ELSEVIER

Catena 40 (2000) 19–35

CATENA

www.elsevier.com/locate/catena

Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remotely sensed data: an example covering the Agri basin (Southern Italy) [1]

F. Basso [a,*], E. Bove [a], S. Dumontet [a], A. Ferrara [a], M. Pisante [a], G. Quaranta [a], M. Taberner [b]

[a] University of Basilicata, Via N. Sauro, 85, 85100 Potenza, Italy
[b] University of Bristol, Bristol, UK

Abstract

The aim of this study is to develop a methodological reference framework, for use at the basin scale, from which environmental sensitivity can be evaluated. In this paper the results of a 3-year investigation into the degradation processes related to desertification in the Agri basin environment (Southern Italy) are presented. Different degradation stages or desertification risks are also evaluated at the plot scale. These data, and the derived results, are integrated into a Geographic Information System (GIS) along with regional scale information layers related to selected environmental and socio-economic factors. The techniques developed at the plot scale are used both to prime and to assess the regional scale measures as they are developed. All data are managed in a GIS which facilitates access to the information and enables it to be updated in a timely fashion. The GIS also enhances data analysis, increasing the interpretability of the data, by enabling cross analysis procedures and various classifications to be performed. As a result, the current landscape genesis can be identified, and appropriate intervention stimulated rapidly. The main aims of the present research are, firstly, to set up an efficient and simple computational structure to evaluate the response of selected thematic layers to degradation phenomena at the

* Corresponding author. Fax: +00-39-971-202269; E-mail: simcer@unibas.it

[1] Funded by MEDALUS III EEC Project. Basso and Pisante had mainly developed agronomical and field level data; Dumontet the evaluation of soil responses; Bove and Quaranta socio-economic aspects; Ferrara and Taberner the other parts as well as the layers structure and the definition and the validation of the model.

PII: S0341-8162(99)00062-4

basin scale and, secondly, to apply the resulting strategy to a specific situation in the Mediterranean Environment.

Keywords: Environmental sensitivity; Desertification; Geographic information systems; Remote sensing; Socio-economic; Land degradation

---

1. Introduction

The concept of Environmental Sensitivity (ES) arose in industrialised countries about 30 years ago and interest was stimulated recently due to the increased incidence and severity of soil degradation (Rubio, 1995). This degradation was caused by uncontrolled forest destruction, water pollution, wind and water erosion, salinisation, and inadequate soil management under both cultivated and uncultivated regimes. One of the major problems affecting the soil is the severity with which the degradation processes reduce soil biological potential. An unsustainable, rapid reduction, which cannot be mitigated using appropriate mechanisms, leads, consequently, to desertification (Thornes, 1995).

The United Nations Environmental Programme (UNEP) continuously rewrote the concept of desertification over the past 20 years. In fact, at the end of the 1970's, the UNEP defined this concept as 'reduction or destruction of soil biological potential is conducive to conditions of desertification, (UNEP, 1977). In the early 1990's they defined it as 'land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities' (UNEP, 1992). From an agronomic point of view there is a substantial difference between degradation and desertification: the former is not necessarily an irreversible process and can be controlled and stabilised with appropriate technical intervention, while the latter is a permanent, practically irretrievable, situation with an almost total loss of biological potential (Basso, 1995). Although soil degradation is largely induced anthropically, via agricultural activities, natural events can also contribute to this phenomenon.

Environmental Sensitivity can be defined, in this context, as the response of the environment, or part of it, to a change in one or more external factors. The relationships between the cause of the change and the effect is often complex because separate environmental components respond directly, but with differing sensitivities, whilst, because of the interrelationships amongst the components, they are also affected indirectly. Degradation occurs when the response is considered deleterious to the 'health' of the environment. What the health of an environment exactly should be, and how a deleterious change is physically defined, are questions open to considerable debate. The situation is made even more complex when one considers the questions involving scale: changing from micro-, through macro-, from local through regional scales involves changing how the environment is defined, how new variables and factors are embodied, and how others become insignificant. Degradation also depends on the perspective of the observer: there are many environmental components which can be measured and changes in each one can be deemed beneficial or harmful. As degradation can arise from many different factors, the importance and relevance of changes in each component, for an individual observer, depends, to some extent, on the interests of that observer.

These measurements, too, can be extremely precise and quantitative, or very broad, nebulous, and qualitative; spatially coherent over scales of millimetres, or cover hundreds of kilometres; instantaneous, or continuously updated; of real physical nature, or of abstract socio-economical character. How can these data be integrated? What are the relationships amongst the factors? These are major issues which are not easily resolved. It is, however, only through an integrated, multi-level, approach that both the different degradation stages and the existing interactions amongst the individual components of the landscape can be evaluated. Today, with high-speed computers, low memory costs, and extensive data resources, scientists are in a position to develop the tools to carry out such integration.

Detailed analysis of the causes and manifestation of degradation require plot scale data, whereas identification, management, and monitoring require continuous data over large areas. In this study, plot scale data is used to characterise evaluation parameters for different degradation stages and desertification risks, however, great importance has been placed on integrating the plot scale data with that from the larger area in order to analyse and study the basin scale environment. Not only can the plot scale data be used to identify the degradation factors themselves, but they can also be used to assess the contribution of the different factors to the different degradation or desertification levels. This information can then be used to define the structure, nature and the score of the different information layers, as well as the algorithms to be used, in the Geographic Information Systems (GIS) in order to define and characterise the basin scale degradation and desertification processes.

The use of a GIS also facilitates the establishment of standardised procedures to integrate alphanumeric and cartographic data with remotely sensed information (Corona et al., 1991; De Jong, 1994; Ferrara et al., 1995; Yassoglu et al., 1995; Basso et al., 1997) and other kinds of data. A GIS also simplifies data handling, providing ease of access to the information acquired and its timely updating, enhances interpretation by facilitating cross data analysis procedures and the application of sophisticated classifications. It is also possible to retrieve and analyse transformation phenomena quickly, as they progress, in order to identify and instigate the necessary intervention.

