FOREST FRAGMENTATION, URBANIZATION AND LANDSCAPE STRUCTURE ANALYSIS IN AN AREA PRONE TO DESERTIFICATION IN SARDINIA (ITALY)

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Abstract. Land degradation and desertification processes represent a serious problem in many Italian regions, as in Sardinia (Italy), and in particular in the north-western part of the island (Nurra region) where urbanization, overgrazing and fires have induced environmental degradation and rapid land-use change. The purpose of the study was to analyse in depth the forest fragmentation process and the landscape dynamics occurring over the 28-years period between 1972 and 2000 in an area prone to desertification in Sardinia. In this study, using satellite remote sensing, Geographical Information System and the software FRAGSTATS three Landsat satellite images were classified into seven land cover types and a stepwise indicator approach was adopted. The results have enabled the identification of areas in which specific spatial patterns occurred at some degree of intensity as degradation factors, thus explaining, at least in part, the sensitivity to desertification of specific areas.

Introduction

In the last two centuries, the impact of human agricultural, industrial and extractive activities on the land has grown enormously, altering entire landscapes with important ecological consequences such as loss of biodiversity, deforestation, soil erosion and desertification.

In Italy, about 21,3% of the land is at risk of desertification, as a consequence of both natural and anthropic occurrences (Costantini et al., 2007). Due to its particular geographical position and its extreme climatic events, such as droughts and floods, Sardinia can be considered a representative area of the typical environmental problems of the Mediterranean Basin. In fact, landscape morphology and climate make the soil very fragile and sensitive to activities that

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do not consider soil suitability and its limitations. In the last decades, urban sprawl[2] along the coastal areas has strongly increased due to new tourist settlements and urban infrastructures. Not only urban sprawl, but also loss of fertile soil, massive water exploitation, overgrazing and fires represent other important causes of the environmental problems on the island (Giordano and Marini, 2008).

Research studies are in progress in order to further investigate where desertification represents a problem, to assess how critical the problem is and, finally, to better understand the processes of desertification. Desertification indicators[3] have been identified as potentially useful tools for both management and monitoring, and the Mediterranean countries are searching for a common methodology for identifying and using such indicators (Desertlinks, 2005).

From this perspective, a change in land cover and landscape represents an important and sensitive indicator that echoes the interactions between human activity and the natural environment (Zhou et al., 2008a). In semi-arid and arid environments, in particular, where fragile ecosystems are dominant, land cover and landscape change often reflects the most significant impact on the environment due to excessive human activity (Zhou et al., 2008b).

Most landscapes of the Mediterranean Basin have been shaped by human-nature interactions over large periods of time. In such cultural landscapes, the main driving factor of changes is human impact, especially in terms of land-use and demography. Land-use and population change usually leads to landscape changes with consequences in terms of habitat fragmentation and alteration. Therefore, a comprehensive assessment of the causes and the extent of landscape change are needed in order to gain a better understanding of the possible ecological consequences such as biodiversity loss, soil erosion and reduced productivity, and as baseline for setting appropriate management and restoration strategies (Plieninger, 2006).

The role spatial pattern plays in ecological processes has made the development of landscape assessment approaches possible for regional

[2] Urban sprawl is commonly used to describe physically expanding urban areas. The European Environment Agency (EEA) has described sprawl as the physical patterns of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas.

[3] The European Environment Agency (EEA) defines an indicator as a parameter or value derived from parameters, which provides information about a phenomenon. Indicators are quantified information that helps to explain how things are changing over time and how they vary spatially. Indicators generally simplify the reality in order to make complex phenomena quantifiable, so that information can be communicated.

Desertification indicators should help to identify where desertification is a current or potential problem and to monitor changes over time.

environmental quality assessment and for monitoring land use and land cover types.

Studying the landscape, its current state (structure) and its future changes (dynamics) enables us to understand the ecological mechanisms and processes that drive changes in landscapes.

Desertification assessment, in particular, has made increasing use of landscape ecology principles, but still few examples of landscape metrics, derived from land use and land cover maps and used to quantify environmental change in arid and semi-arid regions, are found in literature (Sun et al., 2007; Sun et al., 2008).

