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# Network graphs unveil landscape structure and changes

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**Abstract**

Landscape (i.e., land cover, land use or vegetation maps) is a very complex mosaic of thousands of patches, and this makes its interpretation very challenging. Class areas and shared perimeters between classes are two pivotal properties of its structure. In addition, landscape structure changes over time as a consequence of many interacting processes. Hence, there's an urgent need for a synthetic and intuitive representation of its structural attributes. I advocate here network graphs as an aid to interpreting and checking temporal and spatial properties of landscapes. I also suggest several hints to fitter use network graphs in landscape representation. As a case study, I apply network graphs to the Ceno valley (Parma, Italy), but the proposed approach is suitable for any landscape maps.

**Keywords** network graphs; landscape/vegetation maps; landscape structure; landscape change; NetDraw; Ceno valley.

## 1 Introduction

Landscape (vegetation or landcover-landuse map) is defined as a "heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout" (Forman and Godron, 1986). Landscape structure is characterized by the presence and amount of each patch type (vegetation type or landcover-landuse class). Since landscape and vegetation maps are very complex mosaics of thousands of patches, the interpretation of their structure is difficult (Imam, 2011).

Landscapes are also dynamic features (Forman, 1995) whose structure evolves almost continuously. As the landscape is composed of different components all having their own dynamics, many changes will occur simultaneously and continuously, all at their own speed and magnitude. Studying changes of one single, well-defined component is rather simple. But how can the overall change of the landscape, as a holistic entity, be represented?

I provide here the description and application of a graphic approach to landscape structure and change assessment based on the combined use of GIS (Geographical Information Systems) and network graphs. It provides an effective and intuitive tool for a synthetic representation of the inner structure and changes of landcover and/or vegetation maps. Furthermore, the proposed approach is suitable for any landscape maps.

## 2 *Ad Hoc* Network Graphs

I suggest here that network graph representation of landscape structure and change should take into account several hints:

a) since too many polygons (usually thousands of polygons) belong to landscape maps, network graphs should be referred to landcover classes, not polygons;

b) class areas and shared perimeters between classes are key-properties of landscape structure;

c) network graphs should make use of the same colours already present in the referred landscape map, since this makes network graph much more intuitive; on the other hand, landscape maps should employ colours as close as possible to real ones (e.g., water bodies should be blue-coloured and so forth);

d) network nodes should be proportional to class areas;

e) network lines should be proportional to shared perimeter between classes;

f) not only absolute values of shared perimeters should be represented, but also percent values;

g) the network shape should be as intuitive as possible, hence with 4 classes a simple square should be used, with 5 classes a pentagon, and so forth. Different shapes should be justified, for instance one could think using a spring-embedding algorithm (Eades, 1984) which starts by arranging the nodes randomly in space, and then begins moving them in such a way as to minimize energy (Gajer and Kobourov, 2002). This algorithm results in a layout in which nodes with the greatest link density are at the core of the plot, with nodes more isolated on the periphery.

Free network softwares such as NetDraw (Borgatti, 2002) are ideal to the network representation of landscape structure and changes.

## 3 An Applicative Example

The Ceno valley is located in the Province of Parma, Northern Italy. It has been mapped at 1:25,000 scale (Ferrarini, 2005; Ferrarini et al., 2010; Tomaselli, 2003). The Ceno valley can be divided into three belts. The lower supra-mediterranean belt is dominated by *Quercus pubescens* woods. The higher supra-mediterranean belt goes up 1000 m a.s.l. and is characterized by *Ostrya carpinifolia* woods and by the scattered occurrence of *Quercus cerris* woods. The montane belt, starting at about 1000 m a.s.l., is dominated by *Fagus sylvatica* woods. It is characterized by an extensive human use in the form of crops (27.98% of the study area), and wooded landcover given by *Ostrya carpinifolia* (23.45%) and *Quercus cerris* (13.02%) woods. Wetlands occupy about 1.8% of the study area.

### 3.1 Network graph of landscape structure

Fig. 1 shows the study area in 1995. For the sake of simplicity, landcover classes have been arranged into 4 main groups. Croplands include non-irrigated arable land, permanently irrigated land, vineyards, fruit trees, olive groves, etc. Developed areas include continuous urban fabric, discontinuous urban fabric, road networks and associated land, and so on. Vegetated areas embrace broad-leaved forests, coniferous forest, natural grasslands, and so forth. Water bodies stand for water courses, riparian vegetation and lakes.

Fig. 2 shows the network graph relative to the structure of the study area in 1995. Node sizes are proportional to landcover class extensions; node colors are the same as in Fig. 1; line widths are proportional to shared perimeters between classes. Values expressed in km refer to shared perimeters between landcover classes, while percent values refer to the percentage of the class perimeter which is shared with a particular landcover class.

