Geogr. Fis. Dinam. Quat.
29 (2006), 153-163, 8 figg., 5 tabb.

VIOLA BRUSCHI (*), ANTONIO CENDRERO (*), CÉSAR OTERO (**),
ANDRÉS IGLESIAS (***), JAIME BONACHEA (*), MIGUEL LAZARO (**)
& REINALDO TOGORES (**)

THE APPLICATION OF COMPUTER-BASED PROCEDURES FOR THE VISUAL LANDSCAPE SENSITIVITY ASSESSMENT

ABSTRACT: BRUSCHI V., CENDRERO A., OTERO C., IGLESIAS A., BONACHEA J., LAZARO M. & TOGORES R., *The application of computer-based procedures for the visual landscape sensitivity assessment*. (IT ISSN 1724-4757, 2006).

The concept of visual landscape sensitivity is related to both the degree of visibility of new structures and the quality (intrinsic merit) of surrounding landscape. For a given landscape modification, visual impact is directly related to visual sensitivity. There are difficulties to translate that general concept into procedures or practice that can be routinely applied in different realms. A proposal is presented for describing, measuring and assessing visual impact of human interventions. The procedure proposed is based on the use of quantitative parameters that express the visibility of new elements in the landscape (visibility area, viewing population, magnitude of visual intrusion), as well as criteria for establishing a visual quality rank of landscape units affected. Assessment of visual impacts (directly dependent on visual landscape sensitivity) is carried out using qualitative criteria (contrast with surrounding landscape on the basis of visual quality of the unit affected) as well as comparison of different impact- or sensitivity- related magnitudes between the proposed actions and certain reference standards. The procedure, which can be implemented using easily accessible computer tools, makes it possible to rank different alternatives in terms of their visual sensitivity to a given landscape modification.

KEY WORDS: Visual landscape sensitivity, Visual impact, GIS, Computer Graphics tool, Northern Spain.

RIASSUNTO: BRUSCHI V., CENDRERO A., OTERO C., IGLESIAS A., BONACHEA J., LAZARO M. & TOGORES R., *Applicazione di procedure automatiche per la valutazione della sensibilità del paesaggio visuale*. (IT ISSN 1724-4757, 2006).

Il concetto di sensibilità del paesaggio visuale si relaziona con il grado di visibilità di una nuova infrastruttura e con la qualità (merito intrinseco) del paesaggio interessato dalla nuova opera. Per una determinata modificazione del paesaggio, l'impatto visuale è direttamente relazionato con la sensibilità paesaggistica. È abbastanza complesso tradurre il concetto di sensibilità paesaggistica a un procedimento che possa essere applicato sistematicamente e in vari ambiti. Il procedimento proposto è stato studiato per descrivere, misurare e valutare l'impatto visuale prodotto da una determinata attività antropica. La metodologia proposta si basa su l'utilizzazione di parametri quantitativi che esprimano la visibilità dei nuovi elementi che formano il paesaggio (zona visibile, osservatori, magnitudine della intrusione visuale) e su criteri per stabilire la classe di qualità visuale delle unità paesaggistiche interessate dalla nuova infrastruttura. La valutazione dell'impatto visuale (dipendente direttamente dalla sensibilità visuale del paesaggio) viene determinata utilizzando criteri qualitativi (contrasto fra le unità paesaggistiche soggette a impatto e il paesaggio circostante) e la comparazione fra la magnitudine dell'impatto del nuovo paesaggio con gli standard stabiliti in precedenza. Il procedimento, che può essere applicato con l'aiuto di sistemi informatici molto semplici, permette classificare diverse alternative in funzione della sensibilità del paesaggio con rispetto a determinate modificazioni paesaggistiche.

TERMINI CHIAVE: Sensibilità del paesaggio visuale, Impatto visuale, SIT, Spagna settentrionale.

INTRODUCTION

Landscape Sensitivity (LS) has been analyzed and studied from different perspectives: geomorphologic, pedologic, ecologic etc. Due to its multidisciplinary nature, this concept has been used with a variety of meanings, although it normally includes the consideration of changes in landscape processes or characteristics in response to external influences (Brierly & Stankoviansky, 2003).

The term LS was introduced by Brunsden & Thornes (1979) to explain the episodes of erosion and sedimentation in geomorphologic systems. These authors defined LS as the likelihood that disturbing forces, applied to a certain system, generate changes on landscape. Landscape sensitivity is determined by the balance between disturbing and resisting forces (Brunsden, 1993, 2001). The former are gener-

(*) *Departamento de Ciencias de la Tierra y Física de la Materia Condensada, Universidad de Cantabria, Spain.*
(**) *Departamento de Ingeniería Geográfica y Técnicas de Expresión Gráfica, Universidad de Cantabria, Spain.*
(***) *Departamento de Matemática Aplicada y Ciencias de la Computación, Universidad de Cantabria, Spain.*

This work was carried out in part within project GETS (contract: ERBFMR CT97-0162, European Commission). V.M. Bruschi had a grant from the Fundación Marcelino Botín. Thanks are also expressed to the Diputación Foral de Gipuzkoa (DFG) and the Instituto Geológico y Minero de España (IGME) for providing data.

ated by the application on a system of energy derived from external factors, be they natural or human. The latter are internal characteristics of the system that determine its capability to resist change under a disturbance. The instability of a system corresponds to the probability of changes that could disturb the environmental processes (Thomas, 2001). The role of the human factor is considered by Usher (2001) through the concept of "human sensitivity", «essentially due to land use change and water management activities changing the natural sensitivity of hydrological processes and hence human reactions to change varying over time».

As pointed out by Thomas & Allison (1993) human impacts affect landscape sensitivity and can modify landscape in an irreversible way. Human impacts are produced through changes that often imply a degradation of geomorphic (or other) processes. This degradation may be reflected in a loss of landscape qualities significant for human welfare (reduction in productivity, decrease in the capacity of the system to act as a buffer against certain process and consequent increase in hazards etc).

The concept of landscape sensitivity also has a broader meaning, involving landscape characteristics that, although dependent in part on geomorphic characteristics, are not mainly or directly related to geomorphic processes (Holling, 1973; Odum, 1983; Rubio, 1995; Tallis, 1998; Geneletti & *alii*, 2000; Bragg & Tallis, 2001; Burt, 2001; Gordon & *alii*, 2001; Miles & *alii*, 2001; Milne & Hartley, 2001). In all cases, landscape sensitivity is directly or indirectly related to human influence.

The different uses of the landscape sensitivity concept briefly described above refer to the analysis of physical processes (be they abiotic or biotic) that affect landscape evolution. But the same type of concept can also be applied to certain immaterial processes related to landscape perception (González-Bernáldez, 1981). It is well known that the use of landscape by people is more and more determined by its cultural, aesthetic or recreational values (Cancer, 1999), rather than by its production potential. The capacity of an area (a given landscape) to generate economic or leisure activities is very much dependent on people's perception of that landscape. A very important factor for that perception is the visual quality of landscape.

Visual quality of landscape is determined by three large categories of characteristics: geomorphology (relief, landform and materials), land cover/use, and human structures. With some differences, similar factors have been considered by other authors (among others: Ramos, 1987; Canter, 1996; Daniel, 2001). Human perception and the consequent positive or negative reaction to a given panorama results from the combination of those factors (Daniel, 2001). In general, the greater the presence of prominent human elements (buildings and infrastructures) the lower the appreciation of a landscape (this, of course, does not include building of historical or artistic value, which would add value to the landscape). That is, natural elements tend to be more appreciated from the visual point of view than artificial structures.

