XVII^th World Congress of the International Commission of Agricultural Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

FROM THE CONSTRUCTION OF AN ECOLOGICAL NETWORK TO THE DEFINITION OF AN ENVIRONMENTALLY SUSTAINABLE PLANNING MODEL FOR PERIURBAN SPACE

FICHERA C. R[1]. , LAUDARI L[1]. , MODICA G.[1]

[1] C.R. FICHERA, Mediterranea University of Reggio Calabria, Department of Agroforestry and Environmental Sciences and Technologies (DiSTAfA) – Località Feo di Vito – 89122 Reggio Calabria, Tel +39 0965 312681. cr.fichera@unirc.it
[1] L. LAUDARI, luigi.laudari@unirc.it
[1] G. MODICA, giuseppe.modica@unirc.it

CSBE101488 – Presented at the 8th World Congress on Computers in Agriculture (WCCA) Symposium

ABSTRACT Any action of anthropization of the natural environment implies the destructuring of the ecomosaic with varied modes and intensity. If this destructuring stretches in time and space, it will result in phenomena of landscape fragmentation leading to environmental unsustainability due to the change in functionality and in the biological processes. Over the last ten years, field studies have highlighted that the classical methodologies for nature protection are not adequate and have identified ecological networks as the most suitable tool to assure the functional perpetuity of ecosystems (the EU has even formalized their adoption in environmental protection strategies). To tackle such issues, the authors have started a research leading to the construction of a GIS model for the definition of ecological networks. It is based on biological and orographic principles and on the anthropic structure of the territory, thus surpassing classical monodisciplinary approaches. A set of indicators has been defined, structured and associated to this tool to monitor its effects on the territory functionality.
This paper shows the results of the integration of the ecological network with the indicators in a sub-model defined to envisage the possible policies of the new urbanization and to support regional and sub-regional land-use planning tools. The implemented model generates policies of expansion of the urban tissue which do not alter the biological functionality of the ecological network system. The model has been applied to the province of Reggio Calabria (Italy) emphasizing its potentials and limitations as a guiding tool for a sustainable land-use planning.

Keywords: GIS; Ecological Networks; Sustainable urban expansion.

INTRODUCTION The current ecological consciousness demands a new approach in the common physical planning models: the need for a biological functionality must guide ordinary planning actions. This could be achieved through the in-depth study of specific issues related to the analysis of the bio-ecological structure and of landscape fragmentation as well as to the forecasting study of landscape physiognomy. After being suitably indexed, these aspects can be implemented in a dedicated GIS (*Geographic Information System*), which is a quick, flexible and integrable tool for the study of the complex structures of the environmental matrix. A model for the definition of an ecological network as a guideline in the planning process (Fichera et al., 2009) has been implemented within a wider research conducted by the authors for the definition of sustainable landscape planning models that take into account the aspects of ecological connectivity. The developed model consists in a system of algorithms operating on a specific *geodatabase*, structured and implemented in a dedicated GIS that, through the progressive elaborations of the habitat quality and the definition of the core areas, allows to define the structure of the ecological connectivity matrix. The model refers to the two traditional (physiographic and functional) approaches for the definition of the ecological networks and sets an experimental integrated ecological network (Fig. 1). It has been applied to the province of Reggio Calabria (Italy) emphasizing its potentials and limitations as a guiding tool for a sustainable land-use planning.

