Compensation and restoration: quantitative methods

Abstract

Law requires appropriate assessment for all European Sites in the Natura 2000 European network. New projects in high value habitat or a biodiversity hotspot would not be approved if a "no residual impact" outcome is not applied or if their environmental impacts are not effectively offset through meaningful compensation. A multi-metric, quantitative method is used in order to evaluate the impacts over different system components and permits to assess the offset over a wide range of impact. Three different case studies, in different habitats (a mountain grasslands, a coastal area and a coastal wetland) are subject to significant impacts. Project involved are a wind energy park, a port development and a tourist facility. Involved environments are cultural landscapes that tourists and local population wish to enjoy, and the projects have an impact on both the landscape and biodiversity. A quantitative analysis based on system ecology indicators (emergy and exergy) is proposed and landscape ecology is used at an appropriate level of detail. This assessment concludes that is possible to use a mitigation - compensation - restoration scheme in Natura 2000 sites (or of nearby important habitats). Case studies show that an appropriate Assessment would be needed at Strategic Assessment level.

Summary

The analysis has made within the follow scheme: Identification and appraisal of impacts, Assessment of impact metrics thresholds, quantitative measure of impacts, definition and quantification of mitigation, offset and recovery.

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1 Introduction

Environmental impact assessment (or Strategic environmental assessment or biodiversity impact assessment or landscape impact assessment) are in the field of post normal science (Funtowicz and Ravetz, 1991). Post-Normal Science is a concept developed by Silvio Funtowicz and Jerome Ravetz, attempting to characterise a methodology of inquiry that is appropriate for cases where "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz and Ravetz, 1991).

Impact assessment has defined as “any change in means that is linked to the start of some new human activity must be considered an environmental impact” (Underwood, 1991). The assessment of impacts was carried out for each of the environmental issues mainly by the follows aspects (Canter, 1996; Ortolano, 1997; Bettini et al., 2000):
a) identification of baseline environmental information in respect of the site and its environs;
b) identification of potential significant environmental impacts;
c) identification of mitigation measure to reduce adverse environmental impacts and to enhance beneficial environmental impacts;
d) assessment of significance of predicted impacts taking account of any mitigation measure. If this is not applicable the range of potential impacts without mitigation are assessed along the residual impacts that would result if the specific mitigation measure were adopted;
e) compensation of residual impact is made by such remedial or compensatory action.
In this paper a multi-metric assessment of impacts is proposed and used in order to quantify the ecological offsets.

The general method is based on a Landscape approach to environmental impact assessment. Landscape approach considers landscape as one cultural dimension of complexity: is the total human ecosystem (Naveh and Lieberman, 1994); is cultural and historic construction (Farinelli, 2003); is a system, a unit, a domain, and a realized space; is a cognitive space (for a review see Farina, 2006).

2. Methods

The method developed is based on followings several steps.

1. Definition of Homogeneous Environmental Management Units and the analysis of spatial and temporal structure, hierarchy and dynamics over multiple scales (Naveh and Liebermann 1994; Marotta 2006), For this scope a land habitat map was produced, based on landscape ecology (Naveh and Lieberman, 1994). This approach is based on the definition of landscape hierarchy following Naveh and Lieberman: macrochores (large scale units, e.g. coastal systems), mesochores (medium scale units, e.g a lagoon), microcores (littlo scale units, e.g. a saltmsrsh), ecotopes (smallest landscape unit corresponding to a potential vegetation unit) and patches (smallest landscape unit corresponding to the real land cover, or a real vegetation unit).
2. Analysis of the land use changes in the land part of the study area as a systems. Both those steps individuate the landscape features and changes in a multi time framework (Marotta e Mulazzani, 2006).
3. Spatial assignment of indices, this is the basis for landscape analysis (Forman, and Godron, 1986; Marotta e Mulazzani, 2006) and the valuation of indices per each patch type and state. Per each type of patch are assigned a set of value of indices. This method links the land use and sea use with the average value of indices (Marotta et al., 2007). The indices are the metrics used for model the complexity of the impacted system.
4. A multi time analysis made with IDRISI™ (Andes version) in order to assess which change of habitats have modified (from available data in the interval from 1970s to 2000s). The habitats are defined following the EC Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora).
5. The impact quantification using a Before after Control Impact, BACI-like method. All the impacts are quantified using all the indices, i.e. all the metrics. This method is used in both ex-ante impact assessment and follow-up (monitoring and adjusting measures).
6. The residual impacts are compensated using the compensation measure in order to compensate all the impacts (offset of all the indices/metrics).