For instance, the effect of a new structure on human perception depends to a great extent on its degree of visibility, the number of people affected and the visual quality of the surroundings. Other things being equal, an area with high relief and rugged landforms will have lower landscape sensitivity than an area with smooth relief and landforms, because any new object will be less visible in the former, as it will be better «hidden» by the irregular topography. Accordingly, "disturbing forces" that may affect landscape in this sense are those that tend to increase the number or visibility of elements that can negatively affect landscape perception (reduce its visual quality). "Resisting forces" are those that help to minimise the visual effect produced by the former ones. The balance between those two sets of "forces" plays a determining role in the changes experienced by landscape from the visual point of view; that is in visual impacts as perceived by people (Escribano & Martínez, 1989; Canter, 1996; Daniel, 2001; Alberruche del Campo, 2002). It that is so, we could extend the concept of landscape sensitivity to its visual characteristics. It would be of interest to develop and apply methods to measure the visual impacts landscape may experience and assess its sensitivity from that point of view. The process affected in this case is not a physical one, but the immaterial process of landscape perception and appreciation. This process, of course, is ultimately determined by the characteristics mentioned above, which do have a material nature.

METHODOLOGY

The method proposed and tested here is an attempt to developed procedures to describe and measure changes produced by human activities on visual landscape characteristics and assess the sensitivity of a given landscape to those changes. In other words, to assess the capacity of landscape to absorb changes (US Department of Agriculture, 1974) without significantly altering quality as perceived by people (Brown & Daniel, 1986; 1987; Brunson & Shelby, 1992). To do this, the general methodological approach shown in fig. 1 has been applied.

CONCEPTS

A series of landscape characteristics or qualities are defined, and parameters and procedures to measure and assess them proposed. Similar terms have been used by other authors with a different meaning (US Department of Agriculture, 1974; Escribano & Martínez, 1989; Canter, 1996; Daniel, 2001). The definitions presented below do not intend to be an alternative terminological proposal, but simply to clarify the meaning of the terms for the present work.

Visual quality (VQ): it is a subjective concept defined as the position of a given landscape within a rank established on the basis of people's appreciation. It is obviously culturally and geographically dependent and could vary according to the social group considered (general public, managers, experts etc).

Magnitude of visual intrusion (MVI): quantitative expression of the effect of new structures on human perception. This can be considered from two viewpoints: area from

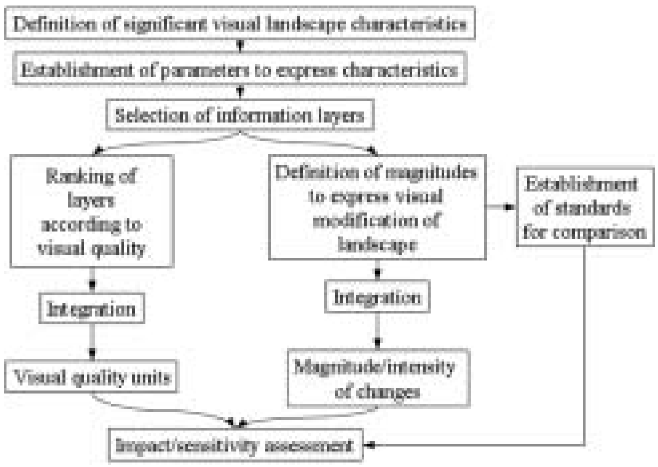


FIG. 1 - Schematic flow diagram of the methodology.

which the structure would be seen («visibility area»; Smardon, 1988) and number of people who could see it («viewing population»; Martin, 1984).

Intensity of visual intrusion (IVI): qualitative assessment of the importance of changes for human perception. Due to its qualitative nature, this concept is more elusive and difficult to define. It can be done on the basis of contrast between the new structure and its surroundings, the extent to which it modifies a given viewing frame, or the «acceptability» of visual modifications established from opinion surveys.

The former concepts and general approach have been applied to the assessment of visual impacts in two case studies, using different procedures for integration of the individual characteristics considered.

Visual landscape sensitivity (VLS): a quality of landscape which expresses the degree to which visual perception of landscape by humans is deteriorated through human intervention. For a given intervention ("disturbing forces" represented by roads, buildings, quarries etc) sensitivity depends on the quality of the landscape affected and its capacity to "hide" the intervention ("resisting forces"). It is assumed that sensitivity increases with landscape quality and decreases with degree of visibility.

APPLICATION TO CASE STUDIES

The above concepts and the general methodology shown in fig. 1 were applied to two different case studies (fig. 2). The aims of both analyses were different and certain details of the procedure used are slightly different too.

The first case study is an analysis of visual landscape sensitivity related to the construction of a new motorway in northern Spain and has partially been described by Bonachea & *alii* (2005). A procedure for determining and integrating the parameters used for the assessment was implemented on GIS (ArcView & ArcGis) and a Computer Graphics tool was applied. The study area (fig. 2) has quite a pronounced relief (Tamés & *alii*, 1991), with narrow valley floors and fairly steep valley slopes (average gradient 25%). The landscape is of a rural character over most of the area, with quite high visual quality. Exceptions to this general character are the surroundings of Eibar and Vergara, two essentially industrial towns, with a degraded visual landscape. Two motorway alternatives were analysed

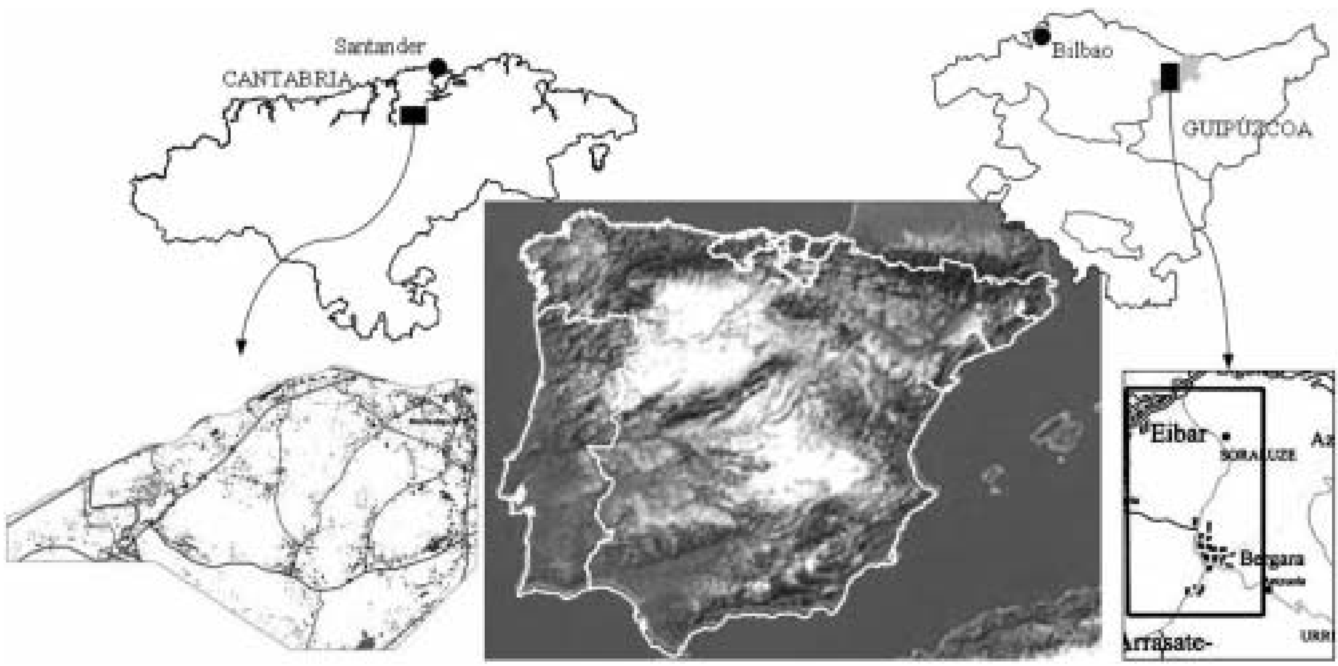


FIG. 2 - Location of study areas.

