Ecosystem services and land use planning. towards a framework to design green infrastructures

Servicios ecosistémicos y planificación del uso del suelo. hacia un marco para diseñar infraestructuras verdes

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Abstract

The raising attention to Ecosystem Services mapping becomes a key element aimed to increase the ecological and economic assessment of planning during decision-making processes. Nonetheless, even if the biophysical assessment of Ecosystem Services reached great results, it remains less explored how to bridge the gap that separates analysis from a project. The land use plan is the product of a long-term interaction between stakeholders and Public Administrations involved in a decision-making process, and often the technological models aimed to visualize the spatial distribution of environmental data do not match the needs of "simple" outputs to reach "complex" solutions. Concerning Ecosystem Services, it has been studied that Green Infrastructures design seems to be a feasible output derived from a highly specialized analytical skill aimed to support territorial projects for land use management. In the paper, a methodology of Green Infrastructure design is proposed, given a spatial distribution of different Ecosystem Services.

Keywords: Ecosystem Services, Land Use Planning, GIS, mapping, Green Infrastructures.

Resumen

La atención creciente al mapeo de los servicios ecosistémicos se convierte en un elemento clave destinado a aumentar la evaluación ecológica y económica de la planificación durante los procesos de toma de decisiones. No obstante, incluso si la evaluación biofísica de los servicios ecosistémicos ha alcanzado grandes resultados, queda menos explorado cómo cerrar la brecha que separa el análisis de un proyecto. El plan de uso de la tierra es el producto de una interacción a largo plazo entre las partes interesadas y las administraciones públicas involucradas en procesos de toma de decisiones; pero a menudo los modelos tecnológicos destinados a visualizar la distribución espacial de los datos ambientales no coinciden con las necesidades de outputs "simples" para llegar a soluciones "complejas". Con respecto a los servicios ecosistémicos, se ha estudiado que el diseño de las infraestructuras verdes parece ser un producto factible derivado de una habilidad analítica

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altamente especializada, dirigida a apoyar proyectos territoriales para la gestión del uso de la tierra. En el artículo se propone una metodología de diseño de infraestructura verde, dada la distribución espacial de los diferentes servicios ecosistémicos.

Palabras claves: servicios ecosistémicos, planificación del uso del suelo, SIG, mapeo, infraestructuras verdes.

Introduction

Recently the attention to Ecosystem Services (ES) mapping has increased (Crossman, Bryan and King, 2013; Kaczorowska, Kain, Kronenberg and Haase, 2016; Lopes, dos Santos, Arede and Baptista, 2015; Pulighe, Fava and Lupia, 2016). ES are the multiple benefits that people obtain from the natural functions of the topsoil/subsoil and their interaction with the atmosphere (Boyd and Banzhaf, 2007; Burkhard, Kroll, Nedkov and Müller, 2012; Fisher, Turner and Morling, 2009). The more such interactions are not compromised by anthropic alteration, the more ES will be delivered naturally and freely to humans conserving the state of the Natural Capital (European Commission, 2011; Maes et al., 2012).

ES are classified into four main categories: supporting services, regulating services, provisioning services and cultural services (Partidario and Gomes, 2013). Many sub-services then compose types and each one of them contributes to providing a healthy and good condition of life for citizens (Mononen et al., 2016; Potschin and Haines-Young, 2013). The anthropocentric consideration of ES approach also considers the financial evaluation of this services, including an estimation of the overall Natural Capital of the environment.

The economic quantification of the ES biophysical values becomes an impacting factor to create awareness among politicians, technicians and administrators on how the land use changes have a broad range of effects on ES (Häyhä and Franzese, 2014; Laurans, Rankovic, Billé, Pirard and Mermet, 2013). The expansion of the anthropic surfaces in natural or agricultural areas (the so-called land take process) is one of the highest threat for ES depletion. But also agricultural practices and other kinds of degrading soil management activities have negative effects on ES: sealing, compaction, salinization, erosion, pollution are, among others, the principal ones (Gardi, Panagos, Van Liedekerke, Bosco and De Brogniez, 2015; Tóth et al., 2013).