The two main aims of the present research phase are, firstly, to set up an efficient and simple computational structure to evaluate the response of selected layers to the phenomena under study and, secondly, to apply the resulting strategy to a specific situation that can be found in the Mediterranean Environment.

2. The study area

The Agri basin is located in the Basilicata Region (Southern Italy). It is, economically and socially, one of the least favoured areas of Europe and is suffering from a land degradation problem that arises from its seasonal extremes of climate and the nature of the geology. Climatically it is a marginal region, parts of which have already experienced desertification whilst some parts are being abandoned and others are threatened by the effects of global warming (Cantore et al., 1987). The area has been chosen to be one of the four Target Areas in the European Mediterranean basin. These areas are

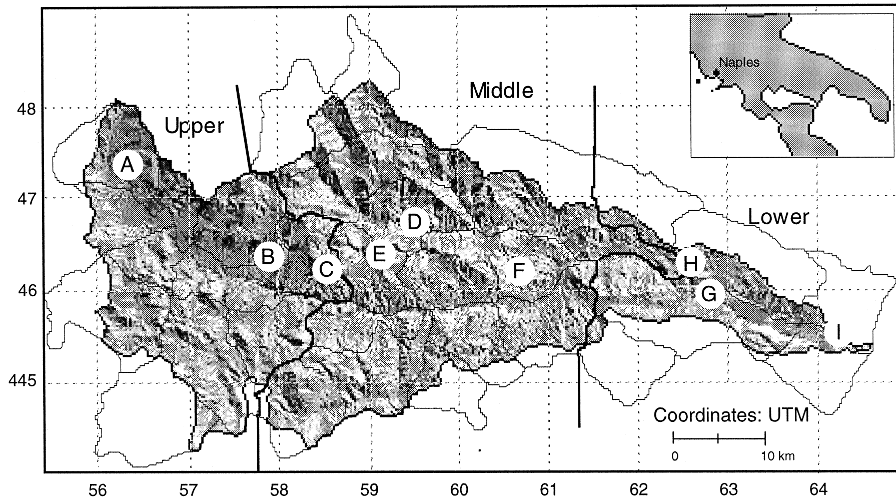

Fig. 1. The Val d'Agri hydrographic basin superimposed with sub-region, municipal boundaries and location of the sampling areas (see Table 2).

experimental test sites for examining desertification processes under the MEDALUS II and III [2] EEC research programmes (Ferrara et al., 1995; Basso et al., 1996a,c; Bove and Quaranta, 1996).

The Agri basin covers 1730 km^2, covering 17% of the Basilicata Region, with a small part in the neighbouring Campania region. The basin can be divided into the Upper, Middle and Lower Agri by both physical–environmental and socio-economic criteria (Fig. 1).

The Upper region of the valley, above the Pertusillo reservoir, has an average elevation higher than 600 m, an area of just under 600 km^2 (28% of the catchment), and is dominated by a valley-floor plain. This region has a population density of 54 inhabitants/km^2.

The Middle Valley stretches from the Pertusillo reservoir to the confluence of the Sauro and Agri rivers, in the municipality of Stigliano, and occupies 47% of the catchment. This is an area of badlands, called 'calanchi', where the population averages 31 inhabitants/km^2.

The Lower Agri Valley, stretching from the Sauro junction to the sea, occupies about 25% of the basin and has the highest population density with 72 inhabitants/km^2. The region includes a fertile coastal zone of Metaponto soils.

From a climatic point of view, the basin presents very different regimes. Along the Ionian coast and in the lowest hilly areas (up to between 500 and 600 m a.s.l.), it assumes the typical mediterranean climate with a high summer drought (rainfall < 150 mm) and a mean, for the hottest month, in excess of 23°C. Whereas in the upper part of the valley the climate becomes more temperate with a hottest summer month mean of

[2] Website at http://www.unibas.it/medalus/agrimed.htm.

between 21 and 23°C and a summer rainfall >150 mm. In the highest area, above 1600 m, the climate is very cold with a long period of snow and an annual rainfall that can reach 2000 mm.

3. Methodology

The Environmental Degradation or Sensitivity of an area is a broad concept, since, depending on context, it can be defined by many different factors, often operating in association. An Environmental Sensitive Area (ESA) can be considered, in general, as a specific and delimited entity in which environmental and socio-economical factors are not balanced or are not sustainable for that particular environment.

The ES to degradation or desertification of an area can also be seen as *the result of the interactions among elementary factors (information layers) that are differently linked to direct and indirect degradation or desertification phenomena*. Severe, irreversible environmental degradation phenomena, for example, could result from a combination of inadequate land management together with a particular set of critical environmental factors (soil, climate and vegetation). The particular set depends on the particular management and environment.

From this perspective, a system which summarises and characterises the main elements, and their interrelationships, which combine to create particular critical situations, of varying severity, would be a very useful tool for decision-makers.

3.1. The layers used

Two of the most important sets of parameters which affect an environment's sensitivity to degradation are the ecological and socio-economical ones. ES is closely related to many environmental factors such as climate, soil, vegetation cover, and morphology where their characteristics, and their intensity, contribute to the evolution and characterisation of different degradation levels or stages. Sensitivity is also strongly linked to socio-economic factors since man's behaviour and his social and economic actions can greatly influence the evolution of numerous environmental characteristics.

Four main criteria were considered when selecting the information layers for the study:

- The relationship with the degradation phenomena or environmentally critical situations;
- The extent of the data coverage;
- The ease of updating the data quickly and economically;
- The fact that the structure of the system will allow the information layers to be refined, developed, or removed as appropriate in the light of experience.

