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ID 1550 | MODELING ECOLOGICAL NETWORKS AND LAND VALUE FOR THE PRIORITIZATION OF NATURAL AREAS CONSERVATION

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1 INTRODUCTION

The strategy promoting Green Infrastructure (GI) from European institutions (2013) considers the spatial structuration of (semi) natural areas as a network and resulting environmental features impacting populations. The strength of the GI's approach lies in the effort to integrate the ecological and social values of natural areas in combination with other land development (Lafortezza et al. 2013): this strategy encourage an integrated approach of space planning at different scales and promote the multiple services associated with natural areas. From a conservation biologist perspective, it is not a new idea, since it is based on environmental continuity, ecological networks and landscape connectivity. Yet, considering natural landscape as a network that offers a structural frame for the development of the biodiversity of tomorrow (and secure some ESS for our societies) forces to rethink our spatial planning approaches.

Landscapes are seen in this paper as a dynamic and structured spaces with a social dimension where management and planning play a key role. Physically, landscapes are composed of artificialized components (Grey infrastructure) and natural components (Green infrastructures) in interaction.

In France, planning process is historically a top-down process based on technical and professional expertise. After several decades of planning at national scale, French government tends to give more decisional power to regional and local scales (i.e., decentralization). Multiple guidance documents of soft planning such as SCOT (Schéma de Cohérence Territoriale/ territorial coherence program), present a mix between national, regional strategies and the translation of European directives about environment and socio-economy. Town planning regulations are now framed by this soft planning, but local collectivities still have to adapt it, dealing with all the contextual and operational components. Their task is to spatially, legally and institutionally define and regulate urbanistic rules at the finest scale (hard planning; Purkarthofer, 2016). Moreover, the planning process is gently opening to democratic participation with mitigate successes. We will focus on a problem coming from the difficulties to take account of the different values of natural areas. These values correspond to different estimations of natural areas in ecological or socio-economical terms.

Findings some tools that could shed light on the importance of the identified stakes are requested, especially in urban areas with high levels of artificialization and under sprawl dynamic. Several tools have already been developed to assess values of natural areas or values of landscapes but they are poorly transferred together to operational field because of their focus on a single value. From conservation biology field, Beier et al. (2011) made a first step to a better cohesion between planning institutions and spatial sciences, highlighting the main technical and organizational points that have to be monitored in order to build a coherent connectivity map at regional scale. But more than a protocol to build a common tool, a common framework between sciences and planning is lacking to take account of all kind of values associated with natural areas.

The awareness of these different values can be seen through the spread of environment concept (70's), biodiversity concept (90's and 2016) and ecosystem services (ESS) concept (70's and reborn in 2005). Santolini et al. (2016) highlight that “The ESS framework could [also] be a useful interface between science and decision-making”. Mobilizing ESS concepts, GI's approach could be the needed hall where science and operational planning meet again. A framework, based on both scientific knowledge and “good practices”, that is claiming to consider the different values of nature at any scales of planning. In urban contexts such as metropolitan areas, GI's approach encourages the participation of new stakeholders to the decision making process. It can also lead to be construed as a guidance to limit urban sprawl and promote urban regeneration.

If in one hand the planning processes become more complex, with more stakes to deal with, in another hand it's aiming to a better integration of the social, economic and environmental components in space. It is slowly shifting from a discontinuous process approach to a continuous one. As a consequence, this context brings scientists to work on several questions about the value of natural attributes as a (dis)service set and about the value of landscapes.

This fresh started Phd project aims first to discuss about technical and methodological contributions identified as useful to clarify some central stakes into future planning and decision making. Our research object deals with the valuation of natural areas through two different prisms: ecology and socio-economic. The main research question of the project can be stated as:

How can the values of (semi-)natural areas be captured, discussed and prioritized into the planning process?

Our final objective is to propose a method allowing decision makers to perceive and assess different values of natural areas. Yet, a part of this research work also aims to understand the relations between the different values associated with natural areas. Our study case will take place in the Grenoble-Alpes Metropole area, a region in France with several degrees of urbanity and a large panel of natural characteristics.

The first section of this paper presents how ecologists assess the ecological value of a landscape through the analyze of an ecological network with connectivity measures. The second section presents econometric methods to capture socio-economical values of a landscape and a method to capture people perceptions of natural attributes in their environment. The last section presents briefly the working prospects of this Phd project.

