D. Geneletti, Int. J. Sus. Dev. Plann. Vol. 1, No. 4 (2006) 419–428

ECOLOGICAL EVALUATION OF LAND: SOME CONSIDERATIONS ON APPROACHES AND SHORTCOMINGS

D. GENELETTI
Department of Civil and Environmental Engineering, University of Trento, Italy.

ABSTRACT
The ecological evaluation of land aims at providing information that can be used to support decision making in nature conservation. It can be seen as the link between the science of ecology and the practice of land management. This paper presents a review of the approaches proposed in the literature to perform ecological evaluation, focusing in particular on the different objectives and criteria, as well as on the way in which they are assessed and on the use of relevant indicators. In addition, the paper proposes a survey on the shortcomings found in current applications. The main problems affecting the practice of ecological evaluation concern the structuring of the evaluation framework: objectives are often poorly defined and not clearly linked to the relevant criteria. In turn, the criteria show problems of correlation and are seldom assessed by means of explicit indicators. This clouds the overall results of the evaluation and undermines their practical use in planning-related procedures.
Keywords: criteria, ecosystems, evaluation, indicators, landscape ecology.

1 INTRODUCTION

Selecting and designating areas of land as nature reserves, allocating different land-use intensities within a nature reserve, assessing the magnitude of the impacts on ecosystems caused by a proposed development, and recommending the most ecologically friendly land corridor to host a new infrastructure are all activities to which ecologists are commonly asked to contribute. They all rely on the preliminary identification of different degrees of significance for conservation associated with the natural areas occurring within the region under analysis.

Nature conservation can be defined as the protection of the natural richness of a landscape. Such a richness consists of elements (soil, geomorphology, vegetation, flora, fauna) that are linked by natural processes [1]. The procedure of assessing the significance of an area for nature conservation is termed ecological evaluation [2]. Hence, the main objective of ecological evaluation is to provide criteria and information that can be used to support decision making in nature conservation. As such, ecological evaluation can be seen as the link between the science of ecology and the practice of land management.

By identifying the most ecologically valuable areas, planning and management practices can be applied so as to maintain the areas' value [3]. This involves, for example, the establishment of protected areas (wildlife reserves, biotopes, site of special scientific interest, etc.) or the identification of the least-damaging location for new industrial settlements.

Landscape ecology addresses the relationship between spatial patterns and ecological processes [4, 5]. As such, it can contribute to ecological evaluation by analysing the role played by the landscape structure and the spatial distribution of the ecosystems for the survival of species and the conservation of nature [6, 7, 8]. In principle, not all ecological evaluations are carried out through landscape-ecology methods and approaches. However, the potential role of landscape ecology in linking ecology with spatial planning and land-use management is increasingly recognized [9, 10]. This paper does not address the broad field and scientific literature of landscape ecology; it is limited to areas where this discipline plays a role in ecological evaluation, according to the framework set out in the following sections.

Generally, planning authorities undertake ecological evaluations to gain insights on the features of the land under their jurisdiction. In particular, ecological evaluation is used to complement other

ISSN: 1743-7601 (paper format), ISSN: 1743-761X (online), http://journals.witpress.com
DOI: 10.2495/SDP-V1-N4-419-428

and more traditional methodologies for natural resources assessment, such as land evaluation and land capability classification [11, 12, 13]. These methodologies are biased toward production-related activities and aim at classifying the land mainly according to its potential rural or forestry use [14]. Having defined here the concept of ecological evaluation and its scope, the next section presents an overview of the main approaches that have been proposed in the literature to make ecological evaluation operational.

2 APPROACHES

According to the definition provided in the previous section, performing an ecological evaluation basically involves classifying the area under analysis into units characterized by different degrees of significance for nature conservation. This requires an evaluation framework to be previously set. In particular, such a framework must specify the objectives of the evaluation, as well as the criteria used to express the degree of satisfaction of such objectives. It must also provide guidance on how to measure and assess each criterion with respect to its significance for nature conservation.