Establishing systems for analysis using information which is difficult or expensive to collect, update, or upgrade, even if valid scientifically, will have limited utility when used for large, complex, environments or when used for continuous monitoring. With the proposed approach, layers can be added or removed as necessary: some layers might be incorporated because it was desirable to investigate some particular aspect of a defined environment in detail, others might be added simply as a first approximation owing to the difficulty of obtaining data or from inadequate knowledge.

The current working set of thematic layers, used in the GIS to assess ES to desertification in the Agri basin, is given in Fig. 2; the sources and mapping scale of the data used to construct the categories are given in Table 1. [3] In this scheme, scores were assigned to the elements of a particular parameter with valid scores ranging from 1, the best conditions, to 2, the worst conditions. A value of 0 was assigned to areas where a measure was not appropriate (unclassified). This scheme means that the layer results are independent of the structure (number of classes, etc.) of the layers. This, in turn, means that the layers can be compared on an equal basis, irrespective of the original data format, and higher level processing is decoupled from the details of the data, and layers can be revised or developed without affecting the remaining structures. The classes and scores assigned were based on the influence and strength of the association that the different layers have with the soil degradation processes and their relationships to the onset of irreversible degradation or desertification phenomena (FAO, 1976; Briggs et al., 1992; Kosmas et al., 1994, 1997; Poesen and Bunte, 1996; Basso et al., 1997). In this presentation, the scale is linear between the extremes, other, non-linear, scales are obviously possible and might even be desirable under certain circumstances — but this is an area which needs further research. A more comprehensive description on how the environmental layers are linked to the degradation or desertification phenomena is given in the works of Kosmas (1998) and Kosmas et al. (1999).

Incorporation of socio-economic data is more problematic. These data are very important in order to evaluate the interactions of mankind with the environment, but their intangibility make them difficult to define. Many indicators have been evaluated to find out their link, through their spatial distribution, to landscape degradation (Marotta and Quaranta, 1996). The temporal dynamics of these indicators is also important: the current situation arises from the current distribution (possibly with some lag involved) whereas the pressure on the environment to change is related, in part, to the rate of change of these indicators. With this in mind, the historical evolution of some of these indicators has also been examined. The change in population density in the Agri over the last 40 years, for example, has been examined for each of the three areas. Population density can have two critical thresholds: at one extreme a sparse population which does not ensure the 'maintenance' of a productive landscape jeopardising its stability and, at the other extreme, high anthropic pressure with respect to the available resources results in high exploitation.

On the other hand, some socio-economic indicators are easily interpreted because they give only one critical threshold (Quaranta, 1997). Elderly, Illiteracy, Retirement, and Employed indexes are indicators directly related to degradation from a demographic

[3] Some categories are often, themselves, a combination of single environmental factors and these categories can be seen as filters to simplify complex interactions in a manner which facilitates the comparison of vastly different types of data.

Soil Quality

Soil Texture

Scores	Classes
1	L, SCL, SL, LS, CL
1.33	SC, SiL, SiCL
1.66	Si, C, SiC
2	S

Rock Fragments Cover

Scores	Classes
1	> 60 %
1.5	20 - 60 %
2	< 20 %

Soil Depth

Scores	Classes
1	> 75 cm
1.5	30 - 75 cm
2	< 30 cm

Drainage

Scores	Classes
1	well drained
1.5	imperfectly
2	poor drained

Slope

Scores	Classes
1	< 6 %
1.33	6 - 18 %
1.66	18 - 35 %
2	> 35 %

Climate Quality

Aspect

Scores	Classes
1	North
2	South

Rainfall

Scores	Classes
1	> 650 mm/yr
1.5	280 - 650 mm/yr
2	< 280 mm/yr

Aridity Index *(Bagnouls - Gaussen)*

Scores	Classes
1	< 50
1.2	50 - 75
1.4	75 - 100
1.6	100 - 125
1.8	125 - 150
2	> 150

Vegetation Quality

Plant Cover

Scores	Classes
1	> 40 %
1.5	40 - 10 %
2	< 10 %

Fire Risk

Scores	Classes
-	Urban; Water.
1	Barren *(soils, exposed rocks, very low vegetated)*; Permanent Agriculture *(olive, vines, almonds, orchard)*; Crops *(maize, tobacco, sunflower, rice)*.
1.33	Cereals; Grasslands; Deciduous *(oak, mixed)*; Mixed Mediterranean macchia-Evergreen forests *(with Q. ilex)*.
1.66	Mediterranean macchia.
2	Conifer.

Erosion Protection

Scores	Classes
-	Urban; Water.
1	Mixed Mediterranean macchia-Evergreen forests *(with Q. ilex)*;
1,2	Mediterranean Macchia; Conifer.
1.4	Deciduous *(oak, mixed)*; Permanent grasslands;
1,6	Evergreen Permanent Agriculture
1.8	Deciduous Permanent Agriculture *(almonds, orchard)*.
2	Crops *(wheat, maize, rice, oats, barley, annual grasslands, ..)*; Vines; Barren *(soils, exposed rocks, very low vegetated)*.

Drought Resistance

Scores	Classes
-	Urban; Water.
1	Mixed Mediterranean macchia - Evergreen forests *(with Q. ilex)*; Mediterranean macchia.
1.25	Conifer, Deciduous, Olives.
1.50	Permanent Agriculture *(vines, almonds, orchard)*.
1.75	Permanent grasslands.
2	Crops *(wheat, maize, rice, oats, barley, annual grasslands, ..)*; Barren *(soils, exposed rocks, very low vegetated)*.

Management Quality

Elderly index

Scores	Classes
1	< 200
1.33	200 - 400
1.66	400 - 500
2	> 500

Employed index

Scores	Classes
1	> 40
1.33	30 - 40
1.66	20 - 30
2	< 20

Illiteracy index

Scores	Classes
1	< 6
1.33	6 - 7
1.66	7 - 10
2	> 10

Retirement index

Scores	Classes
1	< 10
1.33	10 - 20
1.66	20 - 30
2	> 30

Fig. 2. Layers and classes with adopted scores.

