Landscape ecology

a synthetic outline

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1: overview

- a young and fast developing discipline

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A young discipline

- Landscape ecology flourished in Europe from geography, to solve application land use problems by means of an holistic approach

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A young discipline

- The subsequent development in USA, and then in Europe, was more ecologically oriented toward the spatial heterogeneity analysis and its effects on ecological processes, on a more strongly biological basis (e.g. bio-geographic and vegetation succession theories)

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Landscape: a problematic word

- It is an evocative term that present a certain degree of ambiguity
- Since a couple of centuries, thanks to geographers, has assumed a more *scientific connotation*, that allows to circumstantiate a term significance by means of its definition

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Landscape: a problematic word

- A scientific definition should reduce the influence of the historical, cultural, emotional and social complex implication, circumstantiating the significance to each researcher definition

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Landscape: a problematic word

- The reference authors' definitions (e.G. Forman & Godron, 1986; Forman, 1995; Naveh & Lieberman, 1984; Turner, et al. 2001; Wu, 2000; Zonneveld, 1995), have two common denominators
  - A spatial connotation (heterogeneous portion of earth surface made of structures which combine in a reportable way)
  - A holistic perception of the analysed system, built up by a structure of biotic and biotic components functionally interrelated

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Landscape: a problematic word

- The factors that differentiate the several definitions are based on a higher or lower emphasis given to the human processes in the considered system

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Ecology: a problematic word

- On the other hand, the use of the term “ecology” (the study of the biotic relationships with the a-biotic environment) does generate some difficulties to those who consider “ecology” only the study of non human- influenced ecosystems

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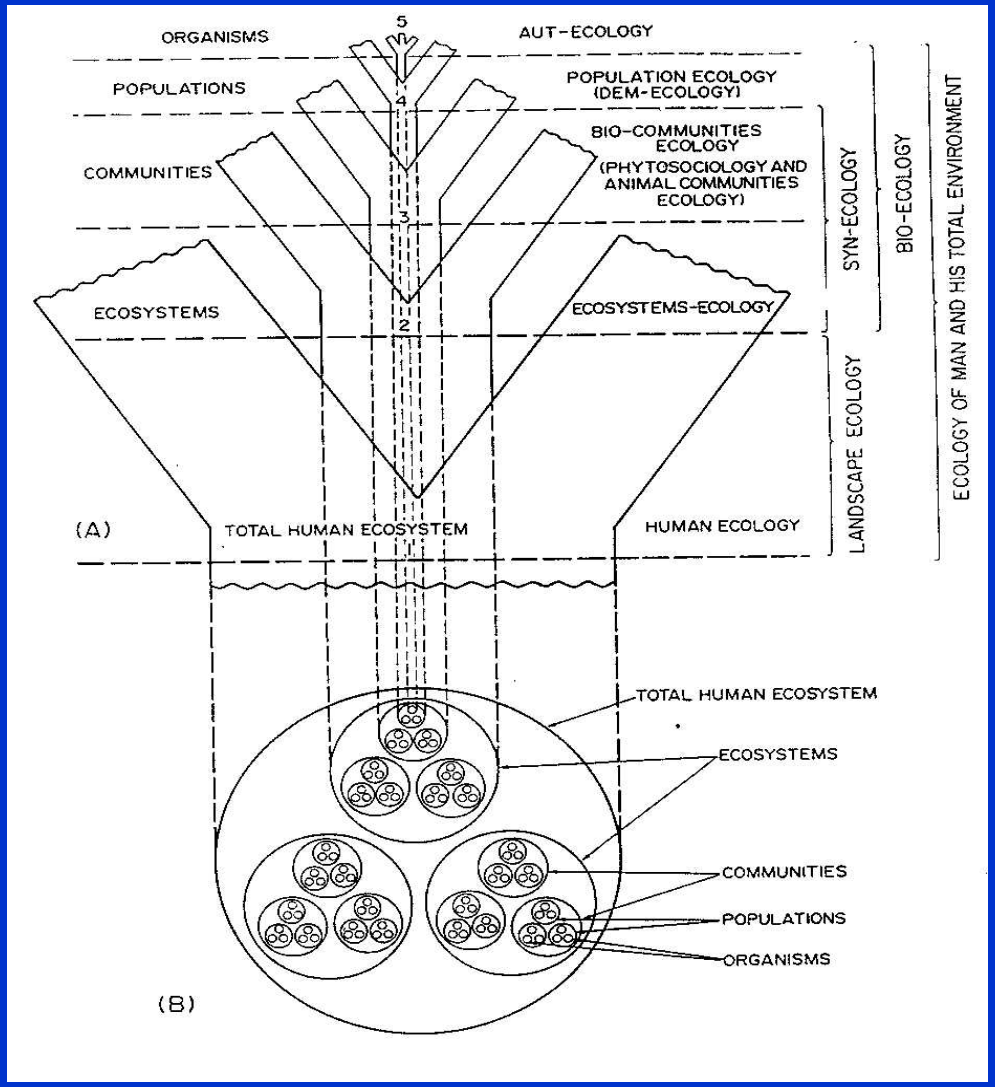
A outline of the interrelation among ecological disciplines (from Naveh, 1984)



