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Methodologies for integrated studies of natural resources: a discussion on ecological-economic zoning

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Abstract - This article examines methodological developments in integrated zoning, which are used in the environmental planning and land use in Brazil. In particular, it focuses on Ecological-Economic Zoning (EEZ), a methodology that has become the primary instrument of territorial planning in the Brazilian government. Throughout its historical development process, EEZ has become an interdisciplinary zoning method, which incorporates various environmental and socio-economic themes. However, there are still several central issues in constant discussion and many challenges to be resolved. Various sides of this discussion are analyzed, and new methodologies are suggested from other research areas, which may contribute to the efficiency of integrated environmental studies.
Keywords: ecological-economic zoning, territorial planning, natural resources, environment, interdisciplinary studies.

Resumo - Metodologias para estudos integrados de recursos naturais: uma discussão a partir do zoneamento ecológico-econômico. Este artigo adentra-se no debate sobre as evoluções metodológicas dos zoneamentos integrados constantes nos instrumentos de planejamento ambiental e de ordenamento territorial do Brasil. Em especial, enfoca o debate promovido em torno da metodologia do Zoneamento Ecológico-Econômico – ZEE - brasileiro, instrumento basilar de planejamento territorial do país. Ao longo de seu processo histórico de desenvolvimento, o ZEE tornou-se um zoneamento amplo, que incorpora diversas temáticas ambientais e sócio-econômicas. Contudo, ainda existem diversos pontos nevrálgicos em constante discussão, bem como vários desafios a serem vencidos. O artigo pretende cobrir várias facetas desse debate, além de sugerir novas metodologias provenientes de outras áreas de estudo, e que podem contribuir para que os estudos integrados de meio ambiente tornem-se cada vez mais eficientes.
Palavras-chave: zoneamento ecológico-econômico, planejamento territorial, recursos naturais, meio ambiente, estudos interdisciplinares.

1 Introduction

1.1 Definition and objectives of the ecological-economic zoning

Ecological-Economic Zoning (EEZ) can be defined, within an academic context, as the area of knowledge responsible for the investigation and representation of the relationships among the territorial ecological and economic features using the possibilities of modern cartography. In Brasil, Article 2 of Federal Decree 4.297, from the year 2002, defines the concepts and objectives for Ecological-Economic Zoning among the set of instruments for environmental management as follows: Art. 2 - EEZ is the mandatory territorial organization instrument for plans, works, public and private activities. It sets forth measures and standards for environmental protection intended to ensure the quality of environment, soil and water natural resources while preserving biodiversity, ensuring sustainable development and the improvement of population's living standards (Brasil, 2002, Federal Decree 4.297/2002, Chap. 1).

1.2 Outlining the history of EEZ and the past and current studies on Economic and Ecological Zoning in Brazil

The first EEZ concept was carried out by the Strategic Affairs Office (SAE) of the Presidency of the Republic, which had also outlined the first guidelines and EEZ's methodologies. In 1988, the government issued its orientation on Ecological-Economic Zoning (EEZ) for the entire country as set forth by Federal Decrees 99.193/90 and 99.540/90 (Fabré & Ribeiro, 2007: p.

62; Marques & Serfaty-Marques, 2007: p. 73-74).

The Ecological-Economic Zoning is largely historically tied to public agencies for planning and implementation of economic development and environmental protection policies. As a result, most of the literature on strategic and methodological development was produced through meetings (called workshops) involving representatives of the executive and academic environments, whose debates were later published. Unfortunately, the quotation standards do not explicitly cover how the public debates are referenced or cited. We consider that it might be suitable, when making reference to these debates, to mention not only the government level involved, but also the author of the speech and his/her respective agency. Such data are deemed essential to make the reader able to relate properly the statements with their source and context.

At a later date, a partnership was established with the *Laboratório de Gestão do Território* – LAGET (Territorial Management Lab - Federal University of Rio de Janeiro) aiming at methodological developments which gave rise to the work of Becker & Egler (1997). Thereafter, INPE (The National Institute for Aerospace Research) was also involved in an official cooperation for the methodological development of EEZ (Brasil, 2001: p. 423, speech of Tereza Cardoso), originating the study of Crepani *et al*. (1996). According to Marques & Serfaty-Marques (2007: p. 80), the recommendations of this official methodology did not properly include themes such as the biological and physical-chemical quality of the aquatic systems, underground aquifers, ecosystems (including fauna and flora) and the anthropic study regarding social aspects. After 1999, how to approach such themes in an EEZ became a recurrent theme in several discussion forums (Marques & Serfaty-Marques, 2007: p. 80).