Table 1
Characteristics of the used layers

Layer	Scale	Source
Soil texture	1:100,000	published data and field sampling (Catizzone, 1979)
Rock fragments	1:100,000	published data and field sampling (Catizzone, 1979)
Soil depth	1:100,000	published data and field sampling (Catizzone, 1979)
Drainage	1:100,000	published data and field sampling (Catizzone, 1979)
Slope angle	1:25,000	DEM (IGM, 25 m contour lines)
Rainfall	1:500,000	published data (Ministero LLPP)
Aridity index	1:500,000	published data (Ministero LLPP)
Aspect	1:25,000	DEM (IGM, 25 m contour lines)
Fire risk	1:50,000	Multi-temporal Classification, Landsat TM data
Erosion protection	1:50,000	Multi-temporal Classification, Landsat TM data
Drought resistance	1:50,000	Multi-temporal Classification, Landsat TM data
Plant cover	1:50,000	Multi-temporal Classification, Landsat TM data
Elderly index	1:500,000	ISTAT, data at municipality level (ISTAT, 1950)
Illiteracy index	1:500,000	ISTAT, data at municipality level (ISTAT, 1950)
Retirement index	1:500,000	ISTAT, data at municipality level (ISTAT, 1950)
Employed index	1:500,000	ISTAT, data at municipality level (ISTAT, 1950)

perspective.[4] In the Agri basin, municipalities having a ratio of 100 children/1000 elderly (the elderly index) can be found, particularly in the Middle area, demonstrating a serious demographic imbalance. These are likely to be abandoned in a few years if no action is taken.

Associated with this indicator, Retirement and Illiteracy are indexes that report on the general economical vitality of the entire Agri basin. If the level of education is low and most people live on pensions, the relationship with the land, and, therefore, with its ‘well-being’, is very insecure increasing emigration pressures (Quaranta, 1997). The Employed index is another very important indicator which indicates the proportion of the employed population working in agriculture. Actually, this index is linked not so much with the requirement for farm labour, but to the lack of any choice in the Agri, high values of the employed index reflect that there is no realistic alternative employment in the area, nor in its surroundings, so people remain in this sector even though income is poor.

One of the particular aspects of the proposed system is that the ES classes are *not directly linked to an absolute value of sensitivity but are related indirectly, and relatively, through scores that define different levels of sensitivity, for different parameters, for a particular area*. As a result, sensitivity calculated at the top layer imposes a common framework on the components of an area. The elements, which are grouped into broad categories, can be investigated and characterised in a different phase by other analyses. A simple cluster analysis, for example, of areas with high sensitivity values at

[4] The Elderly index measures the ratio between those above 65 and those that have reached 5. The Illiteracy index measures the ratio between people having at least 1 year of school and the ones without. The Retirement index measures the ratio between pentioned people and the residents. The Employed index measures the ratio between employed workers and active population.

the municipality level would identify and characterise critical factors (Basso et al., 1998). Or, the effects of different kinds of intervention on the sensitivity can be estimated by simulating the different intervention options (e.g., recovering the functionality of degraded deciduous forest as opposed to the conversion of conifer stands into more efficient deciduous forests).

The selection of the layers is an open process, though only meaningful layers will produce meaningful results, the choice of the layers, and their metric, is not critical: many other layers can be used and they can be subsequently refined in the light of greater knowledge. Different information layers can change the emphasis of the system as other contexts are introduced. Other layers added to the current system, for example, could be: parent material, pedological data, potential evapotranspiration, phytoclimatic classifications, rain erosivity, the biodiversity of the vegetation, the land use sustainability, or the level of environmental protection, etc.

3.2. Computational methodology and preliminary results

The quantification of different ES levels at the basin scale can be carried out by evaluating the overall influence that single information layers have on the phenomena under study.

The first tasks were to establish a data bank and develop suitable techniques to manage the information layers whilst accommodating their different types and levels of detail. Intermediate and final maps were produced after the various elementary layers were rasterised, registered, and referenced to an elementary pixel size of 30×30 m which is the ground resolution of the most detailed layer in the data base (Landsat TM).[5]

The next task was to develop a system which would function irrespective of the number and type of information layers at its most primitive level. This is achieved by adopting a two stage approach as illustrated in Fig. 3. In the first stage, the four single quality layers are first determined from the basic data layers and in the second phase the final sensitivity of an area is evaluated from the quality layers. Each elementary unit in each Quality Layer is estimated as the geometric mean of its own layers:

$$\text{Quality\_}x_{ij} = (\text{layer\_1}_{ij})(\text{layer\_2}_{ij})(\text{layer\_3}_{ij})\ldots(\text{layer\_}n_{ij})^{(1/n)} \quad (1)$$

where i,j represent rows and columns of a single elementary pixel (30×30 m) of each layer and n the number of layers used.

The first level, that of the basic data layers, isolates the rest of the system from the details of the data. The quality layer, level 2, acts as a buffer between the level 1 data layers and the derived ESA layer, level 3. The weight of each quality layer is equivalent so, as with the level 1 components, the results are comparable amongst the layers and the constituents of a particular layer are hidden from the rest of the system. This

[5] Using lower resolutions will have due a loss of information of these layers as well as to all DEM derived ones which have same resolution.