Setting up a suitable framework comes up as the main concern that emerges from the literature on ecological evaluation. Ever since the earliest studies in that field, scientists have attempted to enhance the theoretical definition of the criteria and to provide a rationale for using particular criteria and for guiding the criteria assessment [1, 2, 15, 16, 17, 18, 19, 20]. However, there is no methodology that is accepted as a standard for performing ecological evaluation. The following is a description of the main approaches found in the literature, and in particular of the objectives that they consider, the criteria they propose and the way in which the criteria are assessed.

2.1 Objectives of the evaluation

As stated, the general goal of ecological evaluations is the conservation of nature. However, nature conservation can be addressed by different standpoints, according to the perception of the relationship between human beings and nature. Consequently, the objective of the ecological evaluation depends upon why we want to conserve nature in the first place. With respect to this, two main objectives are found in the evaluation frameworks proposed in the literature:

- Objective 1: the maintenance of natural areas and their biological diversity *per se*.
- Objective 2: the maintenance of the social functions provided by natural areas (cultural, scientific, recreational, etc.).

Pursuing the first objective implies the assessment of ecological qualities only, such as biotic and abiotic features. On the contrary, the second objective considers the benefit to human society derived by the conservation of nature. This implies including characteristics such as the accessibility of a natural area or its aesthetic appeal in the assessment. Most evaluation frameworks address the two objectives at the same time. The objectives of the evaluation are actually rarely stated. However, they can be inferred by the criteria that have been selected.

According to decision theory, an objective represents the reason for action [21]. Therefore, objectives are used to define a desired state that we would like to achieve. On the other hand, in order to express the degree of satisfaction of a given objective, criteria are required. Both objectives and criteria are employed during the evaluation stage, ideally to set out a clear and transparent evaluation framework. The results of the evaluation are then to be applied during the planning and management stage, which represents the ultimate purpose of ecological evaluation.

2.2 Criteria

Every evaluation framework specifies the criteria to be used for the assessment of the relevance of natural areas. Criteria are employed to describe how an area satisfies the conservation objectives that have been set. A number of reviews on the criteria proposed in ecological evaluation can be found in the literature [15, 22, 23, 24]. Most of the criteria have been proposed in the 1970s and in the early 1980s, when the scientific production concerning ecological evaluation was particularly high. From the late 1980s, the main contribution to ecological evaluation was provided by the findings in the discipline of landscape ecology [25, 26, 27, 28].

Table 1 summarizes the criteria most frequently proposed for ecological evaluation. A description of such criteria follows, together with a brief rationale that justifies their use in ecological evaluation. However, there is some argument about both the definition and the rationale of several criteria. Most of the problems are due to the vagueness of some criteria (e.g. representativeness) and the correlation between criteria (e.g. fragility and size seem dependent on each other). Moreover, different interpretations of the criteria often occur when the ecological evaluation is applied to different types of problems (e.g. identifying new natural reserves versus assessing the impact of a proposed development) or in different landscapes (e.g. man-dominated landscapes versus pristine areas).

The description of all the possible meanings of the criteria and the way they have been applied in different situations goes beyond the scope of this paper. The main objective here is rather to provide an overview on how ecological evaluation is carried out in practice. The interested reader can find broader discussions about all the criteria in references [2, 15, 24], and about some specific criteria in references [34, 35, 36, 37, 38].

Criteria that relate to Objective 1 (i.e. the maintenance of natural areas and their biological diversity *per se*):

- *Rarity:* A measure of how frequently certain species or ecosystem types are encountered [39]. It can be meaningfully described only by referring to a scale of analysis (local, regional, etc.). Rarer species and ecosystems are more prone to extinction and therefore their conservation becomes a priority.
- *Diversity:* A measure of the number of different types of species or habitat types that exist in a given area. Species and habitat diversity are often correlated because habitats with high diversity in general provide niches for a higher number of species than homogeneous habitats.

Table 1: Overview of the criteria used more often for ecological evaluation.

