Landscape ecology

and the water quality issue

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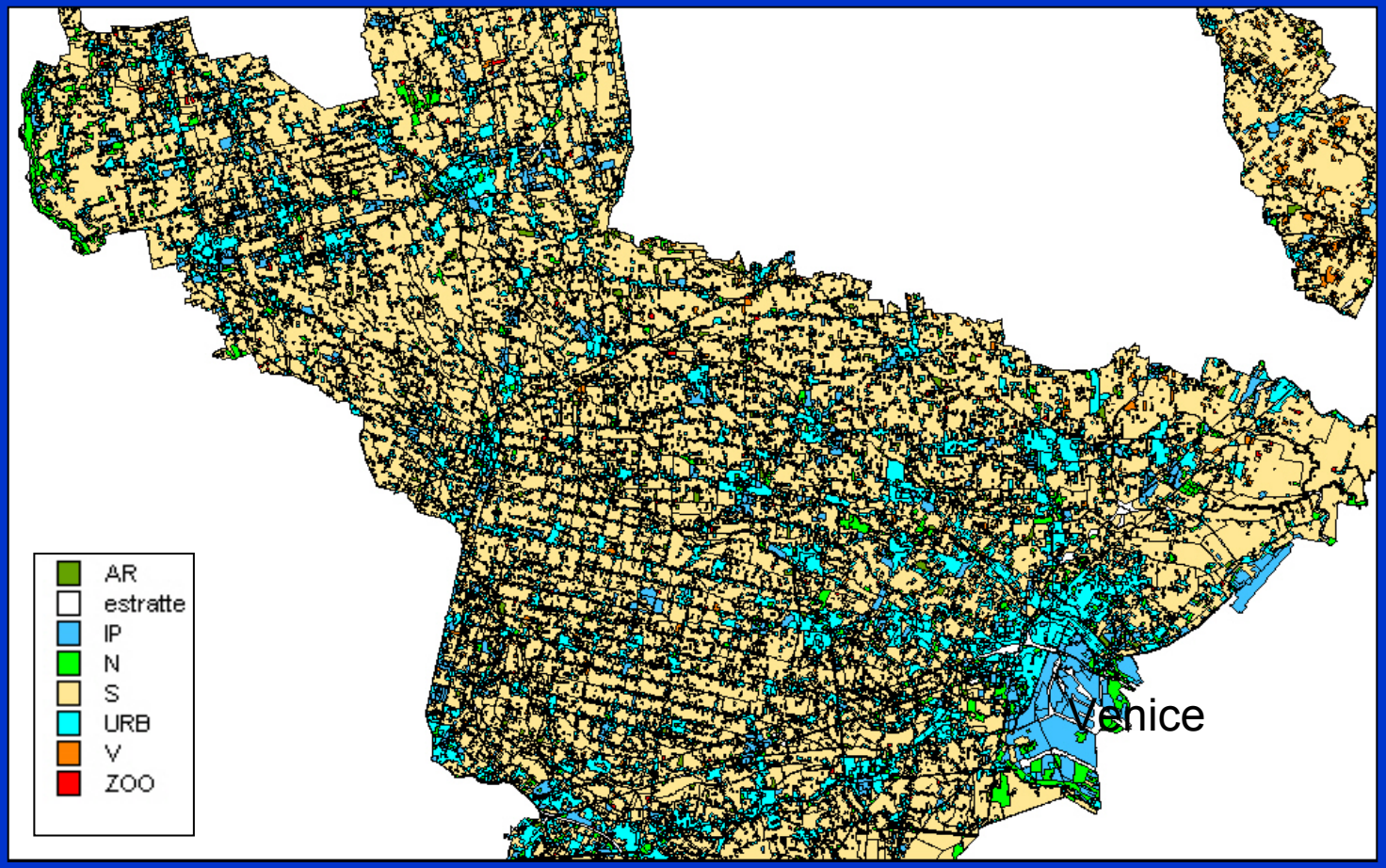
Nutrients removal at the watershed scale



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Nutrients removal at the watershed scale

- Landscape ecology allowed to understand that it is necessary to act both at the local scale and at the landscape scale to improve the water quality of a whole watershed
- At the landscape scale, landscape planning concerns the land-use organization:
  - To improve the watershed water quality, the landscape planning needs to know the relationships among the land-use and the surface water quality

