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Mitigating land degradation in Mediterranean agro-silvo-pastoral systems: a GIS-based approach

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Abstract

Agro-silvo-pastoral systems were studied in central–eastern Sardinia (Italy) to assess their environmental impact in marginal Mediterranean areas. Land cover changes between 1955 and 1996 were assessed by using multitemporal aerial coverages. The shift from extensive to semi-extensive production systems resulted in a decrease in woodland and in a marked increase in artificial pastures. Related field surveys highlighted widespread land degradation processes in areas where pasture amendment actions on land characterised by steep or fairly dissected morphology had been carried out. Starting from a past land suitability classification developed at farm level, a scheme for the evaluation of the land suitability to the creation of new pastures at regional scale was developed by using GIS methodologies. The scheme classifies the land into five land suitability classes as defined in the FAO Framework for Land Evaluation (highly suitable, moderately suitable, marginally suitable, currently not suitable, permanently unsuitable). The land suitability classification performed by the GIS model showed high accuracy if compared to the traditional procedure. The comparison between the land suitability and current land uses allows the identification of areas sensitive to land degradation where land resource conservation programmes can be proposed.

Keywords: Land degradation; Agro-silvo-pastoral systems; Land suitability classification; Land use evolution; Italy

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1. Introduction

Desertification as ''land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'' (UNCED, 1992) is one of the major environmental issues in drylands, also involving north Mediterranean countries (Rubio et al., 1989; European Commission, 1997). Here, peculiar climatic and physical conditions, and severe historical anthropogenic pressure have caused extensive natural vegetation losses, increasing soil erosion by wind and water which result in a reduction of the biological productivity of the land (UNEP, 1994). This is particularly true for some European Mediterranean areas like southern Italy, Spain, Portugal and Greece (Brandt and Thornes, 1986; Van der Leeuw, 1998).

Sardinia (Italy) is an island representative of Mediterranean rural areas, where agropastoralism is the main land degradation driving force. Agropastoral activities, and sheep breeding for milk production in particular, have always played a major economic role in the island; historical accounts report about their presence in Sardinia since 1000 BC (Cherchi Paba, 1974).

During the last century, a progressive and steady increase in sheep numbers has occurred; in particular, in the period 1881–1930 there has been an increase from 845,000 to more than 2,000,000 heads (Le Lannou, 1979), because a deep crisis of agriculture made pastoralism the only possible and profitable economic activity. During the 1970s and the 1980s the rise in sheep milk price resulted in a further marked growth from 2,500,000 to 3,800,000 heads; such increase brought about the intensification of agropastoral activities in hilly and mountain areas, where agropastoralism was the only possible economic activity (Idda, 1978), as well as their expansion to flat areas that had always been used for cultivating crops. The remarkable increase in stocking rates has led to overgrazing phenomena (Enne et al., 1998) as well as to an increase in forest fires traditionally linked to agropastoralism (d'Angelo et al., 1997).

In order to meet the higher feeding requirements of animals, the regional government of Sardinia promoted policies aiming at increasing forage production (Legge Regionale 6/9/1976 n.44 Riforma dell'Assetto Agropastorale) also providing subsidies. Actually, such policies were not accompanied by the necessary guidelines for their implementation; the amendment actions were then carried out on several areas, regardless their specific morphologic and pedologic conditions, resulting in a severe impact on the land: the substitution of wide areas of Mediterranean maquis with artificial pastures, obtained by using fire and deep tillages along the maximum gradient on steep slopes, is a representative example of the negative consequences of the regional regulations.

As a part of the MEDALUS-EC project framework (Mairota et al., 1998) relationship between agropastoral activities and land degradation in Mediterranean marginal areas were studied. During the first phase, the main efforts were devoted to the understanding of the complex animal-vegetation-soil interactions in relation to land degradation processes (Pulina et al., 1998). At present, research activities are mainly focusing on the identification of sustainable agro-silvo-pastoral systems in areas affected and/or threatened by land degradation, based on the assumption that extensive livestock production systems in the Mediterranean are necessary to support local populations and preserve rural landscapes (Seligman, 1996).