INPE was one of the pioneer teams to implement Integrated Zoning, beginning in 1992, thereby setting the basis for further increments to the EEZ methodology. The work of Crepani *et al.* (2001) summarizes the level of difficulty reached by the integrated approach. However, as noted by Thelma Krug, from INPE, in Brasil (2001: p. 31), improving the effect of socio-economic factors on the EEZ maps was still necessary.

During the 1990s, the Brazilian Geological Survey - CPRM (Marques & Serfaty-Marques, 2007) and the Brazilian Agricultural Research Corporation – Embrapa, also established specialized research groups on homogeneous zoning, which eventually would contribute significantly to EEZ discussions.

Despite the methodological advances, Araújo (2006: p. 68-69) makes a rather negative evaluation of the implementation of EEZ's during the 1990s: (1) Several regional divided and dispersed EEZ's were generated during these ten years. Since different methodologies were used, it was not possible to obtain a clear understanding of the national reality; (2) there was not any zoning on a scale compatible with the needs of the federal government, and only two macro-diagnoses were made, one referring to the Legal Amazon area and one to the Coastal Zone; (3) on a scale equal to or greater than 1:250,000, the EEZ encompassed only 11% of the country territory.

The above criticisms raised by Araújo (2006) have shown how EEZ's building up process conflicted with Antônio Theodorovics' proposed guidelines (Brasil, 2001: p. 234), in that regional planning should precede sector planning. A less detailed scale of an EEZ encompassing Brazil would be valuable to provide an overview of handling the most pressing issue strategies for sectorized EEZ's.

Therefore, we can present the following summary of EEZ landmarks in the 1990's:

- 1988: 'Our Nature Program' recommends EEZ for the whole country;
- 1990: A workgroup is created to oversee EEZ performance (Federal Decree 99.193/90) ;
- Establishment of EEZ – CCEEZ's coordination committee (Federal Decree 99.540/90);
- 1991: Establishment of the Ecological-Economic Zoning in the Legal Amazon area (EEZ) – PEEZAL;
- 1992: Consolidation of GERCO - Brazilian Coastal Management zoning methodology;
- 1994: Zoning start-up in Alto Paraguay, Mato Grosso and Rondônia hydrographic basins;
- 1996: The SAE-PR/MMA/LAGET-UFRJ (The Secretariat of Strategic Affairs of the Paraná State / MMA – Ministry of the Environment / *Laboratório de Gestão do Território* – LAGET - Federal University of Rio de Janeiro) methodology applied in the Legal Amazon area.

After the Strategic Affairs Office of the Presidency - SAE-PR was closed down in 1999, EEZ's program responsibility was transferred to the Ministry of Environment – MMA. In 2001, the Ministry of Environment conducted a series of workshops for each region, in order to discuss methodological issues related to Ecological-Economical Zoning (Brasil, 2007a: p. 225). At the end of this sequence of events, a comprehensive evaluation meeting was held in Brasília (Brasil, 2001: p. 11-12, speech of Sérgio Braga).

From 2001 to the present, a number of state agreements was made to expand the ecological-economic zoning coverage area. In 2007, twenty-five per cent of Brazil was covered with completed EEZ's, and a further eight per cent was under implementation (Brasil, 2007b: p.7, speech of Roberto Vizentin). In addition, in 2005 there was an initiative to collect data for a national EEZ in Brazil. It is equally pertinent to emphasize that in 2007, the Ministry of Environment held a biodiversity workshop on ecological-economic zoning (*Workshop Biodiversidade no Âmbito do Zoneamento Ecológico,* Brasil, 2007a), aiming at the improvement of techniques including biotic and ecological factors into the EEZ.

1.3 Objectives

The historical development and implementation of the Ecological Economic Zoning brought to the forefront different approaches to better define the ecological and economic analysis of the territories from a standpoint of the characterization of natural resources. Therefore, this article proposes a critical overview of current methodologies used in studies of ecological zoning, emphasizing their potential, their limitations and challenges for future enhancements. The article's ultimate goal is to examine how increasingly large, safe, and effective integrated environmental studies may be accomplished.