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Nutrients removal at the watershed scale

- Topics of this presentation:
  - 1. The scale question
  - 2. The relationship among landscape spatial characteristics and water quality
  - 3. The literature awareness
  - 4. Applying the knowledge to the landscape management: the “Piano Direttore 2000”
  - 5. Case study : Venice Lagoon watershed

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1. The scale question

- Scale change = different recognizable processes inside the landscape
  - There is a scale effect on the perception, and therefore on the study, of ecological processes
- The scale should be considered when developing predictive models of ecological processes → the results could change over different scale
  - Studies are going on the relationship among landscape structures and nutrients release, or other ecological processes (e.g. migration or habitat selection)

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1. The scale question

- There is not a single scale to fully describe the landscape structures

→ Multiscalar analysis are needed

- Be careful: do not extrapolate statistical relationships at a different scale with respect to the study scale
  - The results will be ambiguous and hardly interpretable

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1. The scale question

- The relationship among landuse and water quality changes when there is a shift in the considered spatial scale (extent)
- The statistical analysis of the relationship leads to different results when considering:
  - The whole watershed
  - The zones next to water bodies
- Potential effects:
  - The relationship changes in significance (Sliva & Williams, 2001; Basnyat *et al.*, 2000; Tufford *et al.*, 1998)
  - The significant independent variables change
  - The variables have a different sign (Norton & Fisher, 2000)

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1. The scale question

- e.g.: Schilling & Libra (2000) nitrate analysis:
  - The watershed extent influenced the relationship among water quality and land use → the relationship was stronger for smaller watersheds
    - Fields next to the water bodies = straight and quick nutrients release from the field to the river
  - Many factors masked this relationship when increasing the watershed area:
    - *in-stream* nitrogen transformations
    - dilution with nitrate-poor waters
    - wide precipitation effect

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1. The scale question

- Changing the extent of the studied area = highlighting the **autocorrelation** (or spatial correlation) of the explaining variables:
  - Their relevance changes with the distance from the point of observation
- The models that consider among the variables the proximity to the river, generally have a greater predictive power than the models that consider simply the land use
- Therefore, this relationship is scale – dependent: landscape behavior with respect to nutrients loads changes with the scale

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1. The scale question

- The knowledge about the variables that drive the nutrients load at the different scales tell us that is necessary to plan the most adequate way and scale of landscape water quality management
  - e.g.: Land use far from the water bodies has a lesser influence on the water quality than the land use next to the water bodies; therefore changing the landscape structures in the buffer (riparian) zones should be more relevant for the water quality than modifying the land-use over the whole watershed

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2. Relationship among landscape spatial characteristics & water quality

- The relationship among land use and non point pollution is studied by means of two different approaches:
  - 2.1 Risk assessment
  - 2.2 Statistical relationship

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2. Relationship among landscape spatial characteristics & water quality

2.1 Risk

- estimate of the probability, on the watershed land use basis, that an undesired event (nutrients release) happens
- Nutrients release at the watershed scale depends not only on the land use types, but also on other factors like the hydrological and pedological characteristics, difficult to estimate
- The risk model estimates the probability that the load exceed a desired threshold

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2. Relationship among landscape spatial characteristics & water quality

- **2.2 Statistical relationship**
  - Empirical relationships among landscape structural, geomorphological and geopedological characteristics and the water quality at the basins outlet
  - Widely used method:
    - Outgoing nutrient load = dependent variable
    - Independent variables = landscape structure (land use, spatial index, etc.), landscape geological and pedological characteristics
    - Statistical analysis, generally multiple regression

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2. Relationship among landscape spatial characteristics & water quality

- The empirical relationships are studied by means of two different approaches:
  - Watershed = black box: variables are independent from their position with respect to the water bodies
  - Spatial configuration: relative position of independent variables from water bodies → influence of spatial pattern on landscape functions (Nutrients fluxes).
  - E.g.:
    - Contributing zones: highlight contributes from the surrounding land
    - Proximity analysis: considers the closeness and the distance using concentric zones

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2. Relationship among landscape spatial characteristics & water quality

- This relationship is studied to have indications for landscape management through planning
- The described relationships have some limits because of:
  - There could be significant variables not considered in the models
  - The available dataset could be limited
  - The relationships are generally modeled non linear basis