Since information on land cover and landscape is critical to understanding environmental issues and changes in arid and semi-arid regions, the integration of remote sensing with Geographic Information System (GIS) techniques is increasingly important for the assessment of environmental problems such as land desertification (Zhang et al., 2008).

In this scientific context, and based on the assumption that many processes of desertification are typically related to the spatial structure of the landscape and its temporal variation, we drawn up the following general objective of the present research: to explicitly explore the concepts and methodology of a landscape approach for the monitoring of desertification.

Up to now, the key research topics in landscape ecology have focused on ecological flows and processes in landscape mosaics, but landscape ecology has been rarely combined with the issue of desertification, in particular in the Mediterranean region.

The objective of the following research was therefore to set up both a conceptual framework and a methodological implementation for land cover and landscape spatio-temporal detection, characterization and assessment based on remote sensing, GIS and landscape analysis. The integration of such instruments was drawn up in order to enhance the understanding of patterns of desertification processes by setting up appropriate synthetic landscape indexes related to specific spatial patterns, which have not been deeply investigated up to now within the framework of the most common methodologies for the monitoring of desertification.

1. Study area

Sardinia, due to its particular geographical position and extreme climatic events such as droughts and floods, is characterized by a lack of water and can be considered a representative area of the typical environmental problems of the whole Mediterranean Basin.

The study area (ca 40° 43’ N, 8° 34’ E) is located in the north-western part of Sardinia (Italy) and includes the municipalities of Sassari, Alghero, Stintino and Porto Torres, comprising approximately 88400 ha (fig. 1).

Fig. 1 - Study area in the north-western part of Sardinia (Italy)

The area is representative of various land degradation and desertification processes such as urban sprawl, massive water exploitation, overgrazing and fire. Furthermore, it offers a wide availability of data, information and studies derived from many national and international projects (Motta et al., 1999; Kosmas et al., 1999; Bandinelli et al., 2000; Zucca et al., 2003; Pittalis, 2003; Motroni et al., 2004; RIADE, 2002-2005; DesertNet, 2002-2004; DesertNet II, 2005 – 2008, Desertwatch, 2004-2006; Ceccarelli et al., 2006).

The study area is characterized by a high geological and morphological complexity and is mostly due to metamorphic rocks partially covered by Tertiary and Neogene sedimentary strata. Human activity has increased the variability of the landscape, by modifying in particular the original structure of vegetation.

The climate is typically Mediterranean dry-subhumid with an abundant amount of rainfall during the autumn-winter period and a small amount of rainfall with very high temperatures during the summer period. Mean annual precipitation values vary between 490 mm and 870 mm. During the period 1961-1990 a mean annual temperature of 16°C was registered. The mean highest temperature was registered in August with a value equal to 29,7°C. Due to these climatic characteristics, soil suffers from low water quantities and, therefore, sclerophyllous vegetation, surviving in water scarce conditions, is widespread in this area.

The area belongs to the phytoclimatic area of Lauretum. Vegetation is characterized by Mediterranean scrub such as sclerophyllous evergreen forests

(Cistus, Oleaster, Pistacia Lentiscus, Quercus suber, Quercus ilex) and other typical Mediterranean species (Calycotome).

As demonstrated in recent studies (Motroni et al, 2004), the area is strongly sensitive to land degradation and desertification with more than half of the territory belonging to critical Environmentally Sensitive Areas (ESAs) or "areas already highly degraded through past misuse, presenting a threat to the environment of the surrounding areas".

2. Methods

For the purposes described above, we drawn up a methodology able to provide quantitative data of interest for the monitoring of desertification and related to forest fragmentation, urbanization and landscape structure dynamics.