2 Methodological analysis of zoning issues

2.1 Environmental zoning issues

The first step of an EEZ is to establish the type and perimeter of the spatial units, which will receive information from the spatial analysis. While Crepani *et al.* (2001) conceptualizes only a basic spatial unit, called the Basic Territorial Unit, an approach with several unit types for each analysis is presented in Brasil (2007a: p. 231). The purpose of this topic is to deepen this discussion.

Crepani *et al.* (2001: p.13), referring to Beckler & Egler (1996), defines UTBs as: "elementary information and analysis cells for an ecological-economic zoning. Like a living being, every cell contains a set of key information for the maintenance and reproduction of life and comprises some fabric that performs certain functions on its development. A basic territorial unit is a geographical entity containing environmental differential attributes which distinguishes it from its neighbors; simultaneously, it keeps dynamic links entangling it into a complex network composed of other territorial units".

The method employed by Crepani *et al*. (2001) holds that it would be feasible to define contours expressing the combination of biotic, physical and human elements reaching a synthetical unit of these combinations through the images derived from remote sensing.

The adoption of UTBs based on remote sensing broke the model as far as the previous multicriteria zoning techniques were concerned. Traditionally, the basic zoning units were defined through the intersection of different thematic maps (geology, geomorphology, pedology, vegetation, average slope). Such is the case of both the Phyto Geomorphic Units - UFG – used by Azevedo & Pinagé (2007: p. 131) – and the Biophysical Landscape Units - UPB, used in the EEZ of the State of Acre (Acre, 2000: p. 97). However, one cannot ignore that the current remote sensing images have a much larger scale than the scales of the thematic mapping available. Furthermore, the different ground covers captured by satellites, whether natural or anthropogenic, are sensitive to the different aspects depicted in the thematic maps.

Nevertheless, Crepani *et al*. (2001) do not deny how valuable the intersection of thematic maps is. Indeed, they still are the main methodology. What is new is precisely that the resultant raster from the intersection of the thematic maps will be incorporated into the UTB polygons, whether this raster is related to quality, vulnerability, or potential environmental risk. Areas corresponding to different values on the final raster map will be computed by an average value according to the proportion of its respective area related to the UTB polygon.

In opposition to the single delimitation of Crepani *et al*. (2001), Brasil (2007b: p 231) presents the following division of spatial units:

- Environmental units: "fragments of geographical space, composed of a set of elements characterizing a particular natural system" Marques & Serfaty-Marques (2007: p 76) indicate the possibility of adopting watersheds as environmental units;
- Environmental geographical units: "They have a spatial support defined" and "they express combinations and relations between physical and biotic components, as well as a convergence towards the creation of a hierarchical and homogeneous unit whose spatial arrangement comes from the basic characteristics and structures of evolution of biotic and abiotic aspects";
- Biogeographical environmental units: "They do not have spatial support defined" and "they are determined from the fractioning of biosphere elements into their biotic and abiotic dimensions, according to different criteria. This creates a set of natural communities sharing most of the ecological processes and similar environmental conditions". This clipping refers more to the experience of ecologists and to the zoning of Conservation Units;
- Territorial units: "They present the functional organization of the territory, namely the way in which society appropriates and transforms the space into an object from its social demands and standards. (...). As examples, "we have (...) states, municipalities, conservation units, etc". Marques & Serfaty-Marques (2007, p 76) consider this a Social Landscape Unit, understood as "a set of economic activities and social inter-relationships that exist in a portion of the territory as a unit of social phenomena";

The differentiation between the boundaries of environmental and social units potentially requires a more refined explanation, mainly in regions like the southeast and south of Brazil where the urban-technological network enables society to set standards not matching the contours traditionally used to study natural landscapes. In practical terms, we must also take into account that most of the data used for a socio-economic diagnosis comes from IBGE (*Instituto Brasileiro de Geografia e Estatística* – Brazilian Institute of Geography and Statistics), which provides this aggregate information spatially, according to conventional administrative boundaries (Silva, 2003: p. 703).