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A first definition of landscape in this discipline

- A mosaic of ecosystems at a higher complexity that is self similar in a recognisable geographical area (from Forman, 1995)

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A first definition of landscape in this discipline

- There is a shift from a vertical ecosystem study to a horizontal study of the ecosystems mosaic
- Surely does not exist one landscape, but as many landscape as are the possible scales of analyses or perception at which we consider the landscape structures and functions

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The scientific core

- *Ecological fluxes in the landscape mosaic*
  - One of the core goals of the disciplines is the study of the mutual relations between the spatial pattern and ecological processes and functions (matter, energy and information fluxes)

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The scientific core

- *Ecological fluxes in the landscape mosaic*
  - There are several progresses in some fields (e.g. biotic flows), but results have to be deepened
  - Questions that are being explored regard how the landscape processes vary within a scale (spatial and or temporal), or what are the functional relationships between these variation and human activities

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The scientific core

- *Causes, processes and consequences of land use changes*
  - Land uses and vegetation cover types tend to determine the landscape structures and to influence the landscape functions and dynamics
  - They are driven by socio economic forces, and the comprehension of their mutual relations are fundamental for landscape management

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The scientific core

- *Non linear dynamics and landscape complexity*
  - Landscapes are complex systems where heterogeneity, non linearity and causality are the norm
  - The emergent properties, the transitions phases and the threshold behaviours characterise most part of the landscapes, and come from the above cited conditions

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The scientific core

- *Scaling*
  - It is a general emergent issue in several human and biological discipline: the scale considerations affect the extrapolation of information from a spatial – temporal scale to another

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The scientific core

- *Relationships among spatial metrics and landscape ecological processes*
  - The basic hypothesis is that spatial pattern does influence landscape functions and processes
  - Spatial metrics had an huge development recently thanks to hardware and software development, but the comprehension of the relationships between metrics and ecological processes has been not equally effective

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The scientific core

- *Relationships among spatial metrics and landscape ecological processes*
  - The possibility of a general estimation of a landscape functions variation by means of the measure of a spatial structural organisation variation, and at what scale range, has yet to be deepened

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The scientific core

- *Integration of human activities in landscape ecology analyses*
  - Ecosystems and landscapes are more and more influenced by human activities at several scales
  - Man and his activity are integral part of the landscape study (structures, functions, processes)

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The scientific core

- *Integration of human activities in landscape ecology analyses*
  - Human influences in terms of perception and values systems, have to be considered the norm and not the exception in the landscape studies

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The scientific core

- *Landscape spatial pattern optimisation*
  - The basic hypothesis is that the spatial pattern influences the matter – energy – information fluxes in a landscape, while the processes create, maintain and modify the landscape structures
  - Research is deepening the ecological implication of the spatial pattern arrangement optimisation (by means of land use organization, management and planning)

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The scientific core

- *Landscape sustainability*
  - The effects of population growing, climate change, land use change, are demonstrating the unpredictable and dynamic nature of landscapes
  - Sustainability is a application field of landscape ecology, but sustainability could not be achieved, from a rigorously scientific point of view, particularly if considered at a broad scale

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The scientific core

- *Landscape sustainability*
  - Actually conservation and sustainability concepts are not so easily defined in the scientific research context, due to the strong influence of the perception-valuation of these concepts filtered by the complex interaction among political, economic, physical and cultural factors