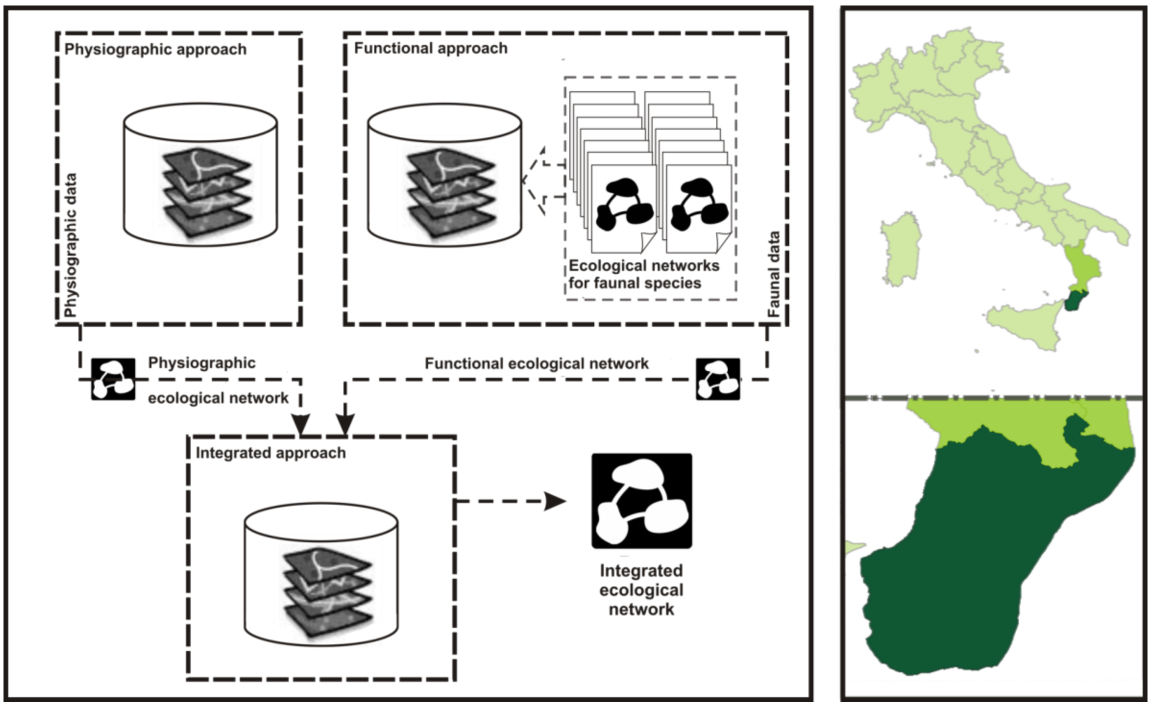

Figure 1. Diagram of the model for the definition of the Integrated Ecological Network and localization of the study area for its application, the Province of Reggio Calabria (Italy).

The model follows Bennett's theoretical approach (2004a; 2004b), which organizes the ecological network as a coherent system of areal components and integrates the peculiar characteristics of physiographic and functional networks. The resulting network allows to obtain a spatial continuity that is functional to wildlife dispersion and has no excessive impact on the territory. Data inputs have been implemented on a *FunConn* model (*Functional Connectivity Modelling*) (Theobald et al., 2006) that, suitably modified and adapted for its application in the Mediterranean area, provides graph theoretic-based analysis methods for landscape connectivity. As a result, an ecological network, which is in keeping with the physiographic and functional theoretical aspects and with all the fundamental characteristics theorized for the ecological networks, has been obtained (Fichera et al., 2009) (Fig. 2). This paper shows the results of the inclusion of the ecological network in a specific model defined to envisage the possible policies of the new urbanization and to support regional and sub-regional land-use planning tools.