(Alternative A: 15 km long with 6 km of tunnels; Alternative B: 16 km long and 1 km of tunnels).

Out of a database consisting of 21 thematic layers (Bonachea & *alii*, 2005) a number were selected for visual landscape assessment: Digital Terrain Model (DTM), Geomorphic Units (GU), Land Cover/use (LC), Roads (R), Motorway Geometry (MG) and Population Centres.

The first step in the procedure proposed was to define and map visual landscape units, according to criteria based on the visual quality of individual components (layers). Visual landscape units were defined by overlay of two thematic layers, large-scale geomorphic or landform types and land cover/use. Those two characteristics were also the basis for the establishment of a visual quality rank. Initially, landform (GU) and land cover/use (LC) types were ranked separately (tab. 1) and then combined (tab. 2). The procedure can be applied using either integrated environmental units (Cendrero & *alii*, 1992) or separate thematic maps (Bonachea & *alii*, 2005). A map of landscape units (LU), ranked according their visual quality, was thus obtained (fig. 3) and contrasted by different experts.

The next steps are schematically illustrated in fig. 4. Intersection of motorway route (MR) and landscape units (LU) was used to determine motorway sectors into each landscape unit (MSLU) affected. Areas of high population density (PD) were determined from the population centres map plus detailed population data (EUSTAT, 1999). This plus areas along the existing road network, including a 100m buffer on each side, were combined to define areas of great visual effect (GVE); that is, the parts of the study area in which the majority of potential viewers are located. The "viewsheds" (VS) or visual basins of each MSLU were then determined using the Computer Graphics tool; viewsheds for different sectors of course overlap (Otero & *alii*, 2004). In fig. 4 the total area of VSs overlap as well as one individual VS are schematically represented.

The intersection of areas from which the motorway will be visible (VS) with areas where potential viewers are concentrated (GVE) defines areas in which the new structures will produce significant visual intrusion (SVI); that is, areas most sensitive to visual alterations of the landscape from the point of view of human perception. The rest of the territory includes areas from which the motorway will not be visible or visibility areas with practically no human presence. SVI provide a means to express visual impact in quantitative terms, on the basis of visibility area (VA; km^2) and number of potential viewers or viewing population (VP; No. of persons). Viewing Population (VP) was calculated by overlay of population centres over the former. If only part of a population centre was within the visibility area, the population affected was assigned proportionally to the viewing area. Overlay of visibility area and roads (and data about vehicle flows) can be used to determine the number of potential transient viewers, but this was not done in the present case.

Magnitude of visual intrusion (MVI) can thus be expressed as a combination of the former:

$$\text{MVI (km}^2\text{persons)} = \text{VA (km}^2\text{) x VP (No. of persons)}$$

Table 3 shows the results obtained for the two alternatives considered in the case study.

TABLE 1 - Categories of visual quality for land cover/use and landform types

Land cover/use type (LC)	Visual quality
Urban areas	1
Industrial	1
Cultivated prairies and crops with hedges	2
Terraced crops and cultivated prairies	2
Afforestations	3
Crops/afforestations mosaic	3
Shrubs	4
Rock	4
Crops/forest mosaic	4
Forests/afforestations mosaic	4
Deciduous forests	5
Mixed forests/shrubs mosaic	5
Landform type (GU)	
Alluvial plain	1
Valley floor and adjacent slope	2
Valley slopes and gentle interfluves	3
Abrupt summits and crests	4
Network of small valleys and interfluves	5

TABLE 2 - Integration of landform (GU) and land cover/use (LC) to define visual quality classes

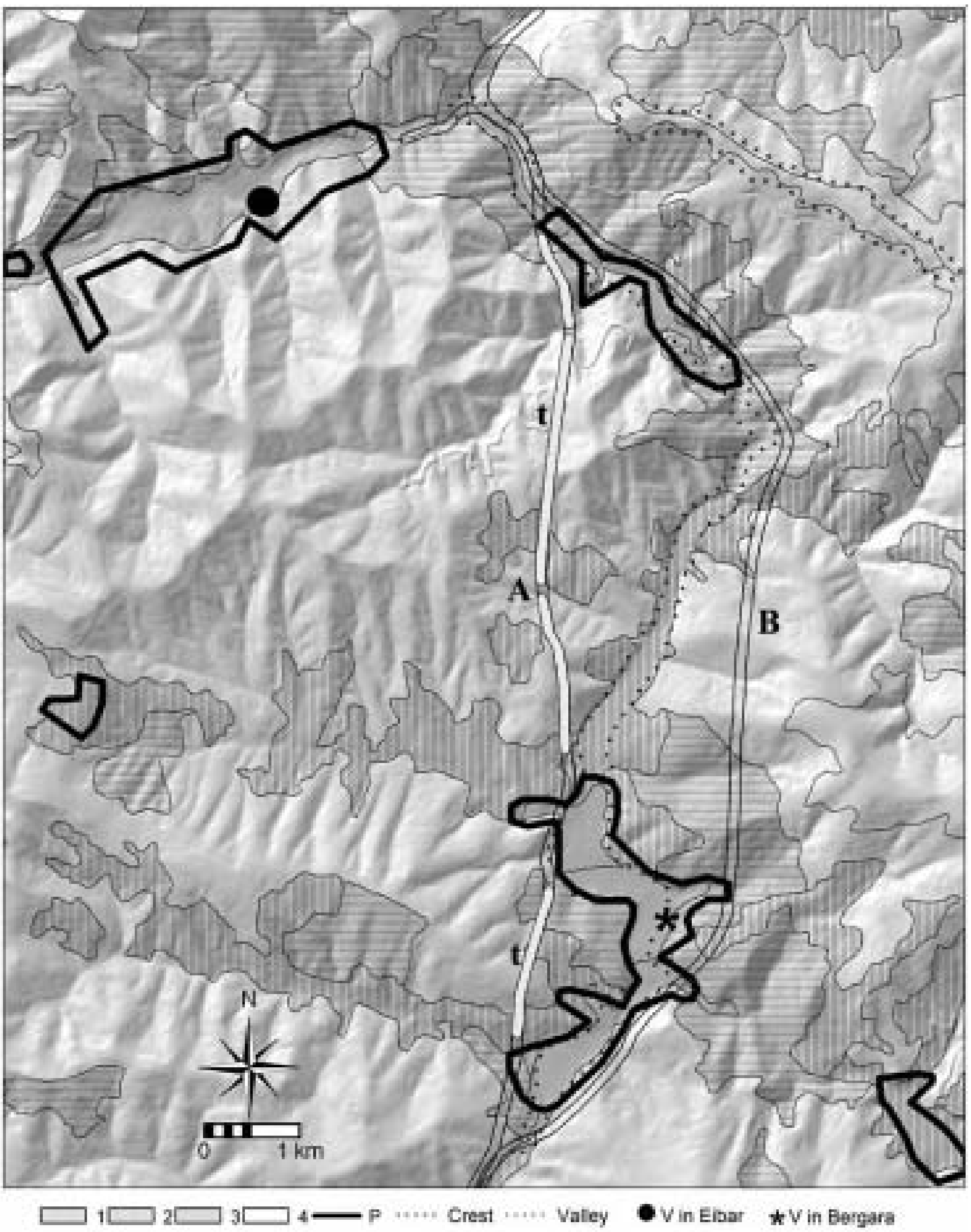
		LC				
		1	**2**	**3**	**4**	**5**
GU	**1**	1	1	2	2	3
	2	1	2	2	3	3
	3	2	2	3	3	4
	4	2	3	3	4	5
	5	3	3	4	4	5