Land use planning should consider such threats, and scientific instruments for mapping ES are now available and ready to be used by planners. Many authors have argued on how the integration of ES assessment during the decision-making phases increase the sustainability of planning tools achieving higher environmental standards for citizens (Artmann, 2014, 2015; Hansen et al., 2015; Kaczorowska et al., 2016; Langemeyer et al., 2016).

Notably, it seems that the connection between the academic study of ES and the real process of urban planning increases when Green Infrastructures (GI) are planned as a tool to create a better environment in urban areas, using the available Natural Capital as an "infrastructure" connected by the different ecosystemic functions that green spaces (for different kinds of urban and rural utilization) deliver (Artmann, 2016; Dige, Liquete, Kleeschulte and Banko, 2014; Tzoulas et al., 2007; Young and McPherson, 2013).

Actually, it seems that GI are a powerful tool to fill the gap that separates the theoretical stage of ES assessment and its use with real planning tools. The land use planning process is a complex ongoing activity conditioned by many stakeholder's interests, and often the academic debate is not considering that even if the knowledge of ES mapping is achieved, then the possibility to put into practice such knowledge (e.g. the land use planning process) is poor (Langemeyer et al., 2016). Thus the attention to GI design becomes relevant for practical purposes.

Green infrastructures

GI design is one of the major contemporary issues for urban policies aimed to increase the well-being and the health of citizens. Some case studies show how the development of green infrastructures should achieve a long-term benefit for people because their goal is to connect the ecological values, with the cultural, aesthetic, furtive and anthropic ones (Arcidiacono, Ronchi and Salata, 2016; Bottalico et al., 2016). The multifunctional value of GI is recognized as the possibility to connect into an urban system the parts where ecological characterization of green spaces (supporting ecosystems) are connected to other ES such as the regulative ones (water purification, evapotranspiration, soil erosion, carbon storage), the provisioning ones (crop production or pollination) and the cultural and recreate ones of fruition (Hansen et al., 2015).

The concept of multifunctionality comprehends the ones that overcome the traditional approach of landscape ecology, which is mainly focused on the design of specie-specific corridors aimed to connect the primary or secondary elements of the environmental system. Such approach is still valid when the target of urban and territorial policies is focused on the naturalistic aspect rather than on emphasizing the different functions that soils can play for human's quality of life and their activities (Commission European, 2012; Lovell and Taylor, 2013; Meerow and Newell, 2017).

The multifunctional approach requests the integration of ES into planning with a spatial assessment of each single ES distribution in the territory. In fact, the GI aren't diffused because their design requires an advanced technical, cultural and political background shared among the stakeholders involved in their application (Crossman et al., 2013; Primmer and Furman, 2012).

Assuming this perspective, a new question emerges from the standard application of urban planning and design rules aimed to fix quantitative green and facilities area per-capita. The traditional rules of public facilities distribution and their spatial assessment should be integrated by a broader definition of the concept of services: from public facilities and spaces to a huge consideration of human ES and their benefits.

Some studies emphasize that when land use change effects are accounted in the cost-benefit trade-off linked to urban transformations, the role played by urban ES should be of great impact for the people's awareness of the real Natural Capital (Arcidiacono et al., 2016; Crossman et al., 2009; Duarte, Ribeiro and Paglia, 2016). As an example, the quality of air in urban areas depends from the different configurations of the impermeable and permeable balance of the urban surface. To keep a high permeability in urban areas means to lower (or abate at all) the public medical costs for cardiovascular/pulmonary diseases for older people, rather than the respiratory diseases for young children (Meisner, Gjorgjev and Tozija, 2015; Mercer et al., 2011; Miranda et al., 2015). If such costs are accounted in urban design projects, then the GI becomes a fundamental tool for well-being, reducing the public expenditure of administrations and increasing the environmental heath of citizens.