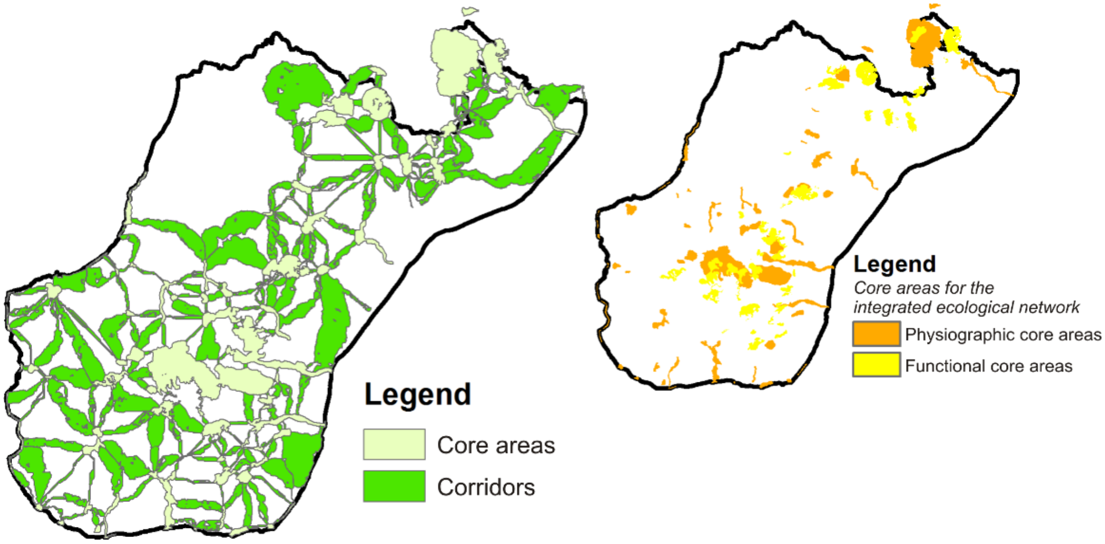

Figure 2. Spatial configuration of the Integrated Ecological Network for the Province of Reggio Calabria and detail of the functional and physiographic core areas (Italy).

MATERIALS AND METHODS With a view to guide the new urbanization towards the respect of the local ecological functionality, this paper proposes a model for a sustainable urban expansion by associating the integrated ecological network with an environmental sustainability index (Fig. 3)

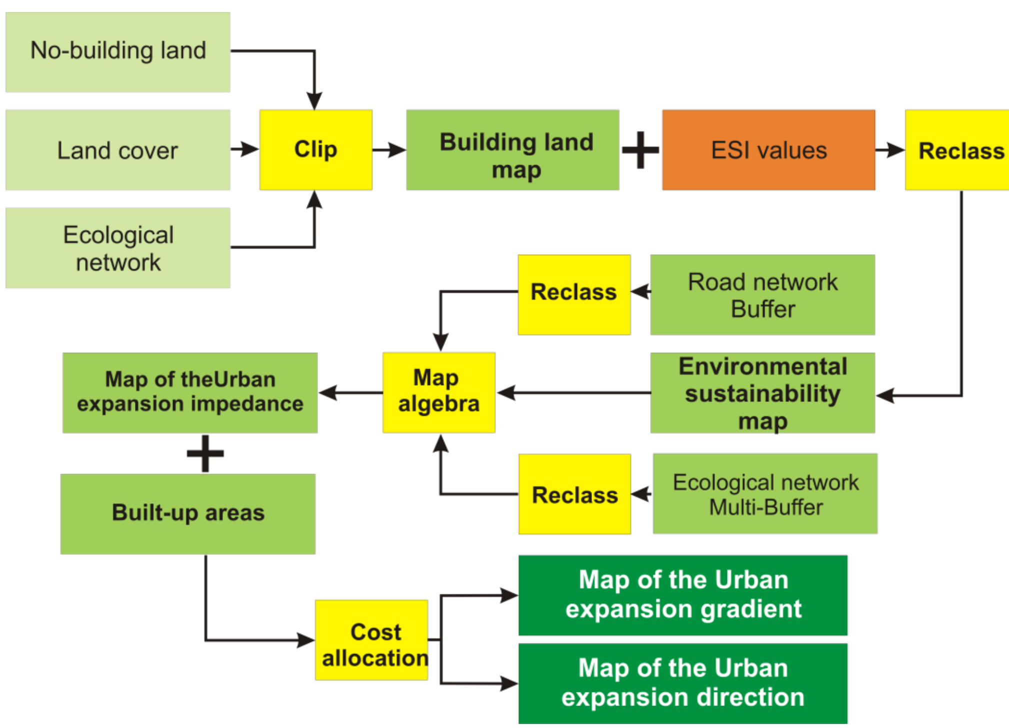

Fig 3. Flow-chart of the proposed model for sustainable urban expansion.