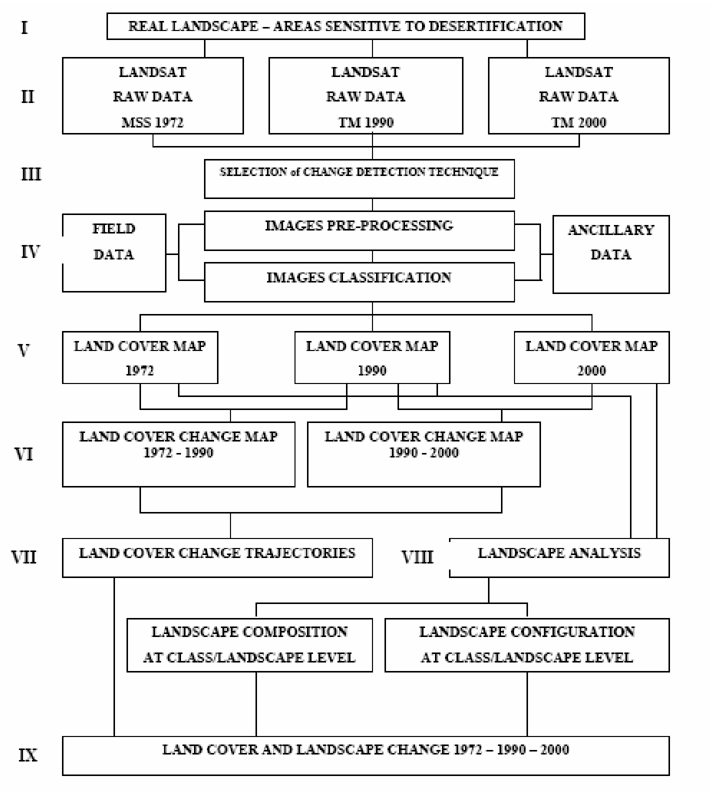

Fig. 2 - Flow chart of the multi-step systematic procedure set up

Hence, we tested the approach in order to assess and to characterise the changes occurred over a period of twenty-eight years in an area prone to desertification, where this kind of investigation has not been experimented on up until now.

The methodology was structured into a multi-step systematic procedure including nine different phases, to be performed one next to another (fig. 2).

Three Landsat images were selected over the study area: Landsat Multispectral Scanner (MSS) of August 13, 1972; Landsat Thematic Mapper (TM) of May 12, 1990 and Landsat Thematic Mapper (TM) of June 27, 2000. Furthermore, twelve orthophotos Italia 2000[19] at the scale 1:10.000, dating back to 2000 and covering the overall study area, were used as reference source of information required for the classification procedure of the Landsat images. Field data were acquired among the data provided in the framework of the DESERTWATCH Project. In particular, we acquired ground truth points covering the study area and we used them as control points for the assessment of the classification accuracies for the three land cover maps. The ESAs (Environmentally Sensitive Areas) map represented the areas sensitive to desertification in Sardinia at a scale of 1:100.000 (Motroni et al., 2004).

Before performing any procedure, Landsat MSS was resampled to 30m × 30m by means of the nearest neighbour technique in order to make the pixel size comparable with that of the two higher spatial resolution images. In the present study, georeferentiation was performed by means of the image-to-image method, as the Landsat TM 2000, which was selected as the reference image, was already georeferenced. A set of 30 GCPs was selected throughout the scenes for the georeferentiation of the images, in a dispersed way including the intersection of roads, the airport runway of Alghero, buildings and avoiding landmarks that can vary during time. In this study, a 1st-order transformation was used to perform georeferentiation for both images. Root Mean Square error was 0,83 pixels for Landsat MSS 1972 and 0,71 pixels for Landsat TM 1990, that means that the reference pixel is 0,83 (24,9 m) and 0,71 pixel (21,3 m) away from retransformed pixel. After georeferentiation, the data file values of rectified pixels were

[19] An ortophoto is an aerial photograph that has been geometrically corrected or orthorectified such that the scale of the photograph is uniform and the photo can be considered equivalent to a map. Unlike an uncorrected aerial photograph, an orthophoto can be used to measure true distances, because it is an accurate representation of the earth's surface, having been adjusted for topographic relief, lens distorsion and camera tilt. Terraitaly – IT2000 was carried out by Compagnia Generale Ripreseaeree SpA of Parma (Italy).

resampled to fit into a new grid of pixel rows and columns. Among the resampling methods available in ERDAS Imagine, the nearest neighbour was selected.