2.2 Potential natural fragility

After identifying the current economic activities and the real possibility of future activities, and once the structure of the regional environmental geographic data has been obtained, area zoning of regional environmental sensitivity can be performed regarding the significant economic activities in land use. The different studies and methodologies already developed and related to Ecological Zoning, Economic-Ecological Zoning and Territorial Planning, are all relevant to such purpose.

The term environmental fragility, also called environmental vulnerability, is achieved through a combined analysis of several attributes of the geographical environment in a calibrated model in such a way to provide (or not) a different level of environmental resistance to certain impacting activities. The first question to be answered, so that the concept of fragility (or vulnerability) is well understood, is: "Vulnerability to what?" (Brasil, 2001: p. 423, speech of Tereza Cardoso da Silva). After all, there are so many ways to use the territory that a "general" environmental fragility map would extremely limit the degree of explanation. Certain environmental settings are more vulnerable to erosive activities, whereas others are more vulnerable to deforestation, pollution or overexploitation of water, and so on.

Natural vulnerability to soil loss

Becker & Egler (1997), Souza (1998), Martins Jr. (1998), Crepani *et al*. (2001), Spörl & Ross (2004), Cabral *et al*. (2005), Figueiredo *et al*. (2006), and Calijuri *et al*. (2007) have already done an extensive job developing Ecological-Economic Zoning associated with the analysis of soil erosion vulnerability in Brazil. This modeling begins with GIS databases, such as litho-stratigraphic geology, and geomorphology, pedology, land use, hydrography, among others. Therefore, besides choosing from among the most appropriate procedures for the situation under consideration, it is also necessary to provide a link to local land use.

Vulnerability of biotic resources

Pires *et al*. (2007: p. 23) commented that the geographic approach used throughout the methodological development of EEZ's has had a heavy influence on the 1960s and 1970s works by the French school related to the Physical Planning of Landscapes. These multi-criteria models of overlapping themes are based on Mac Harg's 1969 proposals, updated by the 1996 Tricard method (Santos, 2004: p. 117). In this epistemological dimension, greater emphasis is placed on physical-geomorphological characterization; ecology and biodiversity are left to play a supporting role (Pires *et al.*, 2007: p. 23). An Ecological-Economic Zoning, which does not incorporate the Ecological foundations, presents a contradiction in the etymology of its definition (Santos, 2004: p. 27).

For this reason, Santos (2004: p. 128, and 143-144) proposes that updates of zoning techniques be sought in the academic line of landscape ecology. This research area has had a long history of studies taking into account spatial functions, flows, processes and a number of other epistemological approaches from Ecology. According to Castro (2005: p. 35), landscape ecology: "...combines the horizontal approach of the geographer with the vertical approach of an ecologist, as the horizontal approach is an inspection of the spatial interrelationships of a natural phenomenon, in contrast to the vertical approach, which is dedicated to the exchange of energy and matter among plants, animals, air, water and soil. This account highlights the dynamic characteristic of the landscape (...)".

A major difficulty to including biodiversity variables in zoning is that many of the studies carried out by biologists, such as inventories of species, are not designed focusing on the spatial data (Fabre & Ribeiro, 2007: p. 66). In contrast, the vegetation maps used in traditional zoning do not allow the analysis, not even on larger scales, of crucial information such as stratification, species composition, dominance, rarity, heterogeneity, phytosociology, and also the information concerning disturbance indicators, such as selective cut, resprouting , damage to the lower strata of the canopy (Santos, 2004: p. 49, 92 and 94) and regeneration succession in general. The major difficulty is in portraying the dynamics of ecological systems through processes based on traditional cartography.

Furthermore, transition zones of vegetation types are difficult to frame in polygons of vegetation maps, and the same thing occurs for complex landscape mosaics combining these types including the differentiation of evolutionary stages spatially distributed in a gradual way (Santos, 2004: p. 93 and 148).

Brasil (2007a: p. 7, 179-181 and 232) also points out the following relevant challenges to the incorporation of the biodiversity variable in an EEZ: development of techniques for valuing biodiversity; incorporation of ecological and econometric models to the EEZ methodology; data scarcity about biodiversity in most regions of Brazil, as follows, a) size and geographical distribution of biodiversity, b) biodiversity values and services, c) rate of biodiversity loss, d) effectiveness of conservation efforts, e) thresholds in biodiversity uses, f) sharing benefits from biodiversity use; incorporation of the relationship between biodiversity and climate change.