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3. Literature examples

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3.1 Risk of nutrients release - land use

- Wickham *et al.* (2003): 4 watersheds in Maryland, USA.
  - Variables
    - Risk thresholds (Kg/ha/yr): load/watershed area.
    - Ecological processes role: variable “in-stream degradation”
    - Land cover, nutrients release coefficient for each land cover class
- Results:
  - High degradation rates = decreasing risk downward
  - River lengthiness = increased retention time
  - Under the same degradation rate, the risk increased downward when the forested surface was less than 20%.
    - → risk variation depends mainly on land use composition

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3.1 Risk of nutrients release - land use

- Management implications:
  - The restoration and reforestation should move upward to be effective
  - Natural land cover (natural – forested area) have a great importance for non point pollution removal

- The estimation depends on parameters choice:
  - Estimated risk: depends on thresholds and event frequency
  - In-stream degradation rate: ecological process → highly variable

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3.2 Empirical models: nutrients – landscape structure

- Wayland *et al.*, 2003: Michigan, USA;
  - Dataset:
    - biogeochemical data, land use
  - Results:
    - Agricultural land use – nitrate concentrations
    - Wetlands and forested areas had a buffering role
- Castillo *et al.*, 2000: Michigan, USA;
  - Dataset:
    - concentrations & loads – land use + geological characteristics + treatment plant.
  - Results:
    - Agricultural land use – nitrate concentrations
    - Phosphorus loads:
      - Geological variables (moraine landscape, fine texture, ploughed) = phosphorus release is strongly associated with solids transport
      - Wastewater treatment plant

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3.2 Empirical models: nutrients – landscape structure

- Daly *et al.,* 2002: Ireland
  - Dataset:
    - phosphorus load – land use + soil characteristics.
  - Results:
    - Poor drained soils – phosphorus release in surface water
    - Seminatural and peat area = buffer areas (negative relationship)
    - But: seminatural areas next to rivers have poor drained soils → they could act as a source

- Jones *et al.* (2001) Maryland, USA.
  - Dataset:
    - nutrients load – land use spatial distribution:
      - %, fragmentation index (forested area), road network density, yearly atmospheric deposition of NO3, slope, erosion potential (%), riparian land use (use + hydrography).
  - Results:
    - Sediments and nutrients load - agriculture, riparian forest, atmospheric deposition and road density.
    - Phosphorus load variability depends mainly on riparian forests.

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3.2 Empirical, space explicit models: nutrients – landscape structure

- Basnyat *et al.* 2000 Mexico Gulf, USA.
  - Dataset:
    - nitrate – land use, soil class distribution, slope.
  - 2 spatial scales:
    - Whole watershed
    - '*contributing zone*': area surrounding the river that could act as a buffer if forested
  - Results:
    - There was any significant relationship at the watershed spatial scale
    - '*contributing zone'* scale: there was a significant relationship among nitrate concentration and forest land use (buffer) and agriculture (source)

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3.2 Empirical, space explicit models: nutrients – landscape structure

- Tufford *et al.* 1998. South Carolina, USA
  - Dataset:
    - N and P – land use (forest, agriculture, urban and wetland)
  - Scales:
    - 4 concentric zones (30, 150, 300 and 600 m), centered on the hydrographic network.
  - Results:
    - The rate of explained variance increased from the first to the second zone;
    - The regression coefficient indicates:
      - agriculture = nitrogen release,
      - Urban land use = phosphorus release,
      - Forest and wetlands = buffer zones
  - Suggestions:
    - The effect of land use changes are maximal if they involve the rivers surroundings

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3.2 Empirical, space explicit models: nutrients – landscape structure

- Sliva & Williams, 2001. Ontario, Canada
  - Dataset:
    - N and P – land use (grass, forest, agriculture, urban land) + geological characteristics
  - 2 Scales:
    - watershed, 100 m-buffer around streams
  - Results:
    - Urban land use = most significant variable, especially for NH4
    - Agriculture = not the most significant variable.
    - Water quality = the correlations are more significant at the watershed scale than at the riparian scale (100m-buffer).
    - No nutrients correlate with landscape variables, except for NH4
  - Why?
    - Point pollution sources upstream (with respect to the sampling points)

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3.2 Empirical, space explicit models: nutrients – landscape structure

