearly flat plains to rolling, irregular plains, to hills, to low mountains, to high mountains (Bailey 2009) and are identified on the basis of three major characteristics: (1) relative amount of gently sloping (<8 %) land, (2) local topographic relief, and (3) generalized profile, i.e., where and how much of the gently sloping land is located in valley bottoms or in uplands (Bailey 2009).

➢Landforms may be described further by considering the topographic sequence of variation, or *soil catena,* of soils and associated vegetation types within each landform.

➢Landforms significantly contribute to the development and maintenance of spatial heterogeneity across a landscape through their multiple effects on soils, vegetation, and animals (Swanson et al. 1988).

➢Even in areas of relatively little topographic relief, such as the glacial landforms of the Upper Midwest of the US or riparian floodplains, physiography contributes to spatial variability in vegetation patterns (e.g., Turner et al. 2004a).

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

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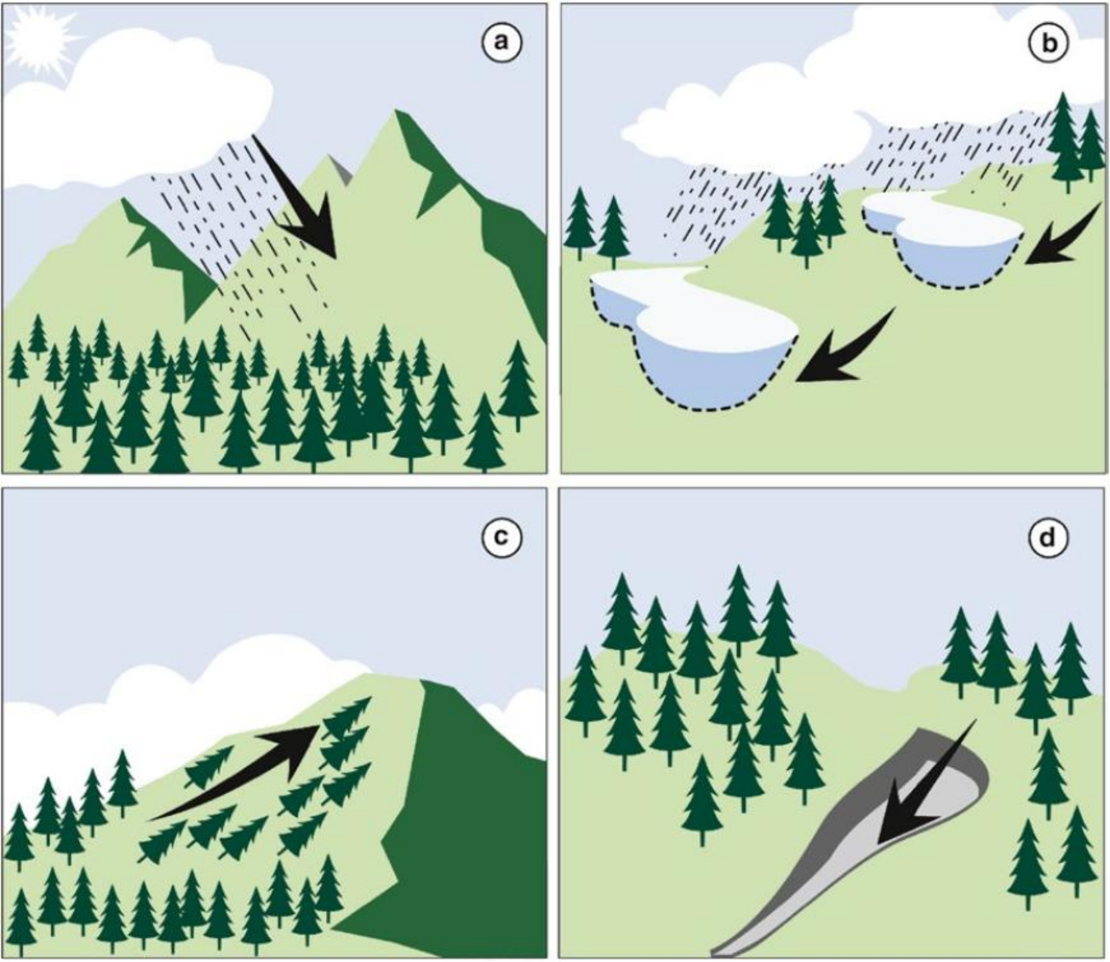
Landform effects on ecosystem patterns and processes



Examples of four classes of landform effects on ecosystem patterns and processes. (**a**) Topographic influences on rain and radiation (*arrow*) shadows. (**b**) Topographic control of water input to lakes. Lakes high in the drainage system receive a greater proportion of water input by direct precipitation that lakes lower in the landscape, where groundwater (*arrows*) predominates; also see Chap. 9. (**c**) Landform constrained disturbance by wind (*arrow*) may be more common in upper-slope locations; also see Chap. 7. (**d**) The axes of steep concave landforms are most susceptible to disturbance by small landslides (*arrow*). Modified from Swanson et al. (1988)

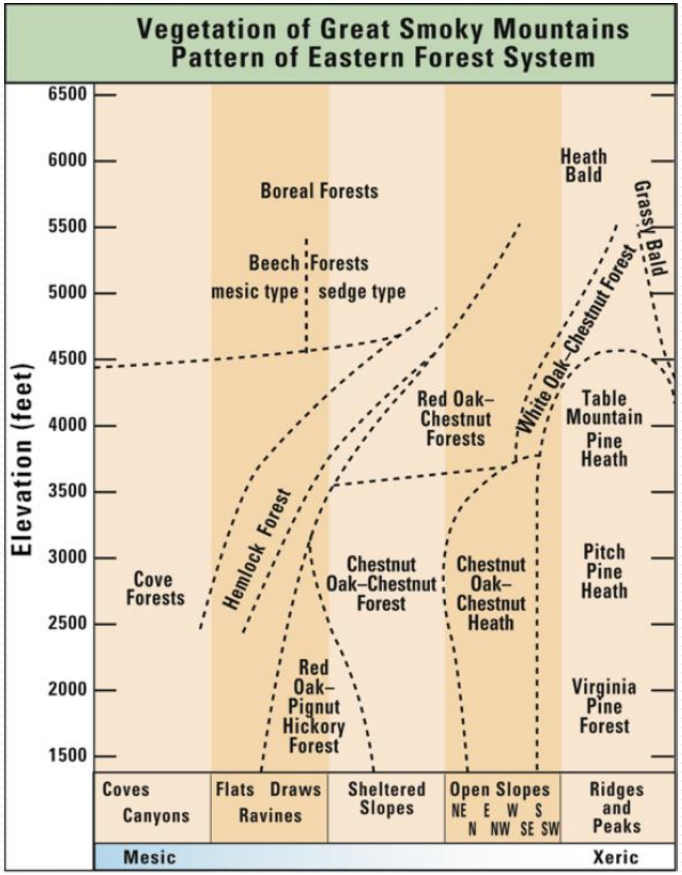
Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

- It was well known that vegetation distributions in space responded to the north-south gradient of temperature combined with an east-west gradient of moisture. Vegetation pattern was further determined by topographic gradients in moisture, temperature, soils, and exposure.

- Thus, at broad scales, it was well established that ecological systems interacted with spatially distributed environmental factors to form distinct patterns.

- In the Great Smoky Mountains (USA), distinct vegetation patterns have formed with elevation, due to temperature, and with exposure, due to moisture (e.g., Whittaker 1952, 1956) .

Whittaker was able to decipher the **environmental signals creating the pattern**. The complex vegetation system was arrayed on a vertical axis of elevation and a horizontal axis representing exposure from moist sites (mesic) to dry, exposed sites (xeric).



Vegetation of the Great Smoky Mountains, the subalpine conifer forests, with respect to gradients of elevation and topography. Adapted from Whittaker (1956).

Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Effects of Soil on ecosystem patterns and processes

- In terrestrial environments, soils provide the mineral nutrients, water, and support medium required by the vegetation. The substrate and soils of the surrounding landscape also affect the chemical qualities of the water in aquatic systems.

- Although it may be associated with particular landforms, there is tremendous spatial variability in *parent material* (i.e., the un-weathered geologic material from which soil develops) across the surface of the Earth. Soils form, in part, through the process of weathering, in which chemical dissolution and physical abrasion break down parent materials.

- Microbial activity is also important, and plant roots play an important role in soil formation. Soils are important in explaining landscape patterns because they differ substantially in many physical and chemical characteristics (e.g., texture, depth, pH, mineral composition) that influence the species that can be supported.

Why Quantify Pattern

- Because landscape ecology emphasizes the interaction between spatial pattern and ecological process, methods by which spatial patterning can be described and quantified are necessary.

- There are numerous practical examples of where quantitative understanding of the pattern is important. First, landscapes change through time, and we may be interested in knowing whether the pattern is different at time *t*+1 than it was at time *t*. Furthermore, we may want to know specifically ***how*** landscape pattern has changed.

- Landscapes have undergone substantial change during the past two centuries, as illustrated in the next figure. Here we can observe that the area of forest has declined through time, and forest patches have become smaller and more isolated.

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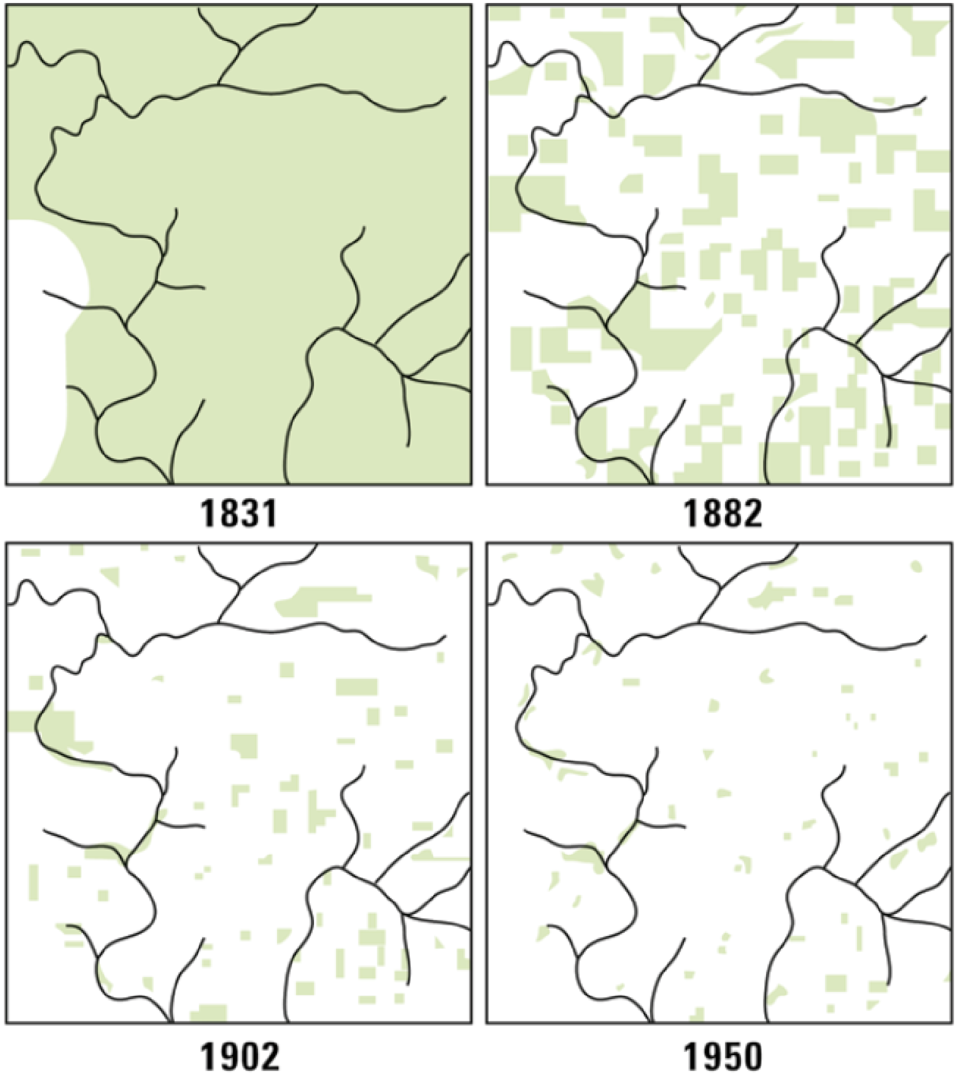


Changes in forest cover (*shaded green*) since the time of European settlement for Cadiz Township in south eastern Wisconsin. This pattern can be observed in many areas and illustrates both the changes in the abundance and spatial arrangement of forest in the landscape. Adapted from Curtis (1956)

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

❑Second, we may wish to compare two or more different landscapes or areas within a given landscape and determine how different or similar they are. In some cases, a political boundary may result in dramatically different landscape configurations within close proximity.