In particular, ESI (Environmental Sustainability Index) indicator has been used (Treu et al., 2000; Magoni and Steiner, 2001) after being suitably modified and adapted for its application in the study area. This index has been employed to measure the ecological stability of the territory in relation to the possible axes of urban expansion. At the same time, the index also allows to identify the vulnerable areas on which the possible actions of impact mitigation and compensation should be focussed. ESI is an index of landscape ecological stability that is founded on Odum's four compartments ecosystem model and provides the conceptual framework for assessing landscape stability (Odum, 1988). In each of the four compartments, or landscape zones (productive areas, protective or natural areas, compromise areas and urban/industrial areas), the various land-uses have different, sometimes even conflicting, functions.

Therefore, a condition of sustainable development can be attained through a balanced dimensional relation and an effective interaction between the different land-uses, which are analysed according to two categories of processes underlying the environmental equilibrium of a territory: Anthropic Pressure (AP) and Environmental Regeneration (ER). The calculation of the ESI is exactly based on the equilibrium between these two categories of processes (AP and ER) with opposite effects and follows four different phases:

- Definition of the homogeneous land cover classes in terms of AP and ER;
- Measurement of the areas of each land-use and estimate of AP and ER unit measures normalized in the interval of values [0, 1];
- Product of the unit areas multiplied by their respective AP and ER values and summation of the two categories of measure to obtain the corresponding total equivalent areas;
- Calculation of the ESI value by means of a comparison between AP and ER equivalent areas.

The calculation of the total equivalent area requires the estimate of the total AP absorption rate of the different land-uses by the different regenerating components; that is, it requires the estimate of the ER equivalent area necessary to redress the equilibrium of a unit of AP equivalent area. The ESI value varies in the range [0, 1]: the null value corresponds to the absence of regenerating land-uses (maximum unsustainability); the value 1 defines contexts exclusively characterized by natural land-uses (maximum sustainability). The value 0.5 corresponds to the condition of equilibrium between the regenerating capability of the environment and the amount of pressures exerted on the same territory and, therefore, it is the threshold value between the two extremes.

In order to achieve a transparent assessment of the quantitative parameters of the levels of AP and ER phenomena, the estimate method Analytic Hierarchy Process, AHP (Saaty, 2008), has been used. This procedure consists in (Saaty, 2005; 2008):

- Modelling the problem as a hierarchy containing the decision goal, the alternatives for reaching it and the criteria for evaluating the alternatives;
- Pairwise comparisons, made through the formulation of judgments from fundamental scale, in order to establish the relative importance of criteria and factors;
- Estimating the *Consistency Ratio* (CR) that expresses the internal consistency of the judgments.

Table 1. Criteria and factors for AP and ER assessment.

	CRITERIA	FACTORS
Anthropic Pressure (AP)	Waste production	*Climate change gas emission*
		Toxic effluent dump
		Toxic waste production
		Air pollution emission
		Biodegradable effluent dump
		Biodegradable waste production
	Energy consumption	*Renewable energy consumption*
	Natural resources consumption	*Renewable natural resources consumption*
Environmental Regeneration (ER)	Ecological cycling and process regulation	*Carbon cycle regulation*
		Water cycle regulation
	Biodiversity	*Biodiversity levels*
	Bio productivity	*Quantity of biomass production*
		Quantity of renewable energy production
	Effluent absorption	*Non climate change gas absorption*
		Effluent absorption