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The scientific core

- *Landscape sustainability*
  - Therefore the implications of these influences on the scientific research have to be deepened, and more applicative tools, able to give information about their reliability in the landscape context and at a defined scale range, have to be developed

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A contribution to the definition of the today's role of landscape ecology from the management point of view

Comprehension of how the landscape spatial pattern is related to the landscape systems functioning, as defined by the steadily evolving context of human needs and land use

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Some reasons why landscape ecology can provide a practical framework for trans-disciplinary studies and management

(adapted from Forman, 1995)

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Shareable models and concepts

- The patch and matrix descriptive model broadly adopted in this discipline (ecotopes that are spatially arranged in a way that can be represented) is intuitive and easily interpretable by researchers of different discipline

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Shareable models and concepts

- Concepts like structure, function, change (evolution, dynamic) give a common sense with strong theoretic root (ecology) to the use of widespread application tools, like the thematic maps

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Structure

- Landscape ecology has highlighted the idea that the spatial arrangement of landscape structures (e.g the relative position of a ecosystems compared to the others) gives information that at the landscape scale are different from those obtained at the ecosystem scale

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Functions

- The processes and functions analyses at the landscape scale allowed to realize that their insufficient consideration run to problems which affect far more and away than a single ecosystem (e.g. a protected area institution alone is insufficient if not supported by a comprehension of the biotic flows at the landscape scale, and how they interact with the protected or non protected landscape structures)

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Dynamic

- The analyses of the landscape structures dynamic change has contributed to detect the evolutionary models that optimise landscape sustainability

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Implicit assumption

- The landscape ecology discipline assumes a implicit multi-scalar approach, regarding the choice of the the scale required to analyse or manage a problem

2: heterogeneity

a intrinsic factor of ecological systems

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The premise

- During the last decades the concept of homogeneous ecosystem shifted toward the more complex concept of heterogeneous ecosystem
- Changing the extension and resolution of the observations, change the conceivable definition of the system

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The premise

- Heterogeneity is one of the organization factors of ecological systems, linked for example to the multi scalar use of the resources or to the diverse life strategies exploitation
- The spatial explicit representation of landscapes allows to study the factors that influence heterogeneity, and at what scales

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The factors: disturbance

- The disturbances are scale dependent, biotic (insects, human activities, migration, exotic species,…) or a-biotic (hurricanes, landslides, salty intrusions, drought,…), and can present stochastic or regime variation

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The factors: disturbance

- Heterogeneity can depend on critical threshold in the disturbance frequency
  - e.g. fire disturbance can change the canopy composition and distribution in a forest if above or below a certain threshold of burned surface

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The factors: disturbance

- The lost of a disturbance regime can change the heterogeneity and the diversity of a landscape
  - e.g. the farmland (human disturbance regime) abandonment (1978-1992) of a Mediterranean coastal area (Montpellier) carried to a rise of woodland cover, a decrease of land use heterogeneity, a decrease of biodiversity (birds: increase of core pan European species, decrease of margin Mediterranean species)

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The factors: dispersion

- The dispersion influences the space distribution of species and life strategies
  - e.g. short range dispersion of some plant species can favours clumped distributions that permit the overstaying of less competitive species because of the bank seeds overabundance

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Man and heterogeneity

- Man is an integral part of ecological systems and is landscapes heterogeneity source
- The landscapes structure is strongly determined by former dynamics: each landscape keeps memory of its transformations
- Man is a dominant evolution factor of most part of (cultural) landscapes

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The landscape memory of transformations

- Three example of distinct rural landscape maps in a Mediterranean coastal zone (Venice hinterland; the maps reported are the up to date Regional Official Map)

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The landscape memory of transformations

- The first landscape is less than five Km airline from the Venice Lagoon
- The dominant landmark is a mesh, with facets of 710 m: it is the Romans' *centuriae*, a land subdivision in equal farm lots for the veterans, in this case the Caesar's veteran of Gallia and Germany campaigns (50-58 BC)
- These structures influenced the subsequent 2.000 years transformations of this landscape