All the above-mentioned reasons are crucial to increase the level of sustainability of complex urban systems at different levels. In the paper, a methodology to design urban multifunctional green infrastructures will be presented integrating different software: InVEST ver. 3.3.3 (Nelson et al., 2011) for mapping ecosystem services at local scale and ESRI ArcGis ver. 10.3 to overlay the values and generate a statistical analysis of composite values distribution.

Methodology

Mapping the ecosystem services

It is widely recognized that to fill the gap between the theoretical debate on ES and their real application in urban design tools and spatial policies it is necessary to give at planners a geographical distribution of the ES biophysical values in the territory of the survey (Baró et al., 2016; Maes et al., 2012; Naidoo et al., 2008).

Up to now, many techniques to account ES and their value are established, and even if new models are now available to provide a fine assessment and a detailed per pixel representation of specific services, the most common use of ES is still the "statistical application" of an index to a land use category, thus to obtain a final index which represent the ES provision for a particular area of analysis (Clerici, Paracchini and Maes, 2014; Naidoo et al., 2008).

Such approach was altogether valid for a wider assessment, while it seems that at finer scale an index-based approach made of the standard provision of specific ES to a land use category is too weak to support a decision-making phase at the local level. Moreover, it is demonstrated that the context-based interaction between soil, topsoil, subsoil and aboveground vegetation highly influences the provision of ES (particularly the supporting ES and the regulative ES) (Sharps et al., 2017).

Software such as InVEST, AIRES or LUCI supports the mapping activity, and the possibility to include a geographical and site-specific ES evaluation into the planning activity is nowadays possible with good results. Mapping requests a technical skill, a sound knowledge of the models and a huge collection of quantitative and qualitative data; nonetheless, the result of an ES spatial assessment should be of great support for planning multifunctional green infrastructures.

Approaching to an ES assessment requires some preliminary steps that define the kind of analysis, the scientific knowledge, the amount of input data and the timing for calculation and interpretation of the results. Therefore, a straightforward method must be clearly defined to 1) select the kind of ES, 2) prepare all input data, 3) increase the knowledge of model workflows and check the intermediate/final results, 4) have a proper interpretation of maps and, 5) summarize the outputs in a composite indicator.

Regarding point 1, the selection must consider covering at least one service per macro-groups (supporting, regulating, provisioning, cultural), then the selection of raster, vector and statistic input has to match the required indications of the selected software. As an example, the use of InVEST (which is one of the most diffuse and worldwide shared mapping software) is facilitated by the InVEST User's Guide that is a fundamental document for practitioners (Nelson et al., 2011).

Point 3 is a crucial one to deliver point 4. If the user is not aware of how the model works, then the interpretation of results would be complicated, rather than mistaken. Each model uses inputs adopting many modelling equ ations which generate intermediate results that are crucial to re-set the parameters of ES models and to verify the results. In that phase, sensitivity analysis is helpful (intended as the measure of variation of output results related to the changing of input parameters) (van Griensven et al., 2006; Muñoz-Carpena, Zajac and Kuo, 2007; Saltelli, 2016).

Considering as an example the Nutrient Retention, rather than the Sediment Retention of InVEST software, the model generates an intermediate process which tracks the runoff index (which is dependent from the Digital Elevation Model) and subsequently, the model interacts with nutrient loading and absorbing values or the erosion values depending on the land use categories (Jetten, Govers and Hessel, 2003; Merritt, Letcher and Jakeman, 2003; Zhang, Fan, Li and Yi, 2017). This model workflow determines that if the interaction with the DEM is not fair, outputs will be inevitably wrong; which will influence the spatial distribution, the biophysical and economic quantification and the final interpretation of the model results. On the other hand, point 5 will be discussed later in the paper.