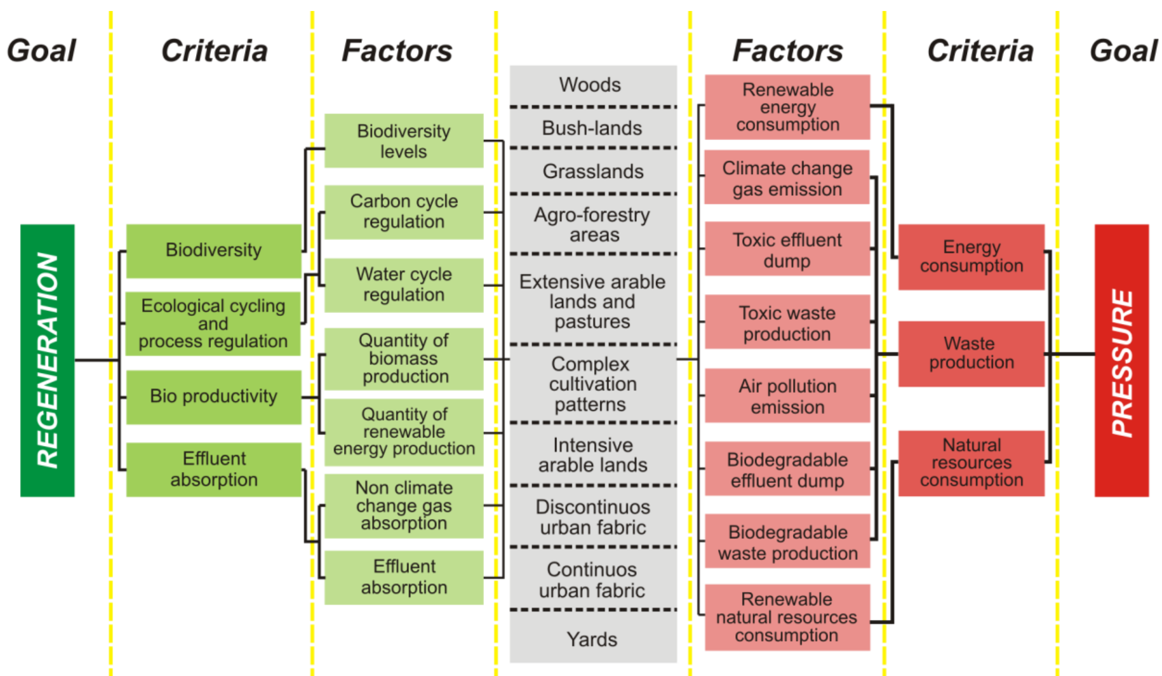

Figure 4. ANP model for Environmental Regeneration and Anthropic Pressure criteria assessment.

The hierarchy of the assessment criteria has been based on the choice of those criteria and factors that, in the ordinary dynamics of land-use management, tend to maximize AP and ER phenomena (Tab. 1); an ANP (*Analytic Network Process*) (Saaty, 2008) has been implemented for each of the two investigated phenomena (Fig. 4) so as to aggregate the results of the assessments of the single factors and criteria. The main feature of this method is that relative judgements are more reliable than absolute judgements, since the former show a closer correspondence to human mental categories. ANP favours the integration of objective and subjective, quantitative and qualitative assessments and exploits the wide range of available information. The consistency of the judgments is estimated by the Consistency Ratio (Saaty, 2005); if inconsistency exceeds the threshold value (0.1), it will be necessary to revise the judgements expressed in the pairwise comparisons.

Assessment of AP and ER factors The ANP model to estimate AP has been structured for the scalar evaluation of the measures of pressure that, starting from the particular (estimate of the pressure unit measures of the single factors), progressively integrates data (estimate of the pressure unit measures of the criteria) until reaching the definition of the overall AP measures that a certain configuration of land-uses can generate on the whole reference territory. It is important to highlight that the Anthropic Pressure criteria related to Energy Consumption and Natural Resources Consumption have only one factor each and, therefore, do not require a pairwise comparison. On the contrary, the AP criterion related to Waste Production is characterised by a descending order of factors where Climate Change Gas Emission ranks the first, since it is the main cause of global impact. It is followed by Toxic Effluent Dump, Toxic Waste Production and Air Pollution Emissions, which show the same impacts, and, finally, by Biodegradable Effluent Dump and Biodegradable Waste Production. In the last phase of the model, the Waste Production criterion is considered as the most significant, since it includes the factors which cause the main environmental problems. It is followed by Energy Consumption and Natural Resources Consumption criteria, which record equal values (fig. 5).