2.1 Impact methods

System analysis is needed in order to assess baseline condition and have to consider a spatial scale and a time scale of geological and ecological interaction with the projects (Bettini et al., 2000). The analysis was made over three different spatial scale as mesochore, microchores ecotopes and patches (Naveh and Lieberman, 1995), and over temporal scales (Wu and Li, 2006), in this case 30 years. In this work the landscape transformations (in all the study areas) are based on analysis of satellite images and aerial photos (from 1975 to 2008).

There are a wide set of definition of which effect constitutes a significant impact (see for a review: Canter, 1996; Ortolano, 1997; Bettini et al., 2000; Sánchez, 2006). The question of significance varies according the environmental system and the impacts under consideration and the context in which the assessment is made. However, where it is appropriate, the level of significance of effect and the level of significance of impacts has been defined using a combination of sensitivity (high, medium, low) of the environmental feature /system in question and the magnitude of impact (high, medium, low and negligible) and his reversibility (short term reversible, long term reversible, irreversible).

The impact, Im, at a time t_j can be defined, as the total variation of a quality Q_i of a system:

$$\mathrm{Im}(Q_i, t_j) = \sum_l \left[Q_i(t_{j-1}) - Q_i(t_j) \right]_l \qquad [1]$$

Quality was introduced as a general health property of the system.

Considering l variations of Q_i along the time interval between t_{j-1} and t_j.. Quality si defined by the set of indices defined in 2.2. The scientific methodology for detecting impacts was developed in the context of Beyond BACI (before, after, control, impact) design (see for example Underwood, 1991): all the indices are measured in the impact and in a control are before and after the project. The description of past changes (1975-2008) at landscape level was made following Forman (1995), definitions: "Perforation is the process of making holes in an object such as a habitat or land type (e.g., dispersed houses or fires in a forest). Dissection is the carving up or subdividing of an area using equal-width lines (e.g., by roads or power-lines). Fragmentation is the breaking of an object into pieces (that are often widely and unevenly separated). Shrinkage is the decrease in size of objects, and attrition is their disappearance."

2.2 Scale, metrics, indices and threshold parameters

Conceptualizing landscape as described by patches of different land and sea use is made with the spatial trasformation of indices in order to use them as model. The data used in order to identifying the total landscape value more completely within different metrics: Emergy (LDI), Exergy, BTC, Percolation.

To take into account all the resources (natural and manufactured) sustaining a system, a useful index is Emergy introduced by Odum (1996). Odum (1996) defined emergy as the quantity of solar energy necessary (directly or indirectly) to obtain a product or an energy flow in a given process. The used units are - as usually it is done (e.g. Odum, 1996) - units of solar energy as the common unit: Solar Emergy = Solar energy required directly and indirectly to make a product or service (units: solar emjoules); Solar Empower = Solar emergy flow per unit time (units: solar emjoules per unit time); Solar Transformity = Solar emergy per unit of available energy (units: solar emjoules per joule). Solar Transformity is defined as the emergy required per unit of product or service. It is the solar energy directly or indirectly necessary to obtain one unit of another type of energy (Odum, 1996). The Empower Density (ED) is the ratio of total emergy to the area (expressed in hectares or m^2), a measure of the spatial concentration of emergy within an area, which is the ratio of total emergy to the surface area of the system. The greater the ED, the more the area becomes a limiting factor for all future development. The Environmental loading ratio (ELR) is the ratio of non-renewable (local and imported) emergy to renewable environmental emergy. Using land-use data and development-intensity measures derived from energy use per unit area, an index of landscape development intensity (LDI) can be calculated for the coastal zones to estimate the potential impacts from human-dominated activities. The intended use of the LDI is as an index of the human disturbance gradient (Brown and Vivas, 2005). The index values are calculated from the non-renewable emergy per land use.

The exergy of a system is the maximum work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is then the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero (Jørgensen, 2006). Eco-Exergy (or ecosystem Exergy) is a measure of ecosystem organization from its reference condition, according to the definition of the distance from thermodynamic equilibrium and can be found as the chemical energy difference between the system and the thermodynamic equilibrium

(Jørgensen, 2006a, 2006b.) Exergy is calculated following Jørgensen (2006) on the average biomass per land use. The exergy index was calculated as the concentration of different groups ci multiplied by
weighting factors bi, based on exergy detritus equivalents according to Marques and Jørgensen (2002). Exergy links the chemical energy of the different species (characterizing the ecosystem) to the information embodied in DNA, as explained by the following equation:

$$Ex = \sum_{i=1}^{n} \beta_i X_i \qquad [2]$$

where βi are the weighting factors and Xi are the concentrations of each group in the system.
Unit exergy detritus equivalents are expressed in g m^2 and can be converted to kJ m^2 using the approximate average energy content of 1 g of detritus,i.e. 18.7 kJ (Jørgensen, 2000).
A variation in exergy values could be due to variations of biomass or to variations of the structural complexity of the biomass.