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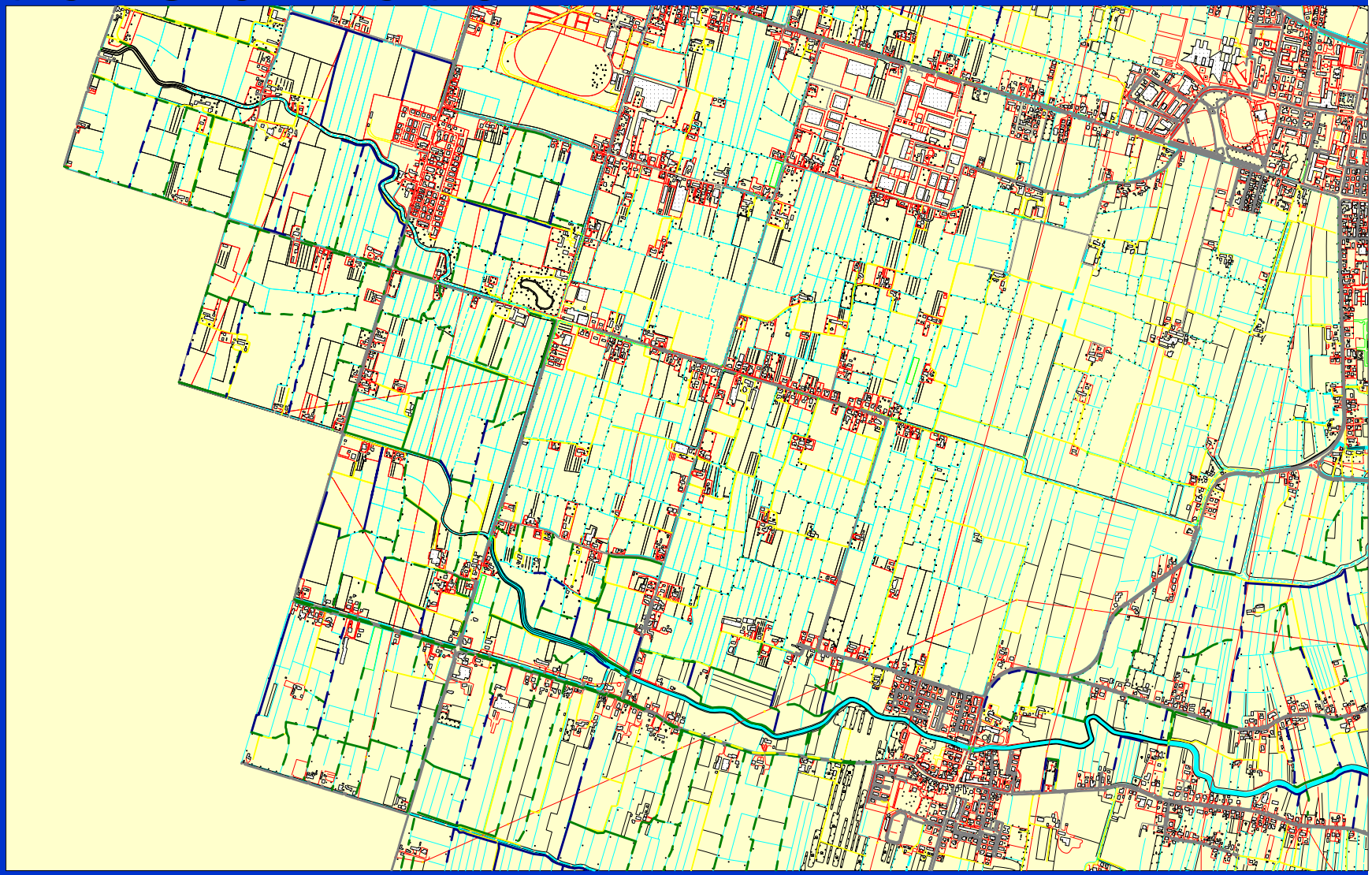
Landscape memory of transformation



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The landscape memory of transformations

- The second landscape is only few kilometres airlines from the Venice Lagoon and from the previous landscape
- In this case the landmarks have organic patterns, defined by river adaptive movement
- All subsequent human transformations have been adapted to these patterns, especially the agricultural ones, that followed the previous contours during few phases of land reclaiming techniques; the second one (named “a cavino) is the visible one.