Criterion	Objective as in Section 2.1	Reference
Rarity	1	[19]
Diversity	1	[15, 18]
Size	1	[29]
Naturalness	1	[16]
Fragility	1	[18, 29]
Representativeness	1	[15]
Connectivity	1	[30, 31]
Educational value	2	[17, 32]
Scientific value	2	[17]
Recreational value	2	[33]

- *Size:* The measure of the extent of a natural area. It is relevant because, all other things being equal, larger sites tend to support more species and higher densities than smaller sites [39].
- *Naturalness:* The degree to which an ecosystem is free from biophysical disturbance caused by human activities [16]. Operationally, it can be interpreted today as the proportion of spontaneous vegetation independently of whether it consists of juvenile or mature stages of the ecologic succession. The more natural, and therefore the less disturbed, the better. This is because the proximity to the natural conditions of a site influences the survival chances of the native flora and fauna. Additional reasons for assessing naturalness are tied to scientific considerations (undisturbed ecosystems are needed to set a reference for assessing the changes that affect disturbed ecosystems), as well as to emotional and recreational benefits [22].
- *Fragility:* The degree of sensitivity of species or ecosystems to environmental changes [29]. The more fragile they are, the greater is the requirement for their protection. Fragility also relates to naturalness in that the conservation of fragile ecosystems requires the maintenance of a high degree of naturalness.
- *Representativeness (or typicalness):* A measure of how well a site reflects all the habitats that are expected to occur in that geographical region [39]. The more representative a site is of a region, the better. The rationale behind it is similar to the one for the diversity criterion: by protecting the most representative sites we are more likely to preserve the total species and habitat diversity of the region under consideration.
- *Connectivity:* A measure of how well the spatial distribution of the natural areas supports the interactions among them. Such interactions (nutrient flows, animal dispersal, etc.) in general allow the areas to sustain a higher number of species and higher population densities. Consequently, the higher the connectivity, the better.

Criteria that relate to Objective 2 (i.e. the maintenance of the social functions provided by natural areas):

- *Educational value:* A measure of the suitability for the educational use of a natural area. Such a suitability may be related to both its ecological features (that, in turn, may be related to criteria such as rarity or representativeness) and its accessibility (e.g. presence of roads, proximity to schools).
- *Scientific value:* The degree of interest of a natural area in terms of current or potential research. It may also be related to the extent to which a site has been used for past research. Sites with good histories (e.g. description of ecosystems' dynamics in the past 50 years) are more valuable to science because they enhance our understanding of ecology [39].
- *Recreational value:* A measure of the relevance of a natural area as a place to be visited or seen by the general public. It is assessed by considering its accessibility, visual attractiveness, facilities, etc.

In order to make the use of such criteria operational for evaluating the conservation relevance of a site it is necessary to establish guidelines for their measurement and assessment. However, this is complicated by the fact that, as mentioned before, the criteria are often poorly defined and correlated with each other. Consequently, the criterion assessment represents a particularly critical step, as discussed next.

2.3 Criterion assessment

The selection of criteria establishes the basis upon which the ecological evaluation is to be made. However, an evaluation framework also needs to specify how each criterion must be assessed. That is, how to relate the 'state' of a criterion with a level of significance for nature conservation.

This level of significance is expressed by value judgments that are generally based on numerical scales (e.g. the range between one and five) or linguistic scales (e.g. very good, good, poor).

Two main paths for criteria assessment can be distinguished (see Fig. 1):

1. the direct assessment;
2. the assessment based on the use of an indicator and on the subsequent transformation of the raw indicator measurements into value scores.

Path 1, i.e. the direct assessment, consists of the assignment of value judgments on the basis of the 'perceived' state of the criterion. This can be best explained by referring to some examples. In reference [40] it is proposed to assess the connectivity of the landscape elements by assigning value scores between 0 and 5 as shown in Table 2. As it can be seen, the approach does not make use of a measurable indicator. It only provides a sketchy description of the conditions that generate the different value scores.