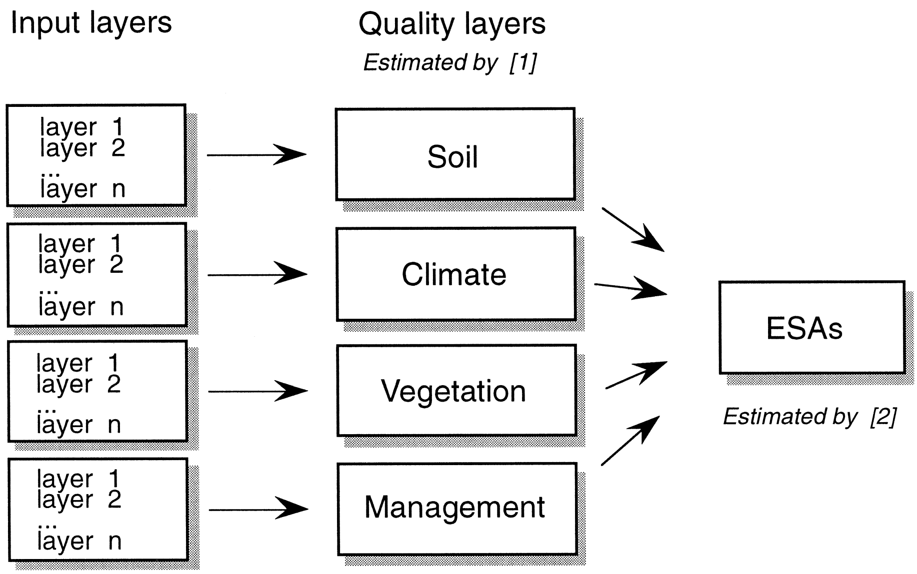

Fig. 3. Scheme of the ESAs estimate.

approach allows the overall ''quality'' themes (or contexts: soil, climate, vegetation and management, which make up each quality layer), to be developed independently and without changing the structure of the overall methodology.

With the four qualities obtained from the above, the ES is estimated by: [6]

$$\mathrm{ES}_{ij} = (\mathrm{Quality\_1}_{ij})(\mathrm{Quality\_2}_{ij})(\mathrm{Quality\_3}_{ij})(\mathrm{Quality\_4}_{ij})^{(1/4)} \quad (2)$$

where i,j represent rows and columns of a single elementary pixel (30×30 m) of each quality and $\mathrm{Quality\_}n_{ij}$ = computed values.

The outlined structure gives equal weights to each level 1 layer when computing each quality (e.g., soil texture has the same weight as other soil layers) and equal weights to each quality in level 2 when computing the final ES irrespective of the number of contributing level 1 layers, i.e., a single climate parameter has, in this case, a higher influence than a single soil parameter. By doing this, the higher level computations in the model are unaffected by the number of level 1 layers this means that a component of the quality layer is not penalised because it does not have many information layers, nor is it exaggerated if it is well specified with many layers.

The ES of the Agri basin, using the method as outlined, is shown in Fig. 4. [7] Similar maps can be produced for each of the quality layer components. All information is

[6] Resulting data still range from 1 to 2.

[7] All calculated values are continuous and were grouped together in eight classes (from 1.0 to 1.8, maximum value found) to better visualise them in figure.

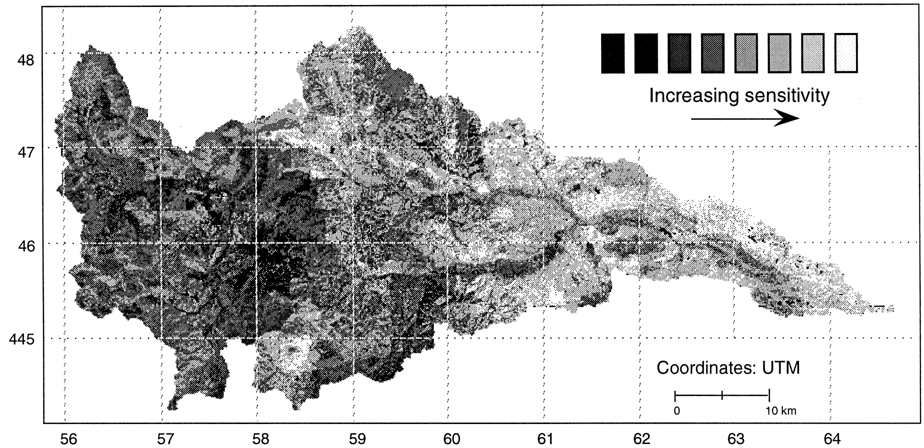

Fig. 4. Environmental Sensitive Areas.

referenced to the elementary surface of 900 m^2 (see [5]), which gives a very detailed mapping. Of course, it is always possible to derive these maps for other territorial limits such as municipalities, municipality groups, geographic regions, climatic zones, etc.

The model, as implemented, is very simple for developing reasons, and a more complex framework, with non-linear computing and variable weighting factors, could be developed. It is hoped that these aspects will be investigated in the near future.

4. Evaluating model performance with indicators at field scale

A preliminary, quantitative, evaluation of the model behaviour and its interpretative capacity can be carried out by analysing the relationships between the derived sensitivity classes and other parameters which are commonly used at the field level to evaluate soil degradation and local sensitivity. It is commonly accepted that some indicators, such as the level of respiration, the microbial C biomass, microbial N biomass and soil organic matter content in the soil are, directly or indirectly, related to soil quality and soil degradation over the long term [8] (Jenkinson and Ladd, 1981; Insam and Domsch, 1988; Insam and Haselwandter, 1989; Anderson and Domsch, 1990; Kaiser et al., 1992; Santruckova, 1992; Anderson, 1994; Basso, 1995; Basso et al., 1996b).

4.1. Methodological approach

For the evaluation of the model performance, representative areas of vegetation cover and land use were identified inside the hydrographic basin taking into account the

[8] The modification of soil microbial biomass is a part of the complex phenomenon which leads to the shortage of the soil organic matter content and, subsequently, gives rise to the panoply of consequences which determine soil erosion.

different ecological situations found there. The areas were defined according to their condition and geographical position. In this way nine main areas (10 ha) were selected for the three main zones of the Agri, three located in the upper, three in the middle and three in the lower valley (Basso et al., 1996a,b). The location of areas and zones in the basin is shown in Fig. 1.