The ecosystem function is measured using the *biological capacity potential* (BTC) (Ingegnoli and Pignatti, 2007). This synthetic function, referred to the main ecosystem, is able to compare landscapes states by measuring the relative relation between respiration and gross production (R/GP) and respiration biomass, R/B (Ingegnoli and Pignatti, 2007):

$$BTC_i = 0.89\Omega - 0.0054\Omega^2$$

$$\Omega = (a_i + b_i),$$

$$a_i = \left(\frac{R}{GP}\right)_i \left(\frac{GP}{R}\right)_{\max} \qquad [3]$$

$$b_i = \left(\frac{dS}{S}\right)_{\min} \left(\frac{S}{dS}\right)_i$$

where i is the landscape patch expressed as plant ecosystems of the ecosphere and R is respiration, GP is gross productivity, B is biomass, dS/S = R/B is the maintenance to structure ratio. BTC measures the state of the same ecotope (or patch) compared to a "healthier" state of the same ecotope which would give a higher value. BTC is expressed as Mcal/m^2/yr, so that it is easy to convert it into Joule/ha/yr. It is possible to define the total BTC of a landscape as the sum of the total patches, if the patches categories and corresponding BTC values are provided in a tabulated form.

Percolation index is based on percolation theory and offers a method to describe predict animal movement. Random maps are generated by randomly filling P cells in the map, where P (probability) is equal to the desired density of filled cells. A cluster is defined as a set of connected cells. At low P, a random percolation map will have many isolated filled cells and small clusters. At intermediate P, clusters become larger and therefore fewer. At high P, the map verges towards being one large cluster. A cluster that reaches from one end of the map to the other is known as a spanning or percolating cluster. Interestingly, random percolation maps demonstrate critical behaviour around a critical point Pc. When P is above Pc = 0.5925, the map will have an extremely high likelihood of having a spanning cluster. Below Pc, it is rare for a cluster to percolate. On a map with regions of varying P, such as digitized tree cover images, the edge of the spanning cluster will indicate a density of Pc (Farina, 2000).

3. Results

Assessment of actual state, landscape dynamics (during the last 30 years) and predicted impacts is implemented for each site. In all the cases there are evidence of impacts on Natura 2000 sites and all the projects affect protected habitats. The data base used are satellite images (for the evaluation of land use dynamics), geomorphologic, soil and vegetation maps, climatic an biomass data (in order to measure the BTC and exergy) and economic, social and energy data (for the evaluation of emergy and LDI). Models are developed using Idrisi land change modeller (Eastman, 2006) and the changes predicted using the indices. The quantitative results are obtained as presented in table 1. Results showing the possibility of quantify impacts. In all the case the resulting impacts are only partially measured in the post impact state: a long term monitoring is needed in order to fully evaluate the goodness of impact model and metrics.

	Percol.		BTC (MJ/m² yr)				LDI				Exergy 10^4 MJ/(m² yr)			
State	A	B	1	2	3	4	1	2	3	4	1	2	3	4
Wind Farm: Moderate impact, perforation	0.3	0.6	6.89	4.02	6.91	3.29	2.00	4.09	2.06	1.00	2.20	0.05	2.26	2.20
Port (marina): Major impact, shrinkage	0.1	0.2	3.92	2.01	3.87	2.67	7.00	8.56	7.03	3.02	0.12	0.03	0.12	1.05
Tourist facility Major impacts atrittion	0.3	0.6	5.07	1.03	5.09	5.00	7.50	9.00	7.50	3.00	0.68	0.09	0.65	1.00

Table 1. Percol. Is Percolation. A: impact loss by the project, B: project with compensation measures; States are: 1= actual state, average in ecotope; 2: Impact assessment result; 3 control ecotope; 4: compensation measures.

Landscape metrics coupled with GIS have proved useful in monitoring the landscape (habitat) changes that have taken place and the future impacts. The indices still provide comprehensive information on the direction, quantity and quality of impacts deriving by the case study projects. The results of the impact matrix (Table 1) and landscape metrics at the microchore scale show the impact on function change (indicators: BTC, LDI, Exergy), structure (change in landscape matrix: composition and percolation change) and composition (change of land use).
Specifically, such metrics provide us a quantitative overview, determining the dimension of changes before the project, and quantifying the offsets over all the different metrics.

4. Conclusions

The dynamic assessment of impacts at different landscape scales is presented and could provide necessary support for policy makers in establishing off set priorities for development as well as evaluation of progress in a multidimensional setting. The multi-indices assessment path could become one of the standard elements of environmentally impact modelling and enable the assessment future landscape change and effects on key habitats. First results show the evidence of the efficacy of the proposed method. Further studies in different case and their follow-ups are needed in order to the improvement of the knowledge about the dynamic performance of the methodology.

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