Guidelines on how to interpret such descriptions are not specified (e.g. what does 'slight connections' mean?). Another example is found in reference [17] and it is related to the assessment of the diversity of natural habitats. The author proposes the assignment of value scores ranging between 1 and 3 according to the conditions described in Table 3. Here the approach suggests that diversity should be assessed by looking at the number of different habitats occurring in the area under investigation. However, the assessor is free to provide his/her own interpretation of terms such as 'very low number' or 'limited number'. Consequently, the assessment is unclear because it provides predefined value scores for undefined ecological conditions. Furthermore, Path 1 relies heavily on the subjective professional judgment of the assessor. Therefore, the assessments are not replicable: different assessors are likely to provide different evaluations of the same feature.

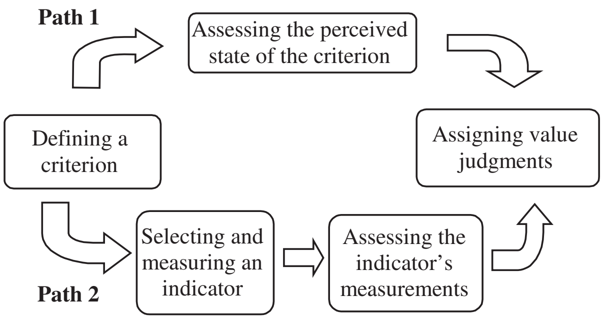

Figure 1: The two paths for the assignment of value scores.

Table 2: Value scores for habitat connectivity.

Description	Score
Inexistent connections	0
Potential connections	2
Interrupted connections	3
Slight connections	4
Existing connections	5

Table 3: Value scores for habitat diversity (linguistic).

Description	Score
Very low number of habitats	1
Limited number of habitats	2
Good or very good range of habitats	3

Table 4: Numerical value scores for habitat diversity [40].

Diversity index	Score
0.30–0.50 or >1.10	1
0.51–0.70 or 0.95–1.10	3
0.71–0.95	5

Table 5: Value score for landscape unit rarity [42].

Relative abundance	Score
>20 examples in the region	0
10–20 examples	1
5–10 examples	2
2–3 examples	3
Only one example	4

The second approach for assessing criteria is more structured and requires the following two steps (see Path 2 in Fig. 1):

1. Defining how each criterion can be measured or expressed in a form that allows evaluation. This usually involves the measurement of specific indicators.
2. Transforming the raw measurements into value scores. This requires the interpretation of the significance of the raw measurement with respect to the evaluation objectives.

Let us see some examples. In reference [40] the diversity of the habitat is assessed by first measuring the diversity index proposed in reference [4]. This index expresses the extent to which one or few habitat types dominate the area under analysis, and nowadays it can be easily computed through a spatial analysis in a Geographical Information System (GIS) [41]. Afterwards, a value score is assigned to the different measurements according to the ranges shown in Table 4.

Another example for assessing rarity is provided by the approach suggested in reference [42]. The rarity of a landscape unit is assessed by first counting its frequency of occurrence within the region of study and then assigning value scores as in Table 5. A similar approach to assess rarity was applied in reference [43], where the potential area remaining (PAR) indicator was computed using a GIS. PAR expresses the rarity of an ecosystem by measuring the ratio between its potential cover and the actual cover remaining in the study area. Subsequently, a functional curve was used to assign a score to each indicator value.

A major advantage of Path 2 is that it allows to keep 'facts' separate from 'values'. Facts refer to objective elements of the evaluation, whereas values refer to subjective ones. In Tables 4 and 5 the facts are listed in the left-hand column and the value judgments in the right-hand column. For instance, it is a fact that the diversity index of a given area is equal to 0.60, but it is a value judgment that such an area scores 3, in a range between 1 and 5. It is worth noting that the decision to use three classes (as in Table 4) or five classes (as in Table 5) is also arbitrary, therefore a value judgment.