❑Numerous small, dispersed clear cuts are evident to the west, where timber was harvested on the national forest, whereas forest is more continuous to the east, within the park.

❑Landscape metrics allow us to determine whether spatial patterns have changed over time, or whether landscapes are different or similar in pattern.

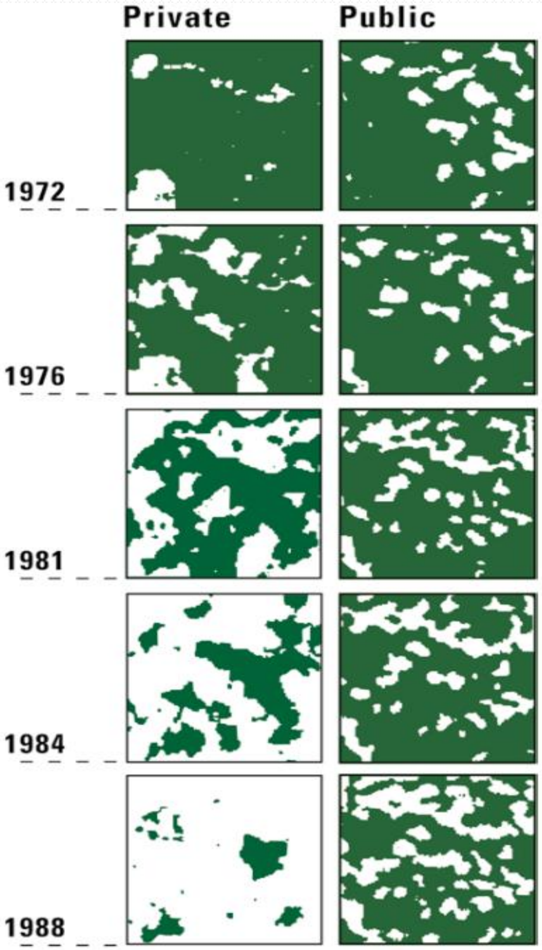
Differences in landscape pattern are apparent along the western boundary of Yellowstone National Park in this false-color aerial photo. The national park lands with relatively continuous forest cover (in *red*) can be seen to the right. To the left, areas with dispersed patches of clear cuts (*white*) on National Forest and private lands are evident.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

❑Third, when considering the effects of different drivers on landscape pattern or future scenarios, we may need to evaluate quantitatively the different landscape patterns that result. Spatial analyses have been especially informative for detecting differences in landscape pattern associated with different categories of landowner.

❑Finally, different aspects of spatial pattern in the landscape may be important for processes such as the movement patterns of organisms, the redistribution of nutrients, or the spread of a natural disturbance.

❑That is, relating spatial patterns to ecological processes first requires the means to describe these patterns. Consequently, spatial pattern metrics play a key role in many landscape studies.



Changes in conifer (*green*) and other forest types for a private and public landscape (2500 ha) with similar initial conditions and rates of change that are relatively high for the ownership types. Landscape metrics were used to quantify the differences in landscape pattern between ownerships. Redrawn from Spies et al. (1994).

Photo Source: Turner MG, Gardner, RH, 2015.

Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Edge Effect

- Edges of habitats reveal species composition, structure, and function representative of the unit of organization as compared with the adjacent area as well as having their own unique array of species and characteristics.

- The edge effect may be represented as a geometric concept: perimeter-to-area (P/A) ratio of a distinct habitat or landscape unit; as that ratio increases, the perimeter, or edge per unit area, increases, making interior portions of the unit progressively closer to an edge. Processes that are affected by transition across the edge (or perimeter, or boundary) may in turn have progressively greater influence on the area inside or outside that edge as the P/A ratio increases.

- Thus, the ‘edge effect’ is a term used to describe the various consequences on plants and animals, which occur as a result of one type of habitat conjoining with another.

Source: M.S. Fonseca, in Encyclopedia of Ecology, 2008

- Edges influence communities through several mechanisms; they act as dispersal barriers or filters, impose mortality, create spatial subsidies (obligate edge crossing), and give rise to novel interactions, especially in the case of invading species.

- Consequences of these mechanisms include microclimate shifts, species shifts, and commonly the introduction of human proximity to previously unperturbed communities.

- Investigations of terrestrial edge effects are far better understood than those in aquatic systems. Overall, edge effects are a rich field of investigation for development of spatially articulated models.

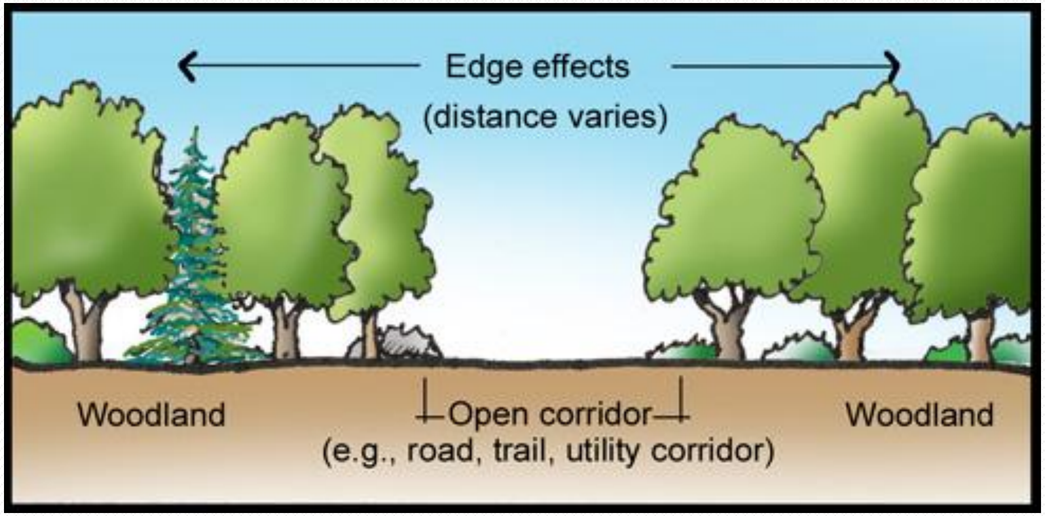


Photo Source: https://www.fs.usda.gov/nac/buffers/guidelines/2_biodiversity/10.html

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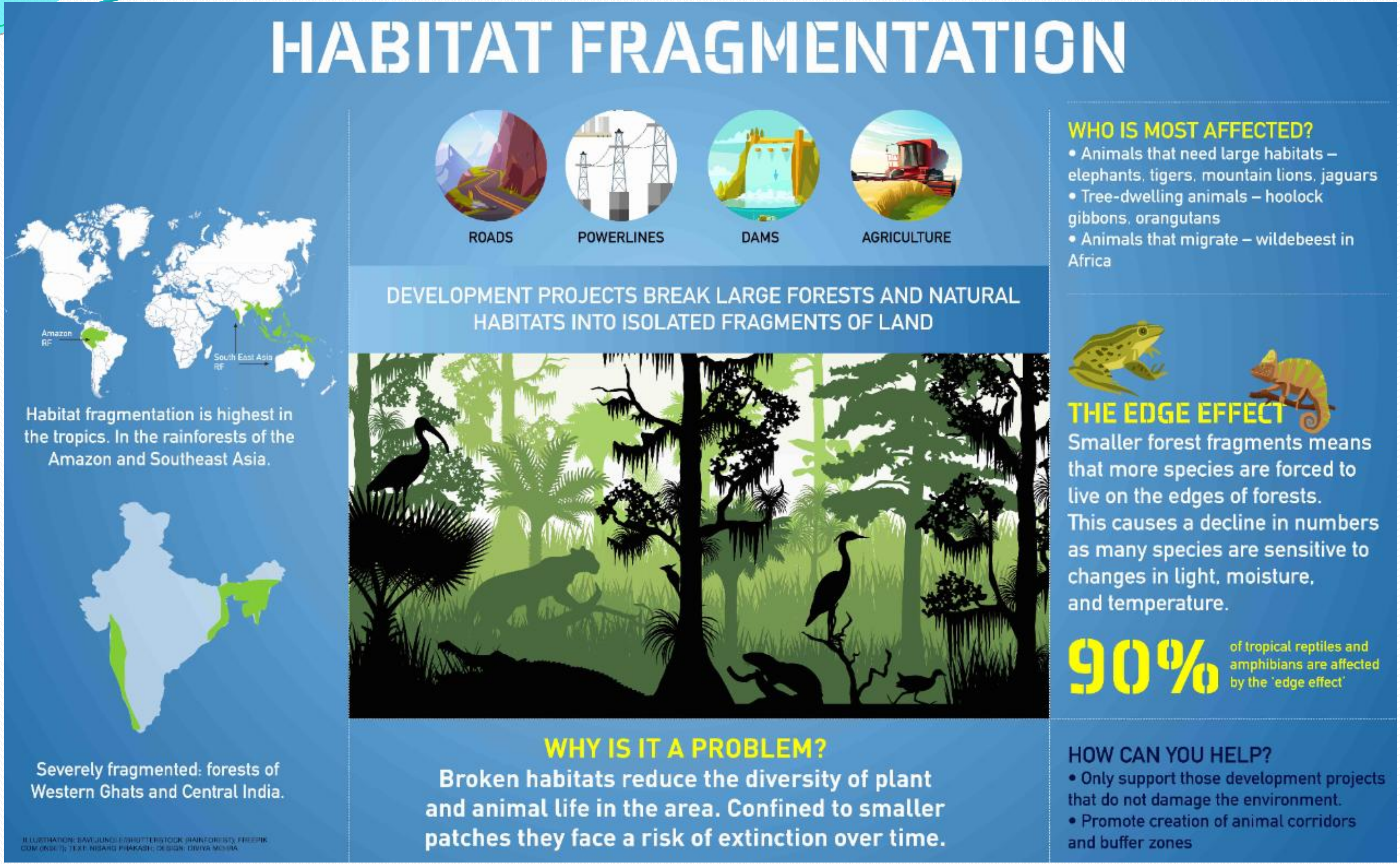
Patch, Edges and Habitat Fragmentation

❖Global urbanization accelerates the mass production and consumption of natural resources causing many types of land-use changes. Therefore, understanding the causes, processes, and ecological consequences of land-use and land-cover changes, including urbanization, is considered as a critical topic in landscape ecology, and clarifying the effects of urbanization on regional biodiversity is crucial for future biodiversity conservation.

❖Among the large-scale landscape changes that may profoundly influence community dynamics, habitat fragmentation is considered to be one of the greatest threats to global biodiversity loss and consequently attracts much attention in landscape ecology and conservation biology.

❖Because of habitat fragmentation, patches are becoming increasingly small and distant from each other and are not always connected. Understanding how this affects the species living in these patches is extremely important for practical applications like restoration of ecosystems and conservation of species. These dynamics are explained fairly well by the theory of island biogeography.



HABITAT FRAGMENTATION

Amazon RF

South East Asia RF

Habitat fragmentation is highest in the tropics. In the rainforests of the Amazon and Southeast Asia.

Severely fragmented: forests of Western Ghats and Central India.

ROADS

POWERLINES

DAMS

AGRICULTURE

DEVELOPMENT PROJECTS BREAK LARGE FORESTS AND NATURAL HABITATS INTO ISOLATED FRAGMENTS OF LAND

WHY IS IT A PROBLEM?

Broken habitats reduce the diversity of plant and animal life in the area. Confined to smaller patches they face a risk of extinction over time.

WHO IS MOST AFFECTED?

- Animals that need large habitats – elephants, tigers, mountain lions, jaguars
- Tree-dwelling animals – hoolock gibbons, orangutans
- Animals that migrate – wildebeest in Africa

THE EDGE EFFECT

Smaller forest fragments means that more species are forced to live on the edges of forests. This causes a decline in numbers as many species are sensitive to changes in light, moisture, and temperature.