For the present research, we chose the post-classification comparison method among the techniques available in scientific literature. Supervised classification was employed in order to classify individual images independently, using a unified land cover classification scheme to ensure that the classifications of the multi-temporal images well matched each other. To perform this process, the computer system was trained to recognize patterns in the data. Training is the process of defining the criteria by which these patterns are recognized. In the present study, a supervised training was performed, in which pixels representing specific land cover features were recognized with the help of ortophotos and available maps. On the basis of the spatial patterns of interest for our research, we defined our land cover classification scheme as it follows: croplands, urban areas, forestlands, barren areas, wetlands and water bodies. By identifying specific patterns, the computer system was then instructed to identify pixels with similar characteristics. The result of training was a set of signatures defining training samples representative of the class to be identified. For each class, a set of about 50 training sample was identified. The maximum likelihood algorithm was here applied to parametric signatures, which are based on statistical parameters of the pixels that are in the training sample. After the classification was performed, the accuracy of the classification was evaluated by comparing it to geographical data that were assumed to be true (ground truth). The classification accuracy obtained for each image, was respectively: 83% for Landsat 1972, 88% for Landsat 1990 and 92% for Landsat 2000.

Following the post-classification procedure, the identification of land cover changes was performed by comparing two-by-two the land cover maps obtained.

The operational phase used the land cover maps resulting from the previous classification as the sources of further procedures. The three land cover maps of 1972, 1990 and 2000 were converted into GRID format and used as the input image into the FRAGSTATS software.

Once the landscape metrics have been performed, we composed specific sets of metrics at class and landscape level, based on scientific research literature, in order to improve the understanding of spatial pattern change of interest for the monitoring of desertification and related to forest fragmentation (Geneletti, 2004; Yu and Ng, 2007; Baskent and Kadiogullari, 2007; Gonzalez et al., 2007; Cakir et al., 2008; Kadiogullari and Baskent, 2008), urbanization level (Weng, 2007; Gonzalez et al., 2007; Keles et al., 2008) and landscape structure (Li et al. 2004).

If we consider forest patches as a resistant component to desertification, then forest fragmentation weakens this resistance, thus favouring the sensitivity level of the area. Hence, to reinforce the interpretation of forest fragmentation, we consider landscape metrics able to capture the increase in the number of forest patches, the reduction in their mean area and the decrease in the largest forest area. In addition, we needed metrics able to assess the isolation of patches and the variation of the physical connectivity of forest ecosystems.

Therefore, we selected the following set of metrics:

Forest fragmentation = NP + AREA_MN + LPI + ENN_MN + COHESION (1)

where:

NP = Number of Patches;

AREA_MN = Mean Patch Area;

LPI = Largest Patch Index;

ENN_MN = Mean Euclidean Nearest Neighbour Distance;

COHESION = Patch Cohesion Index.

Landscape metrics for capturing the spatial pattern of the urbanization degree in areas prone to desertification, were chosen taking into account that the dispersion of buildings leads to a high level of habitat fragmentation. In general, impacts of new buildings may be minor if located in close vicinity to the existing ones (Gonzalez et al., 2007).

In this regard, the urbanization level was analysed by means of the following set of metrics:

Urbanization level = PD + AREA_MN + ENN_MN + LPI (2)

where:

PD = Patch Density;

AREA_MN = Mean Patch Area;

ENN_MN = Mean Euclidean Nearest Neighbor Distance

LPI = Largest Patch Index.

Finally, the set of metrics for the analysis of landscape structure was composed on the basis of the main findings of Li (2004). In particular, we combined landscape metrics able to capture the various aspects of landscape linked to land degradation and desertification, such as landscape fragmentation, land cover diversity and irregularity of patches. Land cover diversity, in particular, is relevant to desertification if we assume that greater land use diversity, in terms of small and contiguous plots of different land uses, generally implies a smaller risk of land degradation and higher biodiversity (Desertlinks, 2005). The following landscape metrics were therefore used for this purpose:

Landscape structure = NP + AREA_MN + SHDI + LSI + ENN_MN (3)

where:

NP = Number of Patches;
AREA_MN = Mean Patch Area;
SHDI = SHannon’s Diversity Index;
LSI = Landscape Shape Index;
ENN_MN = Mean Euclidean Nearest Neighbour Distance.

In order to obtain final synthetic indexes for each spatial pattern, for each landscape metric we calculated the variation, percentage-wise, occurred between the two study periods investigated. Then, we classified them into six classes and we assigned a score based on the positive or negative trend (tab. 1).