The areas were identified through preliminary photo interpretation study of satellite images (Landsat TM), aerial 1:33,000 monochromatic photos, and monochromatic 1:10,000 orthophoto maps, using the following selection criteria:

- Vegetation: cover, distribution, physiognomy and density;
- Management: presence of stripped areas;
- Hydro-geologic disorders: badlands, rill erosion, gully erosion, sheet erosion and landslides;
- Agriculture: types of cultivated areas with particular interest emphasis on arable land.

Within each area, two sampling points were selected at random. For each sampling point, soil samples were collected in order to evaluate the microbial biomass C and N, the soil organic matter content and the respiration activity.

Each sample was collected from the 0–20 cm soil layer and was subsequently analysed in the laboratory. The 2-mm fraction was separated off. Hydrological properties were than examined and, after 5 days of normalisation, the sample was incubated for 22 days. The microbial biomass was determined using the fumigation–extraction method (Sparling and West, 1988). Respiration was measured periodically during incubation using the Soda Trap method (Anderson and Domsch, 1973). The samples were collected in October 1996. Previous tests had shown that interannual variability of the different field indicators was small in stable ecosystems (Anderson and Domsch, 1985; Turco et al., 1994; Basso et al., 1996a,b). A more comprehensive analysis, using more frequent sampling covering a longer period, is currently underway.

Table 2
Characteristics of the sampled parameters (October 1996)

Location (see Fig. 1)	Biomass C mg kg^{-1}, sd	Biomass N mg kg^{-1}, sd	Soil organic matter (%)	Respiration CO_2 kg^{-1}	Environmental sensitivity
Upper Agri					
A	224.310 ± 4.3	54.950 ± 1.2	1.160	259.300	1.29
B	157.405 ± 11.4	39.110 ± 2.9	0.655	126.600	1.35
C	348.500 ± 18.6	70.435 ± 5.6	1.050	288.050	1.28
Middle Agri					
D	224.755 ± 13.6	49.440 ± 4.2	0.680	184.800	1.42
E	111.150 ± 14.4	28.440 ± 2.7	0.430	154.800	1.55
F	202.650 ± 11.1	43.125 ± 4.3	0.590	209.200	1.45
Lower Agri					
G	182.150 ± 5.5	39.600 ± 4.0	0.440	192.500	1.41
H	233.260 ± 8.4	49.920 ± 3.5	0.770	212.100	1.40
I	261.665 ± 10.6	61.550 ± 3.0	1.025	287.550	1.18

The results from the analyses and the corresponding derived ES are given in Table 2. The ES is the mean of the nine pixels centered on the coordinates of the sampling location.

4.2. Results of the validation procedures

The ability of the proposed model to estimate the different levels of ES at the basin scale can be assessed by analysing the relations that exist amongst the different field indicators, taken alone and in combination, and the estimated sensitivity. Fig. 5 shows the plots and regression lines for each of the field indicators vs. the ES's, along with the confidence limits (0.95 level). As can be seen, the trends of the functions in all the cases are as expected; diminution in the level of respiration and the microbial C biomass, microbial biomass N, and soil organic matter contents coincides with an increase in the ES.

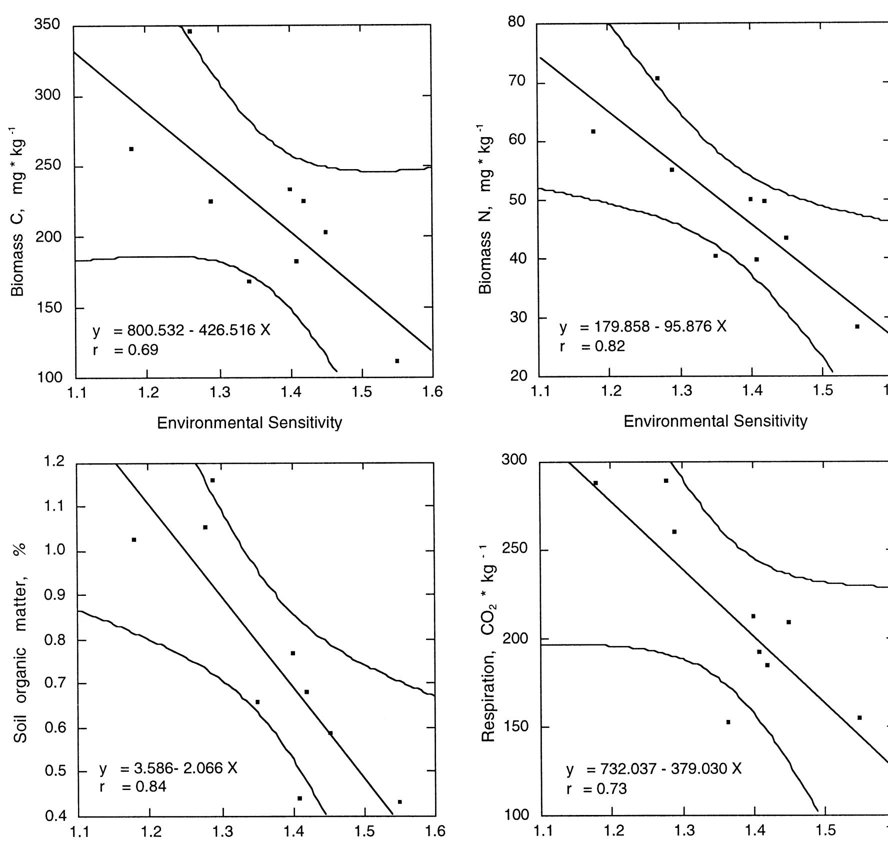

Fig. 5. Regressions of degradation indicators at field scale vs. ESAs estimate with 95% confidence intervals.