2 ECOLOGICAL NETWORKS AND LANDSCAPE CONNECTIVITY

Ecological networks aim at reconnecting fragmented natural areas in landscapes, with different degrees of urbanization. As landscapes are dynamic objects, connectivity is not stable over time. In the following paragraph, we will give a brief definition of landscape connectivity, introduce some modeling approaches and give an outlook of the proposed methods to build our ecological network.

2.1 WHAT IS LANDSCAPE CONNECTIVITY?

Connectivity is the extent to which movements of genes, propagules (pollen and seeds), individuals, and populations are facilitated by the structure and composition of the landscape (Rudnick et al. 2012). It depends both on the distribution of particular habitats in space, on the permeability of the matrix (non-habitats) which is composed of habitats non-suited for a species and on the presence on barriers like cliff, highways, high-speed railway lines or rivers which often are linear object. Assessing connectivity is a species centered approach (Pearson et al., 1996), based on the requirements for species to survive at the population level.

Connectivity can be split in two main components:

i. Functional connectivity (or realized connectivity) describing the states of genes, individuals or populations flows in the landscape. Ecological surveys and monitoring can be deployed to capture this functional connectivity for some species.
ii. Structural connectivity describing the physical landscape: topography, hydrology, type, size and organization of habitats. In conservation planning, the "continuum concept" is mobilized to build ecological corridors between two focal conservation areas. This concept aims to physically link the same types of habitat and is a perfect example of structural connectivity.

These two components are linked, but a "good" structural connectivity does not induce a "good" functional connectivity (Taylor, 2006), whether for the target species or for the others species sharing the same habitat. Some physically disconnected habitat can also present a good functional connectivity for some flying species, like birds, or species with high dispersal capabilities.

When data about the distribution and the realized movements within and between populations is scarce or missing, the structural approach can be a first step to integrate the management of natural areas in decision making (Urban and Keitt, 2001). A potential tool to theoretically assess connectivity is graph theory, which can be defined as an idealized representation of networks pattern (Dragicevic and Sinclair, 2013). This method has been widely mobilized to implement ecological corridors in landscapes. The "Trame Verte et Bleue" program in France is based on graph theory, serving as a high level vision of landscape connectivity in urbanism documents. To go beyond the limits of structural connectivity, in a « learning by doing » process (Kato and Ahern, 2008) and improved by consecutive steps of adaptative planning, Functional connectivity can be assessed by monitoring the distribution and dynamics of species populations.

An alternative to the adaptive planning is to improve modeling of the functional connectivity of ecological networks: the structural networks are enhanced with ecological data related to one or several species. We chose to mobilize this approach also called potential connectivity by conservation professionals.

2.2 MODELLING APPROACH AND METRICS

There are several ways to model the landscape connectivity and most of them use GIS software in order to spatialize the data. Spatial patterns indices, nearest neighbor distance, buffer radius or graph theory are used to evaluate potential connectivity (Calabrese and Fagan, 2004). The strengths of graph theory approach in modeling connectivity are highlighted by Rayfield et al., (2011):

i. The possibility to characterize connectivity at large scales with many habitat patches
ii. The ability to balance data requirements with information content
iii. The possibility to incorporate ecological data, like species biology requirements or dispersal capabilities to build the graph

In other words, by adding the modeling of species-specific dispersal in the graph building, we can assess a potential connectivity of landscape.

To build our ecological network, we chose to mobilize the Graph theory. In this method, we consider habitat patches (nodes) are considered to provide all environmental and natural resources that a focal species needs to realize their entire cycle of life. Those nodes are connected by potentials corridors (edges) which are generated between habitat patches.

In a first step, habitats for individual species are identified at a chosen time. We will mobilize minimum habitat area and habitat quality data for every species in order to identify the potential nodes. In a second step, the species median dispersal distance will be approximated via trait based predictions (Whitmee and Orme, 2013; Mimet et al., 2016). These predictions only exist for terrestrial mammals on which our model will focus. To build the edges of our graph, we selected two main methods which are based on dispersal species-specific distance and on a simplified landscape grid, usually built from land use and/or land cover maps, crossed with topographic models. Each cell has a resistance to movement value, or a probability of dispersion to an adjacent cell.

i. The multiple least-cost paths method is based on the idea that a species will use the shortest way between two habitats in terms of movement costs. This approach is based on species dispersal distance, its capacities to perceive environment and on the landscape resistance to movement. Least-cost method can be used to delineate corridors in more or less elaborate ways for every focal species identified as pertinent at a given scale.

ii. The circuit theory method supposes a more random walk of individuals in the landscape (probability to disperse from a cell to another in the landscape grid). If it can help to delineate corridors spatially, its main strength is that this method allows us to build current density maps with multiple pathways between habitats patches and inform us about existing dispersal bottlenecks in an identified corridor or in the landscape. This method was proven effective for gene flows (Mc Rae and Beier, 2007). Those bottlenecks are labeled of high priority in order to keep or enhance connectivity for a given species.