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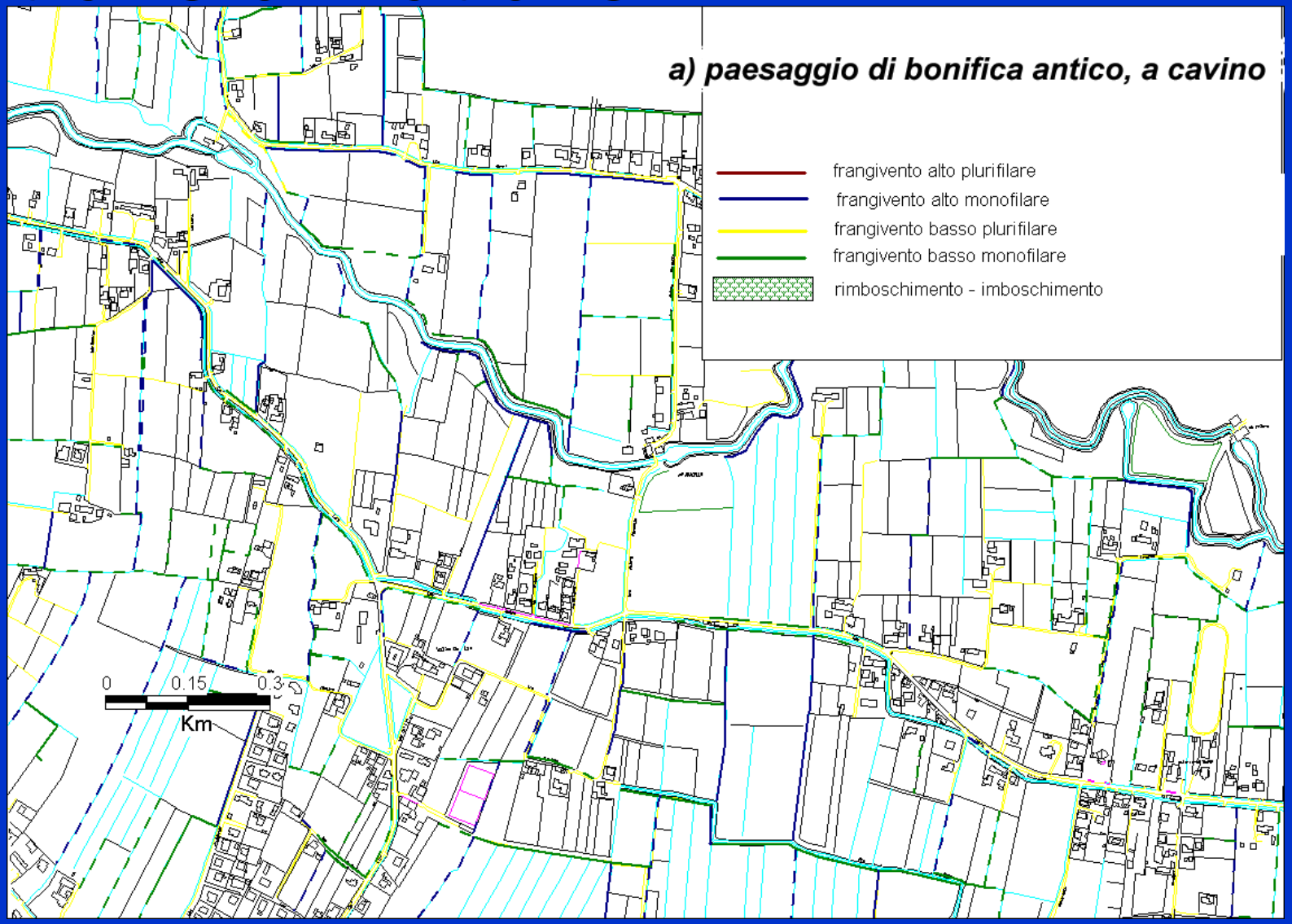
The landscape memory of transformations



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The landscape memory of transformations

- The third landscape is neighbouring the previous one from one side and the lagoon border from the other side.
- It is a young reclaimed landscape (more or less a century) from the lagoon areas
- No previous landmarks are evident in the map, a part the river in the upper side, but only the straight lines for the field reclaiming system