- Norton & Fisher, 2000 Chesapeake Bay
  - Dataset:
    - nutrients – forest land use (%, total extent, % forested stream), soil characteristics
  - Scales:
    - 4 buffers around the hydraulic network (0-100 m, 100-300 m, 300-500 m, >500 m)
  - Results:
    - Fine texture = great runoff potential – no correlations among water quality and forest variables
      - Nutrients transport towards forest less efficient; soil characteristics neutralize forest land use effects
    - Watershed scale: wetland and forests act as a sink for nitrate
    - Phosphorus: related positively with riparian forest (0-100 m), negatively with 100-300m forest
      - Riparian forest acts as a source (reduced soil conditions) and 100-300 m forest as a sink.

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3.3 Statistical methods

- Land use variables
  - Agriculture = main source
  - Forest-wetlands = sink
  - Livestock = source
  - Urban =source:
    - Ammonia and phosphorus by urban wastewater,
    - Runoff by urban surfaces
- Soil variables
  - Watershed soil texture and surface geology, as %.

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3.3 Statistical methods

- Dependent variable
  - Nutrients concentrations or loads
- Statistical methods:
  - Multiple linear regression (mainly)
- Problems and solutions
  - Use of correlated predictors in the regression analysis
    - solutions: screening analysis on predictors to identify the main independent variables, resume different variables into one factor (factor analysis)
  - Limited dataset, not – normal distribution
    - solution: non-parametric analyses

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3.4 Know how overview

- N – loads related mainly to agriculture:
  - as % agriculture
  - as agriculture/natural land rate
- Limiting factors:
  - Geo-morphological and pedologic characteristics could mask these relationships:
    - Groundwater infiltrations (dilution)
    - Detention time (related to hydraulic conductivity) influences the nutrients transformations
    - Slope influences the nitrogen load amount
  - Wastes could mask the analyzed relationships

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3.4 Know how overview

- Phosphorus loads correlated mainly:
  - To urban land use (wastewater);
  - To natural land use (sink)
- Limiting factors:
  - Coarse soils reduce runoff and therefore phosphorus leachate
  - Acid, Fe and Al rich soils or basic, Ca and Mg rich soils immobilize phosphorus by means of compound formation

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3.4 Know how overview

- Natural systems: sink-function with respect to nutrients flows
- Limiting factors:
  - Poor (functional) connectivity decreases efficiency at the watershed scale
  - Hydrological soil characteristics influence nutrients flows
  - They could act as a source: oxidizing and reducing conditions shift because of periodic flooding promote N and P release
  - During flooding
    - N is released as NH4
    - P is solubilized and released

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3.4 Know how overview

- Scale Effect
  - The functional relationships among land use and nutrients loads change if considering different extents:
    - In the river surrounding area, the significant predictors are typical of these zones (e.g. riparian forest, temporally satured soils…)
    - Nutrients released next to the rivers reach quickly the stream and therefore are less modifies by chemical and biological processes, adsorption, infiltrations… → the relationships land-use/nutrient load are more clear
    - In the river surrounding area the main nutrient sources could be excluded (intensive agriculture, urban and industrial land use).

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4 Applying the knowledge to the landscape management

PIANO DIRETTORE 2000

PIANO PER LA PREVENZIONE DELL'INQUINAMENTO E IL RISANAMENTO DELLE ACQUE DEL BACINO IDROGRAFICO IMMEDIATAMENTE SVERSANTE NELLA LAGUNA DI VENEZIA

Plan for the pollution prevention and water quality restoration in the Venice Lagoon watershed.

REGIONE DEL VENETO

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4.1 Goal

- To ensure the typical transition ecosystem characteristics in the Venice Lagoon (stable mesotrophic state, absence of ecotoxic events)
- To indicate restoring-reclaiming actions to fulfill water quality objectives:
  - 3000 t/a N, 300 t/a P discharged in the lagoon
  - 400μg/L dissolved N, 30μg/L dissolved P in the watershed hydraulic network
- The plan it is a part of a special law for Venice
- It was established by the Environmental Safeguard Division of Veneto Region
  - With the contribution of provinces, sanitary units, the local environmental protection agency, the Venice Water Authority
- Approved by the regional council on the 1st March, 2000