The separation between facts and values is not explicit by following Path 1. As a result, Tables 2 and 3 contain value judgments in both columns. Keeping facts and values separate increases the transparency of the evaluation framework and the understanding of the evaluation results. In other words, it will be easier, in principle, to verify why a given value has been assigned to a given area. Analogously, the results of the evaluation are replicable, because the basis for the value assignment is not provided by the assessor's perspective but by objective information.

3 SHORTCOMINGS IN CURRENT PRACTICE AND CONCLUSIONS

One common problem is the lack of a clear statement of the objectives of the evaluation, as pointed out in references [15] and [20]. As a consequence, scientific criteria concerning the inherent biological value of a site are mixed up with criteria related to the services provided by that site or with management considerations. This generates confusion and ambiguity regarding the evaluation results because we simply do not know from which perspective the importance of the natural areas has been determined. For example, the presence of a road in the proximity of a natural area may represent an asset (it increases the accessibility to the site for, say, educational purposes) or a drawback (it is a source of disturbance). Both viewpoints are acceptable, provided that they are clearly stated and coherently followed throughout the evaluation.

Another shortcoming found in ecological evaluations is the correlation between pairs of criteria employed. Several among the most common criteria are not independent, causing double counting in the assessment of the overall significance of natural areas. For example, the complex correlation between size, diversity, rarity and typicalness has been discussed in reference [37].

A third shortcoming is the fact that most criteria assessments tend to follow the approach indicated by Path 1 (see Fig. 1). This is probably because this approach can be set in a simpler way, for it does not require the identification of indicators. However, as discussed, this type of assessment carries the disadvantage of being non-replicable and poorly transparent. Yet, for some criteria, following Path 1 may be the only choice due to the objective difficulty in selecting a suitable indicator.

Complex and long debated concepts, such as the fragility of ecosystems [34], appear hard to represent into measurable parameters. For this reason, it is generally preferred to evaluate them by resorting to the professional judgment of the assessor. In such cases, it is important to define the criterion under analysis with clarity and rigor and to provide extensive guidelines on how to assess it. Else, as it often happens [3], the assessor has too much freedom and consequently the evaluation results are difficult to interpret.

In conclusion, the main problems affecting the practice of ecological evaluation concern the structuring of the evaluation framework: objectives are often poorly defined and not clearly linked to the relevant criteria. In turn, the criteria show problems of correlation and are seldom assessed by means of explicit indicators. This clouds the overall results of the evaluation and undermines their practical use in planning-related procedures such as environmental impact assessments.

The development of GIS technology has supported ecological evaluations by allowing a faster and more accurate computation of key indicators, such as ecosystem shape, connectivity and fragmentation [44, 45, 46, 47]. However, this improvement in the measurement and mapping of ecological parameters is to be integrated with a more structured and transparent framework for their assessment.

This can be done by resorting to methods and techniques developed by the discipline of decision analysis, such as value functions [48, 49]. This knowledge is commonly exploited by other fields of environmental management (soil and water contamination, land-use and resource allocation, etc.), but it is still largely ignored by ecological evaluation studies.

ACKNOWLEDGEMENTS

I would like to thank Prof. A.G. Fabbri, Prof. H.J. Scholten and Dr E. Beinat (SPINlab, Free University of Amsterdam) for their helpful suggestions. The comments of two anonymous reviewers contributed significantly to the quality of this paper.