90% of tropical reptiles and amphibians are affected by the 'edge effect'

HOW CAN YOU HELP?

- Only support those development projects that do not damage the environment.
- Promote creation of animal corridors and buffer zones

Information and photo Source: https://roundglasssustain.com/explainers/explainer-habitat-fragmentation

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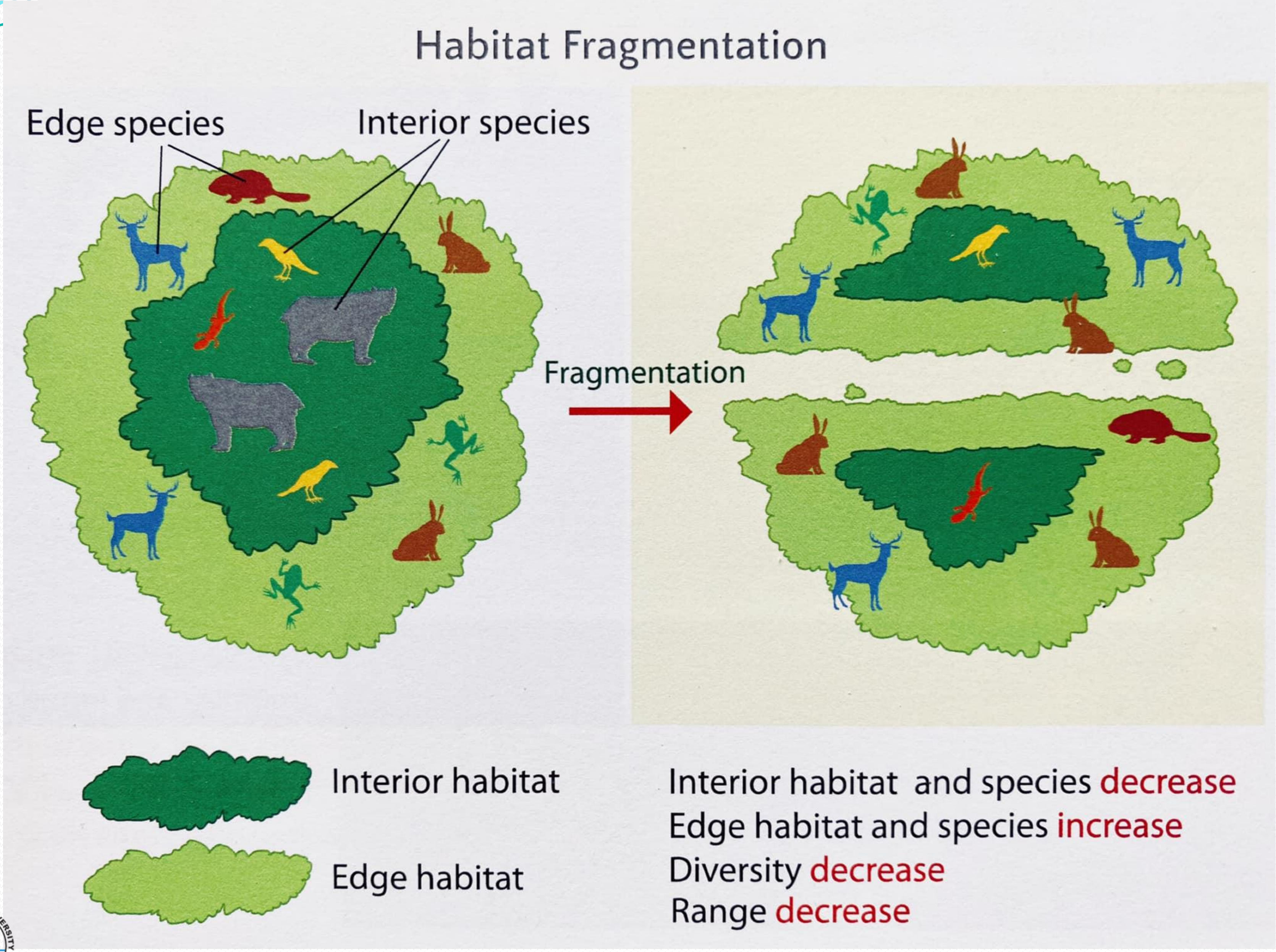

Habitat Fragmentation

Interior habitat and species **decrease**
Edge habitat and species **increase**
Diversity **decrease**
Range **decrease**

Photo Source: https://www.facebook.com/calyxnativenursery/photos/a.109839343939270/156111149312089/?type=3

❖In fragmented landscapes, patch area and shape complexity are important factors determining species diversity within patches. In particular, the positive relationship between patch area and species richness is one of the most general laws in ecology.

❖Compared with small patches, large patches are more likely to intercept potential colonists (‘target area effect’) and have lower extinction rates due to their greater population sizes.

❖Moreover, large patches may have more habitat heterogeneity and are more complex, consequently promoting an increase in the number of species.

❖Because patches with complex shapes have much higher proportions of edge habitat relative to core habitat than patches of the same size with simpler shapes, the population densities of core-dwelling species are likely to decrease in such patches due to edge effects.

❖Recently, the rates of species loss and population declines in small patches were reported to accelerate as a result of synergistic effects between area loss and edge effects.

Source: soga_et_al_2013, Journal of Insect Conservation, 17(2), 421-428

- ❖Differences in species richness and community composition between edge and core zones are distinct only in large patches; differences in small patches are obscured because they have high perimeter/area ratios and their centers are consequently affected by multiple edges.

- ❖Because all areas within small patches are subject to edge effects, forest- dependent species would be expected to disappear.

- ❖The effects of shape complexity on population density and size are altered by patch size, indicating that area and edge effects interact.

- ❖Because habitat fragmentation and perimeter/area ratios simultaneously decrease as patch size increases, the interaction between patch area and edge effects is considered to be universal in terrestrial landscapes and one of the most important processes that degrade biodiversity.

- ❖From a conservation viewpoint, such an interaction suggests that the core zone is more important for the diversity and the number of individuals of core-dwelling species than the edge zone.

Source: soga_et_al_2013, Journal of Insect Conservation, 17(2), 421-428

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- Therefore, urban planners and conservation agencies need to evaluate whether increasing the circularization of patches can compensate for the inherent disadvantages of small urban forests.

- Urban forests offer wildlife habitat and improve human health and well-being, thus detecting interactions between patch area and shape and increasing patch quality by circularizing small patches are crucial for habitat management and restoration in fragmented landscapes.

- If this interaction will degrade biodiversity in small patches in urban areas, clarifying the mechanism of the interaction will be crucial for conserving urban biodiversity in the future.

Source: soga_et_al_2013, Journal of Insect Conservation, 17(2), 421-428

Data used in Landscape analysis

- *Aerial photography*
- *Digital remote sensing*
- *Field mapped data*
- *Published data and censuses*

The widespread availability of spatial data has created myriad opportunities for landscape patterns to be analyzed for many different purposes. It is easy to look up the calculation or equation for any given metric. However, having the framework for the correct use of metrics is critical.

- ✓First and foremost among these is having a well-conceived question/rationale for the analysis.

- ✓It remains easy to fall into the trap of generating a lot of numbers without a clear purpose for the study and recognition of the limitations of the metrics.

- ✓Reporting metrics is not meaningful without an a priori statement of the objectives of the analysis and/or hypothesized pattern changes (i.e., disturbances will cause a decline in the diversity of land-cover types).

- ✓Landscape comparisons can also be plagued by pseudo replication which occurs when comparisons are made among samples that are not truly independent.

- ✓The dangers of pseudo replication are relevant to landscape ecology because the unique attributes of each landscape make statistical controls difficult and independent replicate samples nearly impossible.

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Check List prior to Landscape Pattern analysis

Questions to be addressed……………………

1. What are the scientific or management questions motivating the study?

2. What qualities of spatial pattern are of most interest, and why (i.e., what is the ecological rationale)? how do you expect these qualities to change over time, differ among study areas, or affect processes of interest?

3. Which metrics are potential indicators of the spatial qualities you wish to quantify? Which metrics should be computed for the landscape as a whole, or by cover type, or for individual patches.

4. What spatial data are needed to answer the questions (and are these data available)? are categorical or continuous data better suited for answering the questions? For categorical data, what classification scheme is appropriate, given the objectives of the study?

5. For analyses involving more than one study area or time period, are scales and classification schemes consistent across datasets?

6. What is the accuracy of the spatial data? Is error in the input data likely to affect the numerical results of the analysis? are the source data and classification methods consistent when using results to compare landscapes?

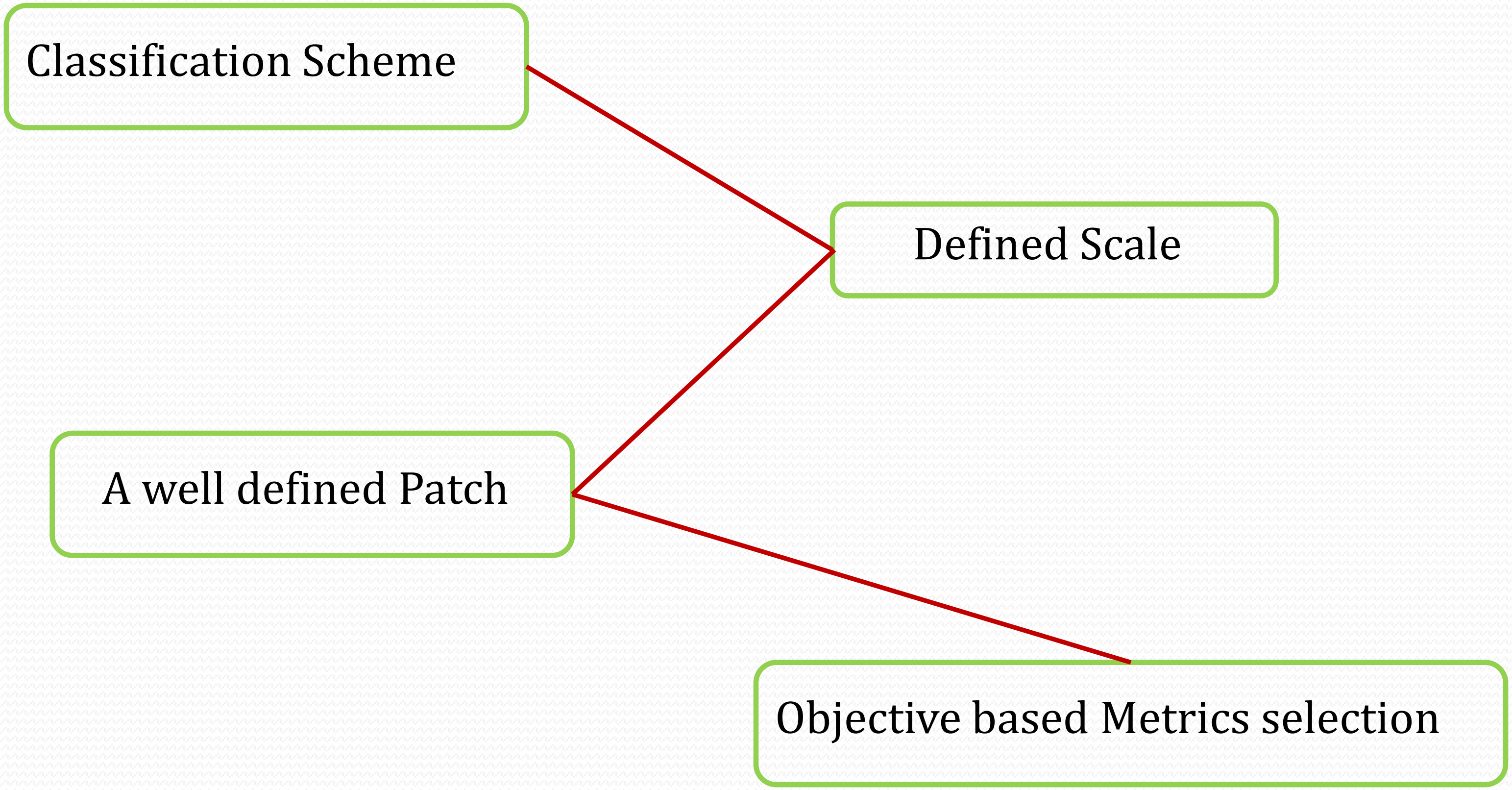
7. how is each metric calculated (i.e., what is the equation)? What is its potential range (i.e., minimum and maximum value)? Is it a normalized, or are the values unconstrained? What are the units?