From multipart data do a network design

Assuming that by using a mapping ES software the condition to have a biophysical ES assessment is reached. Such assessment covers different ES categories: supporting, regulating, provisioning and cultural groups are represented by the raster distribution of a per-pixel value of many biophysical indicators (e.g., tons per pixel of carbon stored in the soil, mm of water filtered per pixel, kg of nutrient removed from streams by runoff per pixel etc.).

Once the maps are prepared and analysed, the distribution of different biophysical values should remain something separated and difficult to explain during a decision-making approach for land use planning. A synthetic representation and approach that keeps the various ES values is required to visualize better the trade-off among different ES maps. Consequently, an indicator that quickly shows areas were different ES are delivered with an overall high value and vice versa is fundamental (Alam, Dupras and Messier, 2016; Salata and Gardi, 2015). Hereafter, some methodological suggestions should be tested and applied to simplify an ES mapping assessment and outline an ES high-value network that supports the construction of GI.

Weighted overlay tool

The proper ArcGis function to obtain a single raster distribution of different ES maps is the weighted overlay tool which sums the values of various raster maps, multiplying each layer for a hand settled weight score. The score can be any positive or negative decimal value. Thus if the mapping output of the single ES is a raster value representation, the map should be directly used by the user to overlay the values into a single composite value map.

This allows the user to normalize the different biophysical values obtaining a final raster map where each pixel range from 0 to 1 with floating values. The output of the weighted overlay function is a fundamental preliminary step because it allows the user to have an initial distribution of ES value over the study area and directly understand where the planned land use change should have a higher impact on the overall ES distribution.

Having an overlay sum of all the raster input will simplify the data visualization but will present several limitations: 1) the original biophysics absolute value of the single ES delivered is lost, which is, from an environmental perspective, an accurate information; 2) weighted overlay does not emphasize which ES, among the ones considered in the analysis, leads the overall score; thus a single comparison between alternative ES scenario analysis cannot be reached; 3) the output of a single composite indicator cannot help spatial policies aimed to maximize a particular ES. As an example, if the local plan is oriented to maximize the quality of air, then the proxy indicator must be the single ES that represents such value (e.g. carbon sequestration), considering its variation due to land use alternative as the only indicator to monitor the policy goal.

Hotspot analysis

Once a user reaches a distribution of a composite ES indicator in the study area, it should be helpful to clearly visualize where the ES assessment generates a concentration of high or low values, to obtain a map easy to understand.

In that case, the Hot Spot analysis creates a spatial distribution of statistically significant values in the territory using the Getis-Ord Gi* statistic. Hotspots and coldspots are important spatial clusters of high value concentrations (hot spots) and low value (cold spots). Using an overlaid map of ES generated by the sum of different ES inputs (as previously mentioned) the ArcGis function will automatically switch on the parts where 'multifunctionality' is significant (red color) making possible to directly identify the areas where the concentration of the overall ES value is high or not: a certain number of pixel clusters delivers a high or of a low multi-functional value. The map distinguishes the significant values (higher or lower) while putting in the "insignificant" class all the other values.

Looking at the output of this map should be of great impact because once the areas with high value are represented, a planning orientation must be taken: it can be decided to maintain the higher values and adopt a spatial policy to support an increase of ecosystemic condition of areas with 'insignificant' value or, at least, to work hard on low value concentrations with de-sealing or land reclaim policies.

Therefore, such function is of great help for planning purposes because it is selective (not all unbuilt areas delivers a multisystem value) and it is evident (the software emphasize only concentrations of significant values leaving in the background the others).

Aggregate polygons

Once the ES composite values are statistically grouped and a user is working in the visualization of the biophysical spatial distribution, some ArcGis tools can better visualizing the selection of attributes to isolate higher value and generate an ES network expected to define areas were multifunctional ES are delivered.