With this aim in view, particular emphasis was laid on the evaluation of land suitability to grazing and to agropastoral activities in general, knowing the importance of rational Land Planning and Management as a mitigation tool. Different authors have dealt with land suitability evaluation (Sys, 1985; Aru et al., 1989; Ongaro, 1995) mainly based on FAO (1976) Framework for land evaluation. During the last decades, following the growing spread of computer technology, applications based on Geographical Information System approach have been developed to evaluate land suitability to different land uses (Giordano et al., 1991; Tang and Van Ranst, 1991; Davidson et al., 1994).

This paper presents an application of land suitability evaluation by using GIS technology; in particular it aims at: (a) investigating the land cover dynamics highlighting the relationship between the intensification of agropastoral systems and land degradation processes; and (b) developing a land suitability scheme to the creation of new pastures that can be applied at regional scale as a tool for the identification of sustainable agro-silvo-pastoral systems in Mediterranean marginal areas.

2. Material and methods

2.1. Site description

The study is conducted on an area of central northeastern Sardinia, reasonably representative of the marginal rural areas of the island (Fig. 1). The test area is located between 40°20′ and 40°31′ latitude North and between 9°34′ and 9°50′ longitude East

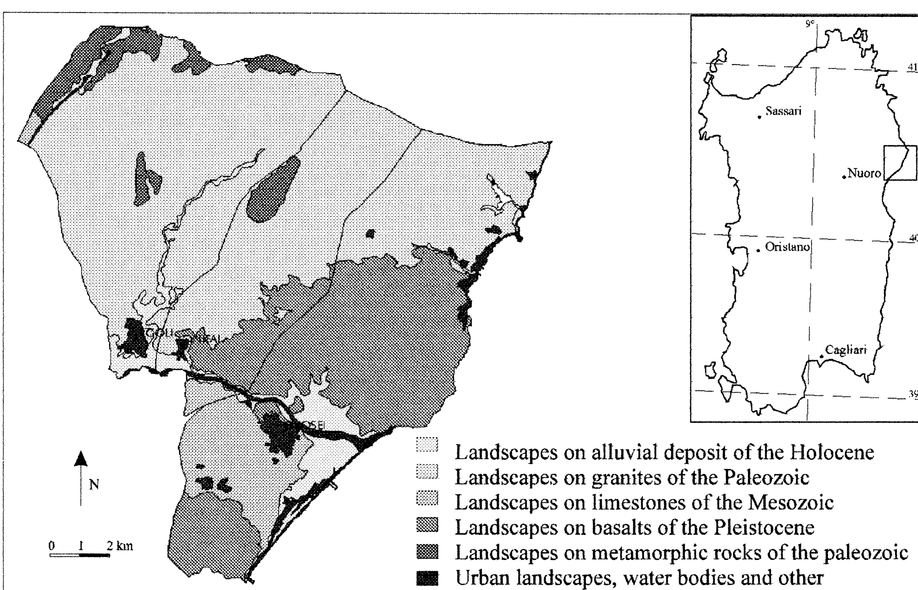

Fig. 1. Location of the study area.

(municipalities of Irgoli, Onifai, Orosei), covering about 20,900 ha. The climate is typically dry sub-humid, with a mean annual temperature of about 17°C and mean annual precipitation ranging from 500 to 700 mm; microclimate varies with elevation which ranges from sea level to 862 m a.s.l.(Monte Senes).

Geology is quite heterogeneous: Paleozoic granites and metamorphic rocks; Jurassic crystalline limestones; Plio-pleistocenic basalts; old and recent alluvial deposits. The landscape is therefore extremely complex: the central part of the area is characterised by alluvial deposits; this large plain divides the basaltic plateau from the limestone relieves of Monte Tuttavista characterising the southern area. To the north and to the west, granites and metamorphic relieves are present; the former show very steep and irregular morphology deeply incised; the latter show quite undulating and flat morphology.

With reference to land use patterns, agricultural area amounts to 11,045 ha, 63% of which represented by meadows and pastures (ISTAT, 1992). According to official data wooded areas cover about 6,000 ha mainly represented by maquis; the limited extension of forest stands (coppice of *Quercus ilex* L.) is the result of the severe anthropic pressure during the last century. In the last decade, there has been a major tourist development in the coastal areas, although agropastoral activities are still the most important economic activity.