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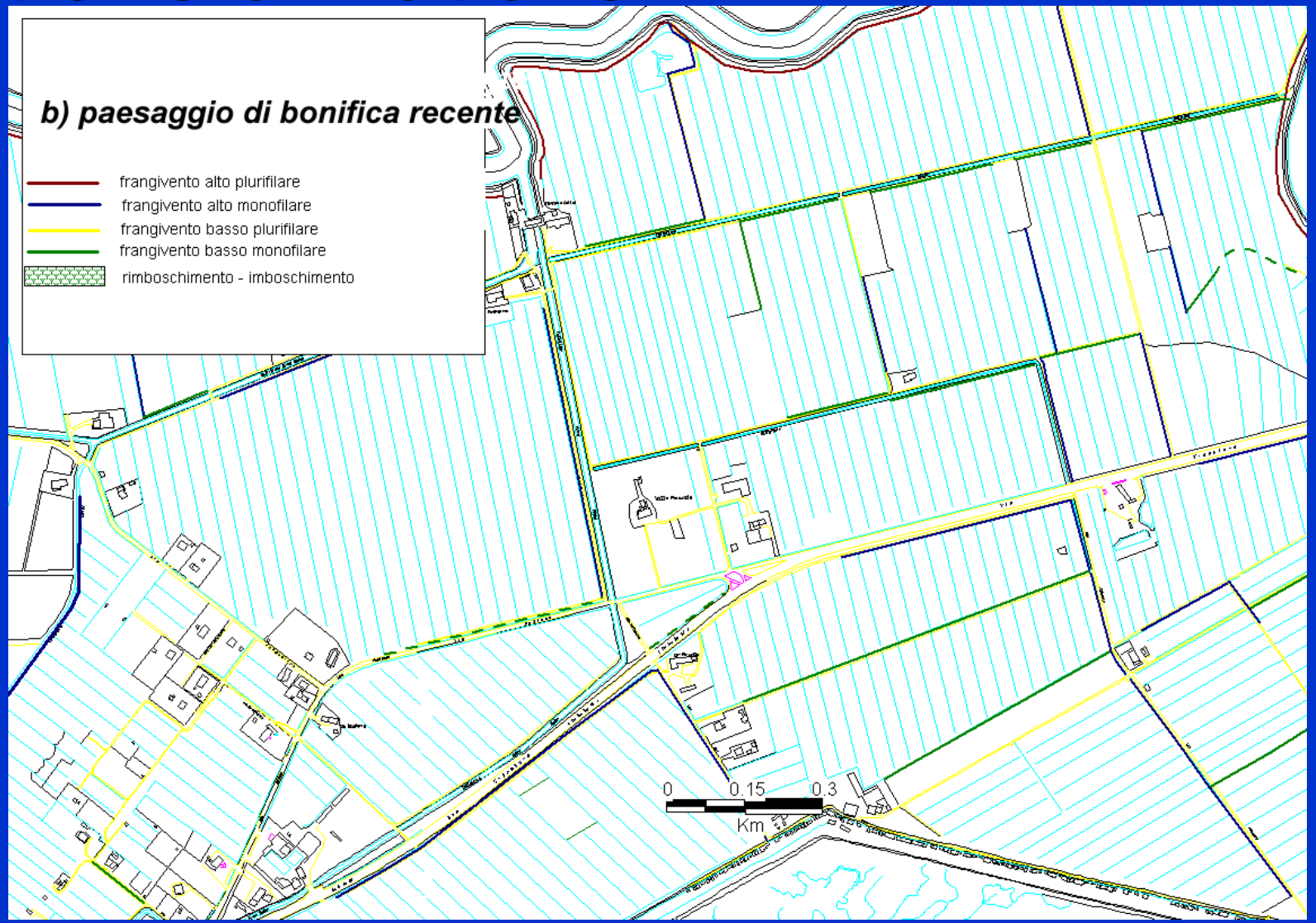
The landscape memory of transformations



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Dynamic and evolution

- A complex system maintain the memory of the conditions that succeeds during its evolution and of the disturbance regimes that are present at different scales
- it is necessary to know the history of a complex system like a landscape to understand it and to manage it

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Dynamic and evolution

- In the case of natural systems, the broad scale studies of some disturbance regimes (fires, insects, hurricanes) allowed to understand the origin and the meaning of some landscape structures and to adapt therefore the management practices
  - e.g the fires management strategy in the great USA parks