Tab. 1 – Classes and scores for the variation of the landscape metric

%	**0 – 20 %**	**20 – 40%**	**40 – 60%**	**60 – 80%**	**80 – 100%**	**> 100%**
Positive	0	+ 1	+ 2	+ 3	+ 4	+ 5
Negative	0	- 1	- 2	- 3	- 4	- 5

The final indexes were then calculated by means of the algebraic sum of the scores and then classified into the following five classes: low (- 25 ÷ –15) medium – low (- 15 ÷ - 5), medium (-5 ÷ + 5), medium – high (+ 5 ÷ + 15), high (+ 15 ÷ + 25).

The indexes thus obtained have the potential to reflect in a synthetic value various aspects of the spatial pattern investigated and their variation over time.

3. Results

We analysed the change of the urbanization and forest fragmentation spatial patterns occurred at class level and the change of the landscape structure at landscape level, by means of specific sets of metrics selected in order to reinforce our interpretation. Furthermore, we set up a classification system for each landscape metrics in order to combine them and to obtain synthetic indexes. In the following figures the maps of the synthetic indexes are illustrated.

Figure 3 illustrates the synthetic index of forest fragmentation for the two periods investigated. As seen in the figures, both maps indicate the municipality of Stintino as the area in which the process of forest fragmentation was the highest. Here, in fact, a very clear trend toward forest fragmentation was observed with a continuous trend over time toward an increase in the number of forest patches, a decreasing mean patch area and a reduction in the largest forest patch, connected to an increase in the isolation of forest patch and a decline in the forest connectivity.

The high values of the index found in the municipality of Stintino clearly reflect a persistent process over time, in which all the landscape metrics experimented negative trends.

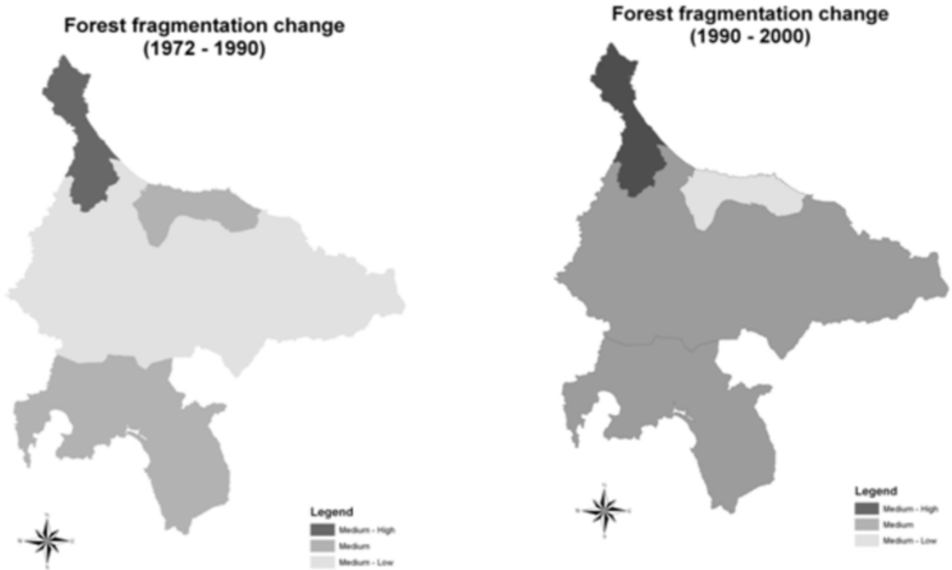

Fig. 3 - Synthetic index of forest fragmentation change (1972 – 1990; 1990 – 2000)

In figure 4 the change of the urbanization level that occurred in the area over time is illustrated.

The synthetic index of urbanization change does not reflect only the enlargement of urban areas, but the way how it took place over time. As illustrated in the figure the municipalities of Porto Torres and Sassari showed a medium – high level of urbanization between 1972 and 1990. As enlightened in Weng (2007), the degree of fragmentation of urban areas is positively related to the degree of urbanization.

In these areas, the fragmentation of urban landscape is clearly linked to the strong increase in the urban density of the area and the strong reduction in the mean urban areas. New small urban areas are in some way dispersed in the landscape and not adjacent to each other, thus leading to an increase in habitat fragmentation and to more severe impacts (Gonzalez-Abraham et al., 2007).