2.2. Land cover and soil mapping

Available aerial photographs (1955, 1989) taken over the study area were acquired; a preliminary photomosaic inspection allowed the delineation of the main physiographic units. Traditional photointerpretation procedures were then applied to derive the pedological map and the multitemporal land cover maps (1955 and 1996) at 1:25,000 scale.

With reference to land cover mapping, the CORINE legend was used; the different classes were then grouped into the following main typologies: agricultural lands (arable and permanent crops, complex cultivation patterns), natural pastures (natural and semi-natural), artificial pastures, shrublands, Mediterranean maquis, woodlands and forest plantations. The 1996 land cover map was derived by updating the information acquired from the 1989 aerial photographs using SPOT-HRV data and field surveys.

Soil surveying and mapping were carried out by delineating the landscape units on the basis of photointepretation and field surveys. Twenty-six map units were identified; soil profiles were described, samples were collected and analysed. Soils were classified according to Key to Soil Taxonomy (Soil Survey Staff, 1997) and the legend of the Soil map of the World (FAO/UNESCO/ISRIC, 1988).

2.3. Land cover dynamics

Land cover maps were digitised and acquired into a GIS implemented via ARC-INFO software. Statistics of land cover classes in 1955 and 1996 were obtained and land cover changes were highlighted.

The complex land cover dynamics was derived by overlaying the two maps. Emphasis was laid on the changes from natural vegetated areas to agricultural lands and pastures.

Table 1
Simplified scheme for the evaluation of land suitability to the creation of new pastures (artificial pastures); landscapes on intrusive rocks

Characteristics		Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Currently unsuitable (N1)	Permanently unsuitable (N2)
(1) Altitude (m a.s.l.)		< 600	600–800	600–800	800–1000	> 1000
(2) Slope (%)		0–2	2–6	6–15	15–55	> 55
(3) Aspect	< 1000 m a.s.l.	S	E–W	N		
	> 1000 m a.s.l.	S	E–W			N
(4) Vegetation cover (%)	Shrubs	< 2	2–10	10–25	25–50	> 50
	Trees	< 2	2–10	10–20		> 20
(5) Rockiness (%)		Absent	< 2	2–5	5–10	> 10
(6) Stoniness (%)		< 0.1	0.1–3	3–15	15–50	> 50
(7) Length of dry season (days)		< 60	60–90	> 90		
(8) Frost hazard (freq.)		Absent	rare	rare for many years	common	frequent
(9) Flood hazard (freq.)						
(10) Soil depth (cm)		> 60	60–40	40–20	20–10	< 10
(11) Soil texture		L; CL	SCL; SL	SCL	LS	S
(12) Structural stability		High	medium	low	very low	absent
(13) Base saturation (%)		> 75	75–50	50–30	< 30	
(14) Water availability (%)		> 15	15–10	< 10		

2.4. Evaluation of land suitability to the creation of new pastures

One of the main objectives of the research was the evaluation of land suitability to *the creation of new pastures*. This study was carried out on a test area (Orosei municipality).

Following a careful assessment of the characteristics influencing land suitability (Table 1), significant variables for the evaluation of land suitability to the creation of new pastures were identified: slope, soil depth, rockiness, stoniness, vegetation cover, aspect, soil chemical-physical characteristics. The latter is an index resulting from average values of pedological characteristics acquired from soil samples (texture, structure stability, base saturation and water availability).

To acquire information on these variables, two main layers were acquired into a GIS in addition to the existing *land cover* layer: (i) *soil*, obtained by digitising the 1:25,000 soil map available for the whole study area, and (ii) the Digital Terrain Model (DTM) derived from the topographical map elevation data (IGMI, 1993). Aspect, elevation and slope layers were then automatically derived from the DTM.

Variable values were converted into suitability coefficients (Fig. 2) calculated on the basis of specific weighting functions which take into account the relative importance of each variable and its importance in relation to the value. Fig. 3 shows the function for the vegetation cover variable.