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4.2 Guideline

- Prevention actions:
  - They must be favored and sustained by laws and benefits to reduce pollutant loads since their generation
- Reduction actions:
  - Point pollution: actions to reduce the wastewater amount
- Increasing of the streams auto-depuration potential:
  - Removal of residual wastewater and non-point pollution
- Diversion actions:
  - Extraordinary action, applied only for exceptional events: waters are diverted into the rivers that flow into the Adriatic sea to avoid the loads to enter the Venice Lagoon

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4.3 Landscape actions

- Actions to restore and increase the auto-depuration potential of the hydraulic network, applying the knowledge related to wetlands and buffer zones.
- 1: Stream re-naturalization
  - Aim: to reconstruct a natural aquatic environment, increasing the detention time.
  - Actions: to increase the riparian vegetate area and to maximize the flooded riparian area
    - Restoring the riparian vegetation to sustain biological communities;
    - Re-calibrating the stream beds in the reclaim network;
    - Realizing floodplains to promote the flood flow to be laminar and slow; in normal conditions, they have a natural and recreational function.

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4.3 Landscape actions

- 2: Wetlands recreation
  - Creating free-flooded wetland to the side of streams (e.g. abandoned pits);
  - Surface wetlands as tertiary treatment (wastewater and reclaimed water)
  - Estuary wetlands: recreation of 2 wetlands at the outfall of main rivers.

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4.4 Knowledge-actions comparison

- The “Piano Direttore 2000” acts on the watershed with actions that have been shown to be effective for the nutrients removal
- However, the change of spatial scale could modify the cause-effect relationships
- We investigate which relationships among water quality and landscape structures are significant in the Venice Lagoon watershed at different spatial scale, to obtain useful management information