8. What is the correlation structure among the metrics computed in your analysis? (provide the descriptive statistics of the distributions of each metric, and always check the correlation structure among metrics in your own study by inspecting scatter plots and calculating correlation coefficients!) What is the most parsimonious set of metrics that answers the questions?

9. What method will be used to determine whether metrics (or comparisons made through time or among landscapes) are significant both statistically and ecologically? how will the values, differences or trends of the metrics be interpreted ecologically?

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Critical points to be considered before analysis…………..



Classification Scheme

Defined Scale

A well defined Patch

Objective based Metrics selection

Numerous metrics can be computed for a landscape dataset. Commonly used metrics within five broad categories are: metrics of landscape composition; measures of spatial configuration, including contagion and patch-based metrics; fractals; surface metrics; and spatial graphs.

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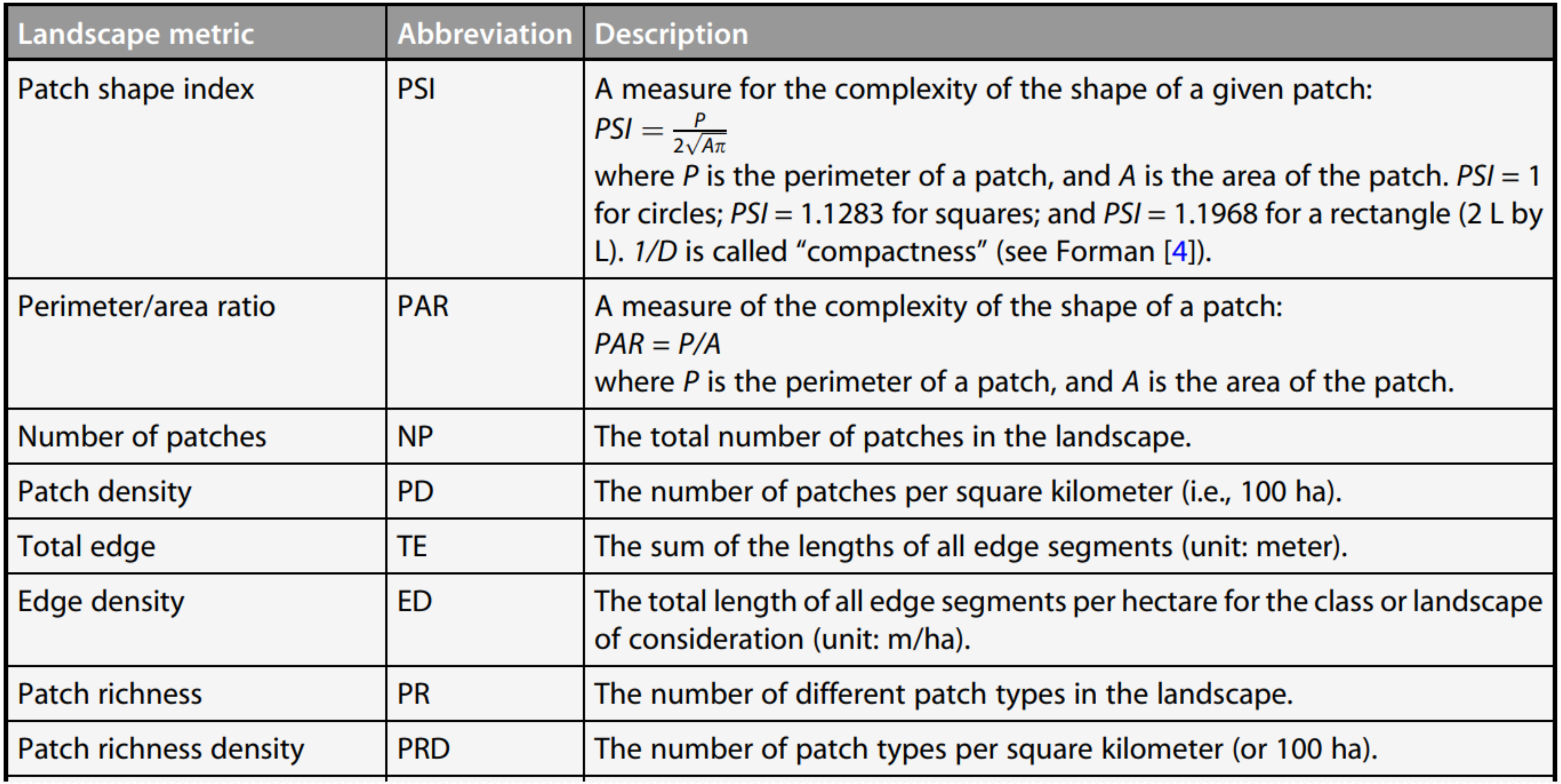
Some commonly used landscape metric



Landscape metric	Abbreviation	Description
Patch shape index	PSI	A measure for the complexity of the shape of a given patch: $PSI = \frac{P}{2\sqrt{A\pi}}$ where *P* is the perimeter of a patch, and *A* is the area of the patch. *PSI* = 1 for circles; *PSI* = 1.1283 for squares; and *PSI* = 1.1968 for a rectangle (2 L by L). *1/D* is called "compactness" (see Forman [4]).
Perimeter/area ratio	PAR	A measure of the complexity of the shape of a patch: $PAR = P/A$ where *P* is the perimeter of a patch, and *A* is the area of the patch.
Number of patches	NP	The total number of patches in the landscape.
Patch density	PD	The number of patches per square kilometer (i.e., 100 ha).
Total edge	TE	The sum of the lengths of all edge segments (unit: meter).
Edge density	ED	The total length of all edge segments per hectare for the class or landscape of consideration (unit: m/ha).
Patch richness	PR	The number of different patch types in the landscape.
Patch richness density	PRD	The number of patch types per square kilometer (or 100 ha).

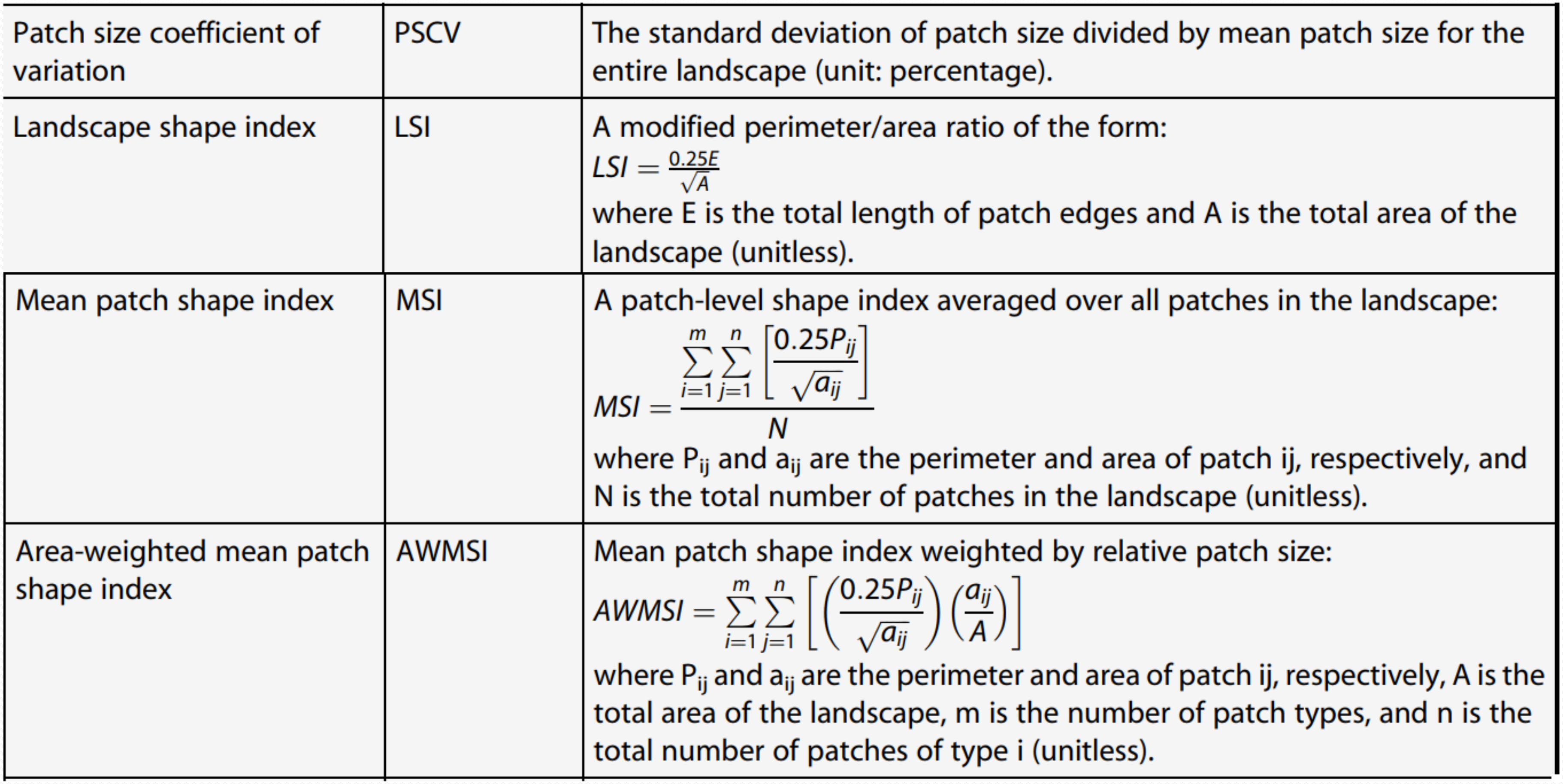
Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Some commonly used landscape metric

Shannon's diversity index	SHDI	A measure of patch diversity in a landscape that is determined by both the number of different patch types and the proportional distribution of area among patch types: $H = -\sum_{i=1}^{m} p_i \ln(p_i)$ where m is the total number of patch types and p_i is the proportion of the landscape area occupied by patch type i.
Dominance index	D	A measure of the degree of dominance by one or a few patch types in a landscape: $D = H_{\max} + \sum_{i=1}^{m} p_i \ln p_i$ where $H_{\max}$ is the maximum diversity when all patch types are present in equal proportions, m is the total number of patch types, and p_i is the proportion of the landscape area occupied by patch type i. Small values of D tend to indicate landscapes with numerous land use types of similar proportions.
Largest patch index	LPI	The ratio of the area of the largest patch to the total area of the landscape (unit: percentage).
Mean patch size	MPS	The average area of all patches in the landscape (unit: ha).
Patch size standard deviation	PSSD	The standard deviation of patch size in the entire landscape (unit: ha).

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Some commonly used landscape metric



Patch size coefficient of variation	PSCV	The standard deviation of patch size divided by mean patch size for the entire landscape (unit: percentage).
Landscape shape index	LSI	A modified perimeter/area ratio of the form: $LSI = \frac{0.25E}{\sqrt{A}}$ where E is the total length of patch edges and A is the total area of the landscape (unitless).
Mean patch shape index	MSI	A patch-level shape index averaged over all patches in the landscape: $MSI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\frac{0.25P_{ij}}{\sqrt{a_{ij}}}\right]}{N}$ where P_{ij} and a_{ij} are the perimeter and area of patch ij, respectively, and N is the total number of patches in the landscape (unitless).
Area-weighted mean patch shape index	AWMSI	Mean patch shape index weighted by relative patch size: $AWMSI = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{0.25P_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{A}\right)\right]$ where P_{ij} and a_{ij} are the perimeter and area of patch ij, respectively, A is the total area of the landscape, m is the number of patch types, and n is the total number of patches of type i (unitless).