REFERENCES

[1] Ploeg, van der S.W.F. & Vlijm, L., Ecological evaluation, nature conservation and land use planning with particular reference to methods used in The Netherlands. *Biological Conservation*, **14**, pp. 197–221, 1978.
[2] Spellemberg, I.F., *Evaluation and Assessment for Conservation*. Chapman & Hall: London, 1992.
[3] Smith, P.G.R. & Theberge, J.B., Evaluating natural areas using multiple criteria: theory and practice. *Environmental Management*, **11(4)**, pp. 447–460, 1987.
[4] Turner, M.G., Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics*, **20**, pp. 171–197, 1989.
[5] Forman, R.T.T. & Godron, M., *Landscape Ecology*. Wiley: New York, 1986.
[6] Burke, V.J., Landscape ecology and species conservation. *Landscape Ecology*, **15**, pp. 1–3, 2000.
[7] Bridgewater, P.B., Landscape ecology, geographic information systems and nature conservation. *Landscape Ecology and Geographic Information Systems*, eds. R. Haines-Young, D.R. Green & S. Cousins, pp. 23–36. Taylor & Francis: London, 1993.
[8] Hannson, H. & Angelstam, P., Landscape ecology as a theoretical basis for nature conservation. *Landscape Ecology*, **5(4)**, pp. 191–201, 1991.
[9] Fernandes, J.P., Landscape ecology and conservation management. Evaluation of alternatives in a highway EIA process. *Environmental Impact Assessment Review*, **20**, pp. 665–680, 2000.
[10] Opdam, P., Foppen, R. & Vos, C., Bridging the gap between ecology and spatial planning in landscape ecology. *Landscape Ecology*, **16**, pp. 767–779, 2002.
[11] Davidson, A.D., *The Evaluation of Land Resources*, Longman: Harlow, 1992.
[12] FAO, *A Framework for Land Evaluation*, FAO: Rome, 1976.
[13] Klingebiel, A.A. & Montgomery, P.H., *Land Capability Classification*, USDA Soil Conservation Service: Washington, DC, 1961.
[14] Zonneveld, I.S., *Land Ecology. An Introduction to Landscape Ecology as a Base for Land Evaluation, Land Management and Conservation*. SPB Academic Publishing: Amsterdam, 1995.
[15] Fandiño, M., Framework for ecological evaluation, PhD thesis, University of Amsterdam, 1996.
[16] Lesslie, R., Mackey, B. & Preece, K.L., A computer-based method of wilderness evaluation. *Environmental Conservation*, **15(3)**, pp. 225–232, 1988.
[17] Wright, D.F., A site evaluation scheme for use in the assessment of potential nature reserves. *Biological Conservation*, **11**, pp. 293–305, 1977.
[18] Ratcliffe, D.A., Criteria for the selection of natural reserves. *Advancement of Science*, **27**, pp. 294–296, 1971.
[19] Tubbs, C.R. & Blackwood, J.W., Ecological evaluation of land for planning purposes. *Biological Conservation*, **3(3)**, pp. 169–172, 1971.

[20] Roome, N.J., Evaluation in nature conservation decision-making. *Environmental Conservation*, **11(3)**, pp. 147–152, 1984.

[21] Janssen, R., Multiobjective decision support for environmental management. Kluwer: Dordrecht, 1992.

[22] Smith, P.G.R. & Theberge, J.B., A review of criteria for evaluating natural areas. *Environmental Management*, **10(6)**, pp. 715–734, 1986.

[23] Usher, M.B., *Wildlife Conservation Evaluation*, Chapman & Hall: London, 1986.

[24] Margules, C.R. & Usher, M.B., Criteria used in assessing wildlife conservation potential: a review. *Biological Conservation*, **21**, pp. 79–109, 1981.

[25] Jobin, B., Beaulieu, J., Grenier, M., Bélanger, L., Maisonneuve, C., Bordage, D. & Filion, B., Landscape changes and ecological studies in agricultural regions, Québec, Canada. *Landscape Ecology*, **18(6)**, pp. 575–590, 2003.

[26] Langevelde, F. van, Claassen, F. & Schotman, A., Two strategies for conservation planning in human-dominated landscapes. *Landscape and Urban Planning*, **58**, pp. 281–295, 2002.

[27] Zurlini, G., Amadio, V. & Rossi, O., A landscape approach to biodiversity and biological health planning: the map of Italian nature. *Ecosystem Health*, **5(4)**, pp. 294–311, 1999.

[28] Poudevigne, I. & Baudry, J., The implication of past and present landscape patterns for biodiversity research: introduction and overview. *Landscape Ecology*, **18(3)**, pp. 223–225, 2003.

[29] Ratcliffe, D.A., *A Nature Conservation Review*, Cambridge University Press: Cambridge, 1977.