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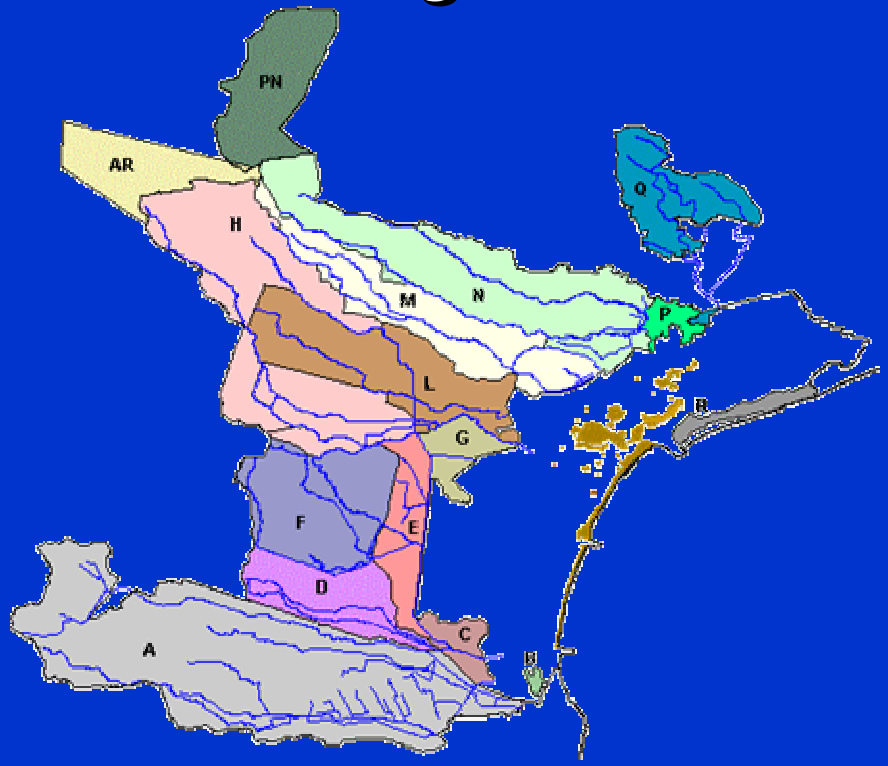
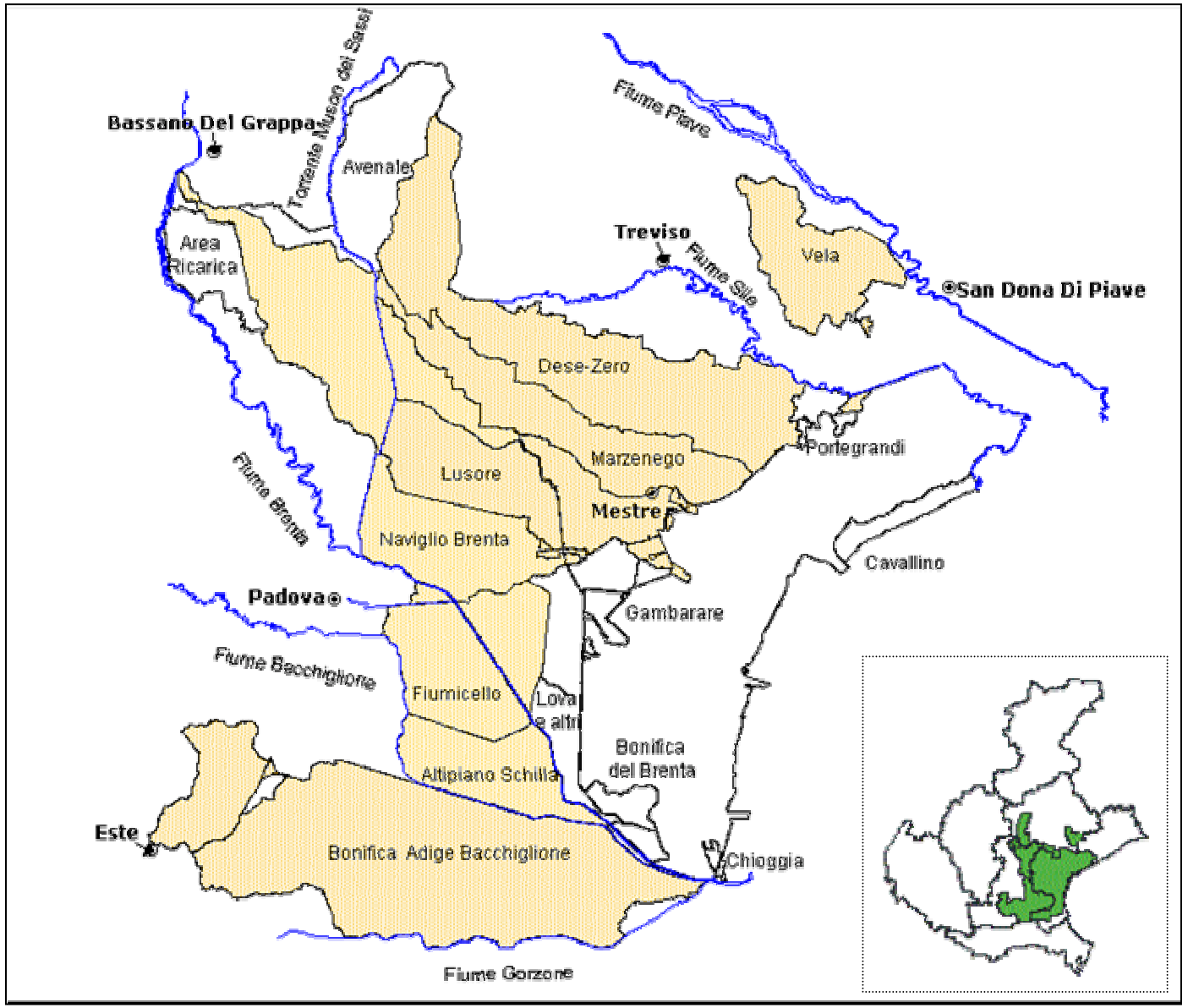
5 Case Study: Venice Lagoon watershed



This work belong to a research program on Landscape Ecology

(landscape structures and functions role with respect to biotic, hydrologic, socio-economics flows at different spatial and temporal scales)



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5.1 Research goals

- To study the relationship among
  - Landscape structures, at different spatial scales
  - Nutrients loads in the Venice Lagoon watershed
- To support the management interventions planning

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1.5.1 Research goals

1. verify the relationships among land use and water quality
   - % land use, nutrients loads outflow
2. estimate the role of pedologic variables
   - Soil texture, hydraulic characteristics, permeability
3. estimate the influence of landscape organization
   - **Heterogeneity:** Shannon Index (“richness” and “regularity” (distribution) of ecotones in the area.
   - **Fragmentation:** Effective Mesh Size. Effective area where flows do not intercept barriers.
   - **Drainage density** (km/ha): watershed streams total length/watershed area.
4. analyze the effect of the scale on the detected relationships and variables
5. estimate the role of agro-forestry systems