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

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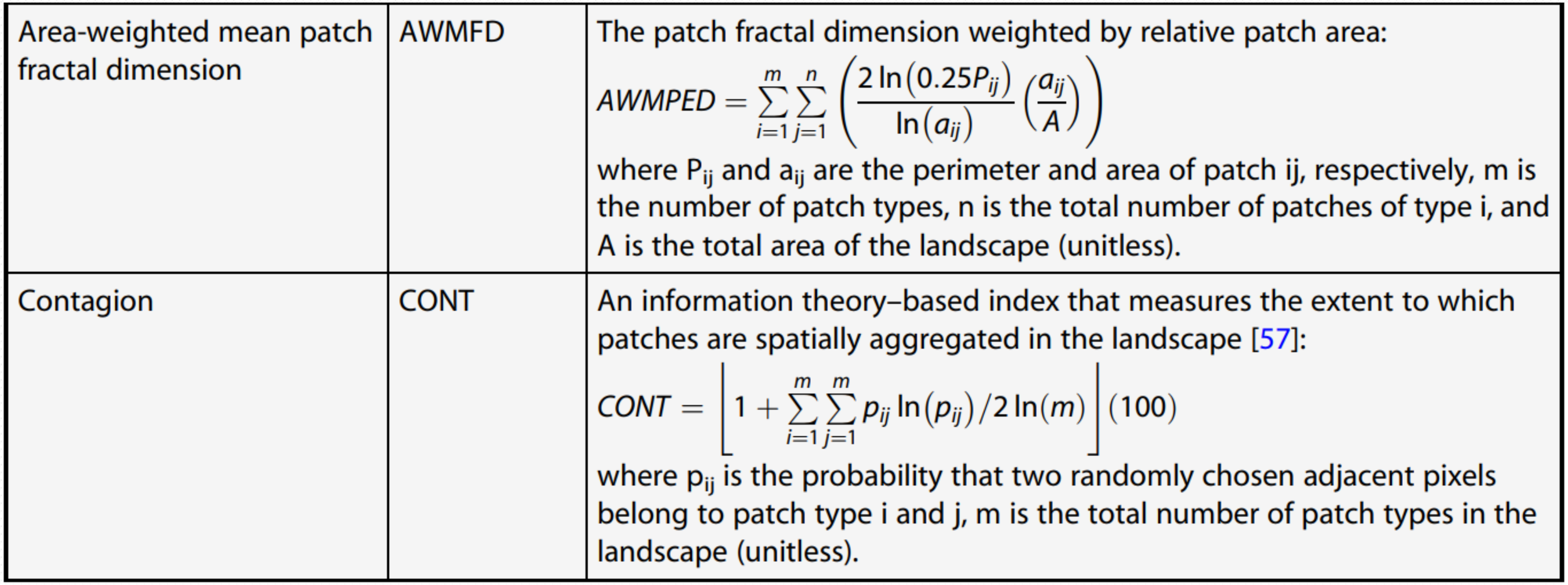
Some commonly used landscape metric

Double-log fractal dimension	DLFD	The fractal dimension for the entire landscape which is equal to 2 divided by the slope of the regression line between the logarithm of patch area and the logarithm of patch perimeter: $DLFD = \frac{2}{\left[\frac{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\ln\left(P_{ij}\right)\ln\left(a_{ij}\right)\right)\right]-\left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln\left(a_{ij}\right)\right)\right]}{\left(N\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\ln\left(P_{ij}{}^{2}\right)\right)\right)-\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln\left(P_{ij}\right)\right)^{2}}\right]}$ where P_{ij} and a_{ij} are the perimeter and area of patch ij, respectively, m is the number of patch types, n is the total number of patches of type i, and N is the total number of patches in the landscape (unitless).
Mean patch fractal dimension	MPFD	The average fractal dimension of individual patches in the landscape, which is the summation of fractal dimension for all patches divided by the total number of patches in the landscape: $FD = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln\left(0.25P_{ij}\right)}{\ln\left(a_{ij}\right)}\right)}{N}$ where P_{ij} and a_{ij} are the perimeter and area of patch ij, respectively, m is the number of patch types, n is the total number of patches of type i, and N is the total number of patches in the landscape (unitless).

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Some commonly used landscape metric



Area-weighted mean patch fractal dimension	AWMFD	The patch fractal dimension weighted by relative patch area: $AWMPED = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln(0.25P_{ij})}{\ln(a_{ij})}\left(\frac{a_{ij}}{A}\right)\right)$ where P_{ij} and a_{ij} are the perimeter and area of patch ij, respectively, m is the number of patch types, n is the total number of patches of type i, and A is the total area of the landscape (unitless).
Contagion	CONT	An information theory–based index that measures the extent to which patches are spatially aggregated in the landscape [57]: $CONT = \left\lfloor 1 + \sum_{i=1}^{m}\sum_{j=1}^{m} p_{ij}\ln(p_{ij})/2\ln(m) \right\rfloor (100)$ where p_{ij} is the probability that two randomly chosen adjacent pixels belong to patch type i and j, m is the total number of patch types in the landscape (unitless).

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

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One metric is insufficient to characterize a landscape, yet there is no standard recipe for determining how many and which ones are needed.

A useful set of metrics to quantify landscape pattern should meet several criteria, including:

(1) the metrics should be selected to answer a particular question or meet a particular objective;
(2) the measured values of the metrics should be distributed over the full range of potential values and the behavior of the metrics should be known;
(3) the metrics should be relatively independent of each other.

Independence can (and should always) be tested by examining the correlation structure among a set of potential candidate metrics. In addition, the analyst must recognize (and carefully choose) the classification scheme used to categorize the data, the spatial scale of the data and any user defined rules (e.g., patch definition).

This set of decisions, along with the accuracy of the spatial data, places important constraints on the analysis and interpretation of landscape pattern. As a first approximation, the extent of the study landscape should be 2–5 times larger than landscape patches to avoid bias in calculating landscape metrics; grain size should be 2–5 times smaller than the spatial features of interest.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Statistical Significance of the data

- ❑A long-standing challenge in landscape ecology has been ascribing statistical significance to differences in landscape metrics either through time or among landscapes.

- ❑In cases where a single number is reported for a landscape (e.g., a patch density or value of contagion), we often have little understanding of the degree to which landscape pattern must change to detect an ecologically important or statistically significant change in the numerical value of the metric (Wickham et al. 1997).

- ❑This has led to a variety of challenges in studies that compare landscapes (e.g., is a Dominance value of 0.75 different from 0.80?), and some erroneous conclusions (e.g., inferring a landscape has become more fragmented when C declines from 0.88 to 0.86).

- ❑In statistical analyses of empirical data, significance is typically assessed by estimating the variance among replicate samples. In landscape ecology, replication is challenging at the very least, and often times impossible.

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Organisms and Landscape pattern

❖Organisms live in heterogeneous environments; they grow, reproduce, disperse, and die in landscapes that are spatially variable and temporally dynamic. Understanding the interactions of organisms with their environment is, of course, a major focus of ecology; understanding the interactions of organisms with the spatial heterogeneity in their environment is a key emphasis of landscape ecology.

❖Much research relating organisms to landscape pattern was motivated by issues associated with *habitat loss* and *fragmentation*. In many landscapes worldwide, expanding human land use has caused natural habitats to decline, and remaining habitat often has been apportioned into small, isolated patches.

❖Landscape ecologists have mounted field studies, developed simulation models, and conducted experiments to understand and predict the consequences of habitat fragmentation for a wide variety of organisms.

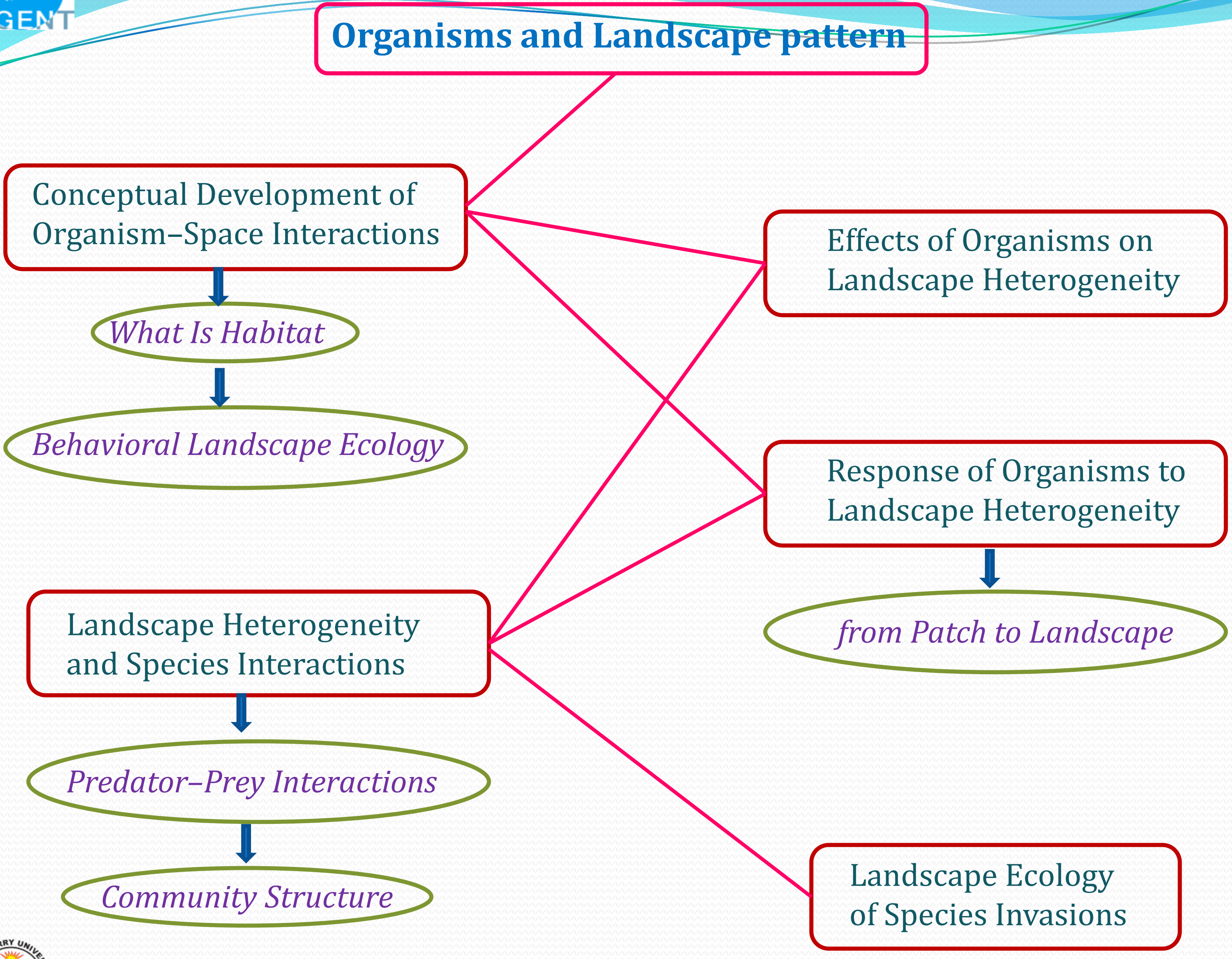
❖To maintain *biodiversity* (the abundance, variety, and genetic constitution of native animals and plants), ecologists also recognized the need for a landscape perspective to complement population, community, and ecosystem considerations. It is not only the local habitat amount and quality that matters for organisms, but also the composition and configuration of the surrounding landscape.

Important Definitions

Subject	Definition
Landscape function	The horizontal and vertical exchanges of organisms, energy, material, and information in a landscape.
Metapopulation	The total population system that is composed of multiple local populations geographically separated but connected through dispersal.
Landscape Connectivity	The degree of a landscape to facilitate or impede the exchange of organisms, energy, material, and information among landscape elements. This is sometimes referred to as landscape functional connectivity, which is a function of both landscape structural connectivity and the movement characteristics of the species or process under consideration. Landscape structural connectivity is simply a measure of how spatially connected the elements in a landscape are, without reference to any particular ecological process.
Landscape sustainability	The ability of a landscape to maintain its basic environmental, economic, and social functions under ever-changing conditions driven by human activities and environmental changes. Landscape sustainability emphasizes the optimization of the composition and spatial configuration of the landscape so as to achieve a high level of resilience or persistency.

