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The Integrated Assessment of Land Degradation

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Abstract

This paper reviews recent findings on the complex field of land degradation (LD) with focus on the Mediterranean Basin and Italy, in particular. The LD definition and assessment methods are examined in the light of the most important natural and human driving forces of the phenomenon, such as land use and climate changes. Various methodological issues are dealt with from multidisciplinary perspective with the aim of providing the ground for the development of integrated approaches: monitoring needs, assessment of costs, development of mitigation strategies, etc. Factors affecting land vulnerability to degradation are classified into bio-physical and socio-economic drivers with some examples of applications in Italy. The role of determinants such as agricultural development, population growth, and urban sprawl is recognised as important but still ambiguous and thus needs further studies. Based on these findings, policy responses aimed at mitigating LD and thus reducing desertification risk are discussed and methodological proposal are presented.

Key-words: Land Degradation, climate change, agriculture, monitoring strategies, mitigation costs, Italy, Mediterranean basin.

1. Introduction

Over the last decades, Land Degradation (LD) became one of the most severe threat for the environment and human survival. Desertification, which is an irreversible process of LD, has gained growing attention of the international community about its devastating potential on the natural environment and the human society. In the World nearly 69% of useful drylands for agriculture has suffered soil erosion and degradation. In more than 100 countries, nearly 17% of world population is affected by desertification, forcing people to leave their farms or their villages. Many other countries, like those from southern Europe, although by now do not suffer explicit consequences of LD, show increasing environmental fragility induced by both bio-physical (especially climate) and socio-economic causes (Rubio and Recatalà, 2006).

Following the United Nations Convention to Combat Desertification (UNCCD), desertifica-

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tion was defined as LD in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. In other words, worsening environmental conditions is well expressed by serious (or even complete) loss in soil fertility. Based on United Nations estimates, the phenomenon affected about 70% of arid lands, amounting to 30% of the world cultivable land. The problem is particularly severe in Africa and in some developing countries in Asia, South America and the Caribbean, but it affects also the United States, Australia and Southern Europe (United Nations, 1977). According to OECD, processes of soil degradation are mainly due to erosion, submersion, acidification, salinisation, soil compaction, surface crusts and compact layers along the profile, loss of organic matter, deterioration of the soil structure, accumulation of toxic substances, as well as loss of nutrients (Puigdefabregas and Mendizabal, 1998).

Desertification is often triggered by initial conditions of environmental fragility. Causes are linked to several factors (of both natural and anthropogenic nature) that work as a complex system of interactions. In this context, climate change makes ecosystems even more sensitive and fragile because it increases the normal climate aggressiveness. The socio-economic causes, instead, are generated from the impacts of human-derived pressure linked to urban expansion and economic activities, especially when the above-mentioned factors involve an unsustainable exploitation of natural resources. Each of these environmental hazards, even if not immediately producing observable effects, can create an instability in the ecosystem equilibrium. Therefore, changed environmental conditions may lead to land vulnerability. That is to say a decreased resilience of the ecosystem which can ultimately causes a real damage (Montanarella, 2007).

In Italy, desertification shows effects on very limited areas in southern regions (Basilicata, Apulia, Calabria, Sardinia and Sicily) where unsustainable anthropogenic pressures on the natural environment occur in combination with dry or even semi-arid conditions (Salvati and Zitti, 2008a). As a consequence, the same environment reduces its biological potential and agricultural productivity lowers. In other areas, where LD processes are not particularly evident at the moment, the potential risk of desertification is increasing. This is in turn due to worsening climatic conditions caused by decreasing amounts of precipitation, and more frequent heavy rainfall events, as well as intensification of soil erosion, intensive crop systems, and urbanisation (Salvati and Zitti, 2005).

The circumstances described above show that desertification concerns not only arid and/or marginal areas, but it can affect also agro-ecosystem with relevant role for agricultural productions (Salvati and Zitti, 2009).