3: theory

the theoretic roots of the discipline

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A summary

- For space reasons it is not possible in this presentation to give a sufficient prospectus of this issue
- Thus it is simply reported a list of the theoretic fields which are useful as a context for this discipline, and a outline a of selected books and journals to deepen the issues

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Theoretic background

- Biological theoretic field
  - Ecological succession theory
  - Bio-geographic population theory
  - Metapopulation theory and models
- Relationships among aesthetic, ethic and ecology
  - Kant and Schopenhauer thinking
  - Alfred North Whitead thinking
  - Bio-centric and socio-centric paradigms
  - Ethic and ecology, sustainability

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Theoretic background

- Aesthetic, perception and landscape ecology
  - Perceptive theories, psychology of perception and preference
  - Perception, cognition and valuation theories (biological, informational)
  - Relations between perception and aesthetics
  - Relations among perception, valuation, action and landscape ecology

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Theoretic background

- Physical theories
  - Systems complexity theory
  - Scaling issues
  - Hierarchical organization theory
  - Emergent properties
  - Non equilibrium theory
  - Dissipative structures theory
  - Information theory
  - Chaos theory
  - Fractal geometry
  - Percolation theory

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Reference journals and books

- Landscape Ecology. Publisher: Springer.
- Landscape and urban planning. Publisher: Elsevier.
- Forman R.T.T 1995. Land Mosaic. Cambridge University Press. Cambridge
- Burel F., Baudry J., 1999. Ècologie du paysage. Concepts, méthodes ed applications. Ed.TEC&DOC, Paris
- Turner M., Gardner R.H., O'Neill R.V. 2001. Landscape ecology in theory and practice. Springer Verlag, New York
- Franco D. 2000. Paesaggio, reti ecologiche ed agroforestazione. Il Verde Editoriale, Milano

4: structures, functions, pattern

relationships

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The ecotpe

- It is a earth portion that can be mapped where the within functions (trophy chains, hydro geological cycles, ..) and structures (communities, …) variability is lower than the outside
- It is a pragmatic, unifying and functional model

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Patch and corridors

- Ecotopes can differ in the shape, more elongated - linear (corridors), or not (patches); the dominant patch type in a landscape is defined as matrix
- Patch and corridors can differ for several biotic (composition) and physic attributes (dimension, shape,…), or for the origin (generating disturbance)

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Patch and corridors

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The patch, corridor and matrix model

- This descriptive model is commonly used in landscape ecology, and assumes the ecotope as a reference unit
- Its use it is relatively simple in cultural landscape, but in some cases (e.g. forestland) the ecotopes borders could result difficult to be distinguished

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Ecological networks

- Go to

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Functions and processes

- Landscape functions (and processes) can be conceptually connected to the ecological definition of function, so that at the landscape scale they correspond to biotic or abiotic matter/energy flows (anemometric, hydro-geochemic, trophic, reproductive)
- Landscape availability of resource can be generated by landscape functions, and they in turn can be connected to landscape structural pattern

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An example of landscape processes: the spatial transformation

- 5 types of spatial process have been synthesised: dissection, fragmentation, shrinkage, perforation, attrition (Forman, 1995)

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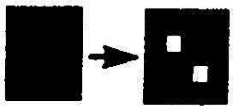
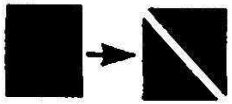
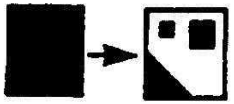
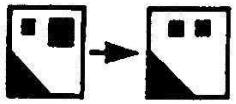
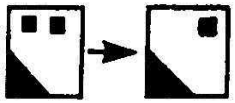
Spatial processes effects (from Forman, 1995)

Spatial processes	Patch number	Average patch size [1]	Total interior habitat [2]	Connectivity across area [3]	Total boundary length [4]	Habitat	
						Loss	Isolation
 Perforation	0	–	–	0	+	+	+
 Dissection	+	–	–	–	+	+	+
 Fragmentation	+	–	–	–	+	+	+
 Shrinkage	0	–	–	0	–	+	+
 Attrition	–	+	–	0	–	+	+

Footnotes. [1]Perforation = "0" if size is measured as diameter rather than area; Attrition = "0" or "–" if patch lost is ≥ average patch size. [2]Shrinkage or Attrition = "0" if patch changed had no interior habitat. [3]Perforation = "–" if random straight routes are measured; Shrinkage or Attrition = "–" if measured as probability of object crossing using patches as stepping stones. [4]Shrinkage = "0" or "+" if portion lost makes no change or increases boundary of the patch.