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5.2 Research method

- Study areas:
  - Watershed scale; 100 m-buffer and 50 m-buffer around rivers and reclaim channels
- Choice of 100m and 50m values:
  - Pragmatic: we had to consider increasing proximity to the stream
  - Ecological: the literature reported that at these distances from the river there is a change in the processes that influence nutrient release

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5.2 Research method

- Predictors selections on ecologic basis
  - Land use
    - Hypothesis: the main categories (on extent basis) are more significant at the watershed scale, while the natural and forest categories are more significant in the riparian zone
    - We add preferentially the variables at the different scales, after observing the trend with respect to the dependent variables (nutrient loads)
  - Structure Index:
    - Excluded from the 50 m – buffer, too limited in extent to let the index to be significant
    - Heterogeneity: the index is stable within the adopted scale range
    - Fragmentation: it is conservative only with an extent > 6km
    - Drainage density: it can be calculated only at the watershed scale

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5.3 Results

- There is a constant correlation among land uses, soil characteristics and spatial indexes
  - Agriculture is linked to loam soils, cities are linked to sandy soils: these associations had a socio-economic and cultural reasons
  - The Shannon Index is linked to urban land use, while EMS is linked to agriculture: these associations are caused by the map characteristics (satellite data)

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5.3 Results

- Goal 1: verify the relationships among land use and water quality
- Nitrate
  - Significant relationship between nitrate load and cattle farms
- Ammonia
  - The main relationships involves urban land use and Shannon Index at the watershed scale
  - The relationship between ammonia load and urban land use is non-linear: it changes over the 15% urban land use threshold

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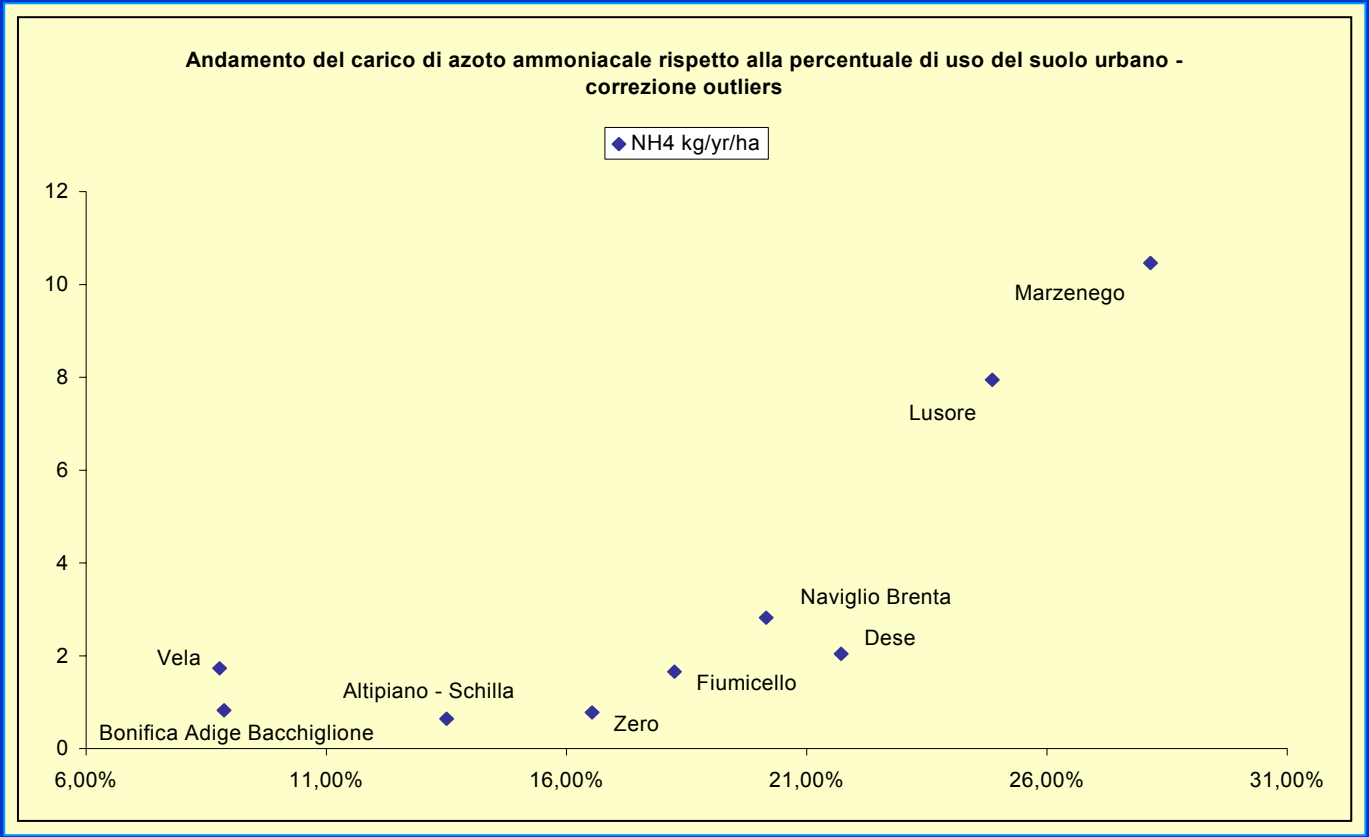
5.3 Results