Beyond the difficulties to select connectivity metrics, building permeability or the resistance grid is the critical part of the modeling. The resistance value of each cell is a proxy of the real crossing cost for a particular species. Moreover, as it is difficult to assess the pertinence of a resistance value through a component of the landscape for a given species, the values are generally “expert estimates” or extrapolated from field survey (e.g. GPS tracking).

However, it is fundamental to understand the limitation of modeling and metrics used in order to assess connectivity (Kindlmann and Burel, 2008). These connectivity metrics depend on the focal species, landscape/time scales, and spatial neighborhood. Pascual-Hortal and Saura (2006) proposed to test simple metrics under scales and landscape complexity changes. The most common way to assess landscape connectivity is to use a set of different metrics, informing us on element, component and network scales (Rayfield et al. 2016).

All those methods are currently used mostly for a single species and can be mobilized for operational work on fine scale. The choice to work with some focal species and not others seems to be a strong bias to legitimate a corridor planning to preserve biodiversity at large scale.

2.3 MULTISPECIES APPROACH

Optimally, we have to take into account every species present in a landscape. Currently, multispecies approaches are still in development. We present here some approach to deal with this issue.

A common way to take account of several species is to build several species-specific networks. Poodat (2013) suggests to represent the connectivity outcomes seen as different alternatives, then to let the decision makers to fix planning prioritization choices.

In a case of a located arrangement, like a structure to cross a highway, Mimet et al. (2016) propose to mobilize multivariate representations and to choose the location that can concern the most of the species. As an alternative, some authors propose to create some cluster of species with the same ecological characteristics (dispersal capabilities, preferred habitat types kind and minimum habitat area) in order to build virtual model species. This approach by cluster can also work at broad scales as demonstrated by Correa Ayram et al. (2017) who have built three virtual species from forest areas in order to obtain three scales of landscape connectivity The last way is to build a multispecies ecological network is to study the connectivity of an umbrella species habitat. Theoretically, an umbrella species is supposed to live in an ecological network overlaying several others species specifics networks. Yet this approach has encountered many critics from operational fields: professionals highlighting a problem of network viability as the optimum habitat quality cannot be the same for a lot of species due to resources and niches competition.

2.4 RESEARCH OUTLOOK

In this first part, we presented several approaches used to build ecological networks in conservation planning. From a planning perspective, a linear corridor identified at regional scale, either by habitat continuum or by least-cost paths method can be stated at local scale by mobilizing circuit theory approach. If the data is accurate enough and mobilizing graph theory approach (Crombette, 2016), urban corridors can be designed in highly artificialized areas, in order to enhance ordinary biodiversity. To fulfill this purpose, it does not always require connecting two or more natural spaces nodes. A current density map based on several species characteristics could give us an estimation of the importance of an area in terms of connectivity. At last, this current density map could inform us on some areas with high medium or low value of connectivity, opening preferably some areas to urbanization for conservation purpose.

These methods offer some ways to preserve biodiversity by taking account of the different flows present in (semi)natural landscapes. Yet this ecological valuation of natural areas only represents a dimension of the landscapes value and brings some more questions in a planning perspective. Decision makers also need to take account of other parts of natural landscapes value, through different valuation methods in order to answer questions.

Do the areas of high connectivity value match with high socio-economical values of natural landscape perceived by people? Locating and detecting potential conflictual areas between ecological and socio-economical stakes looks like a prerequisite to state a consistent development strategy. We will present the methods we chose to capture the socio-economical values of natural landscape in the next part.

3 PERCEIVED NATURAL AMENITIES

The fragmentation of landscape has ecological impacts, but has also direct and indirect impacts on society. People can set a positive or negative value of some landscape's attribute depending on their perception of the environment, their personal sensitivity and practices.