TABLE 3 - Magnitude of Visual Intrusion and Visual Impact values of the two motorway alternatives

	Alternative A	Alternative B
VISIBILITY AREA (VA) (km^2)	34.8	54.9
VIEWING POPULATION (VP; Nº persons)	15,581	20,427
MAGNITUDE OF VISUAL INTRUSION (MVI) (km^2persons)	542,218	1,103,058
VISUAL IMPACT (VI) (km^2personsCF)	**108,443**	**303,092**

MVI is thus expressed in strictly quantitative terms (although the magnitude used to measure it, km^2persons, may not have an easy-to-grasp meaning). The meaning of the results in tab. 3 is that alternative B goes through areas with greater visual landscape sensitivity (the new structure will produce a visual effect on a larger portion of the territory and a greater number of people, thus affecting human perception to a greater extent). In other words "resisting

FIG. 3 - Map of visual quality units and motorway alternatives. 1-4: visual quality class; P: population centres; A and B: motorway alternatives; t: tunnel sectors; *V visual reference points in Eibar and Bergara (see text).



forces" in these areas counteract to a lesser extent "disturbing forces" represented by the motorway. That is, generally speaking MVI will be greater in populated than in isolated areas (other factors being equal).

MVI provides a quantitative expression of visual impact, but landscape perception and appreciation is also qualitative. It is therefore convenient to find some means to express the sensitivity of a given landscape unit to the visual intrusion produced by a new structure on the quality perceived by viewers.

A simple way to do this is to consider that the higher the visual quality of the unit hosting the new structure the greater the intensity of the visual affect. That is, the sensitivity to visual modification of a pristine, high visual quality unit will be greater than that of a highly transformed unit. This relationship is qualitative, but can be represented by means of a linear value function (fig. 5). Of course, other types of value functions can be used, but this represents an easy-to-apply, straightforward assumption. The fig. expresses the relationship between visual quality of units and a correction factor (CF) that can be applied to the values obtained for MVI. Units with high visual quality would have CF = 1 and the former value not change. Units with very low visual quality would have CF = 0 and MVI would be reduced to nil. This is equivalent to saying that highly degraded, low visual quality units would not be vi-

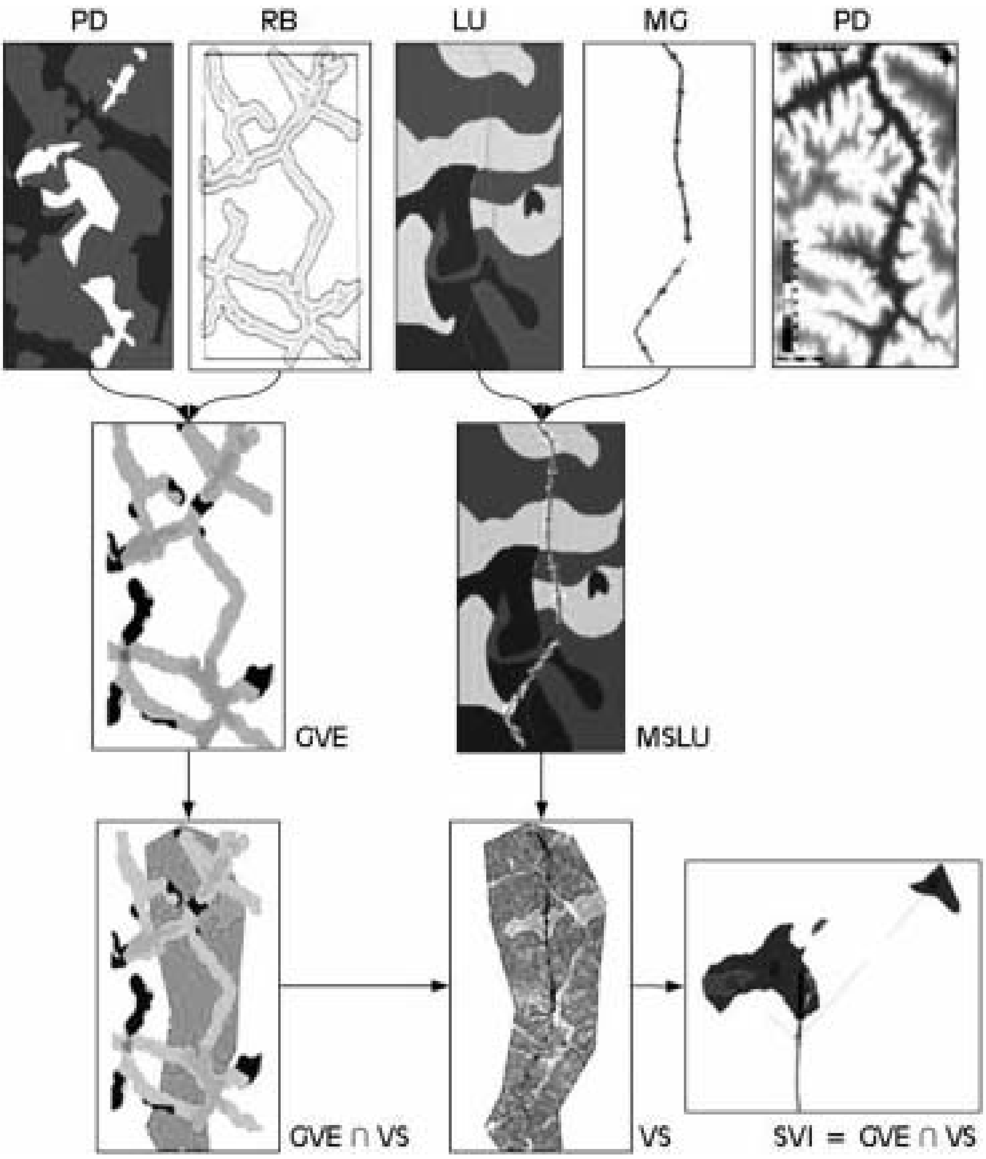


FIG. 4 - Procedure followed for determining areas of significant visual impact. Thematic layers. PD: Population density; MG: Motorway Geometry; LU: Landscape units; RB: Road Buffers; DTM: Digital Terrain Model; MSLU: Motorway's sections in Landscape Units; CMSLU (centroids); GVE: Areas of Great Visual Effect; VS: Viewsheds; SVI: Areas of significant Visual Impact.