- "**Threshold effect**": the relationship is clearly linear only when the independent variable grows over the threshold.

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5.3 Results

- Total phosphorus
  - The most significant relationship involves the variables natural land use and the soil texture, at the 50m-buffer scale
  - The interventions should be addressed at the riparian zone, with particular attention at the soil texture
- Natural zones: they act as a source, differently from the literature results
  - This category is highly heterogeneous (it comprehend very different kinds of natural land uses)

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5.3 Results

- Goal 2: estimate the role of pedologic variables
- The soil texture influences nutrients loads at every study scale, with different significance:
  - Clay sub-basins = reduced load per area unit
  - The interventions in the other basins should prioritise the reduction of the total load that enters in the lagoon

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5.3 Results

- Goal 3: estimate the influence of landscape pattern
- The pattern indexes
  - describe the effect of the main land uses on the landscape structure
  - depend on the grain of the map used
  - add information with respect to the land use (expressed as % surface)
    - Shannon index vs % urban land use: the nutrient release is not only linked to the civil wastewater but also to the urban surfaces that act as a preferential way for nutrient flows
    - Drainage density: it is linked to nitrate removal because it characterizes the detention time in the hydraulic network

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5.3 Results

- Goal 4: analyze the effect of the scale on the detected relationships and variables
- The main relationships at the watershed scale involves
  - Urban land use – NH4 and P
  - cattle farms – NO3 and P.
- The main relationships at the 100 and 50m-buffer scale involves
  - Soil texture
  - Natural land use (their behavior needs to be more deeply analyzed to be completely interpreted)
- Intervention scale
  - Nitrogen: watershed scale for the main processes
  - Phosphorus: structures of the riparian zones

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5.4 Critical elements

- The dataset is only a year long
  - Numerically reduced
  - Not enough representative of the time scale of the studied processes (e.g. 2002 was exceptional raining …)
  - Sensitive to outliers
- The Venice Lagoon watershed has a complex hydraulic network
  - The most part is artificially managed
  - Nutrients loads at the outflow comprehend also point pollution (wastewater)

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5.4 Critical elements

- Nitrate
  - the absence of strong relationships is caused by
    - Texture influence → confirmed by literature
    - The hydraulic management of reclaimed sub-basins sustain denitrification
    - The concentration decreases from upstream to downstream because of the (recharge) groundwater pollution and infiltrations

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5.4 Critical elements

- Urban land use:
  - It is responsible of masking because it is focused along coastal areas (where are located the sampling points)
  - The watersheds reported in the literature had generally a lower urban land use < 10% the the Venice watershed studied basins (8-28%)
  - Masking could be involved also in the relationship between phosphorus and clay texture: the clay sub-basin have the less urban land use % (low P sources)

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5.5 Conclusions

- The study increased the learning about the multiscale relationships among spatial structures, processes and functions of the analyzed landscape, to promote the management of its resources
- Among the considered variables, the release and the transport of nutrients were influenced mainly by soil characteristics and urbanization: these variables tended to mask other relationships
- These results led also to evaluate solutions to the analytical limitations experimented during the study, and to highlight some processes hardly interpretable (involving natural land use) that should be deeply analyzed