Biodiversity is defined as "the variability among living organisms from all sources, including, among others, terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (UN, 1992).

Therefore, this expanded notion of biodiversity also includes the diversity of environments (ecosystems) and intra-species genetic variability (Clevelário Jr., 2007: p. 46). Brasil (2007b: p. 232) points out that this expanded notion allows the inclusion, within the variable biodiversity of a EEZ, of biotic factors such as natural biotic resources, ecosystem services, scenic beauty, ecosystemic integrity, diversity of human-environment relationship and a bio-technological potential, as well.

The concept of eco-region in studies of landscape ecology refers to "a set of geographically defined natural units sharing most of their species, ecological dynamics and environmental conditions, and whose ecological interactions are essential for their long-term permanence (...), and that involves relatively homogeneous areas with a biota able to respond adaptively to the prevailing environment." (Pires *et al*., 2007: p. 27).

Brasil (2007a: p. 235-237) also refers to aquatic eco-regions, which can be identified as areas with similar hydrological environmental factors within watersheds, connected by aquatic ecological corridors. Souza (2007) has a review of state-of-the-art zoning in aquatic ecosystems. The aquatic eco-regions suffer impacts related to human influences such as use and water pollution, construction of dams and commercial fishing, so that zoning their vulnerability in the context of EEZ turns out to be strategic (Brasil, 2007a: p. 237).

The concept of bioregion is wider and primarily geared towards the managerial aspects when identifying areas that should receive similar environmental policies (Pires *et al*., 2007: p. 28). Such nuances differentiating the concepts of bioregion and eco-region should be kept in mind during all zoning phases. The incorporation of biodiversity in an EEZ should focus on bioregional conservation strategies *in-situ* and *ex-situ* (Pires *et al*., 2007: p. 27).

According to Clevelário Jr. (2007: p. 44-47), biodiversity indicators follow two different models. The first model indicates the state of biodiversity in the region. The second type measures the value of this biodiversity whether for livelihood, economic activities, or as environmental services. The spatial distribution of this second type of indicator also adds to the EEZ the possibility of using bio-prospection, *i.e.*, to drive the research and production efforts to sites with greater economic potential of using biodiversity (Clevelario Jr., 2007: p. 49). Zuanon (2007), presents how potential stock and carbon sequestration variables were included in the EEZ of Manaus, and compare their wealth generating capability within the Carbon Credit Market with the alternative possibility of deforestation and timber sales. Zuanon (2007: p. 127), also considers the environmental services rendered by the native vegetation in reducing the need to treat the raw water which supplies a city.

Another way to address the biodiversity indicators is to follow the EPR (Brasil, 2007a: p. 236) pressurestate-response categories. This model is used not only for biodiversity, but also for the general environmental planning and has become a reference model for the World Bank and OECD (Santos, 2004: p. 68-69). State indicators are approximately equivalent to the first model indicated by Clevelário Jr. (2007), but also include an investigation of how the population is affected. Pressure indicators include the use of biotic resources, but also their destruction by conversion of land use or pollution. Finally, the response rates indicators are concerned with the measures being taken by the government and society towards biodiversity conservation.

Both indicator classifications, Clevelário Jr. (2007) and Brasil (2007a), are useful to assess to what extent the variables to be incorporated into the EEZ cover the key strategic issues.

Ecosystems have cyclic seasonal processes, which could only be fully considered with the inclusion of a study about temporal variations (Fabré & Ribeiro, 2007: p. 69). The availability of financial resources to undertake such studies sets a limit on the explanatory power of the variables related to the biotic systems.

The explanation provided by biodiversity zoning is considerably expanded with the completion of transects that are spatially planned at the site, depending on the availability of financial resources and qualified professionals (Fabré & Ribeiro, 2007: p. 61). Another significant contribution is the study of ethno anthropological knowledge of the local population, and on the state of biodiversity and its use by society (Fabré & Ribeiro, 2007: p. 70).