The regression lines of the single functions and the confidence limit bounds indicate that, despite the limited number of samples, the relationships are, on the whole, acceptable even though in three cases there are two samples out of nine outside the confidence limits. The r values: 0.69 for biomass C; 0.82 for biomass N; 0.84 for organic matter content; and 0.73 for respiratory activity are good given the problems (even if the correlation for the biomass C is quite low), associated with the spatial variability of the indicators at the field level, in comparing point with areal measurements. Some error will be introduced by our basic simplifying assumption of linearity in the response function. If all four variables are used in a multiple regression an adjusted r^2 of 0.79 is achieved.

It must also be taken into account that the results presented here are not being used to define allometric relationships but only to illustrate that, in general, the system is producing sensible measures of ES in a congruent framework. Considering, also, the differences in the nature and scale of the data being compared, and the simplified nature of the system, the results from the proposed evaluation system are acceptable and encouraging.

5. Comments and conclusions

There is a need for systems which allow us to identify and understand the factors that combine and accelerate land degradation in order to adequately manage the land and its resources. The system being developed, outlined here, can be used to isolate current degradation phenomena. To do this, cross-analysis techniques are applied to the data in the information layers. The information in these layers comes from a variety of sources — some based on pre-existing themes, some based on combinations of these themes, and some created ex novo from other analyses.

The system enables not only the degradation phenomena to be identified but also the information layers and causal paths to be preserved allowing the origin of the degradation to be identified and examined. Linking areal scale information, with detailed studies of land degradation at the plot scale, increases our understanding of the dynamics of degradation and the interrelationships amongst the causal factors. Furthermore, the detailed plot scale can be used to evaluate and control at the field level conclusions and considerations from basin scale studies, primarily through the use of remotely sensed information and modelling.

The proposed method of Sensitivity Evaluation also has a specific per se descriptive value: it can be used as a common framework whereby further, and different, analyses can be used to investigate, define, and qualify the contents of the classes.

It must be emphasised that the main reason for this Environmental Sensitivity Evaluation Model is to define a reference framework to be used in analysing various situations within the Mediterranean Environment under the following operational constraints:

(i) The system must be reasonably simple to establish, robust in operation, and widely applicable;

(ii) The selection of the information layers is made, not only on the basis of their actual information content (i.e., their relationship with the phenomena under study), but also as a function of our ability to obtain and update the data with ease and economy.

(iii) The system must be adaptable and accommodate the development and refinement of the existing information content and the addition of new information.

The emphasis of this presentation has been on a static system, however, degradation, sensitivity, and management are all dynamic entities. Considerable attention is currently being paid to developing the system as a continuous monitoring system in which data can be updated and compared over a range of time scales. To this extent, some layers can be considered static, whose environmental parameters change slowly, or rarely, if at all, and by their nature are infrequently measured or mapped (e.g., soil type), whilst others are more dynamic (e.g., vegetation biomass). Some data are essentially cost free and their use depends on their utility and availability (e.g., gauge station data), whilst others might be highly desirable but their cost precludes frequent updating. In any event, the aim of such a monitoring system is to define and predict trends and changes in the Environmental Sensitivity of a defined environment so as to promote efficient and optimal management.

References

Anderson, J.M., 1994. Functional attributes of biodiversity in land use systems. In: Greenland, D.J., Szabolcs, I. (Eds.), Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK.

Anderson, J.M., Domsch, K.H., 1973. Quantification of bacterial and fungal contributions to soil respiration. Arch. Mikrobiol. 93, 113–127.

Anderson, J.M., Domsch, K.H., 1985. Carbon link between microbial biomass and soil organic matter. In: Perspectives in Microbial Ecology, Proceedings of the 4th International Symposium on Microbial Ecology. Society for Microbial Ecology, Lubjana, Slovene, pp. 467–471.

Anderson, J.M., Domsch, K.H., 1990. Application of eco-physiological quotients ($q CO_2$ and $q D$) on microbial biomass from soils of different cropping histories. Soil Biol. Biochem. 22, 251–255.

Basso, F., 1995. Difesa del Suolo e Tutela dell'Ambiente, Pitagora (Ed.), Bologna, pp. 486.

Basso, F., Bove, E., Ferrara, A., Pisante, M., Basso, B., 1996a. Progetto MEDALUS III (Mediterranean Desertification And Land Use): processi di desertificazione nel bacino dell' Agri in Basilicata. Conference on Scientific Research in Basilicata, 29 February–1 March, pp. 34–36.

Basso, F., Pisante, M., Costanza, M., Saccente, D., Ciarletta, G., Landi, G., Dumontet, S., Mazzatura, A., 1996b. Land degradation and desertification indicators in Agri. Medalus III First Annual Report, King's College, London, pp. 156–174.

Basso, F., Bove, E., Del Prete, M., Pisante, M., 1996c. The Agri Basin, Basilicata, Italy. In: Atlas of Mediterranean Environments in Europe: The Desertification Context. Wiley, London, pp. 144–149.

Basso, F., Bellotti, A., De Natale, F., Ferrara, A., Pisante, M., 1997. Analisi del rischio di degradazione del suolo in aree agricole della Basilicata: una proposta metodologica. Agronomia XXXI 3, 864–871.

Basso, F., Bellotti, A., Bove, E., Faretta, S., Ferrara, A., Mancino, G., Pisante, M., Quaranta, G., Taberner, M., 1998. Degradation processes in the Agri Basin: evaluating environmental sensitivity to desertification at basin scale. Proceedings International Seminar on Indicator for Assessing Desertification in the Mediterranean, Porto Torres, Italy, 18–20 September. In press (information at: nrd@ssmain.uniss.it).