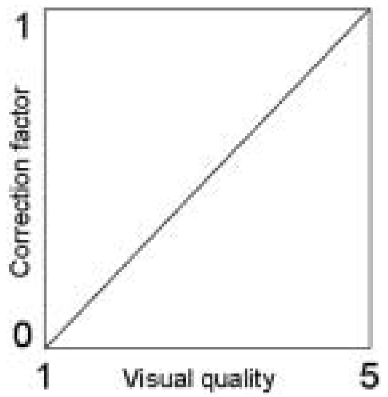


FIG. 5 - Value function representing the relationship between the visual quality of landscape units and a correction factor applied to magnitude of visual intrusion values.

sually affected by the introduction of new structures. The opposite, of course, would be the case of high quality units, much more sensitive from this point of view.

The results obtained through the application of this procedure are presented in tab. 3. This result shows that indeed alternative B is worse using sensitivity criteria related to contrast with hosting units. This alternative has a MVI approximately double than the one of alternative A. Moreover, its visual impact is nearly triple. This means that not only it is seen from a larger area and by more people, but that its contrast with the surroundings is also greater. That is, alternative B affects areas of higher visual landscape sensitivity.

An alternative approach to incorporate the degree of contrast between new structure and surrounding landscape, as perceived by viewers, is to simulate a series of "realistic viewing frames" (fig. 6) with the motorway in-

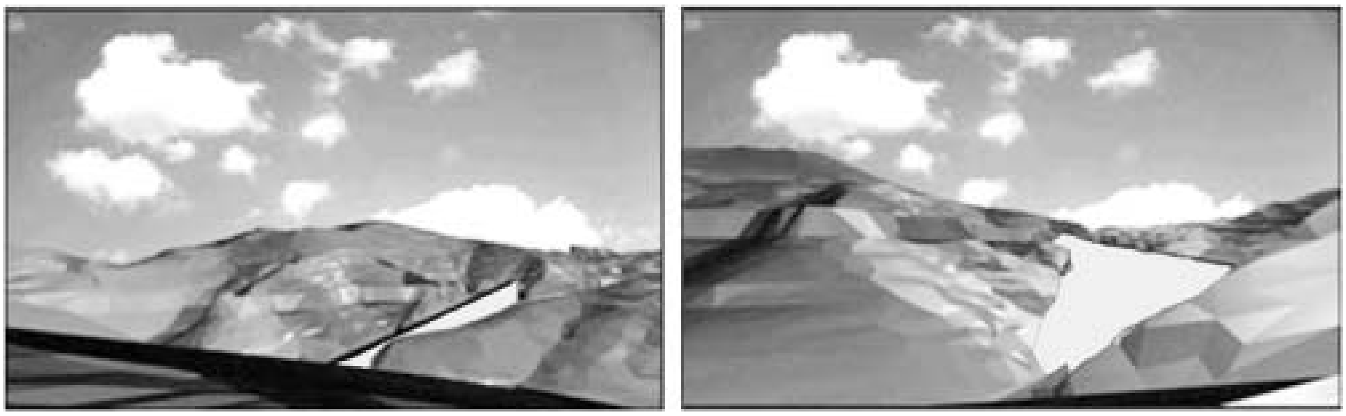


FIG. 6 - Examples of realistic views to calculate the percentage of viewing frame occupied by new structure and qualitatively assess the intensity of visual intrusion.

corporated (Bishop & Leahy, 1989; US Department of Agriculture, 1977; US Department of the Interior, 1980; Shepard, 1989; Bishop, 1999). Centroides of MSLU can be used as significant view targets or "emitters" and CSVI as view "receivers". A simulation of results can be generated automatically. The intensity of visual intrusion (IVI) can then be expressed in terms of the percentage of the viewing frame occupied by the new structure. Different realistic views can be obtained and used to establish quality ranks on the basis of questionnaires administered to selected potential viewers (Kaplan & *alii*, 1972; Kaplan, 1975; Daniel & Boster, 1976; Stamps, 1990; Stewart & *alii*, 1984, Steinitz, 2001). Fig. 6 shows two such realistic views; the option on the right represents a greater visual intrusion.

The latter approach was applied to a few CMSLU and CSVI and results obtained were not very different from the ones derived using the former procedure. However, as the second method as not yet been systematically applied to the whole study area, a meaningful comparison between the pros and cons of the two options cannot be made at this stage.

The sensitivity of landscape to the introduction of the new structures that represent a visual modification can also be assessed by comparing the new element with already existing human structures or natural landforms. In the present case this has been done, on the one hand, by comparing the MVIs of motorway alternatives and two large, prominent buildings in the study area, one in Eibar and one in Vergara (fig. 3).

Visibility area, viewing population and MVI of both structures are quite similar (8.34 km^2, 1,898 persons; 15,829 km^2persons and 10.4 km^2, 1,419 persons; 14,758 km^2persons). The average was taken as the standard. Magnitude ratios (r = MVI Motorway alternative/MVI reference standard) are r(A) = 35.4 and r(B) = 72.12 if comparison is made with the whole motorway. A more appropriate comparison, however, is with the average visual effect of individual motorway sectors. In this case the values obtained are r(A) = 0.82 and r(B) = 0.97. Magnitude of visual effect of motorway sectors is therefore slightly below that of existing large buildings. If the cumulative effect of all sectors is considered the effect is obviously much greater.

On the other hand, contrast with natural landforms was assessed through the Degree of Landform Change (DLC). This is an expression of the relative size of new, artificial structures and natural landforms. In other words, it is a means to express the magnitude of land surface geometry change represented by new structures. As the visibility of landforms and structures is determined to a great extent by their vertical section, DLC can be expressed by the ratio between the «average vertical sections» (AVS = average height x length) of new, artificial and natural landforms of a similar general shape (crests or valleys in the case of linear structures).

DLC = AVS structure / AVS reference landform

It is clear that DLC will be greater in smooth, gentle relief areas than in rugged areas with marked relief (large natural landforms).

To calculate DLC, the thematic layers used were DTM and MR. The AVS of motorway alternatives and of the two largest linear landforms in the study area, one positive and one negative (fig. 3) were calculated. They are main river valley and a pronounced NW-SE crest at the Northeast corner of the study area. Average vertical sections obtained are: river valley: 15,200?20m (304,000 m^2); crest: 4,900?40m (152,756 m^2). Average vertical sections obtained for alternatives A and B are respectively 8,425?10m (84,250 m^2) and 12,628?36m (454,608 m^2). The size ratios (rs) obtained were: rs(A) Valley = AVS(A) / AVS(V) = 0.28; rs(A) Crest = AVS(A) / AVS(C) = 0.55; rs(B) Valley = AVS(B) / AVS(V) = 1.5; rs(B) Crest = AVS(B) / AVS(C) = 3. That is, the "artificial landform" represented by alternative B represents a significant modification compared to natural linear landforms in the area, especially if crests (more comparable to the shape of a motorway) are considered.

The procedure described makes it possible to express the visual effect of the motorway in both quantitative and qualitative terms. It takes into account the relative size of the new structures and other artificial structures or natural landforms in the area, its visibility in terms of area and people affected and the degree of contrast with the quality of surrounding landscape. The results obtained show in all cases that alternative B produces a higher visual impact; that is, the balance between "disturbing" and "resisting" forces affecting landscape perception is more favourable in the case of alternative A.