The signatories to the Amazon Cooperation Treaty, including Brazil, agreed to adopt the Habitat Quality Index - IQA, as a minimum indicator of Biodiversity, according to the following formula (Marques & Serfaty-Marques, 2007: p. 81):

IQA = RE + EV + FA + QC

In which the acronyms represent the following variables:

RE = Specific Richness

EV = Vulnerable Species

FA= Dependency on the Environment

QC = Quality of Vegetation

Fabré & Ribeiro (2007: p. 66-70) highlight how they used the biodiversity indicator for the ecological-economic zoning of the Amazon. The methodology of the variable survey incorporated the IQA, but also added a number of additional nuances. It is worth noting the following comments on the themes used as fallow.

- Quality of vegetation: Information on spatial heterogeneity, fragmentation, and connectivity were used. The authors recommended the improvement of information through additional data, such as density and canopy height, species distribution, specific richness, trophic levels of the energy cycle and characterization of the quality of the aquatic environment;

- Key species: Also known as ecosystem engineers, "they reported the species whose loss has a disproportionate impact on the community when compared to the loss of other species" (Pires *et al.*, 2007: p. 30). The biome was analyzed through expert knowledge focusing on top predators and pollinator animals;
- Dependency on habitat: This refers to the degree of endemism. As a general guideline, as the rarest species require specific environmental conditions, they tend to be more specialized.
- Particularly at closer range scales, zoning the sensitivity to the biotic resources is mandatorily driven to the adequacy of land use to comply with the environmental legislation, including the percentage of preservation (Legal Reserve) and the permanent preservation areas (water body edges, steep slopes and hilltops) – as presented by Catelani *et al.* (2003), Nascimento *et al*. (2005) and Ribeiro *et al*. (2005). This approach should also be combined with fragmentation analysis, ecological importance and fragment conservation, according to the detailed methodology by Carvalho & Louzada (2007), already used for the Ecological-Economic Zoning of Minas Gerais state.

Qualitative and quantitative sensitivity to the use of the water resource

Sergio Braga, from SDS/MMA, also points out that the relationship between risks and water resources needs further refinement and reflection in EEZ's methodology (Brasil, 2001: p. 223). Thales Sampaio, from CPRM, adds that water resources provide a powerful interface among population, vegetation and physical attributes of the territory (Brasil, 2001: p. 224). Therefore, water resource analysis can be seen as a way to better synthesize EEZ multidimensionality.

Furthermore, the analysis of water resources provides a dynamic view of the territory, which is still one of the challenges the EEZ methodology has to overcome. With the analysis of river networks, also comprising the watershed approach, it is possible to track and even the predict the causal chains of environmental impacts, such as water use, pollution dispersion, impacts on the ichthyofauna migration, among others (Santos, 2004: p. 85).

Among the analytical techniques of water resources, it is also possible to analyze patterns and drainage density, as the CPRM zoning team has being doing in their work. Anthony Theodorovics, from CPRM, indicates a number of zoning possibilities based on the drainage system using the pertinent information on the relief system whenever needed (to infer information about drainage density), as well as waterproofing, aquifer recharging, drainage standard, tectonic control, river beds carved by erosion, entropy (in terms of preferred orientation), drainage system, slope and predominant hillside form (Brasil, 2001: p. 237). Nevertheless, the author emphasizes that an EEZ analysis is only deemed finished when the effects of these attributes on occupation and land use are considered.

The zoning of sensitivity of the water resource, including its quantity and quality, is a key indicator for the ecological and economic planning of the agricultural hydrographic watersheds. From the simplest methods of analysis, for instance, proximity to water bodies (Valente, 2005; Calijuri *et al*., 2007), new variables such as irrigation, limits and occupation of aquifer recharge areas and water body drainage areas can be added, comparing the current hydrography with the IBGE's 1964 hydrographic map. These new variables may yield a more consistent modeling of water resource sensitivity, as proposed by Martins *et al*. (1994).

Final maps of environmental vulnerability

As a summary of environmental issues, an integrated analysis of these three maps of environmental sensitivity is carried out, producing an overall map of the Ecological Environmental Sensitivity oriented to the local economic activities. This overall map contains a combination of the relevance of three factors: Soil, water and biotic resources. To combine such factors, a paired comparison method (Saaty, 1977; Saaty, 1980 *apud* Valente, 2005 & Eastman, 2003) can be used through a standard query involving the region's entrepreneurs, as well as researchers with direct experience in studies of environmental zoning.