In economy, two kind of approach coexist to evaluate the implicit prices of the landscape attributes. The first one is based on revealed preferences from the market condition (e.g. hedonic pricing method), every comportments that can be observed from real market of a good or service. The second one is based on stated preference (e.g. contingent valuation method). Both approaches are well described in literature, but hedonic pricing method offers us two advantages. First, this method is spatially explicit, and can be integrated under GIS software. Second, some reference close to our case study on periurban landscapes are already available (Cavailhes et al., 2007). We plan to mobilize this method in order to capture the impact of natural amenities on property prices or rents.

3.1 NATURAL AMENITIES AND HEDONIC PRICING

Hedonic pricing (Rosen, 1974) is an econometric method based on revealed preference theory. It is built in order to analyze people' choice from empirical data. Applied to real estate field, this method supposes that a (real or rental) property is a composite good divisible into a set of characteristics but sold as one. Those characteristics co-determine the property price and can be embedded (dwelling area, age of housing, etc.) or extrinsic, like neighborhood factors spatially localized (commuting costs, accessibility or proximity to amenities or services).

An amenity is originally an economical term used to describe a non-produced public good that have no explicit price. The presence of characteristic set of amenities (e.g. proximity and accessibility to schools, health services, urban parks, natural areas, etc.) can attract some people whose work may not be the main purpose to select a location (Chen et al., 2008). It can be identified as a driver of development at regional (Ullman, 1954) or city scale (Clark et al. 2002). Natural amenities are more specific and can be define as"[…] elements of the environment (e.g., climate, water bodies, coastlines, mountains, and forests) that attract people" (Kovacs et al., 2017). We will adopt a more generalist definition proposed by Schaeffer and Dissart (personal communication): A natural amenity for a group of people or firms is a (bundle of) place-based biophysical attribute(s) that generate(s) localized benefits valued by most members of this group.

Amenities are heterogeneously distributed in the landscape and scarce in a given context: lakes or trees in highly artificialized areas, health services in rural areas etc. The literature on natural amenities does not show a clear result between natural characteristics of landscape and property price (Brossard et al., 2011): it is all context and data dependent. Moreover, impacts from a bundle of natural amenities on property prices can be constant, or depend on distances between amenities and property location. These inconsistent results could be explained by the quality of environmental data used in modeling process. Natural areas of landscapes are mostly simplified into ground cover layers, without taking account of the use of spaces. Brossard et al. (Ibid.) proposed to cross ground cover data with the legal status of plots to overcome this issue. It is an approach that may offer a representation closer to the real accessibility to some areas. It could also bring a better estimation of "futures ground cover changes" (e.g. private woods/farmland that could be opened or closed to urbanization. Inconsistent results could also come from a spatial modeling issue as the study area extent can also capture several effects that an amenity can have on real estate market at different scales. We will see in next part how to go beyond this limit.

3.2 MODELLING ISSUES

In practice, a spatial regression model is built in order to explain the price of the property, or the rent (explained variable), by a set of characteristics (explanatory variables). Assuming the market is in equilibrium, we can estimate the marginal price of a characteristic impacting the property price, referred as the willingness to pay of the good' owner. The selection of the characteristics is a critical issue for the interpretation of the model and exposes it to critics. In order to build the model, two approaches can be mobilized: a machine learning approach where characteristics are selected from empirical data or an approach by choice where characteristics are selected on the base of their importance in case context, or in the literature. To sum it up, the categories of explanatory variables mainly used in hedonic pricing literature are structural variables (e.g. dwelling area, number of rooms, parcel size …), neighborhood variable (e.g. income, travel time to work, distance to road/railroad/golf course …) and natural amenities from open spaces (e.g. distance to nearest forest/park, forest density, shape of the patch…).

In order to get a robust estimate of the marginal price of a characteristic, it is essential to reduce all kind of correlation (spatial and a-spatial) between the variables of the model. Yet, some limits of statistical analysis of spatial data reside in the difficulties to get rid of it, even if some methods allow us to go through these issues

In one hand, endogeneity between variables can create interpretation biases and inconsistency of coefficients. It is the case when two or more characteristic can be explained by another one omitted in the regression, or by a characteristic that we can't capture. E.g., the neighborhood prestige can be hard to measure by itself, but it plays a major role into real estate market through a "between us" effect. The price of property depends on the location of amenity and inversely, so it is not possible to compartmentalize the pure effect of each variable. Endogeneity can also be observed through the correlation between a characteristic and the error term of the model. A way to take account of heterogeneity consists in using instrumental variables correlated to endogenous characteristics and independent to model residuals.