In figure 5, the synthetic index of landscape structure change is represented. As seen in figure 5, the municipalities of Stintino and Porto Torres

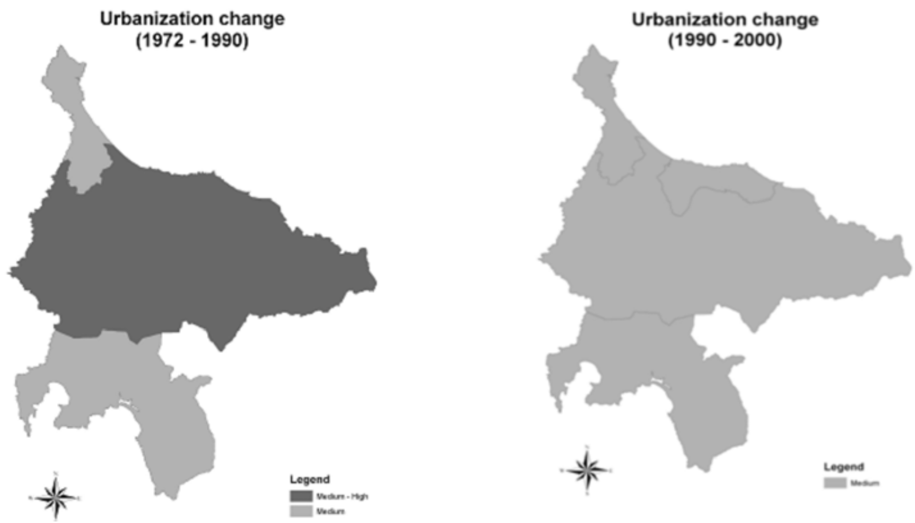

Fig. 4 - Synthetic index of urbanization change (1972 – 1990; 1990 – 2000)

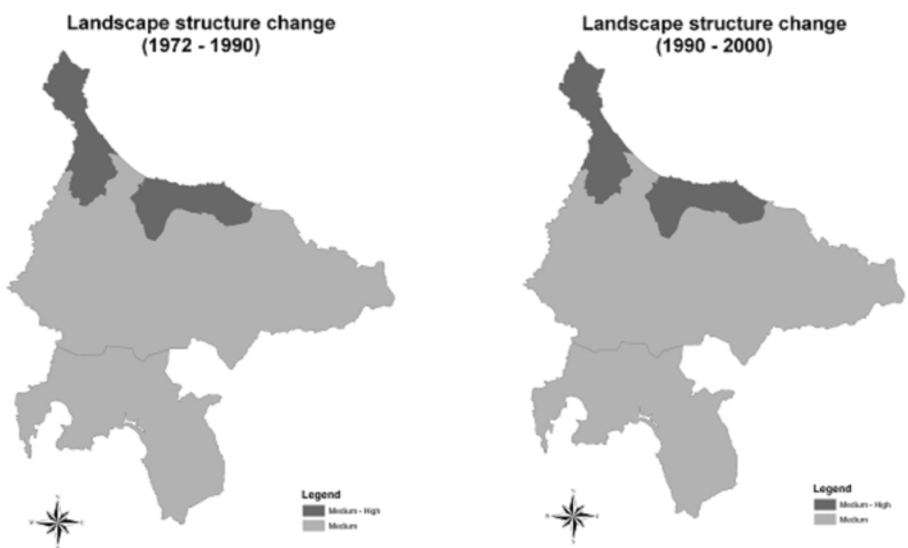

Fig. 5 - Synthetic index of landscape structure change (1972 – 1990; 1990 – 2000)

showed the highest level of change in the landscape structure toward a more fragmented landscape characterized by increasingly smaller and contiguous patches per unit area, decreasingly heterogeneous land cover structure, more irregular patches and closer links with each other. These results were found to be in accordance with the research findings found in literature for areas prone to desertification and land degradation (Li et al., 2004; Herzog et al., 2001).

In particular, the municipality of Stintino was the only municipality in which the diversity index continuously decreased over time, according to the assumption that the greater land use diversity is, in terms of small and contiguous plots of different land uses, the smaller the risk of land degradation and the higher biodiversity (Desertlinks, 2005).