This article introduces a simple framework for the assessment of LD in the Mediterranean Basin with a special focus on Italy. Sewction 2 frames the topic within a theoretical framework based on the state of the art of the international literature. Section 3 discusses the role of quantitative monitoring of land vulnerability in support of LD assessment, to inform mitigation policies carried out at the national, regional, and local level. Section 4 addresses the methodologies aimed at estimating costs and integrated assessment of LD at different spatial and temporal scales. Section 5 provides some concluding remarks with relevance for policy making.

2. Theoretical framework

Water stress and LD processes are both linked to climate and land use changes and their effects on the hydrological cycle. Therefore an integrated analysis of land and soil conditions have to be carried out with the aim to realise measures to mitigate ecological risk and prevent environmental disasters especially over desertification hot-spots. Population growth, expanding cities, and arable land reduction created increasing pressure on water supply. By modifying the hydrological balance, climate change and longer severe droughts contribute to determine higher risk over already vulnerable land and its agricultural activities. Water is inherently renewable but when the abstraction rate exceeds the natural rate of recycling water, stress develops. Competition for scarce water resources will probably increase in the future along the raising demand by all water users, thus exacerbating current problems of water scarcity and overexploitation of available water resource – especially of the groundwater – leading to water stress and aridity conditions triggering off desertification process in the Mediterranean Basin (Venezian-Scarascia et al., 2006).

The increasing climate variability is causing higher frequency of flood and erosion processes and longer drought periods. The knowledge of the quantity of renewable and available water resources at different times of the year (and at the adequate spatial resolution) is essential for the assessment of the economic and environmental impact induced by changes in regional hydrology and for integrated land/water use planning (Salvati et al., 2009).

In Italy the availability of water resources is usually limited during the dry summer period, when water demand is increasing, rainfall amounts are poor and radiation levels promote high evaporative demands, particularly where crops with high water requirements are grown. In these conditions the risk of crop yield loss becomes relevant, in particular when irrigation water may be subject to limitations due to competition with other sectors, or to poor quality. In the Mediterranean area precipitation restricted to a short rainy period, with rates fluctuating significantly from year to year and characterised by high intensity, increases runoff which in turn limits infiltration to the root zone and may induce floods, erosion and LD (Salvati et al., 2008a). Good agronomic practices can play a fundamental role to facilitate water infiltration and to reduce the overland surface flows thus facilitating water harvesting, all together with reforestation, perennial vegetation cover, and land conservation practices, such as terrace settlements, but the exodus of rural people from hilly and mountainous areas to cities still occurring around the Mediterranean has the effect of stopping the maintenance of land and rural landscapes (Salvati and Zitti, 2007a).

Avoiding catastrophic events rather than government measures to refunding people for damages suffered from floods, erosion and water stress, is essential because the financial support in the first case can promote also rural development and employment. The multi-functionality of the agriculture and the positive externalities by the agro-forestry ecosystems are nowadays well recognised. Mitigation of hydrogeological disasters and environment conservation are at the basis of any sound environmental policy (Salvati et al., 2008b).

To bring into operation a coherent policy aimed at protecting land, soil, and water from degradation processes, integrated land planning has to be carried out. To facilitate water and land resources planning specific indicators can be used in order to assess the available water supply and to define suitable measures that allow reducing the adverse impact of LD and promoting a sustainable rural development (Tab. 1).

3. Land degradation monitoring and assessment

Despite the considerable number of issues at stake, at the moment LD and desertification investigations are based on qualitative or semi-

Table 1. Research themes and related indicators to study desertification processes in potentially vulnerable areas in Italy.

Renewable water assessment		Actual evapotranspiration/precipitation Water runoff/superficial water consistence Water uptake/groundwater amount Effective infiltration/precipitation Water supply availability/inhabitant
Water use		Civil sector water demand/total renewable water supply Total irrigation volume/total renewable water supply
Sustainable irrigation		Irrigation water derived from surface water courses/ Total irrigation volume Irrigation water derived from groundwater/Total irrigation volume
Land water management	Rainfed arable land	Erosion vulnerable land/total arable rainfed surface Flood vulnerable land/total arable rainfed surface Contour settled land/total arable rainfed surface Drained land/total arable rainfed surface
	Irrigated land	Erosion vulnerable land/total irrigated land Flood vulnerable land/total irrigated land Contour settled irrigated land/total irrigated land Drained irrigated land/total irrigated land