ROCKINESS		
Value	Class	Coefficient
0	S1	1
0-2	S2	1-15
2-5	S3	15-30
5-10	N1	30-60
10-100	N2	80-1000

STONINESS		
Value	Class	Coefficient
0	S1	1
0-3	S2	1-10
3-15	S3	10-20
15-50	N1	20-40
50-100	N2	40-1000

SOIL DEPTH		
Value*	Class	Coefficient
	S1	1-13
	S2	13-26
	S3	26-39
	N1	39-80
	N2	80-1000

PHYSICAL-CHEMICAL CHARACTERISTICS		
Value*	Class	Coefficient
1	S1	1
2	S2	7
3	S3	12
4	N1	25
5	N2	50

VEGETATION COVER (Shrub)		
Value	Class	Coefficient
0-2	S1	1-15
2-10	S2	15-30
10-25	S3	30-51
25-50	N1	51-100
50-100	N2	100-1000

VEGETATION COVER (Tree)		
Value	Class	Coefficient
0-2	S1	1-5
2-10	S2	5-10
10-20	S3	10-15
-	N1	-
20-100	N2	30-1000

SLOPE		
Value	Class	Coefficient
0-2	S1	1-15
2-6	S2	15-30
6-15	S3	30-51
15-55	N1	51-100
>55	N2	100-1000

ASPECT		
Value	Class	Coefficient
S	S1	1
E; W	S2	5
N	S3	10
	N1	
	N2	

Fig. 2. Values and related coefficients of the variables for the model of land suitability to the creation of new pastures. *The variables depend on the landscape. Each landscape has therefore its own weight functions.

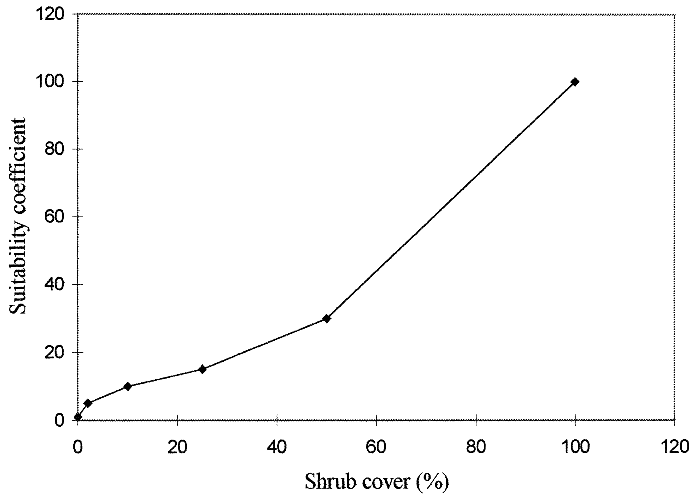

Fig. 3. Weighting function for the vegetation cover variable (shrubs).

The cumulative Suitability Index (SI) was then derived by summing the suitability coefficients of variables:

$$\mathrm{SI} = C_s + C_r + C_{st} + C_v + C_a + C_{sd} + C_{pc}$$

where: C_s is the suitability coefficient for slope; C_r, rockiness; C_{st}, stoniness; C_v, vegetation cover; C_a, aspect; C_{sd}, soil depth; C_{pc}, physical–chemical characteristics.

Land suitability class was then assigned to SI.

Algorithms were developed using ARC Macro Language (AML) to automatise classification procedures and restitution of the land suitability map. Map accuracy was evaluated by comparing the results of the automatic classification with those from traditional procedures mainly based on pedological units.

3. Results and discussion

3.1. Land cover / use dynamics

Table 2 summarises the main land cover changes in the study area occurred during the period 1955–1996. Particularly evident is a marked reduction (−35.6%) in forested areas (woodlands, maquis and forest plantations) from 8358 to 5513 ha, which is to be totally ascribed to maquis (−61.4%). On the contrary, forest plantations extension has tripled, as a consequence of reforestation activity, which represents one of the few sources of seasonal employment.

With reference to grassland, a decrease (−16%) in natural pastures can be observed while the extension of artificial pastures has almost doubled (from 1711 to 3388 ha).