3 Possible use of landscape ecology and agronomy methodologies

Landscape Ecology, as a field of scientific knowledge, seeks to reconcile the study of structure, dynamics and function of ecological systems (relationship of living things to each other and to the abiotic system) based on the analysis of spatially heterogeneous mosaics (Forman & Godron, 1986; Metzger, 2001). For this purpose, it combines studies and indexes traditionally used in biology and ecology, analyzing how they change the landscape through modeling and spatial analysis. Based on the patch-corridor-matrix model (Forman, 1995), Landscape Ecology brings the possibility of studying the environmental impacts through fragmentation analysis, connectivity and edge effects into the landscape units, which can be natural systems and / or anthropogenic systems.

There are several indices and spatial analysis of

Landscape Ecology that can be incorporated into the ecological-economic zoning. Table 1 presents the main criteria proposed by O'Neill *et al.* (1994), Ritters *et al.* (1995) and Eiden *et al*. (2000) for characterization of the landscape.

One of the classic methodologies of multi-criteria zoning for conservation is Systematic Planning Biodiversity Conservation – PSC. The PSC assigns degrees of relevance for the conservation of forest fragments according to the following variables (Rodrigues *et al*., 2007: p. 52-53), as fallow:

- Representativeness: Each type of ecological fragment must have a minimum of preserved areas;
- Complementarity: Takes into account the existing level of protection over the territory (as Conservation Units, Sustainable Use Areas, etc.), and calculates how to obtain the largest number of conser-

Table 1. Indicators and spatial analysis techniques for Landscape Ecology compiled and adapted from Carrão *et al*. (2001).

	Indicators	Formula	Description
Indicators of Landscape Composition	Richness (R)		Wealth for each class is the respective number of areas; wealth for the landscape is the total number of classes existing within its boundaries.
	Diversity (H)	$H = -\sum_{k=1}^{m}(P_k)\log(P_k)$	Has value 0 when only a single area (class) exists in the landscape (so, there is no diversity). Its value increases as the number of classes increases, if the proportion of area occupied by the different classes is the same, or due to both.
	Dominance (D)	$D = H_{\max} + \sum_{k=1}^{m}(P_k)\log(P_k)$	Has value 0 when only a single area (class) exists in the landscape (so, it is perfectly homogeneous). Its value increases as the number of classes decreases, if the proportion of area occupied by the different classes is wider, or due to both.
	Area and perimeter (AP)		The value of the area or the values of the perimeter of each class is near 0 whenever the area is unusual in the landscape; such value is equal to the area or the total landscape perimeter if it is composed of a single class
Indicators of Landscape Configuration	Contagion (C)	$C = 1 + \sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij}\log(P_{ij})/m\log(m)$	The contagion approaches 0 whenever the distribution of neighborhoods between classes is highly heterogeneous. It is equal to 1 when all classes are also each other's neighbors.
	Fractal dimension (F)	$F = 2S$, em que $S = \frac{m\sum AP - (\sum A)(\sum P)}{m\sum A^2 - (\sum A)^2}$	Its value is close to 1 for areas with basic perimeters, such as circles or squares, and approaches 2 for exceptionally jagged perimeter areas.
	Dissemination and Juxtaposition (IDJ)	$IDJ = \frac{-\sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij}\log(P_{ij})}{\log\left(\frac{m(m-1)}{2}\right)}$	The value approaches 0 whenever the distribution of neighborhoods between classes is highly heterogeneous. It is equal to 100% when all classes are also each other's neighbors.
	Polygon of the largest area (LPI)	$LPI = \frac{\max_{j=1}^{m}(a_{ij})}{TA}(100)$	This indicator approaches 0 as the polygon of the largest area decreases. When the landscape is composed of a single element, its value is 100%.
	Density of Elements (DE)	$DE = \frac{n_i}{TA}(10000)(100)$	It is equal to the number of elements that exist for every 100 hectares for each class. For the landscape, it is equal to the number of elements in any class within each 100 hectares.
	Density of borders (DF)	$DF = \frac{f_{ij}}{TA}(10000)$	The value of this indicator is equal to 0 when there is only one area in the landscape (so, there are no boundaries among classes). It increases as the number of areas increase and with the increasing irregularity of their perimeters.