	Waste production	Energy consumption	Natural resources consumption
Waste production		3.0	4.0
Energy consumption			3.0
Natural resources consumption			

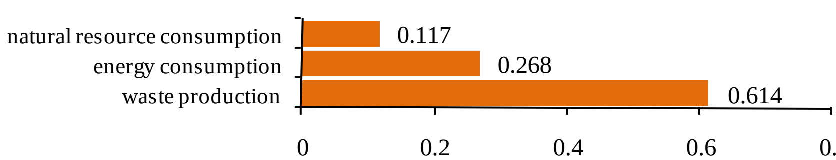

Figure 5. Pairwise Comparison Matrix of the Anthropic Pressure criteria and normalized principal eigenvector of priorities.

ER values have been estimated by utilizing the same ANP method. The ER criterion related to Biodiversity has only one factor and, therefore, does not require a pairwise comparison. The Ecological Cycling And Process Regulation, Bio-productivity and Effluent Absorption criteria show a weighed comparison of their constituting factors. In particular, as regards the Ecological Cycling And Process Regulation criterion, the Carbon Cycle Regulation factor has been considered slightly more significant than the Water Cycle Regulation factor, since the former is strictly tied to the problems of global sustainability. With reference to the Bio-productivity criterion, the Quantity of Biomass Production factor has been considered more important than the Quantity Of Renewable Energy Production factor, since the latter is marginal in comparison with the energy resources used in anthropic activities. Finally, in the case of the Effluent Absorption criterion, the Effluent Absorption factor has been considered secondary in comparison with the Non Climate Change Gas Absorption factor, which is linked to often problematic impacts on human living conditions. In the last phase of the model, the Ecological Cycling And Process Regulation criterion has been considered as the most important, followed by other criteria with equal values (Fig. 6).

	Ecological cycling and process regulation	Biodiversity	Bio productivity	Effluent absorption
Ecological cycling and process regulation		3.0	3.0	3.0
Biodiversity			1.0	1.0
Bio productivity				1.0
Effluent absorption				

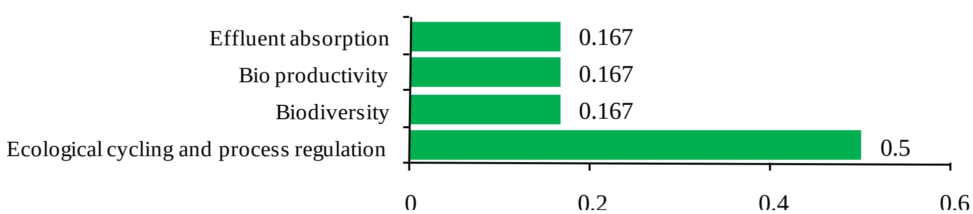

Figure 6. Pairwise Comparison Matrix of the Environmental Regeneration criteria and normalized principal eigenvector of priorities.

<u>ESI assessment</u> After obtaining the eigenvectors of AP and ER matrices, the ESI was calculated through the following passages:

- The multiplication of the land cover areas by the respective AP and ER values;
- ESI calculation, expressed as the ratio of the total equivalent area of regeneration ($VA_{regeneration}$) to the total equivalent area ($VA_{regeneration}$ + $VA_{pressure}$), defined for each land cover class:

$$ESI = {}^{VA_{regeneration}}\!\Big/_{VA_{regeneration}} + VA_{pressure}$$

– The calculation of the ecological stability index (α) obtained, by successive approximations, multiplying the pressure equivalent area of the previous passage by a natural number, until obtaining ER values of the median land cover classes (Extensive Arable Lands and Pastures and Complex Cultivation Patterns) which are as close as possible to 0.5 (situations where regeneration phenomena tend to compensate pressure phenomena);
– Definitive ESI calculation, suitably weighed by the ecological stability index:

$$ESI = {VA_{regeneration}}\Big/{VA_{regeneration} + VA_{pressure} \cdot \alpha}$$

Table 2. Regeneration and Pressure values expressed as equivalent area (ha) and ESI value for each of the land cover classes defined in the model (α = 1.4).