Source: DOI: 10.1007/978-1-4614-5755-8_11- Jianguo Wu, 2013

Organisms and Landscape pattern



Conceptual Development of Organism–Space Interactions

What Is Habitat

Behavioral Landscape Ecology

Effects of Organisms on Landscape Heterogeneity

Response of Organisms to Landscape Heterogeneity

from Patch to Landscape

Landscape Heterogeneity and Species Interactions

Predator–Prey Interactions

Community Structure

Landscape Ecology of Species Invasions

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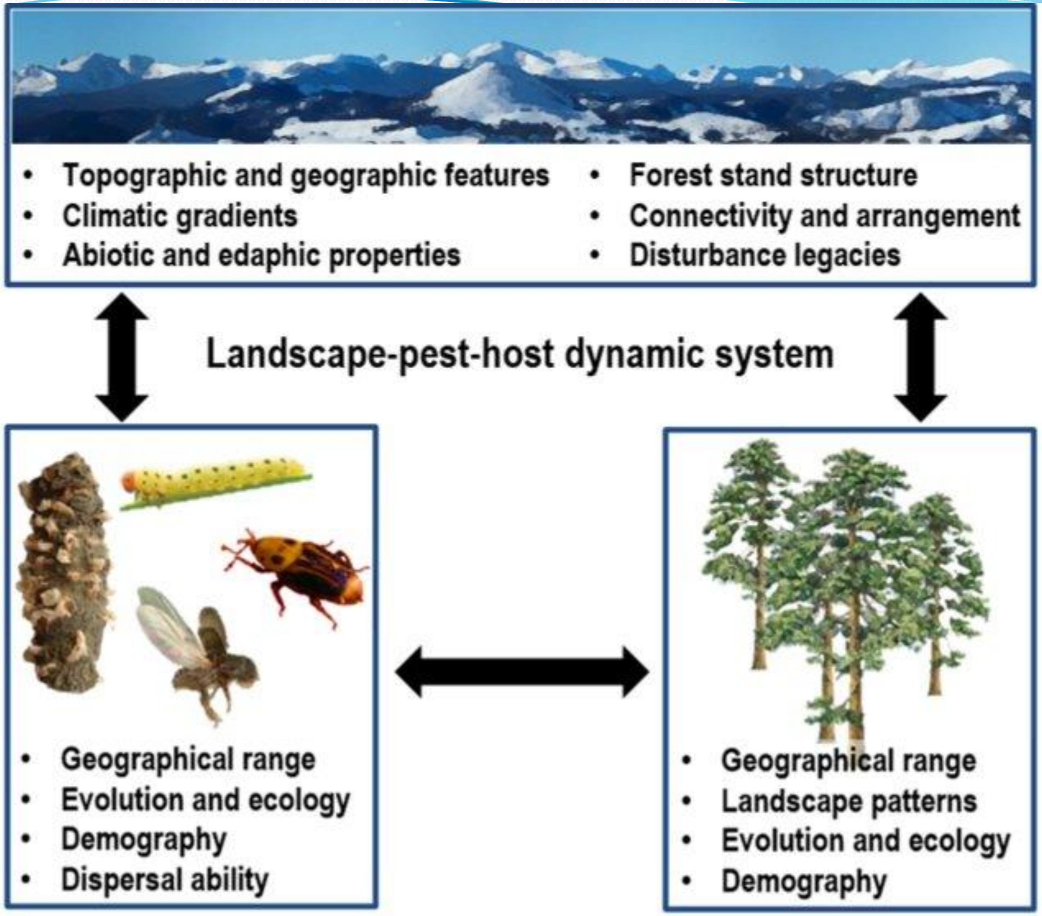
Interactions among landscape factors



- Topographic and geographic features
- Climatic gradients
- Abiotic and edaphic properties
- Forest stand structure
- Connectivity and arrangement
- Disturbance legacies

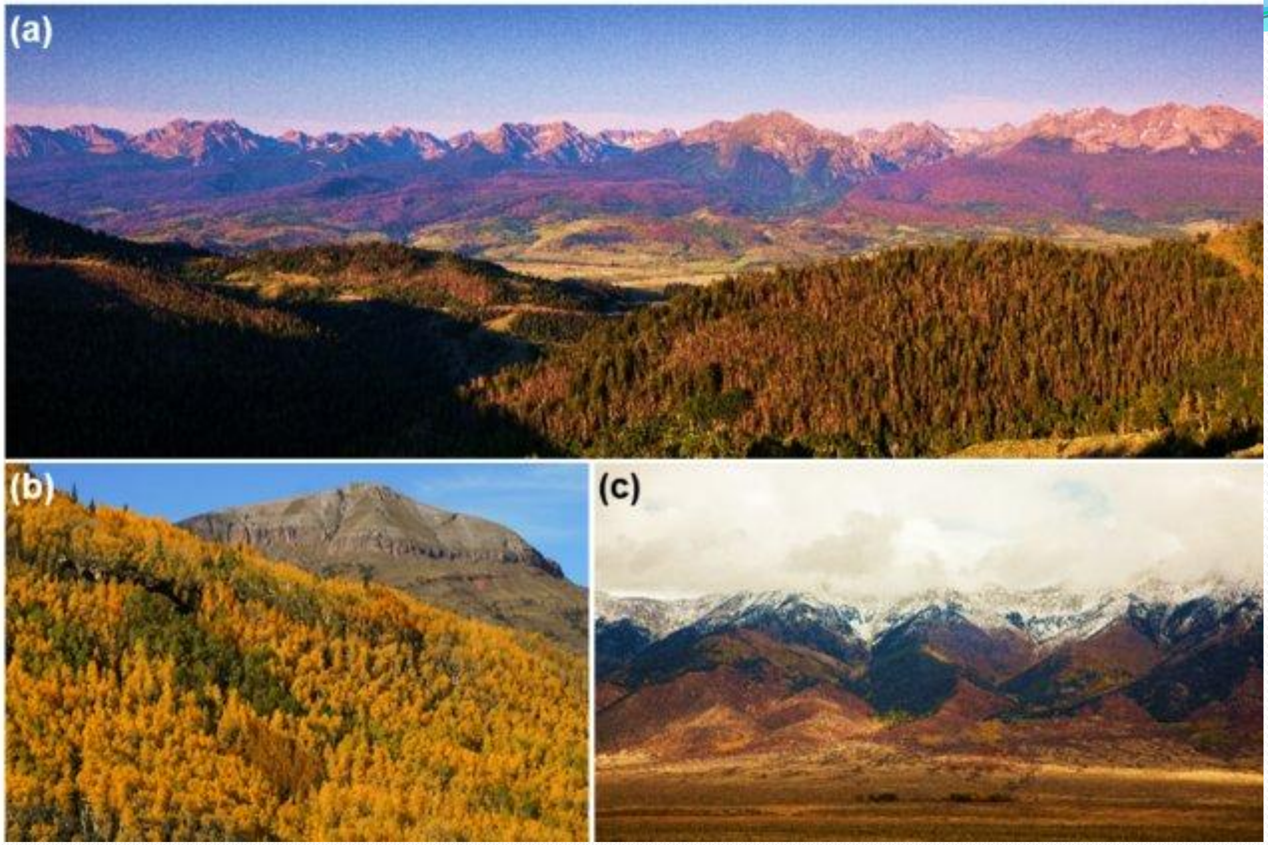
Landscape-pest-host dynamic system

- Geographical range
- Evolution and ecology
- Demography
- Dispersal ability

- Geographical range
- Landscape patterns
- Evolution and ecology
- Demography

Conceptual diagram of the interactions among landscape factors (top panel), forest-pest populations (lower left panel), and their primary host species (lower right panel). Landscape factors with clear influences on biotic interactions include but are not limited to: (1) topographical and geographical effects on local/regional climates and abiotic environments, (2) variation in edaphic properties that can affect forest stand structure and tree health, (3) formation of natural barriers or connections which influence the movement of organisms, and (4) legacies of past forest disturbances.

Source: Scott Ferrenberg, Curr Landscape Ecol Rep, 2016; DOI 10.1007/s40823-016-0005-x



Tree mortality from pests can occur over large spatiotemporal scales with variable influences of landscape features. Insect epidemics have affected millions of hectares of forests in temperature regions as in the case of the mountain pine beetle (Dendroctonus ponderosae) damage (red trees on the far valley slope) in northern Colorado, USA, shown in panel (a) (photo has been altered for increased color saturation to enhance visibility of dead trees). Tree genotypes and phenotypes, illustrated on a small scale in panel (b) with variable leaf change rates on different aspen (Populus tremuloides) clones, are frequently spatially arranged on the landscape in relation to various features/processes with important consequences for forest pest dynamics. Forest pests can also be impacted by forest stand position on the landscape. For example, position in relation to elevation, aspect, and latitude can dramatically influence climate as demonstrated by the elevational-temperature cline and shift in tree cover on northern versus southern aspects of montane valleys in panel (c).

Source: Scott Ferrenberg, Curr Landscape Ecol Rep, 2016; DOI 10.1007/s40823-016-0005-x

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The Theory of island biogeography

This landmark theory was proposed by two scientists; MacArthur and Wilson in 1963. Initially, this theory was proposed to explain the distribution and abundance of species living in islands separated by oceans. Soon, the theory found other applications.

For example, it was applied to communities living in alpine mountaintops; they are in effect islands isolated by the ocean of space separating them. Similarly, they were applied to cave communities; the conditions separating the cave from the land above was as inhospitable as an ocean.

Once habitat fragmentation in a landscape became a problem that could not be ignored, ecologists happily extrapolated this theory into landscape ecology. The fragmented patches of land represented islands, and the large corridors in between were the "ocean".

The picture here shows a fragmented forest. As seen the patches of forest are spread in a background of grasses just like islands in an ocean.

Source: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/

How does this theory apply to landscapes?

- The theory applies exactly as it did in a ocean-island situation. The theory comes up with a correlation between size of the island and the number of species in the island. Also it correlates the distance of the island from the next and the number of species on both islands.

- In any area, the species composition is a direct result of two variables; the rate of immigration and the rate of extinction (or emigration). These are the two variables considered in this theory.

- The theory proposes a linear positive relationship between the size of the island and the number of species on it. This means that larger the island, more the number of species present on it (or less is the extinction rate).

- In terms of connectivity, the theory says that nearer the islands, greater is the species richness because it allows for easier dispersion among individuals of the two communities (in other words, greater immigration).

Source: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/

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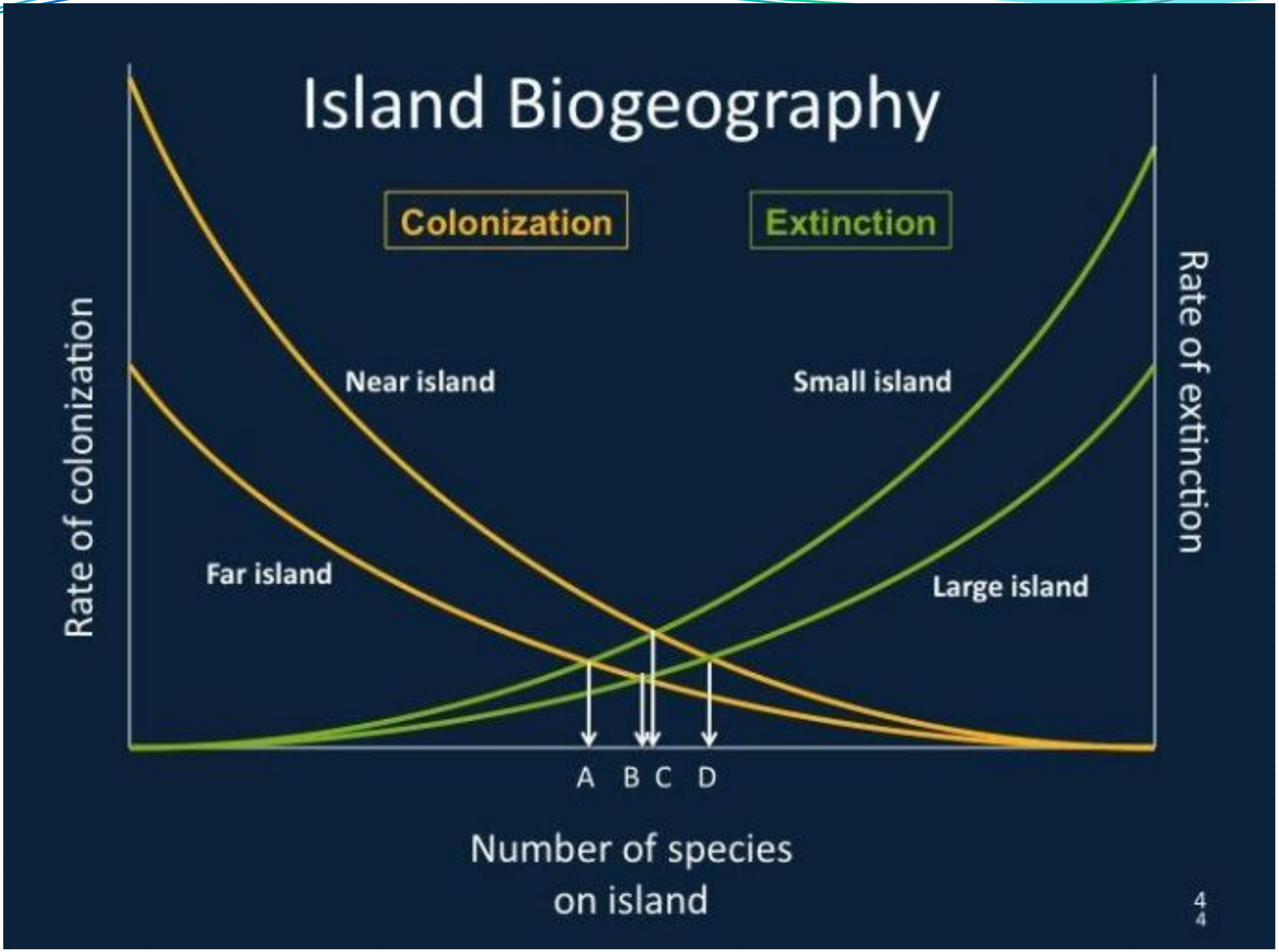