Parameters**:**
m = number of occupational groups present in the landscape;
P_k = proportion of landscape occupied by class of k;
Hmax = log (m);
P_{ij} = probability of an element of class *i* being adjacent to an element of class *j;*
A = area of each landscape element (m^2);
P = perimeter of each landscape element (m);
max(a_{ij}) = area of the largest landscape polygon (m^2);
TA = total area of the landscape (m^2);
n_i = number of elements in class *i* (for the landscape is the sum of all classes);
f_{ij} = dimension of the boundary between class elements *i* and elements of class *j* (for the landscape is the total sum of borders, considering only a single time the border *ij*, i.e., considering the same *ij* the same as *ji*).

vation goals with a minimum of chosen areas;

- Irreplaceability: Probability that a given fragment has of being protected to achieve a certain set of goals for the preservation of ecosystems;
- Efficiency: Cost-effectiveness, in order to protect larger areas with minimal resources;
- Flexibility: There is more than one viable alternative for achievement of goals. This allows a margin for negotiation and inclusion of new information on the cost of conservation;
- Vulnerability: Risk of destruction or imminent alteration of the ecological fragment. Involves factors such as rate of deforestation, agricultural capability, and presence of endangered endemic species. Azevedo & Pinagé (2007: p. 132) also choose to include the variable Proximity in the PSC, i.e., they consider the proximity of the fragments, the permeability of the occupation matrix and the possibility of ecological connection corridors. The PSC helps in the selection of sets of occupation, which will have the lowest environmental impact on an EEZ through the integrated analysis of such attributes.

Pires *et al*. (2007: p. 33) point out that the Ecological Footprint Method (Wackernagel & Rees, 1999 *apud* Pires *et al*., 2007) can contribute to the sustainability analysis of the socio-economic diagnosis. This method analyzes the amount of energy and natural resources required by a regional community and then compares the current availability in the region. Thus, it creates the possibility of establishing a link between natural resource studies and socioeconomic studies, which have been presented so far as separate chapters in the EEZ's and have had little connection with each other.

A current methodology in agronomy is the execution of agricultural suitability (Ramalho Filho & Beek, 1995) and usability potential (Lepsch *et al*., 1991) mappings. Both are based on studies of soil, topography, climate, and water availability, indicating greater feasibility for production under the various types of technological management. Such indications help to prevent inadequate management practices for the occupation of certain areas, which would result in degraded soil environments and a history of unsuccessful undertakings. Moreover, mapping prospective agricultural soil suitability and usability potential are effective means to model the dynamics of the future occupation of a region, considering that entrepreneurs tend to seek areas of higher yields. A combination of land suitability mapping and the aforementioned PSC method may be used as design basis for optimal use of the territory (Martins Jr. *et al*., 2010a) by allowing the search for a scenario able to reconcile the optimal points of both environmental conservation and agricultural production.

Concepts such as moisture profile and capillary tension, essential to assess the land suitability, gain potential interest when the relationship between soils, vegetation and water recharge systems are considered. To the extent that phenomena such as interception, evapotranspiration, infiltration and runoff are influenced by the type of vegetation, the hydrological availability of the soil is the basis for the transfer of concepts, theories and methodologies from areas of academic studies on land suitability and landscape ecology for the management of hydrological resources (Schröder, 2006; Martins Jr. *et al.*, 2010b). This is a promising opportunity for integration of key areas for Ecological-Economic Zoning.

4 Conclusion

The academic milieu related to environmental planning is fertile for the development of feasible methodologies for EEZ's. The greatest difficulty lies in combining all these possibilities of advancement in a consistent and capable framework of practical implementation. The increasing complexity of environmental diagnostics requires professionals with broad and multidisciplinary education, able to handle the integration of knowledge coming from different disciplines.

It is essential to maintain discussion forums for information exchanging and reflections on existing methodologies. Only then, it will be possible to map the gaps and challenges still existing, as well as opportunities for the new areas of thematic expansion.

EEZ's ultimate goal would be to realize the interconnected web of economic and ecological relationships over the territory (Brasil, 2007a: p. 11). This is not an easy task, for systemic thinking involves network processing by non-linear causality (Brasil, 2007a: p. 232), which significantly increases the complexity of the analysis required.

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