Land cover classes	***Value for land cover***		***ESI***
	VA Regeneration	*VA Pressure*	with α = 1.4
Woods	99738.807	6642.605	0.915
Bush-lands	20241.239	2412.168	0.857
Grasslands	4164.683	541.460	0.846
Agro-forestry areas	1126.295	262.271	0.754
Extensive arable lands and pastures	3756.521	2186.111	0.551
Complex cultivation patterns	42675.047	38243.298	0.444
Intensive arable lands	6598.746	12154.922	0.279
Discontinuous urban fabric	164.830	1168.545	0.092
Continuous urban fabric	659.410	7208.651	0.061
Yards	113.026	1808.410	0.043
Values for the provincial territory	179238.604	72628.442	***0.638***

Application of Sustainable urban expansion model In order to define the possible real expansion direction of the urbanized matrix, the areas that cannot be concerned by new urbanization (already urbanized areas, connection infrastructures and areas with a slope of over 75%), protected areas, industrial and communication poles and, evidently, the areas included in the ecological network have been excluded from the reference territory. The resulting area corresponds to the whole territory that can be subject to urbanization (Poelmans and Van Rompaey, 2010). The cost allocation method has been used to identify the expansion direction of the urban matrix. According to this method, the cells, generated by the already urbanized matrix, tend to expand with a gradient guided by the impedance of the specific territorial components and of the distance cumulated from the area of origin. ESI has been used as impedance factor, so as to give priority to those land uses whose replacement with urban tissue implies a lower differential of AP characters (Table. 2).

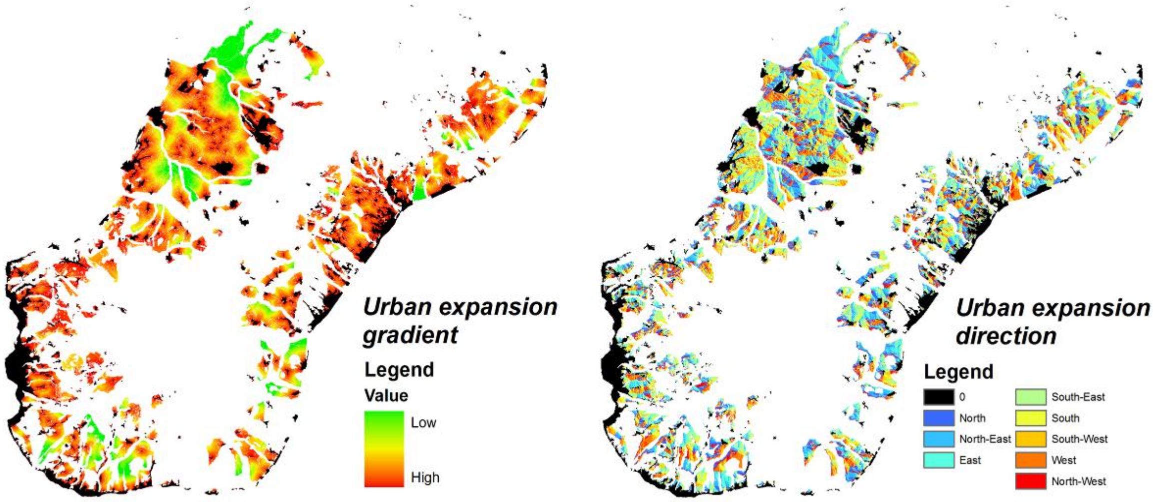

Fig 8. Maps of the urban expansion gradient and of the urban expansion direction.

In particular, besides reclassifying land uses according to ESI, buffers have been generated for the road network and for the ecological network: the former (200 m per side) has been reclassified assigning a value of 0.5, due to the role of the road network as urban attractor; the latter (100 m per side) has been reclassified according to a gradient of environmental disturbance which derives from the anthropized matrix, in order to reduce the disturbance effects on the ecological network. Once these data were integrated, the urbanization area was obtained through overlay mapping procedures, with weighed values depending on attractors and detractors (Li et al., 2010) (Fig. 8). The obtained data show that the network, in its function of planning invariant, is not a static constraint which "freezes" the territory in a certain configuration, but rather a dynamic tool able to guide the interventions on the territory ensuring, at the same time, the priority to keep its bio-ecological functionality.