The second case study concerns the analysis of visual landscape sensitivity within a general assessment process for the determination of areas adequate for limestone quarries (crushed rock for aggregate) in an area near Santander, northern Spain (fig. 2).

The study area is made up of Mesozoic materials, among which massive, lower Cretaceous limestones are the most abundant. The relief is moderately rugged, with karstic massifs as a characteristic landscape element. Natural land cover has been intensely altered, with Eucalyptus and grass fields as the most extensive types. Population density is quite high, with constructions (houses, industries) distributed throughout the area.

TABLE 4 - Units in information layers (landform units, LU; land use/cover units, LC; human occupation units, H) ranked according to visual quality

CODE	LANDFORM UNITS	VISUAL QUALITY
1	Doline field	4
2	Depressions with small lakes or ponds	4
3	Large, flat-bottomed depressions, surrounded by pronounced slopes	3
4	Moderate to steep slopes with irregular karst morphology	4
5	Moderate to steep slopes (15-50%), not very rugged	3
6	Prominent karst massifs with well developed lapies morphology	5
7	Small fluvial valleys, with flat bottom and gentle slopes (5-15%)	1
8	Small isolated reliefs surrounded by gentle gradients	5
9	Fluvial valley with well-developed alluvial plain	4
10	Medium-amplitude valleys, with a narrow alluvial plain and moderately steep valley slopes (up to 50%)	2
11	Wetlands, partly drained	2
12	Slopes with gentle to moderate gradient (5 - 25%)	1
CODE	**LAND USE/C0VER UNITS**	**VISUAL QUALITY**
A	Deciduous forests (mainly oak and green oak)	5
B	Green oaks and shrubs	5
C	Mosaic of green oak, shrubs and Eucalyptus	3
D	Shrubs and bushes	4
E	Cultivated grasslands with small patches of shrubs and deciduous trees	3
F	Cultivated grasslands with rock outcrops covered by green oak	3
G	Grass and other cultivated crops	2
H	Eucalyptus afforestations	1
I	Wetlands vegetation	4
CODE	**HUMAN OCCUPATION UNITS**	**VISUAL QUALITY**
I	Industrial area and high density urban area	1
II	Medium density urban areas	2
III	Rural nuclei	3
IV	Isolated buildings	4
V	Practically no human occupation/structures	5

TABLE 5 - Combination of information layers to obtain landscape visual quality units

LU \ LC	1	2	3	4	5
1	1	1	2	2	3
2	1	2	2	3	3
3	2	2	3	3	4
4	2	3	3	4	5
5	3	3	4	4	5

LU/LC \ H	1	2	3	4	5
1	1	1	2	2	3
2	1	2	2	3	3
3	2	2	3	3	4
4	2	3	3	4	5
5	3	3	4	4	5

The aim of visual sensitivity analysis was to identify, among limestone outcrops with potential for exploitation, those with the lowest visual sensitivity; that is, where future quarries would cause minimum visual impact (Smardon & *alii*, 1986).

The general procedure was implemented using ArcGis. The results obtained from this part of the analysis were integrated with those regarding other environmental factors, but this aspect will not be discussed here.

The procedure to map and rank visual quality units was quite similar to the one previously described, but instead of two information layers three were used (landform units, vegetation/land cover, human occupation). Units in the three layers were ranked according to visual quality (tab. 4) and then combined in two steps (tab. 5). A map of visual quality units was thus obtained (fig. 7). As in the former case, high quality areas are considered to be more sensitive to the visual impact produced by human modifications (quarries). Accordingly, in the initial selection procedure classes 4 and 5 were labelled as «highly sensitive» and eliminated at this stage of the analysis.

Visibility was determined quantitatively, measuring the area from which a given outcrop is visible. This was assessed through comparison with the visibility of geomorphologically and visually relevant points in the study area, used as reference standards. The two highest peaks in the area, corresponding to the summits of the karstic massifs, were used as reference standards (fig. 8). Visibility area was measured

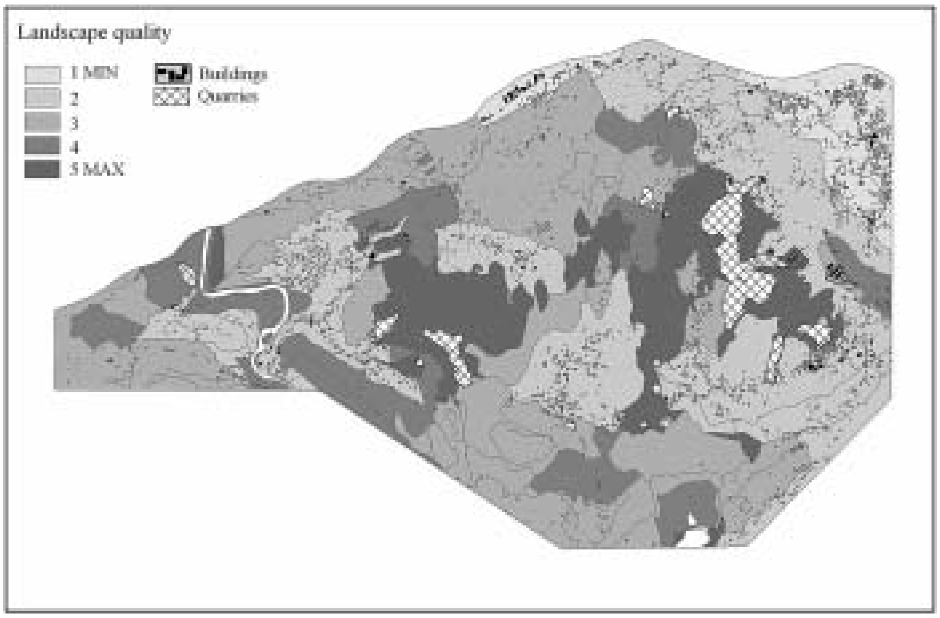


FIG. 7 - Landscape quality map.

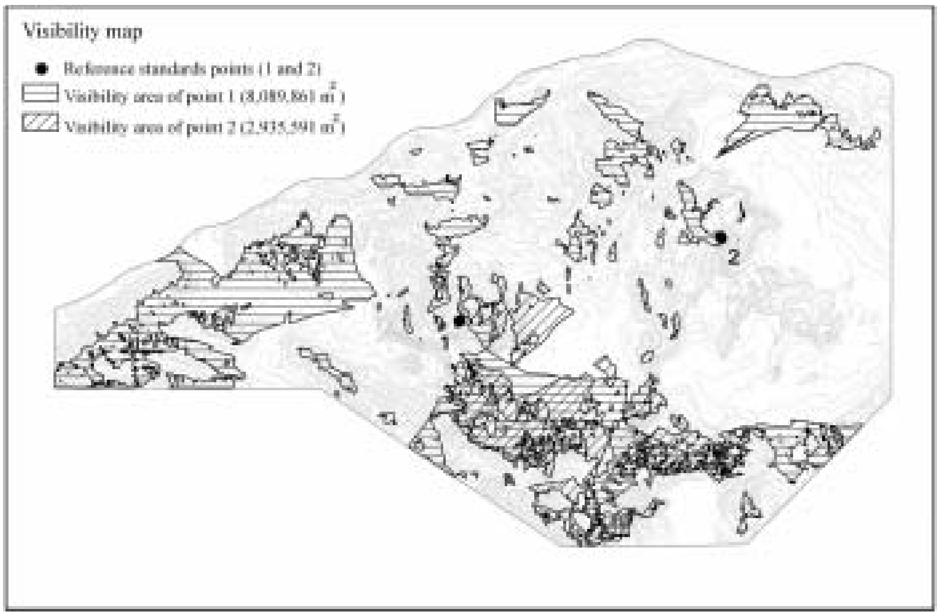


FIG. 8 - Visibility areas for points 1 and 2 (the two highest peaks in the study area) used as reference standards.

using ArcGis and is shown in fig. 8. Visibility area for those points is 8,089,861 m^2 for point 1, and 2,935,591 m^2 for point 2 in the map. The average was used as reference standard. Visibility area of the outcrops considered varied between 107,521 m^2 and 988,725 m^2. Visibility ratios (Voutcrop/Vstandard) thus varied between 0.02 and 0.2. Outcrops with visibility ratios above 0.15 were considered as highly sensitive and eliminated from the selection process.