Several structural properties of the study area immediately emerge:

- the landscape under study is dominated by the presence (more than 32,000 hectares) of vegetated areas and contiguities (more than 1000 km) between vegetated areas and croplands;

- water bodies are polarized toward vegetated areas (78.5 km; 66.52% of shared perimeter);

- while croplands are common neighbors to water bodies (25.42% of shared perimeter), water bodies are only occasional neighbors to croplands (2.65%);

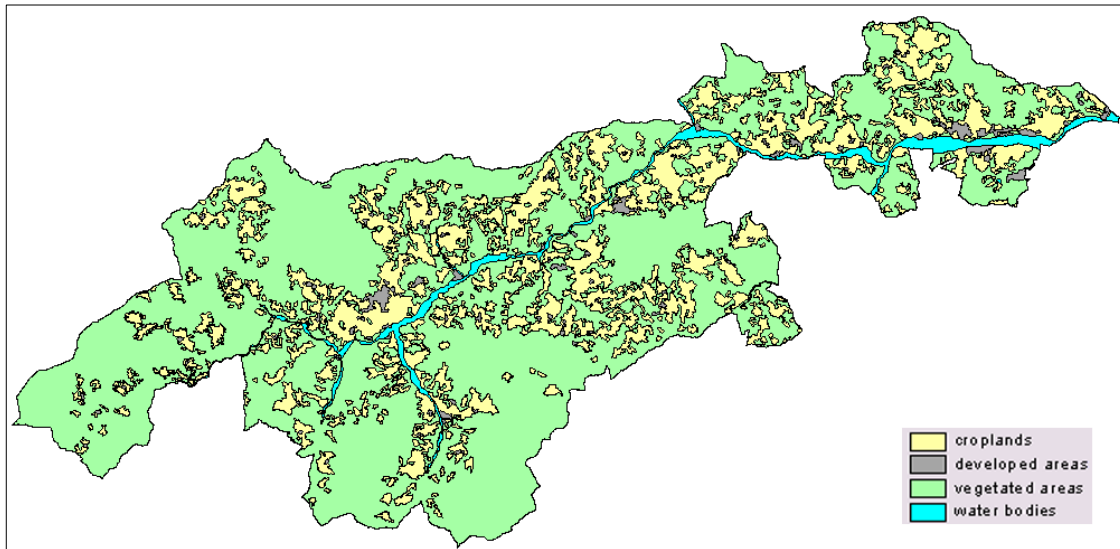- developed areas are polarized towards croplands (94.7 km; 69.68% of shared perimeter).