Bove, E., Quaranta, G., 1996. EC Agricultural Policy Impact on Land Use in Southern Italy: The Case of Clay Hill Areas in Basilicata Region. Proceedings International Conference on Land Degradation, Adana, Turchia, 10–14 June, 18 pp.

Briggs, D., Giordano, A., Cornaert, M., Peter, D., Maef, J., 1992. CORINE soil erosion risk and important land resources in the southern regions of the European Community. EUR 13233, Luxembourg, 97 pp.

Cantore, V., Iovino, F., Pontecorvo, G., 1987. Aspetti climatici e zone fitoclimatiche della Basilicata. Pub. no. 2 CNR, Istituto di Ecologia e Idrologia Forestale, Cosenza, 49 pp.

Catizzone, M., 1979. Carta dei Land System della Val d'Agri. Pub. no. 60 CNR, Centro di Studio per la Genesi, Classificazione e Cartografia del Suolo, Firenze, 35 pp.

Corona, P., Ducoli, V., Ferrara, A., 1991. Metodologie avanzate di pianificazione forestale. In: I Boschi Italiani: Valori Naturalistici e Problemi di Gestione. Soc. Ital. pro Montibus et Silvis (Ed.), Bologna, pp. 145–159.

De Jong, S.M., 1994. Applications of reflective remote sensing for land degradation studies in a mediterranean environment. Netherlands Geographical Studies, 177, KNAG, Utrecht.

FAO, 1976. A framework for land evaluation. FAO Soils Bull. (Roma) 32.

Ferrara, A., Pisante, M., Harrison, A.R., Taberner, M., 1995. The use of spatial relationship analysis to study the Agri-basin with remotely sensed images. MEDALUS II Final Report, King's College, London, pp. 67–83.

Insam, H., Domsch, K.H., 1988. Relationship between soil organic carbon and microbial biomass on chromosequences of reclamation sites. Microb. Ecol. 15, 177–188.

Insam, H., Haselwandter, K., 1989. Metabolic quotient of the soil microflora in relation to plant succession. Oecologia 79, 174–178.

ISTAT, Annuario Italiano di Statistiche 1950–1997. Istituto Italiano di Statistica.

Jenkinson, D.S., Ladd, J.N., 1981. Microbial biomass in soil: measurement and turnover. In: Paul, E.A., Ladd, J.N. (Eds.), Soil Biochemistry, Vol. 5. Marcel Dekker, New York, pp. 415–471.

Kaiser, E.A., Mueller, T., Joergensen, R.G., Insam, H., Heinemeyer, O., 1992. Evaluation of methods to estimate the soil microbial biomass and the relationship with soil texture and organic matter. Soil Biol. Biochem. 24, 675–683.

Kosmas, C., 1998. Qualitative indicators of desertification. Proceedings International Seminar on Indicators for assessing desertification in the Mediterranean, Porto Torres, Italy, 18–20 September 1998. In press (information at: nrd@ssmain.uniss.it).

Kosmas, C., Moustakas, N., Danalatos, N.G., Yassoglu, N., 1994. The effect of rock fragments on wheat biomass production under highly variable moisture conditions in Mediterranean environments. Catena 23, 191–198.

Kosmas, C., Ferrara, A., Gerontidis, St., Briasouli, H., Pisante, M., Detsis, V., Pithas, C., Quaranta, G., 1997. Key indicators in defining and mapping environmentally sensitive areas to desertification. MEDALUS III 4th Interim report, King's College, London, pp. 124–146.

Kosmas, C., Poesen, J., Briasouli, H., 1999. Key indicators of desertification at the ESAa scale. In 'Manual on Key Indicators of desertification and Mapping Environmentally Sensitive Areas to Desertification'. MEDALUS III Project, King's College, London. In press (information at: medalus@medalus.demon.co.uk).

Marotta, G., Quaranta, G., 1996. L'applicazione in Italia delle politiche strutturali, Working Paper no. 5, Istituto Universitario Navale, Facoltà di Economia. Università di Napoli, 41 pp.

Poesen, J., Bunte, K., 1996. The effects of rock fragments on desertification processes in Mediterranean environments. In: Brandt, J., Thornes, J. (Eds.), Mediterranean Desertification and Land Use. Wiley, London, pp. 247–267.

Quaranta, G., 1997. Interazioni tra strumenti di politica agricola e politica economica: un'ipotesi interpretativa del loro impatto su famiglie-aziende dell'Alta Val d'Agri. In: Marenco, G., Perone-Pacifico, C. (Ed.), Le Piccole Aziende e la Nuova Politica Agricola dell'Unione Europea: Problemi Economici e Strutturali. Franco Angeli, Milano, pp. 214–222.

Rubio, J.L., 1995. Desertification: evolution of a concept. In: 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.

Santruckova, H., 1992. Microbial biomass, activity and soil respiration in relation to secondary succession. Pedobiologia 36 (6), 341–350.

Sparling, G.P., West, A.W., 1988. Modifications to the fumigation–extraction technique to permit simultaneous extractions and estimations of soil microbial C and N. Comm. Soil. Sci. Plant. Anal. 19, 327–333.

Thornes, J.B., 1995. Mediterranean desertification and the vegetation cover. In: 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. 169–194.

Turco, R.F., Kennedy, A.C., Jawson, M.D., 1994. Microbial indicators of soil quality. In: Defining soil quality for sustainable environment. SSSA Spec. Publ. 35, 18.

UNEP (United Nations Environmental Programme), 1977. Draft plan of actions to combat Desertification. UN Conference on Desertification, Nairobi.

UNEP (United Nations Environmental Programme), 1992. World Atlas of Desertification, Edward Arnold, Seven Oaks.

Yassoglu, N., Kollias, B., Tatsis, E., Filis, E., 1995. The use of geographical information systems in the assessment of natural hazards. In: 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. 617–625.