In another hand, the spatial dimension of the model bring a spatial correlation issue that we have to take into account, otherwise the regression coefficients are biased and cannot be mobilized to estimate a marginal price (Le Gallo, 2002). Spatial autocorrelation is based on the first law in geography: "Everything is related to everything else, but closer things more so" (Tobler, 1970). To detect the spatial structure of the data, we have to analyse if a characteristic is randomly distributed in space, or clustered (high values in a contiguous area, low values in another) or "chess like distributed" (high values area surrounded by low values area and inversely).

Several spatial models already exist and are exposed and discussed in Gelfand et al. (2010) or Anselin et al. (2013). Yet, according to these issues, the data "quality" have to be tested in order to select which spatial models can be applied (Anselin, 2002) to calculate consistent marginal prices. To sum it up, the hedonic pricing approach can help us to capture a monetary value of natural amenities through real estate prices. But several technical and data related complications can lead to misinterpret the results.

3.3 LOCAL KNOWLEDGE

Even if we can identify which natural amenities are preferred through a will to pay to benefit from it, we are far to be able to capture the resident local knowledge of the environment. Human and social sciences developed several methods to capture it, but results are usually hard to capture, qualitative, vague, and hard to incorporate in planning processes (Rentanen and Kahila, 2009). Still this local knowledge has been identified as fundamental to build and legitimate a planning decision in the eyes of the public (Douglass and Friedmann, 1998). We did not delve enough to present different approaches to capture local knowledge, we will focus on a single concept that could be mobilized in our study.

The concept of Public participation GIS (PPGIS) could be an approach mobilizing people through a map-based participation tools permitting to capture the local knowledge of environment and the value of landscape for people. This map could be overlaid and compared with results from ecological and econometric models. This PPGIS concept has been criticized because of the complexity of GIS interaction, unable to mobilize non expert people and thus far from people experiences of environment exhaustiveness (Poplin, 2012). But development of user friendly SIG tools and open source technologies allow more and more people to express their perceptions and their value.

Methods like softGIS developed in Aalto University (Finland) take account of the needs of planners in operationalizing terms (Rantanen and Kahila, 2009; Kyttä et al., 2013): testing the representativeness of the people answering to a survey program, feeding back the users on the results, questioning the complementarity between technical and local knowledge and thus their weight in decisional process etc. Data from local knowledges captured via a softGIS approach could even be incorporated in hedonic pricing approach (Czembrowski et al. 2016). In this last approach, the local knowledge is used in order to improve the quality of environmental data mobilized in the hedonic pricing model.

Yet, in order to capture a 'social' value of landscape from residents perceptions, several other approaches have still to be considered.

4 WORKING PROSPECTS

At a later stage, the doctoral work will focus on the discussion about convergences and contradictions between the selected values associated with natural areas (cf. section 2 and 3.). Both a force and a limit of our project is to propose methods spatially-explicit methods. The interest of spacialization is to offer a medium support between different kinds of values (ecological, economic or social) and a critic of this approach is that non spacialized values are not taken into account.

Our final goal aims to discuss and propose technical advices in spatial specific contexts to shed light on the prioritization choice of a value over another under urbanization pressure and sprawling process. Some prioritization tools have been jointly developed between scientists and planning actors and can take a lot of forms. We already identified two kinds of tools that can be used in order to shed light on prioritization of land use for nature conservation, both based on GIS approach. Moilanen et al. (2005) have developed the Zonation software, a tool based on a weighted prioritization process. Strength of the weighted approach is to propose a prioritization but a drawback of this approach is a lack of local flexibility since this weight is based on a global choice of prioritization. Another way to support decision is to mobilize GIS-Based Multiple-Criteria Decision Analysis, a modeling process often considered as a complex black box by decision-makers (Greene et al., 2011). Consequently, those tools do not challenge the discussion prior to decisional process and thus are not widely mobilized. Ultimately, the researcher can inform and supplement the planning process, mobilizing and crossing different methods and technique, but also have to bring support tools that can be mobilized. The choice to use it does not only depend on the tools accuracy, but also of their acceptability by decision makers.

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