The simplest way to obtain a multifunctional network from a Hotspot analysis is to operate a selection by the attribute function that is aimed at select areas where ES value is statistically high. It could be decided in the selection whether to select areas with higher values or to include also areas of "insignificant" value to obtain a wider range.

The aggregate polygons function is a suitable tool for generating an output that matches together different fragmented patches into ones with a continuous geometry to reduce the total number of the polygon in the shape file. Considering the use of Hotspot analysis as an output that can be used to select attributes above a threshold of significance (hotspot clusters), the aggregate polygons function operates in the way of polygonal de-fragmentation obtaining a continuous geometry where a high multisystem value is guaranteed.

Such operations are merely a geometrical refinement of the hotspot analysis and are aimed at creating a continuity in the definition of a structured geometrical shape that should be considered as a benchmark for a GI definition.

Results

The ArcGis functions mentioned above are the ones that, over the last years of experimentation in the utilization on InVEST mapping for land use planning purposes, guarantee that the output generated from ES mapping is summarized and used to design the framework for a green multifunctional infrastructure, which differs from the traditional ecological network. This does not mean that other functions are not helpful, rather than other methodologies are not efficient or straightforward, but it represents an easy way to keep the analytical background into the procedure to design a planning tool.

As a methodological paper, here is reported a way that should be adapted by site-specific condition, using the most appropriate ES, and with the need that each Public Administration precedes the decision-making process. Nevertheless, the transformation of a multi-part layer analysis into single-part ones is a straightforward method to simplify the way ES are analysed for planning purposes and it seems to reach high success concerning the representation and comprehension factors.

ES are often represented with in-depth analytical maps difficult to interpret and sometimes the utilization into the planning process is complicated rather than counterintuitive. The aim of this methodological paper is to present a simpler way to transform an analytical ES package into an easy-to-understood map of multisystemic value.

This approach has several limitations inevitably. At first, the representation of a multisystemic map of ES is not coincident with a GI. GI is a normative infrastructure that requires a geometrical design definition constructed using a great discretional interpretation: an in-depth knowledge of the planning rules and the land use regulation that often does not match with ES values. Undeniably, one of the failures that affect GI design is the underestimation of the building rights that generate the real estate condition of land uses, while the real estate properties is a key element to designing GI. In fact, GI design should take into account ES values, but also the potential disvalues generated by the planned transformations or areas where the anthropic system threatens the environmental landscape: in those areas, GI should be designed to plan ecological compensation or restoration measures (Pistocchi, Calzolari, Malucelli and Ungaro, 2015; Salata, 2014).

Secondly, this approach does not consider that ES should have different percentage weight in their utilization. In this methodology, a "normalization" process has been suggested assuming that all ES are evaluated with the same percentage weight. Nevertheless, in most cases, this assumption is neglected, and many ES are grouped or differently weighted according to the purpose of the specific assessment or research (Crossman et al., 2009; Meerow and Newell, 2017).

Conclusion

ES assessment seems to increase its direct utilization for land use planning purposes. Nonetheless, it remains difficult to find standard methodologies to define how the spatial distribution of many biophysical values are used to define a land use plan.

The fact that ES are nowadays a key issue in the debate around the environmental sustainability does not imply that the scientific knowledge related to mapping activity is used in the real planning process. Too often, ES remains as an academic exercise to demonstrate that the frontier of the environmental assessment associated with land use plan is supported by new empirical, technological and methodological analysis.

However, as the ES approach is considered relevant and crucial to obtain benefits for citizens, it is necessary to share a discussion on how the mapping activity can be used to define areas where environmental and planning mitigation or compensation should be selected by the local land use plan. Assuming this perspective, the paper tries to emphasize what kind of GIS functions are directly suitable to shift from an ES assessment to a GI framework design. The selected functions are just representative of some simple operations that are helpful to comprehend the spatial distribution of many ES values better. The aim of the brief methodology is to achieve an advancement of research which keeps an eye to the effective utilization of ES into planning tools instead of debating on their theoretical development.

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