MacArthur and Wilson's equilibrium theory of island biogeography model (1963) which demonstrates how the number of species on an island is determined by the rates of colonization/immigration and extinction at equilibrium. Available at http://californiachannelislands.blogspot.com/2012/04/macarthur-and-wilson-ii-archipelagos.html

Source: Wang, A.W. (2021) 'Natural laboratories' in perspective: a review of literature on theories of island biogeography. *Routes* 2(1): 15-22

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Applications of island biogeography

- This theory has seen **vast applications in conservation efforts** to preserve biodiversity. Most national parks and wildlife sanctuaries built in the 1980s have strongly relied on this theory for guidance.

- In case of places with high possibilities of natural disturbance like fires or floods, it is ideal to have patches of habitat in the protected area. While a single patch would certainly contain more number of species, it would be in great danger of being completely wiped out if a disturbance occurred.

- If the total species composition was spread between small patches of moderate number of species, patches that have not been affected by the disturbance will be able to recolonize the patches that were destroyed.

- Hence, smaller but interconnected patches have been proposed for such conservation settings.

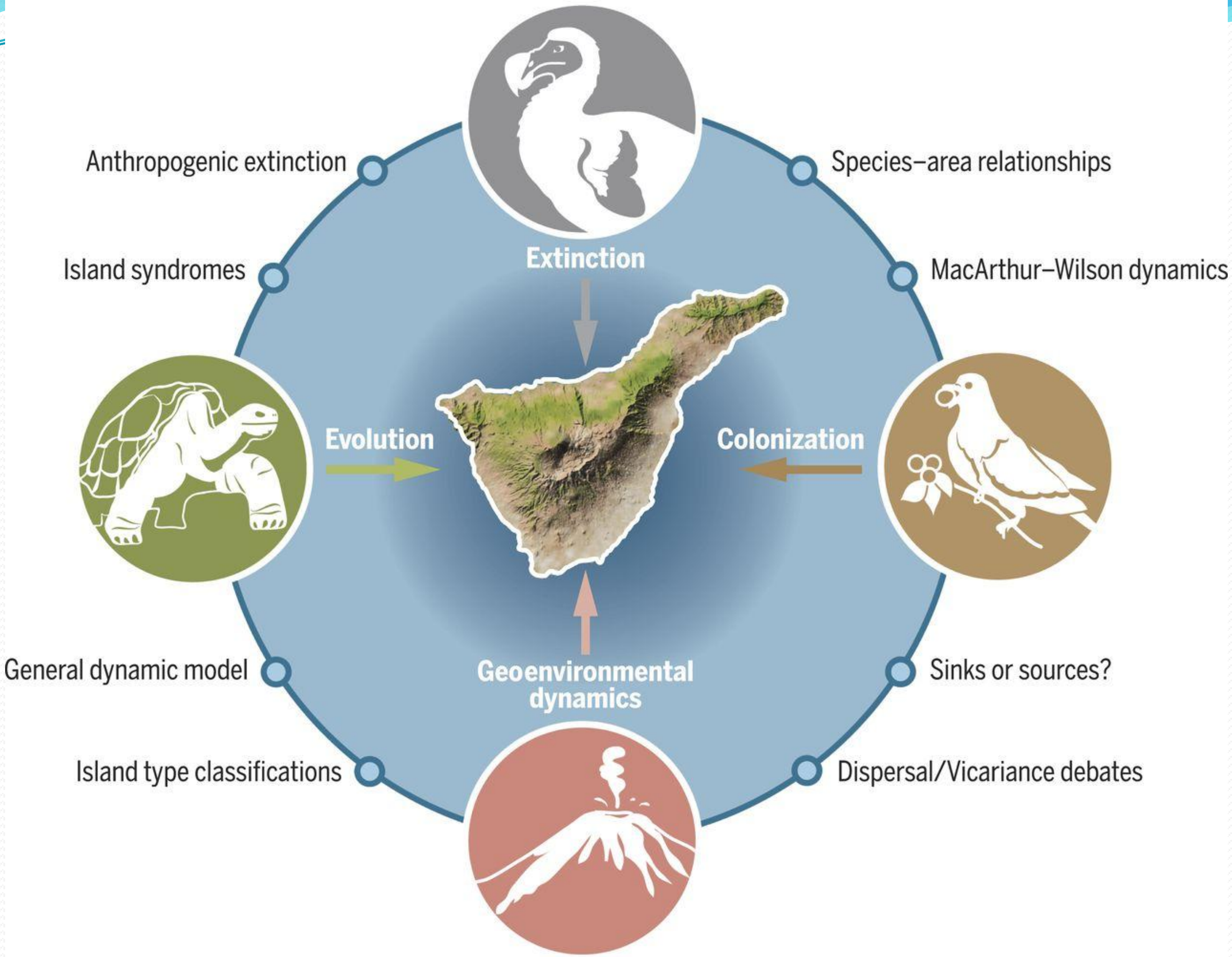
Source: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/

- It also **helped understand the development of endemic species** in isolated areas. When a patch become extremely isolated, the immigration rates would be reduced to almost zero. This would allow the species in that community to evolve and adapt to that ecosystem specifically, leading to specialized adaptations (otherwise called endemism). These species would only be found in that region.

- It also **explained high extinction rates due to a fragmented landscape**. If patches become very isolated, the species would not be able to migrate in times of a catastrophic event (natural or man-made). These species could very easily become extinct.

- **A highly fragmented landscape also prevented natural migration and movement** habits of large mammals like elephants. A highway cutting through a large forest could destroy a natural route for elephants of that forest. Elephants are highly sensitive to such disturbances; it can lead to severe problems within the elephant population. Further, such fragmentation has lead to many human-wildlife conflicts.

Source: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/



Islands provide model systems for the investigation of the fundamental biogeographical processes of migration, diversification, and extinction

Source: R. J. Whittaker et al.,Science357,eaam8326 (2017). DOI: 10.1126/science.aam8326

Is this theory perfect?

- No. As with any theory, this theory was also met with severe criticism. In special conditions, the controlling variables of this theory were known to become invalid.

- For example, if a patch was very close to a large, un-fragmented forest, there would be constant movement of species to and fro. Rates of immigration/emigration would too high because of very good connectivity, rendering the size of the patch immaterial.

- It does not consider the dynamics of the food web in a patch and how that could influence species composition.

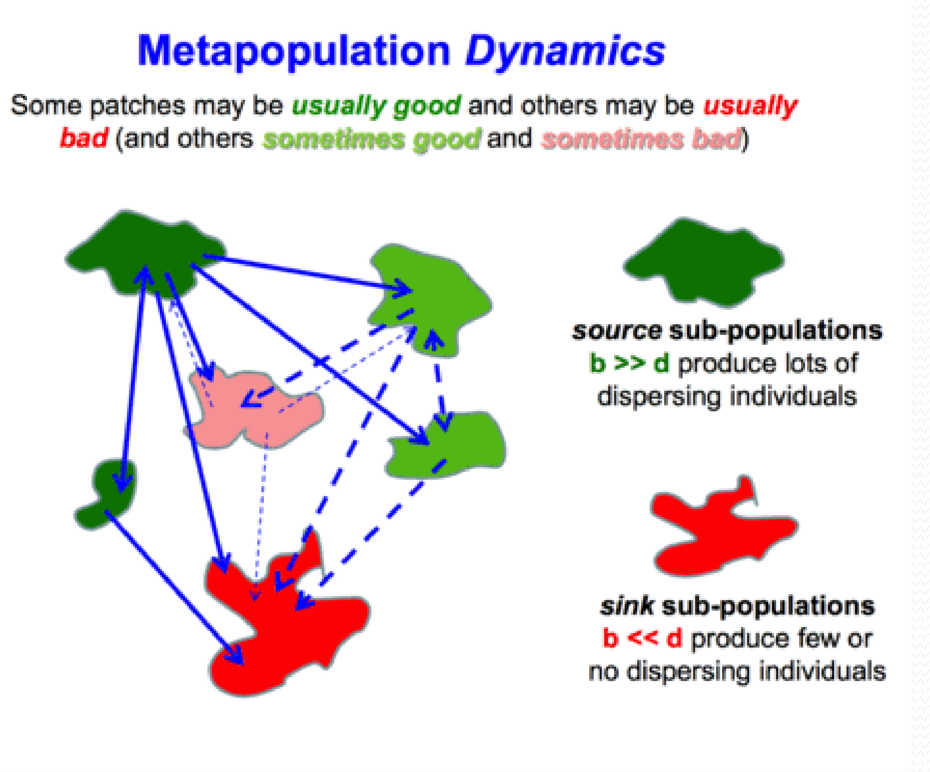
- The theory also assumes that the patches (or islands) are in equilibrium; this is rarely the case because patches always have frequent disturbances.

Source: https://eco-intelligent.com/2016/10/13/the-theory-of-island-biogeography/

Metapopulation

Metapopulation, in ecology, a regional group of connected populations of a species. For a given species, each metapopulation is continually being modified by increases (births and immigrations) and decreases (deaths and emigrations) of individuals, as well as by the emergence and dissolution of local populations contained within it.

As local populations of a given species fluctuate in size, they become vulnerable to extinction during periods when their numbers are low. Extinction of local populations is common in some species, and the regional persistence of such species is dependent on the existence of a metapopulation. Hence, elimination of much of the metapopulation structure of some species can increase the chance of regional extinction of species.



Metapopulation *Dynamics*

Some patches may be ***usually good*** and others may be ***usually bad*** (and others ***sometimes good*** and ***sometimes bad***)

source **sub-populations**
b >> d produce lots of dispersing individuals

sink **sub-populations**
b << d produce few or no dispersing individuals

Source: https://easyandadvancedbiology.wordpress.com/2020/04/03/metapopulation-in-ecology-2/

Metapopulation Theory:

A metapopulation consists of a set of sub-populations, occupying distinct habitat patches and connected through the dispersal, migration or human-mediated movement of individuals between patches. Emerging in the 1960's, the metapopulation theory describes how species population dynamics are affected by spatially distant habitats.

Habitat fragment size, connection, colonization and extinction key parameters used by metapopulation theory to determine species spatial persistence. The theory of metapopulation is pertinent to conservation as many species exist as metapopulations, particularly in fragmented environments.