**Fig. 1** Year 1995. Ceno valley (4 landcover classes).
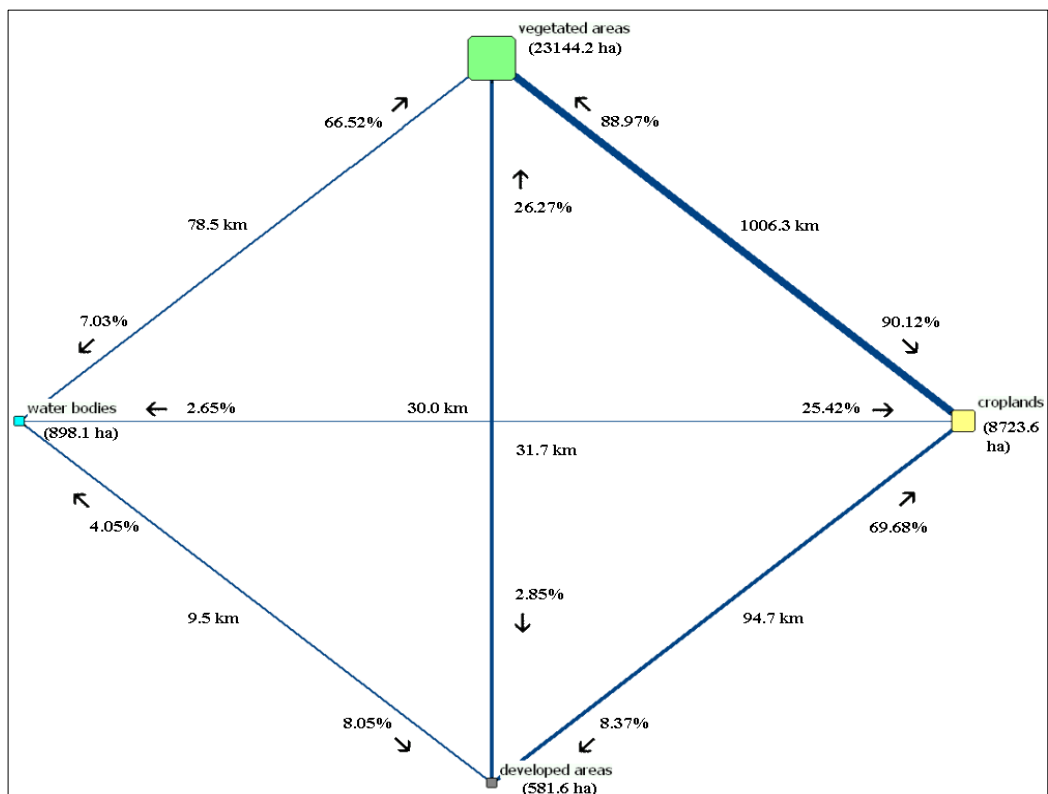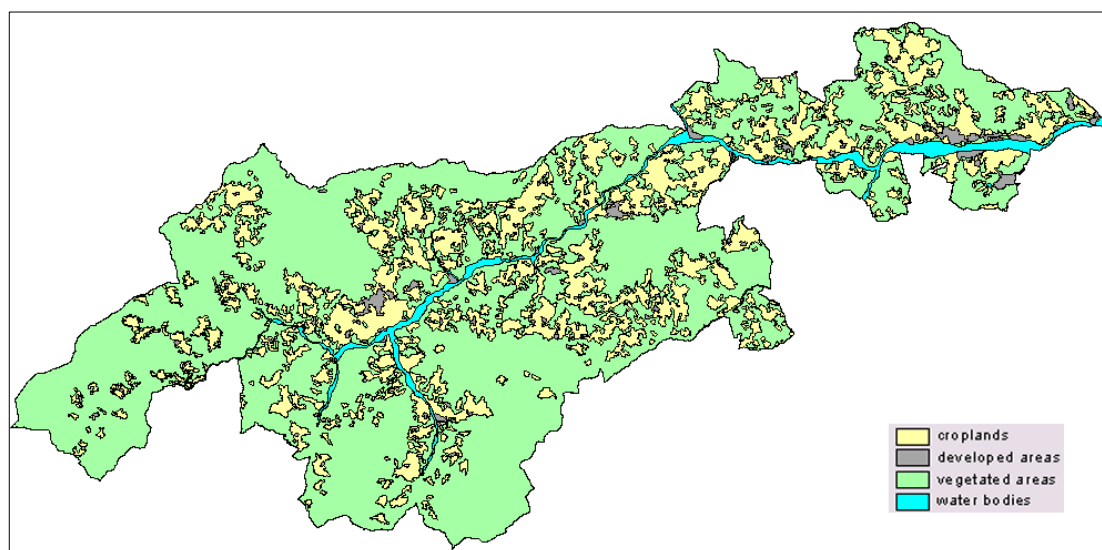


**Fig. 2** Network graph showing the structure of the Ceno valley in 1995.

### 3.2 Network graph of landscape changes

Fig. 3 shows the study area in the year 2000. Landcover classes have been arranged into 4 groups.



**Fig. 3** Year 2000. Ceno valley (4 landcover classes).

Fig. 4 shows the network graph relative to landscape changes in the 1995-2000 period. Node sizes are proportional to landcover class extensions in the year 2000; node colors are the same as in Figures 1 and 3; line widths are proportional to hectares switched between classes. Percent values among parentheses refer to class increase or decrease between 1995 and 2000.

During the 1995-2000 period, the main dynamics were for vegetated areas and croplands, as 59.2 hectares shifted from croplands to vegetated areas (this dynamic was typical of land abandonment in the higher portion of the valley) while 23.1 ha changed from vegetated areas to croplands (a typical lowland transition in the study area).

Developed areas grew (+8.7%) as well, since they gained 24.7 ha from croplands, 9.7 hectares from water bodies, and 20.7 hectares from vegetated areas. They just lost 3.4 hectares in favor of vegetated areas in the higher portion of the valley, where discontinuous urban areas have been colonized by the natural expansion of broad-leaved and mixed forests.