CONCLUSIONS Of course, ecological networks cannot be considered as a solution tool for environmental problems, yet it has the advantage to exploit the concepts and criteria of conservation in order to further widen the debate about the theme of ordinary planning, where the anthropic and natural data are often analysed separately. Therefore, the ecological network can be a tool of connection between these issues, which reconsiders the concept of network itself, with a view to highlight its character of territorial infrastructure. If, on the one hand, the application of the ecological network is crucial for landscape protection and sustainable planning, on the other hand, it is not sufficient by itself to modify the current trends, though it is included in the ordinary procedures of draft of management plans. As a consequence, it is important to weigh in detail the situations of matching land use with protection of the environmental functionality, by enhancing the resulting potential synergies. Therefore, ecological networks can be an adequate tool to tackle the problem of environmental isolation; to ensure, at the same time, biological functionality and to avoid excessive impacts on the real organization of land uses. It is a system where ecological and physiographic aspects merge, thanks to an interpretation of the concept of ecological network linked to a new and rational landscape planning and management. Such a planning and multidisciplinary approach to the structuring of ecological networks allows: to face the problems the processes of landscape fragmentation and transformation induce on biodiversity and on the ecological processes; to formulate directives and to plan interventions for the solution and mitigation of such processes by following a spatial and dynamic criterion extended to the whole territory concerned.

REFERENCES

Bennett, G. 2004a. Linkages in Practice: a Review of Their Conservation Value. IUCN, Gland (Switzerland) and Cambridge (UK). 28 pp.

Bennett, G. 2004b. Integrating Biodiversity Conservation and Sustainable Use: Lessons Learned From Ecological Networks. IUCN, Gland, Switzerland, and Cambridge, UK.

Fichera C.R., Laudari L., and Modica G. 2009. Ecological networks as a key in sustainable landscape planning to solve landscape fragmentation. XXXIII CIOSTA - CIGR V Conference 2009, Reggio Calabria (Italy).

Magoni, M., and F. Steiner. 2001. The Environment in the Provincial Plan of Cremona, Italy. Environmental Management Vol. 27, No. 5: 639–654.

Marulli, J., and J. M. Mallarach. 2005. A GIS methodology for assessing ecological connectivity application to the Barcelona Metropolitan Area. Landscape and Urban Planning 71 (2005) 243–262.

Saaty T. L. 2005. Theory and Applications of the Analytic Network Process, Pittsburgh, PA : RWS Publications, 4922 Ellsworth Avenue, Pittsburgh, PA 15213.

Saaty T. L. 2008. Relative Measurement and its Generalization in Decision Making: Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors - The Analytic Hierarchy/Network Process". RACSAM (Review of the Royal Spanish Academy of Sciences, Series A, Mathematics) 102 (2): 251–318.

Theobald D.M., Norman J.B., and Sherburne M.R. FunConn v1 User’s Manual: ArcGIS tools for Functional Connectivity Modeling, 2006, Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO.

Treu. M. C., M. Magoni, F. Steiner, and D. Palazzo. 2000. Sustainable landscape planning for Cremona, Italy. Landscape and Urban Planning 47 (2000) 79-98.

Xiao J., Shen Y., Ge J., Tateishi R., Tang C., Liang Y., Huang Z. 2006. Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. Landscape and Urban Planning 75 (1-2): 69-80.

Jat M. K., Garg P.K., Khare D. 2008. Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. International Journal of Applied Earth Observations and Geoinformation 10 (1): 26-43.

Li Y., Zhu X., Sun X., Wang F. 2010. Landscape effects of environmental impact on bay-area wetlands under rapid urban expansion and development policy: A case study of Lianyungang, China. Landscape and Urban Planning 94 (3-4): 218-227.

Poelmans L., and Van Rompaey A. 2010. Complexity and performance of urban expansion models. Computers, Environment and Urban Systems 34 (1):17-27.