Discussion and conclusions

On the basis of the analysis and comparison of the landscape metrics at different levels, and by means of an appropriate combination of landscape metrics into synthetic indexes, we identified areas in which specific spatial patterns related to land degradation occurred in a more intense way. By means of the methodology implemented, we assessed and characterised the spatial patterns as they occurred in the study area over the twenty-eight years period investigated.

In the present research study, we explored and tested the concepts and methodology of a landscape approach in areas prone to desertification, where this kind of investigation has not been experimented on up until now. Up to now, the key research topics in landscape ecology have focused on ecological flows and processes in landscape mosaics, but landscape ecology has been rarely combined with the issue of desertification, in particular in the Mediterranean region.

The study provided an example of the integration of remote sensing, Geographical Information Systems and landscape analysis in order to monitor the environmental changes that took place over a period of twenty-eight years. The methodology implemented and the indicators set up proved to be powerful tools for the characterisation of the spatio-temporal dynamic of landscape in an area prone to desertification. The use of a landscape approach allowed for an assessment of specific spatial patterns related to land degradation and desertification that can be used in developing practicable application plans at the regional level in desertification prevention planning and decision-making. Furthermore, the landscape indicators investigated and set up in the present research represent important tools able to integrate the standard approach commonly used until now for the monitoring of desertification, as they represent rather new indicators able to provide additional and complementary information to those provided by the most common approaches and indicators. In particular, the analysis of forestlands and urban areas and the use of indicators related to forest fragmentation, urbanization and landscape structure allowed us to identify noteworthy differences among the municipalities.

The synthetic index performed for forest fragmentation analysis, clearly demonstrated that the forest landscape of the municipality of Stintino has moved into a more fragmented structure, with more small fragments of forests that are more isolated, more irregular and less spatially connected. Here, in fact, forested areas were broken-up into smaller, more fragile, more irregular and more isolated units in favour of urban and crop areas, thus reducing their ability to resist the desertification and to recover from disturbances. Larger and better-connected ecosystems, in fact, are typically more fitting at conserving biodiversity and preventing soil erosion and land degradation than smaller and more isolated ones.

The tourist vocation of Stintino represented the main driving force behind the changes that occurred, as new tourist settlements were built mainly along the northern side of the coastal areas. Rapid development of urbanization and tourism thus increased the demand for proper infrastructure such as roads, water facilities and utilities. As a result, areas used for settlements have expanded in extreme proportions, as planned urbanization. The obvious consequence was that this kind of urbanization consumed areas of agricultural land and forested areas that could be the cause of many harmful impacts on ecosystem structure, function and dynamics with negative consequences on biodiversity, biogeochemical cycles and land resources.

In the municipality of Sassari, between 1972 and 1990, the new urban settlements grew in a sparse way, thus making the landscape more fragmented and denoting a high degree of urbanization with potential negative effects on the properties and functions of the ecosystem (Gonzalez-Abraham et al., 2007). This process was found to be similar to that occurred in the municipality of Porto Torres. The urban sprawl that occurred around the city of Sassari, which is the second city of Sardinia, was the obvious consequence of the process of urbanization from small rural villages to the urban centres. Urbanization has been quickening due to an increase in population and to migration from rural to urban areas, due to employment opportunities in the main urban center. As the city grew, the increasing concentration of population and economic activities demanded that more land be developed for public infrastructure, housing, industrial and commercial uses.

The synthetic index performed for the analysis of landscape structure change provided useful information about the evolution of the territory toward a more fragmented landscape characterized by increasingly smaller and contiguous patches per unit area, decreasingly heterogeneous land cover structure, more irregular patches and closer links with each other. These results were found to be in line with the research findings found in literature related to desertification and land degradation (Li et al., 2004; Herzog et al., 2001). This type of landscape structure did not facilitate the conservation of landscape, as larger and connected ecosystems are typically better at conserving biodiversity and at preventing soil erosion and land degradation than smaller and more isolated ones (Desertlinks, 2005).

The results obtained derived by the synthetic indexes set up and performed for the purpose of the present research, demonstrated to be able to identify the areas in which specific spatial patterns occurred at some degree of intensity as degradation factors thus explaining, at least in part, the sensitivity to desertification of specific areas.

The results of the study that actually performed analyses and monitoring of land cover and landscape change over time have, therefore, made an important step towards warning the authorities of the features of the past and current land cover and landscape changes and their consequences.

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