Fig. 4 shows land cover dynamics between 1955–1996. Maquis was subjected to the main changes: only 26% of the original area remained unchanged, while 39% degraded

Table 2
Land cover changes in the study area, 1955–1996

Land cover/use typologies	Surface (ha)		Difference (ha)
	1955	1996	(1955–1996)
Agricultural lands	2454	2932	+479
Natural pastures	3334	2803	−531
Artificial pastures	1711	3388	+1677
Shrublands	4216	5462	+1246
Woodlands	1625	1517	−108
Mediterranean maquis	6241	2409	−3832
Forest plantations	687	1582	+895
Other	627	796	+169

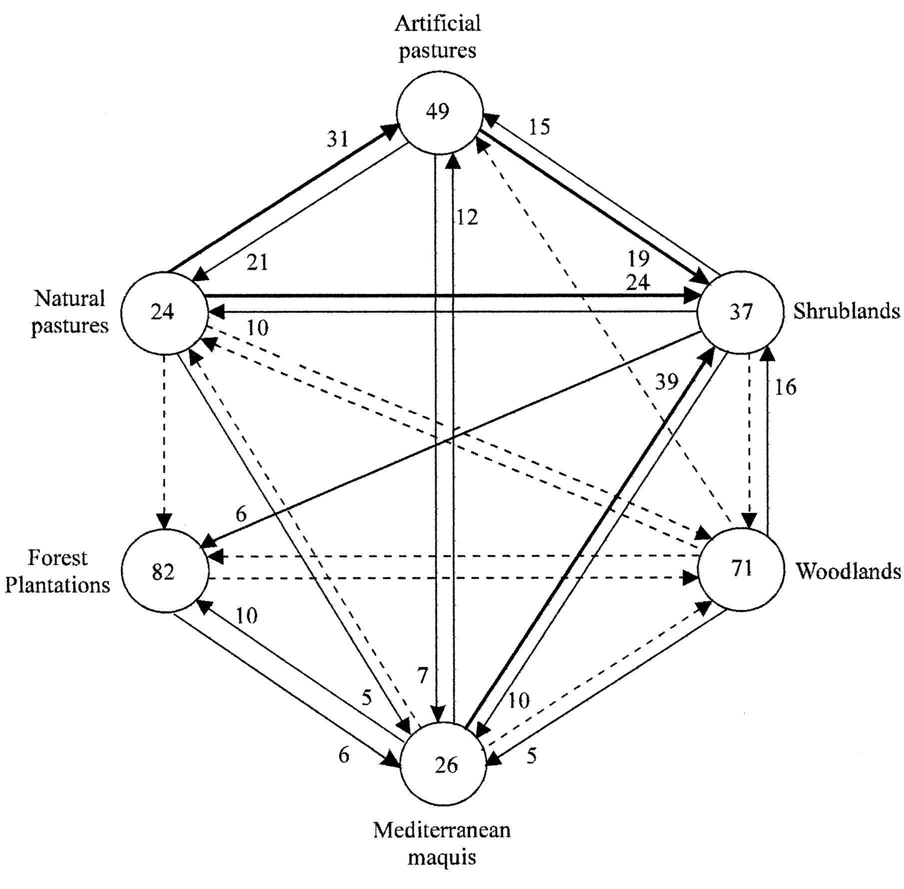

Fig. 4. Land cover dynamics, 1955–1996. Numbers in the circles indicate the percentage of unchanged area for each land cover typology. Numbers near the arrows indicate the percentage of changed area from one land cover type to another. Dotted lines indicate land cover changes involving less than 5% of the area.

Table 3
Origin of current artificial pastures (ha) by slope class

Land cover in 1955	Slope		
	< 15%	15–25%	> 25%
Agricultural lands	90	2	1
Natural pastures	659	182	185
Artificial pastures	826	10	3
Shrublands	214	187	219
Woodlands	13	14	6
Mediterranean maquis	646	77	54

into shrublands, about 12% was transformed into artificial pastures and 10% was reforested. Only a small amount (< 5%) evolved towards woodlands. With reference to the latter, 16% degraded into shrublands as a consequence of forest fires, often linked to pastoralism, while 71% remained unchanged.

In relation to land degradation processes, the main land cover changes are undoubtedly related to the creation of artificial pastures. Table 3 summarises the origin of artificial pastures since 1955; 24.8% of these areas were artificial pastures also in 1955; the remaining originated from natural pastures (30.3%), maquis (22.9%), shrublands (18.3%), and, although to a lower extent, from agricultural lands (2.7%) and woodlands (1%).