The final visual sensitivity assessment was carried out through a combination of visual quality and visibility criteria. Outcrops within landscape units of quality classes 3 or lower, and visibility ratios lower than 0.1 were considered to have low sensitivity. Those with visibility ratios between 0.1 and 0.15 are considered visually sensitivity areas, in which exploitation could be acceptable if certain visual impact mitigation measures are implemented. fig. 9 shows the distribution obtained.

This case study illustrates that in certain cases, in which proposed activity affects a relatively small area and has a concentrated visual impact, a simplified procedure can be implemented to identify low visual sensitivity zones. As in the former example, both quantitative and qualitative criteria are applied.

FINAL COMMENTS

The method proposed is an attempt at assessing the sensitivity of visual landscape to different types of modifications caused by human activities. This method provides the basis for the quantitative description of visual impacts using absolute magnitudes (visibility area, viewing population, magnitude of visual effect) or comparisons with the visibility of existing structures or natural landforms (visibility ratios, degree of landform change). The method should be preferably applied at scales greater than 1:50,000. At lower scales the calculation of visibility area is less precise. The assessment of impacts is based on those comparisons as well as the degree of contrast between the proposed changes and the surrounding landscape, assuming that the greater the visual quality of the hosting unit, the higher the contrast with the new element.

Although the balance between "disturbing" and "resisting" forces affecting visual perception of landscape cannot be established in absolute terms, it is possible to compare different alternatives and identify those for which such balance is most favorable. The whole procedure can be implemented using technological tools which are easily accessible in either professional or academic environments.

The use of the types of magnitudes proposed for the expression of visual impacts makes it possible to establish standards (local or general) to measure the visual performance of new human activities and to define visual sensitivity thresholds that could be used for regulation purposes, or for facilitating public participation in EIA processes.

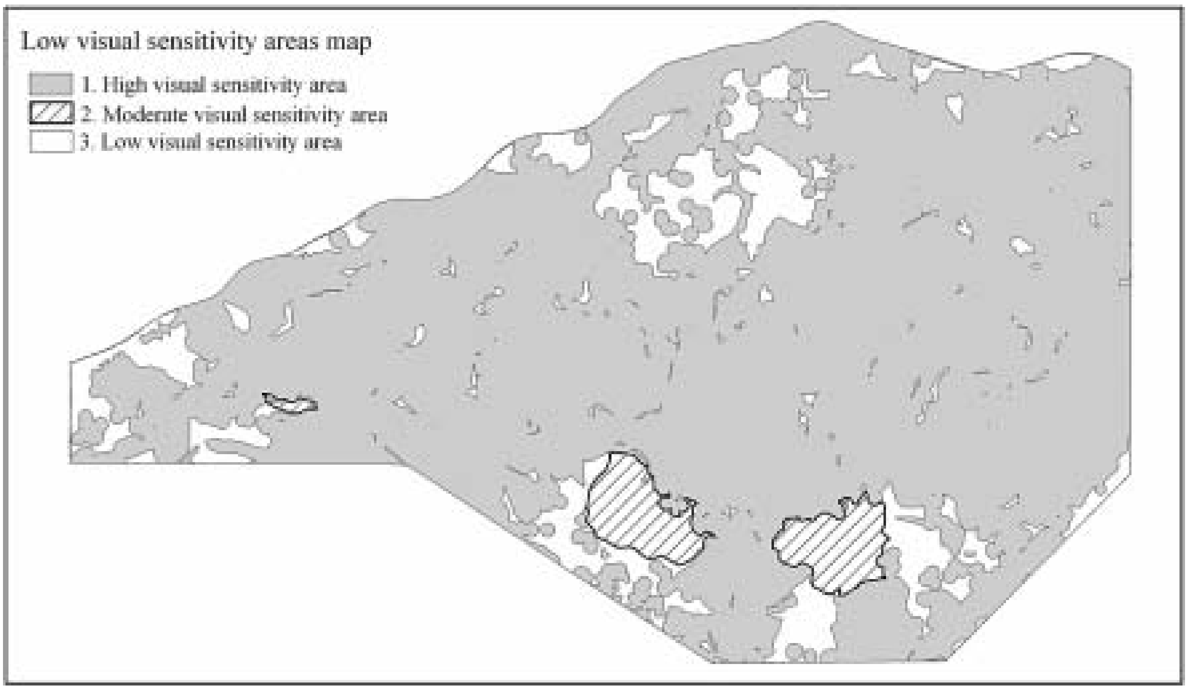


FIG. 9 - Map of low sensitivity areas for limestone quarries. 1) High sensitivity areas defined on the basis of visual landscape as well as other environmental criteria. 2) Moderate visual sensitivity areas, where mitigation measures for visual impacts should be implemented. 3) Low sensitivity areas (visual and other).

REFERENCES

ALBERRUCHE DEL CAMPO E. (2002) - *El análisis de la fragilidad visual mediante SIG*. In: «Los sistemas de información geográfica en la gestión de los riesgos geológicos y el medio ambiente». Luis Laín Huerta. Ministerio de Ciencia y Tecnología. Instituto Geológico y Minero de España, 219-230.

BISHOP I. (1999) - *Modelling landscape change: visualization and perception*. In: «Landscape Character: Perspectives on Management and Change». The Stationary Office, Edinburgh, 150-161.

BISHOP I. & LEAHY P.N.A. (1989) - *Assessing the visual impact of development proposal: the validity of computer simulations*. Landscape Journal, 8, 92-100.

BONACHEA J., BRUSCHI V.M., REMONDO J., GONZÁLEZ-DÍEZ A., SALAS L., BERTENS J., CENDRERO A., OTERO C., GIUSTI C., FABBRI A., GONZÁLEZ-LASTRA J.R. & ARAMBURU J.M. (2005) - *An approach for the incorporation of geomorphologic factors into EIA of transportation infrastructures; a case study in northern Spain*. Geomorphology, 66, 95-117.

BRAGG O.M. & TALLIS J.H. (2001) - *The sensitivity of peat-covered upland landscapes*. Catena 42, 345-360.

BRIERLY G.J. & STANKOVIANSKY M. (2003) - *Geomorphic Responses to Land Use Changes*. Special Issue Catena, 51 (2-3).

BROWN T.C. & DANIEL T.C. (1986) - *Predicting scenic beauty of forest timber stands*. Forest Science 32, 471-487.