[30] Knappen, J.P., Scheffer, M. & Harms, M., Estimating habitat isolation in landscape planning. *Landscape and Urban Planning*, **23**, pp. 1–16, 1992.

[31] Environmental Protection Agency, *Considering Ecological Processes in Environmental Impact Assessments*, US Environmental Protection Agency, Office of Federal Activities, 1999.

[32] Gehlbach, F.R., Investigation, evaluation, and priority ranking of natural areas. *Biological Conservation*, **8**, pp. 79–88, 1975.

[33] Wright, R.G., Principles of new park area planning as applied to the Wrangell-St Elias region of Alaska. *Environmental Conservation*, **12(1)**, pp. 59–66, 1985.

[34] Nilsson, C. & Grelsson, G., The fragility of ecosystems: a review. *Journal of Applied Ecology*, **32**, pp. 677–692, 1995.

[35] Götmark, F., Naturalness as an evaluation criterion in nature conservation: a response to Anderson. *Conservation Biology*, **6**, pp. 455–458, 1992.

[36] Poldini, L. & Pertot, M., Criteri di indicizzazione del valore naturalistico sull'esempio del Carso triestino-goriziano. *Informatore Botanico Italiano*, **21**, pp. 1–9, 1989.

[37] Usher, M.B., Implications of species-area relationships for wildlife conservation. *Journal of Environmental Management*, **21**, pp. 181–191, 1985.

[38] Cooper, C.F. & Zedler, P.H., Ecological assessment for regional development. *Journal of Environmental Management*, **10**, pp. 285–296, 1980.

[39] Edwards-Jones, G., Davies, B. & Hussain, S., *Ecological Economics. An Introduction*, Blackwell Science: Cornwall, 2000.

[40] Palmeri, F. & Gibelli, M.G., Valutazione di impatto ambientale e paesaggio: il caso della ferrovia Trento-Malè. *Esercizi di ecologia del paesaggio*, ed. V. Ingegnoli, pp. 169–201, Città Studi: Milano, 1997.

[41] Eastman, R., *IDRISI Kilimanjaro. Guide to GIS and Image Processing*, Clark Labs, Clark University: Worcester, MA, 2003.

[42] Rivas, V., Rix, C., Frances, E., Cendrero, A. & Brunsden, D., The use of indicators for the assessment of environmental impacts on geomorphological features. *Geomorphology and*

Environmental Impact Assessment, eds. M. Marchetti, M. Panizza, M. Soldati and D. Barani, *Quaderni di Geodinamica Alpina e Quaternaria*, **3**, pp. 157–180, 1995.

[43] Geneletti, D., Biodiversity impact assessment of roads: an approach based on ecosystem rarity. *Environmental Impact Assessment Review*, **23(3)**, pp. 343–365, 2003.

[44] Larson, B.D. & Sengupta, R.R., A spatial decision support system to identify species-specific critical habitats based on size and accessibility using US GAP data. *Environmental Modelling and Software*, **19**, pp. 7–18, 2004.

[45] Lee, J.T., Bailey, N. & Thompson, S., Using geographic information systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chitren Hills, UK. *Journal of Environmental Management*, **64**, pp. 25–34, 2002.

[46] Aspinall, R. & Pearson, D., Integrated geographical assessment of environmental condition in water catchments: linking landscape ecology, environmental modelling and GIS. *Journal of Environmental Management*, **59**, pp. 299–319, 2000.

[47] Lee, J.T., Elton, M.J. & Thompson, S., The role of GIS in landscape assessment: using land-use-based criteria for an area of the Chiltren Hills area of outstanding beauty. *Land Use Policy*, **16**, pp. 23–32, 1999.

[48] Beinat, E., *Value Functions for Environmental Management*, Kluwer Academic Publishers: Dordrecht, 1997.

[49] Geneletti, D., Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. *International Journal of Applied Earth Observation and Geoinformation*, **5**, pp. 1–15, 2004.