Pasture amendment actions (brush and stone removal, deep tillages by means of heavy machinery) have a severe impact on the environment, particularly when they are carried out on steep slopes and unsuitable lands. The overlay of current land cover map and slope map reveals that 27.7% (940 ha) of current artificial pastures are located on areas whose slope is higher than 15%. This dynamics is to be mainly ascribed to the shift from extensive to semi-extensive grazing systems occurred during the last 25 years: the increasing cheese market, the favourable sheep milk price and EU and Regional Government incentives were the main driving force towards an over-exploitation of land resources. Such economic contingency favoured sheep breeding: according to official data (ISTAT, 1972, 1992), the total number of sheep increased by 80% reaching 22,220 heads. Average stocking rate is about 1 sheep ha^{-1}, with peaks up to 1.6 sheep ha^{-1} in municipalities where agropastoralism is the only economic activity.

Field surveys conducted on artificial pastures showed widespread land degradation processes; the most evident effects are both the loss of surface horizons and the related appearance of sheet and rill erosion processes which cause the appearance of Leptsols (soil depth lower than 20–25 cm). On these areas, grasses have undergone a quanti-qualitative degradation in terms of species composition and palatability.

3.2. Land suitability to the creation of new pastures

Fig. 5 shows the map of land suitability to the creation of new pastures automatically derived from the GIS model. The application of the model to the test area highlighted its effectiveness; the comparison with the results obtained from the application of the

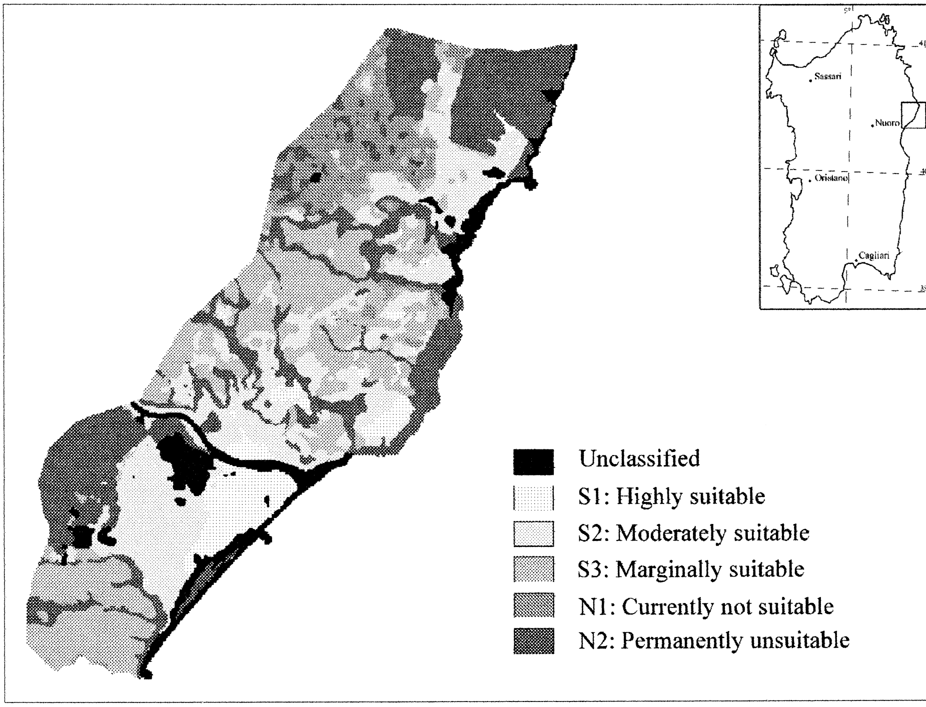

Fig. 5. Map of land suitability to the creation of new pastures (Municipality of Orosei).

traditional evaluation procedures (Table 4) showed the high accuracy of the model (90%).

Table 4
Comparison between land suitability to the creation of new pastures classification obtained from traditional procedures and from the application of the model
S1: highly suitable; S2: moderately suitable; S3: marginally suitable; N1: currently unsuitable; N2: permanently unsuitable.