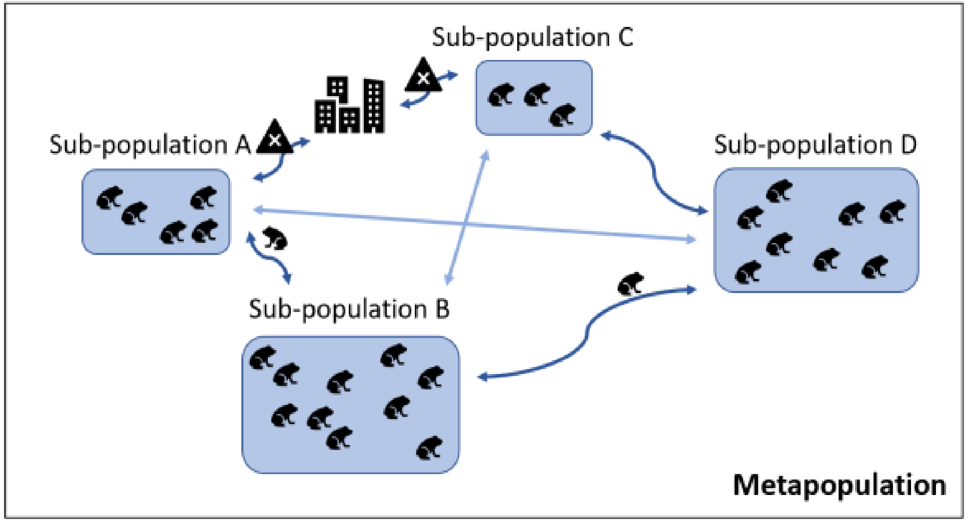
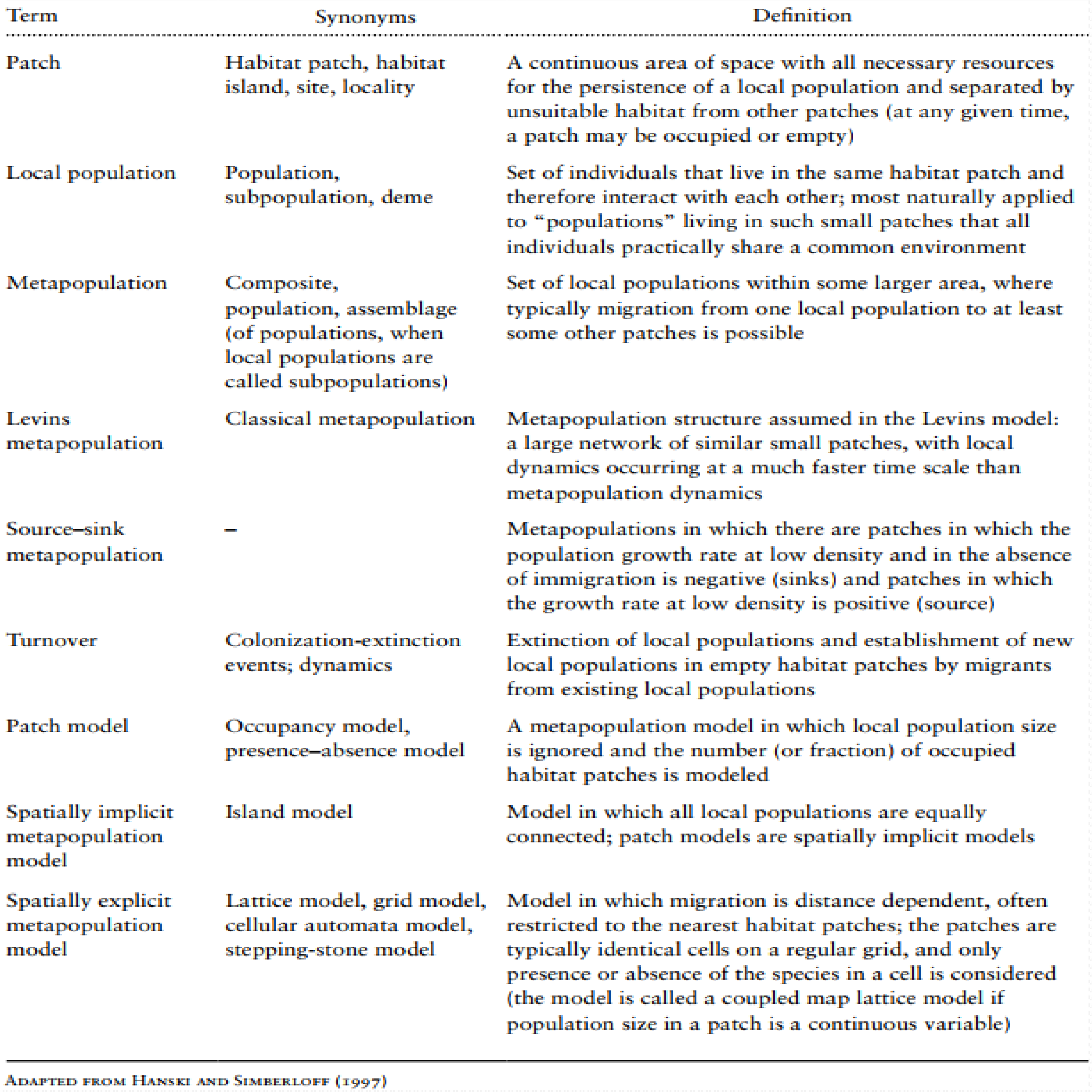


Figure 2: A metapopulation consisting of several sub-populations. These sub-populations occupy distinct habitat patches which remain connected through individual migration. As shown in between sub-population A and sub-population B there can be barriers to migration. Increasing connectivity between habitat patches will increase likelihood of species success, according to metapopulation theory. Figure Credit: Penny Ixer.

Source: https://biol420eres525.wordpress.com/2019/04/12/application-of-metapopulation-theory-to-conservation/

Definitions and synonyms of terms used in metapopulation studies



Term	Synonyms	Definition
Patch	Habitat patch, habitat island, site, locality	A continuous area of space with all necessary resources for the persistence of a local population and separated by unsuitable habitat from other patches (at any given time, a patch may be occupied or empty)
Local population	Population, subpopulation, deme	Set of individuals that live in the same habitat patch and therefore interact with each other; most naturally applied to "populations" living in such small patches that all individuals practically share a common environment
Metapopulation	Composite, population, assemblage (of populations, when local populations are called subpopulations)	Set of local populations within some larger area, where typically migration from one local population to at least some other patches is possible
Levins metapopulation	Classical metapopulation	Metapopulation structure assumed in the Levins model: a large network of similar small patches, with local dynamics occurring at a much faster time scale than metapopulation dynamics
Source–sink metapopulation	–	Metapopulations in which there are patches in which the population growth rate at low density and in the absence of immigration is negative (sinks) and patches in which the growth rate at low density is positive (source)
Turnover	Colonization-extinction events; dynamics	Extinction of local populations and establishment of new local populations in empty habitat patches by migrants from existing local populations
Patch model	Occupancy model, presence–absence model	A metapopulation model in which local population size is ignored and the number (or fraction) of occupied habitat patches is modeled
Spatially implicit metapopulation model	Island model	Model in which all local populations are equally connected; patch models are spatially implicit models
Spatially explicit metapopulation model	Lattice model, grid model, cellular automata model, stepping-stone model	Model in which migration is distance dependent, often restricted to the nearest habitat patches; the patches are typically identical cells on a regular grid, and only presence or absence of the species in a cell is considered (the model is called a coupled map lattice model if population size in a patch is a continuous variable)

ADAPTED FROM HANSKI AND SIMBERLOFF (1997)

Source: Turner MG, Gardner, RH, 2015. Landscape Ecology in Theory and Practice, 2nd Edition, Springer Nature

Landscape ecology Practices in Planning

- ❖The goals of landscape planning, design, and management include the identification and protection of ecological resources and control of their use through plans that ensure the sustainability of these resources.

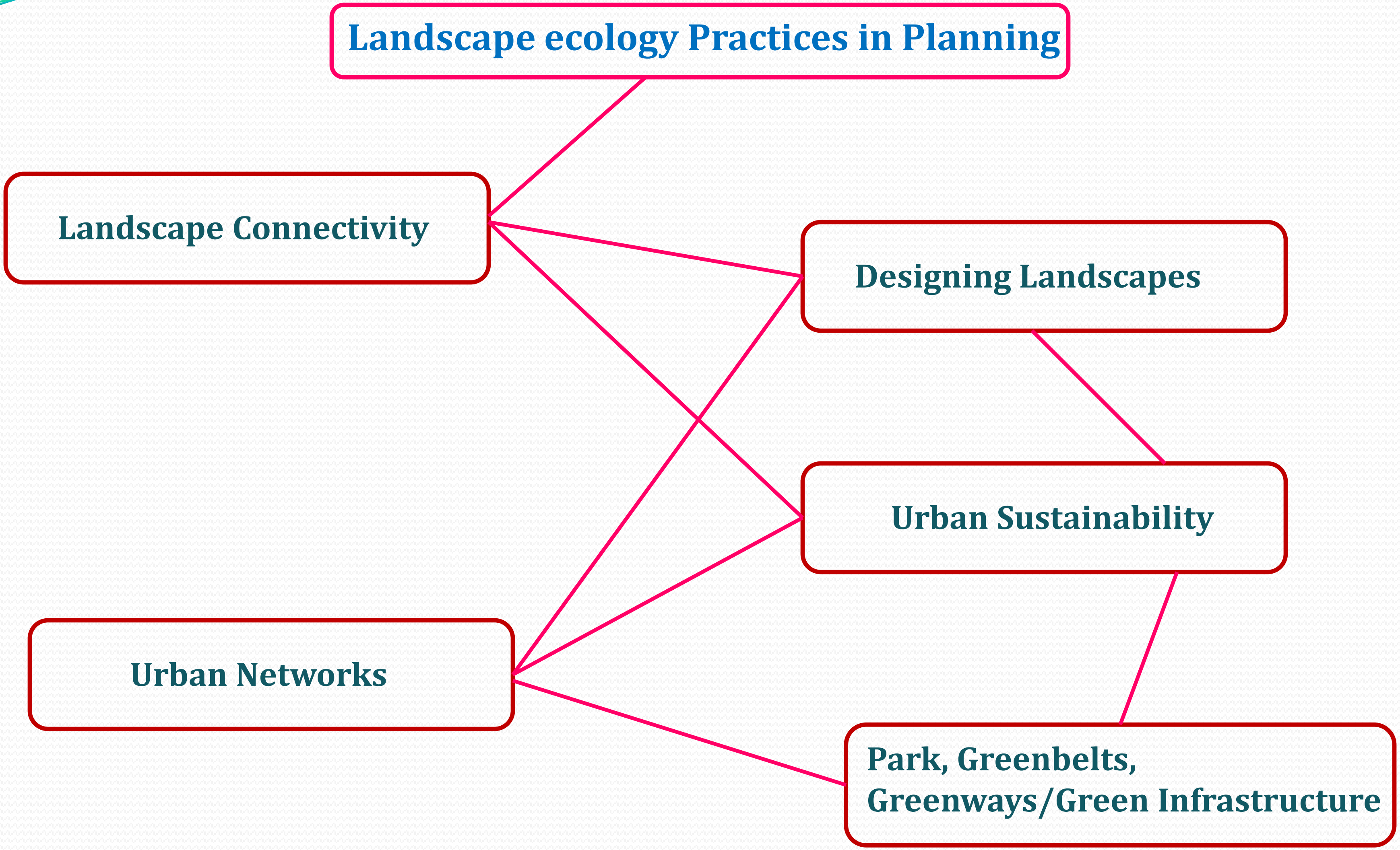
- ❖Consequently, landscape planning is a primary basis for collaboration and knowledge exchange between planners and landscape ecologists.

- ❖Designing extensive ecological networks for conserving different taxa has also been an important component of land planning across Europe.

- ❖In North America, early examples included plans for ecosystem management of crown forests in Ontario, Canada and studies aimed at conservation design.

- ❖Managing landscapes to meet conservation goals will continue to be necessary if ecological resources are to be preserved.

Landscape ecology Practices in Planning



Landscape Connectivity

Designing Landscapes

Urban Sustainability

Urban Networks

Park, Greenbelts,
Greenways/Green Infrastructure

URGENT

URGENT – Urban Resilience and Adaptationfor India and Mongolia

https://urgent-project.net

Project Funded by:

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