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An example of landscape processes: the spatial transformation

- Spatial transformations are studied in order:
  - to detect the landscape transformations that minimise the negative ecological impacts for each spatial change processes
  - to detect some general concepts of sustainable landscape management which balance the ecological effects of each spatial process: non of them represent the optimum one for all ecological effects

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Landscape pattern and landscape functions

- If the pattern of the landscape structures influences the landscape processes (biotic flows/biodiversity, hydro geological fluxes, cultural processes), then the management of landscape processes is correlated to the landscape pattern management
- In the next slides some example of the use of these pattern parameters for biodiversity analyses and management

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Landscape pattern parameters

- Heterogeneity
- Connectivity
- Fragmentation

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Heterogeneity

- Heterogeneity is an estimate of the evenness and richness of the landscape pattern. Its variation can affect organism's interactions, adaptations and distribution
- It can affect the biodiversity of the most vagile taxa as a function of the dispersal/perceptive level of the considered populations
- There is not a single method to estimate this parameter

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Heterogeneity and biodiversity

- Regarding the effect of heterogeneity on species richness and abundance two hypothesis are available
  - *habitat fragmentation*: there is a negative biotic effect of habitat fragmentation in comparison to continuous habitat
  - *habitat complemtantion/supplementation*: the matrix mitigate the habitat absence (supplementation) or host new species that depend either on the habitat or on the matrix (complementation).
- Experimental results do not support univocally either one hypothesis or the other, but probably a mix of the two can be case by case representative

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Connectivity

- Connectivity tries to estimate the functional-specific relationship between ecotopes, not necessarily physically connected. Some landscape patterns influence some landscape fluxes (functions, processes: e.g. fires propagation, biotic fluxes, ill dispersal)
- Connectivity is considered both structurally (assuming that ecotopes contiguity influence landscape function) and functionally

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Connectivity

- Connectivity is mostly treated as independent variable (e.g. estimating the effect of a structural metric on a landscape process) and rarely as dependent variable
- Besides the intrinsic limits of spatial metrics, the problem is that even when some empirical relationships between the metrics and the studied process are selected, they could be ecologically inconsistent, ignoring critical aspects of the considered function

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Connectivity

- In the case of biotic fluxes the estimated impacts can be irrelevant or negative for other populations
- Considering organisms with similar vagility, we can for example utilize other ecotopes than the connected ones

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Connectivity

- The modeling approach is normally used to study the connectivity as dependent variable; it remains fundamental for verifying and formulating new hypothesis, but is rarely tested on the field
- Considering how difficult is to define in a common way the connectivity, some methods can be used for application purpose, like the cost distance metric, that account for the parametric estimate of the ecological quality of ecotopes

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Fragmentation (process)

- A landscape fragmentation process influences its biodiversity causing a reduction of some species' favorable habitats and, consequently, an increase of their energy demand for survival
- This correlation is scale dependent and at the intermediate level it is linked to: (a) favorable habitats size and mutual distance ; (b) species dispersal capacity; (c) the differences within and among species

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Fragmentation (process)

- Several works have focused to analyze the effect of this process on biodiversity, but the use of fragmentation as a control variable or as a comparison parameter is complicated by the non-existence of a specific accepted measure to estimate it, complicated by the overlap between indicators used to evaluate it and the ones used to estimate heterogeneity

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Fragmentation (process)

- Furthermore, it is not as reliable as a predictive tool (conservation management) due to secondary effects such as inter-specific relations, habitat alteration deriving from fragmentation itself and the great variability of the single species reactions

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Effects of land use pattern on landscape process: an example

- The biotic water quality estimations (by means of IBI, HI) results as a general rule negatively correlated with urban and agricultural land use extension and positively correlated with wetlands and forests extention
- The correlation tend to increase at the watershed scale and decrease at lower scale (extension and resolution); biotic quality tend to be less influenced by riparian buffer systems than land use at the watershed scale

5: methods

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- There is no way in this presentation to deepen this wide issue
- Refer to the lectures for several examples about the very different methods used