Pedological unit	Land suitability class (traditional procedures)	Land suitability class (GIS model)
Unit 33	S3–N1–S2, depending on rockiness, vegetation cover, etc...	S3 = 86%
Unit 34	S2	S2 = 87%; S3 = 8%
Unit 43	N2	N2 = 97%
Unit 44	S2	S2 = 83%; S1 = 17%
Unit 51	N2–N1–S3–S2, depending on slope, vegetation cover, lithology (mainly N2)	N2 = 48%; N1 = 32%; S3 = 18%; S2 = 2%
Unit 52	S2	S2 = 58%; S3 = 31%
Unit 53	S2–S1	S2 = 81%; S1 = 7%

In general, higher classification accuracy was achieved for both highly suitable (S1) and permanently unsuitable (N2) areas. High correspondence between pedological units and suitability units were also found for landscapes having homogeneous morphology (e.g., on basalts rather than on granites). A lower accuracy was achieved for intermediate situations (S3–N1 classes in particular). On these areas a more accurate field validation was carried out.

In particular, two map units characterised by heterogeneous soils and highly variable characteristics were considered: unit 33 located on basalts and unit 51 located on granite bedrock with highly irregular morphology. According to the GIS model output, map unit 33 is to be almost entirely ascribed to the S3 class; on the contrary, map unit 51 is quite heterogeneous ranging from N2 to S2.

With reference to map unit 33, the land suitability class was mainly influenced by the average values assigned to rockiness and soil depth. Depending on slope, the unit was classified as N1 ($> 15\%$) or S2 ($< 15\%$); vegetation cover density had little influence. Notwithstanding, S3 class reflects the average suitability of the unit. Detailed field surveys showed that the model classification was highly influenced by the quality of data (spatial resolution).

The suitability classification of unit 51 was mainly influenced by slope. The areas subjected to afforestation were classified as N2; the remaining, mainly covered with Mediterranean maquis, was classified as N1. Such results often overestimated the real suitability of the land characterised by limitations typical of the N2 class. However, small areas were correctly classified as S3 and S2, reflecting the real land suitability.

The results obtained for the other map units were generally satisfactory; the highest accuracy was obtained for landscapes on alluvial deposits and limestones.

4. Conclusion and perspectives

In this study, GIS procedures were used to evaluate the role of agropastoral activities in Mediterranean rural areas as land degradation driving force.

It has been highlighted that the shift from extensive to semi-extensive livestock production systems strongly altered the landscape of Sardinian rural areas. The comparison between 1955 and 1996 land covers showed an increase in agricultural areas (mainly used for grazing) and a decrease in woodland due to shrub clearance and fires which acted synergistically. The extension of shrubland (about 26% of the study area) can be undoubtedly related to fire occurrence, while artificial pastures are the result of land clearance by heavy machinery.

A detailed analysis of the complex land cover dynamics has shown that pasture amendment actions on unsuitable areas often lead to land degradation, particularly in areas characterised by uneven morphology.

The case study presented has highlighted that the lack of technical guidelines supporting the implementation of such policies can result in an intensification of land degradation processes.

In this context, land suitability evaluation can constitute a preliminary tool towards better land management to mitigate land degradation.

The model presented in this paper deals with the evaluation of land suitability to the creation of new pastures; its relevant aspect is the use of information deriving from different layers (land cover, soil, aspect, slope, elevation) allowing the maximisation of available information. This constitutes an alternative approach to the FAO framework for land evaluation based on the identification of land units to which a suitability class is assigned. Furthermore, the parametric approach proposed bypasses the problems of the limiting factor approach often used in land evaluation. With the proposed model the cumulative suitability index is always a weighted average of all variable values. The overlay between the land suitability map derived from the model and the actual land cover/use map is a simple but effective methodology for the identification of areas threatened by land degradation, on which land resource conservation programmes can be elaborated involving all levels and sectors of the community.

Apart from the potential of GIS technology in displaying, manipulating and analysing the large amount of spatial data required in any land resource investigation, this kind of approach seems to be cost-effective because of (i) the wider and wider diffusion of computer technology in public administrations involved in land planning and management, (ii) the availability of existing databases on environmental resources in digital format at local and regional scale and (iii) the already existing expertise due to the large diffusion of GIS discipline in academic curricula.

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