BROWN T.C. & DANIEL T.C. (1987) - *Context effects in perceived environmental quality assessments: scene selection and landscape quality ratings*. Journal of Environmental Psychology 7, 233-250.

BRUNSDEN D. (1993) - *Barriers to geomorphological change*. In: Thomas D.S.G. & Allison R.J. (eds.), Landscape Sensitivity. Wiley, 7-12.

BRUNSDEN D. (2001) - *A critical assessment of the sensitivity concept in geomorphology*. Catena 42, 99-123.

BRUNSDEN D. & THORNES J.B. (1979) - *Landscape sensitivity and change*. Institute of British Geographers Transactions, 4, 463-484.

BRUNSON M. & SHELBY B. (1992) - *Assessing recreational and scenic quality: how does new forestry rate?* Journal of Forestry, 90 (7), 37-41.

BURT T.P. (2001) - *Integrated management of sensitive catchment systems*. Catena, 42, 275-290.

CANCER L.A. (1999) - *La degradación y la protección del paisaje*. Cátedra, Geografía Menor, Madrid, 247 pp.

CANTER W.L. (1996) - *Manual de Evaluación de Impacto Ambiental. Técnicas para la elaboración de estudios de impacto*. Mc Graw Hill, 840 pp.

CENDRERO A., LÜTTIG G. & WOLFF F.CH. (1992) - *Planning the use of the Earth's surface*. Springer Verlag, Berlin - New York. 556 pp.

DANIEL T.C. (2001) - *Whither scenic beauty? Visual landscape quality assessment in the 21st century*. Landscape and Urban Planning, 54, 267-281.

DANIEL T.C. & BOSTER R.S. (1976) - *Measuring landscape easthetics: the scenic beauty estimation method*. USDA Forest Service Research Paper RM - 167, Rocky Mountain Forest and Range Experiment Station, Fort Collins CO, 66 pp.

ESCRIBANO BOMBÍN R. & MARTÍNEZ FALERO J.E. (1989) - *Gestión del espacio visual: visibilidad, cuenca visual*. Arbor, nº 518-519. Tomo CXXXII, 155-178.

EUSTAT (1999) - *Información estadística por temas*. Instituto Vasco de Estadística, Vitoria.

GENELETTI D., FABBRI A. & MOLTRER A. (2000) - *Assessing environmental sensitivity for impact studies on transportation systems*. International Archives of Photogrammetry and Remote Sensing., 33, Supplement B7.

GONZÁLEZ BERNÁLDEZ F. (1981) - *Ecología y paisaje*. Blume, Madrid, pp. 256.

GORDON J.E., BRAZIER V., THOMPSON DES B.A. & HORSFIELD D. (2001) - *Geo-ecology and the conservation management of sensitive upland landscapes in Scotland.* Catena, 42, 323-332.

HOLLING C.S. (1973) - *Resilience and stability in ecological systems*. Annual Review of Ecological Systems, 4, 1-23.

KAPLAN R. (1975) - *Some methods and strategies in the prediction of preference*. In: «Landscape assessment: values, perceptions and resources». Dowden, Hutchinson, & Ross, Stroudsburg, PA, 118-129.

KAPLAN S., KAPLAN R. & WENDT J. (1972) - *Related preference and complexity for natural and urban material*. Perception Psychophys, 12, 350-356.

MARTIN J. (1984) - *Visual impact assessment techniques for single site appraisal*. Fifth International Seminar on Environmental Impact Assessment, University of Aberdeen Aberdeen, Scotland, 1984.

MILES J., CUMMINS R.P., FRENCH D.D., GARDNER S., ORR J.L. & SHEWRY M.C. (2001) - *Landscape sensitivity: an ecological view*. Catena, 42, 125-141.

MILNE J.A. & HARTLEY S.E. (2001) - *Upland plant communities - sensitivity to change*. Catena, 42, 333-343.

ODUM H.T. (1983) - *Systems Ecology*. Wiley & Sons, New York, 644 pp.

OTERO C., BRUSCHI V.M., CENDRERO A., IGLESIAS A., LÁZARO M. & TOGORES R. (2004) - *An application of computer graphics for landscape impact assessment*. Lecture Notes in Computer Science, Springer-Verlag, Berlin-New York.

RAMOS A. (1987) - *Diccionario de la naturaleza: hombre ecología y paisaje*. Espasa-Calpe. Madrid, 694 pp.

RUBIO J.L. (1995) - *Desertification: evolution of a concept.* Fantechi R., Peter D., Balabanis P. & Rubio J.L. (eds.) «EUR 15415 Desertification in a European Context: Physical and Socio-economic Aspects», Brussels-Luxembourg. Office for Official Publications of the European Communities, pp. 5-13.

SHEPARD S.R.J. (1989) - *Visual simulation. A user's guide for architects, engineers, and planners*. Van Nostrand Reinhold, New York, NY., 215 pp.

SMARDON R.C. (1988) - *Visual Resource Assessment Procedure for US Army Corps of Engineers*. Instruction Rep. EL-88-1, US Army Waterways Experiment Station, Vicksburg, Miss.

SMARDON R.C., PALMER J.F. & FELLEMAN J.P. (1986) - *Foundations for visual project analysis*, Wiley and Sons, New York, 141-166, 295-299, 310-333.

STAMPS A.E. (1990) - *Use de photographs to simulated environments. A meta-analysis*. Perceptual Motor Skills, 71, 907-913.

STEINITZ C. (2001) - *Visual evaluation models: some complicating questions regarding memorable scenes*. Landscape and Urban Planning, 54, 283-287.

STEWART T.R., MIDDLETON P., DOWNTON M. & ELY D. (1984) - *Judgements of photographs versus field observations in studies of perception and judgement of the visual environment*. Journal of Environmental Psychology, 4 (4), 283-302.

TALLIS J.H. (1998) - *Growth and degradation of British and Irish blanket mires*. Environment Review, 6, 81-122.

TAMÉS P., MENDIOLA I., PÉREZ C., ORTEGA I., SALAZAR A., DE ALBA S., GALLARDO J., PORTERO G., HENAR M., OLIVÉ A., DÍAZ DE TERÁN J.R., FRANCÉS E. & CENDRERO A. (1991) - *Geomorfología y edafología de Guipúzcoa*. Diputación Foral de Guipúzcoa. San Sebastian. 128 pp.

THOMAS M.F. (2001) - *Landscape sensitivity in time and space - an introduction*. Catena, 42, 83-98.

THOMAS D.S.G. & ALLISON R.J. (1993) - *Landscape sensitivity*. 347, Wiley & Sons, New York, 347 pp.

US DEPARTMENT OF AGRICULTURE, US FOREST SERVICE (1974) - *National forest display management*. Vol 2, Chap.1, The Visual Management System, Handbook 462, US Department of Agriculture, Washington, DC.

US DEPARTMENT OF AGRICULTURE, US FOREST SERVICE (1977) - *Landscape management visual display techniques.* FSH6/77, US Department of Agriculture, Washington, DC.

US DEPARTMENT OF INTERIOR, BUREAU OF LAND MANAGEMENT (1980) - *Visual simulation techniques.* Washington, DC.

USHER M.B. (2001) - *Landscape sensitivity: from theory to practice*. Catena, 42, 375-383.

(Ms. received 23 November 2005; accepted 31 July 2006)