Water bodies had a 0.09% increment, in particular caused by a transition coming from vegetated areas. This was due to changes from natural grasslands to riparian vegetation (that has been classified as water body here). It's interesting to note that, although croplands and water bodies share 30 km of perimeter, there have been minimal dynamics between them, mainly due to local choices and restrictions in the political government of the study area.
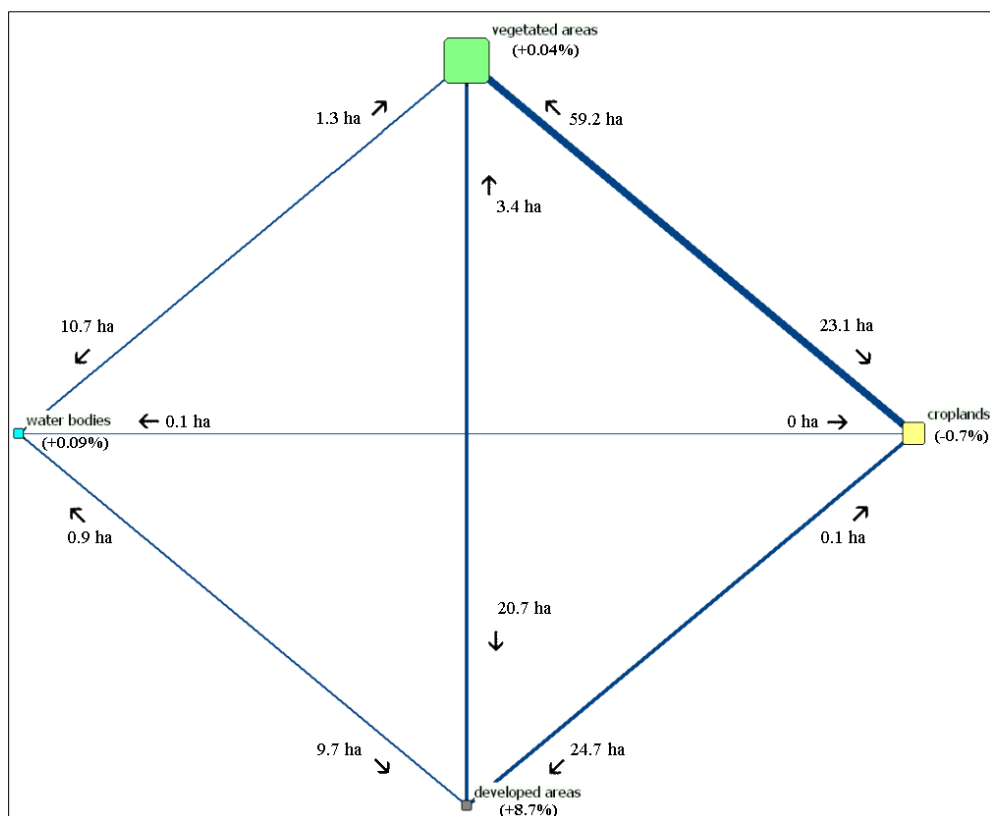
**Fig. 4** Network graph showing landcover changes in the Ceno valley between 1995 and 2000.

## 4 Discussion and Conclusions

Network graphs are ideal to the purpose of representing landscape structure and its changes over time. Based on the visual inspection of the network diagrams, a synthetic and intuitive representation of the main landscape properties is feasible.

I proposed here that several hints should be adopted in order to make network graphs maximally easy to interpret. I also suggest that the combination of GIS and network graphs is as useful as the landscape is complex, and number of landcover classes and dynamics among them is high. Finally, I state that network graphs can be successfully applied to any landscape maps and transitions.

## Acknowledgments

## References

Borgatti SP. 2002. NetDraw network visualisation. Analytic Technologies, Harvard, MA, USA

Eades P. 1984. A heuristic for graph drawing. Congressus Numerantium, 42: 149-160

Ferrarini A. 2005. Analisi e valutazioni spazio-temporale mediante GIS e Telerilevamento del grado di Pressione Antropica attuale e potenziale gravante sul mosaico degli habitat di alcune aree italiane. Ipotesi di pianificazione. Ph.D. Thesis, Università degli Studi di Parma, Parma, Italy

Ferrarini A, Bollini A, Sammut E. 2010. Digital Strategies and Solutions for the Remote Rural Areas

Development. Acts of Annual MeCCSA Conference, London School of Economics, London, UK

Forman RTT, Godron M. 1986. Landscape ecology. John Wiley & Sons, New York, USA, 1986

Forman RT. 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK

Gajer P, Kobourov SG. 2002. GRIP: Graph drawing with intelligent placement. Journal of Graph Algorithms and Applications, 6: 203-224

Imam E. 2011. Use of geospatial technology in evaluating landscape cover type changes in Chandoli National Park, India. Computational Ecology and Software, 1(2): 95-111

Tomaselli M. 2003. *C*ORINE map of the Ceno Valley. Technical Report, Centro Studi Val Ceno "Cardinale Antonio Samorè", Bardi, Italy