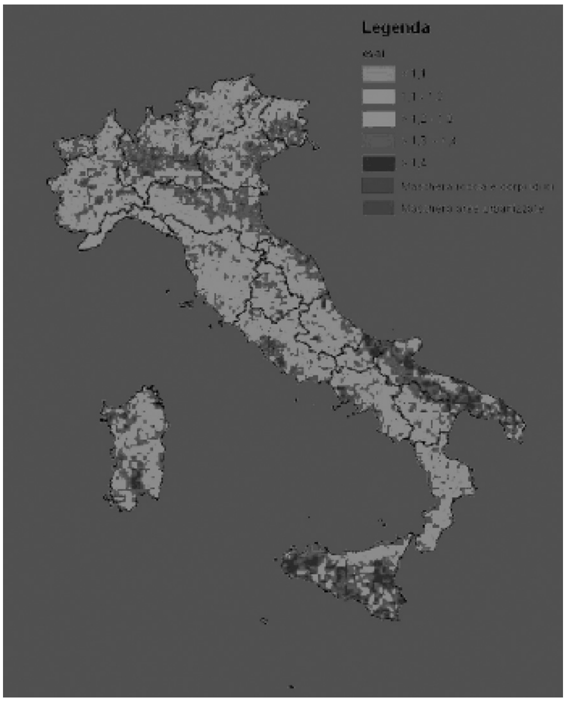

Figure 1. The ESA index estimated in Italy in 2000.

quantitative methods that produce empirical classifications expressed in relative terms. All methods use elementary indicators to develop composite indexes of land vulnerability (Ceccarelli et al., 2006 for a review). Several authors pointed out that in order to identify efficient methodologies which evaluate effectively the state of desertification process is really problematic. The multiplicity of statistical and other geographically-related (e.g. remote sensing) data seems to be not capable to cope with the needs for an efficient monitoring of desertification risk even in developed countries. This means that there is certainly scope for further empirical studies and methodological approaches (Seely and Wohl, 2004).

3.1 Environmental Sensitive Area (ESA)

Among the procedures aimed at assessing the level of land vulnerability, the Environmentally Sensitive Area (ESA) framework appears to be the most frequently applied in the Mediterranean basin and other arid and semi-arid environments. Recent studies (Ferrara et al., 2005; Fraser et al., 2005; Sepehr et al., 2007; Ali and El Baroudy, 2008; Spilanis et al., 2008, Lavado Contador et al. 2009) have underlined the efficiency and the effectivness of systems of indicators developed under the EU-funded MEDALUS III and DESERTLINKS projects (Kosmas et al., 1999; Kosmas et al., 2000a; Basso et al., 2000; Brandt, 2005; Ferrara, 2005; Ferrara et al., 2005). This is due to a relative simplicity in model building and flexibility in the use of relevant indicators (Basso et al., 2000). The ESA Index (Kosmas et al., 1999; Basso et al., 2000) estimates the level of LD which affects a specific area by means of four groups of indicators describing bio-physical processes and economic aspects, providing information on vegetation, climate, soil and management by assessing 15 different variables (Kosmas et al., 2000a; 2000b; 2000c; 2003).

It must be emphasised that the main goal of the ESA model was 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 easily obtain and update the data;
(iii) the system must be adaptable and accommodate the development and refinement of the existing information content and the input/removal of information.

The methodology adopt a two-phases process (Kosmas et al., 1999; Basso et al., 2000). In the first step, the elementary data layers are combined to give four (quality) indicators for soil, climate, vegetation, and land management through computation of the geometric mean of the basic data layers:

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

where x is the variable class (e.g. climate aridity, soil depth, etc.), i and j are rows and columns of a single cell in the raster layer (i.e. the value associated to each considered spatial domain), and n is the number of layers (i.e. variables) used. In the second step, the Environmental Sensitivity Area of each elementary unit is evaluated from the quality layers:

$$ES_{ij} = (Quality\_1_{ij} * Quality\_2_{ij} * Quality\_3_{ij} * Quality\_4_{ij})^{(1/4)} \quad [2]$$

where i,j are rows and columns of a raster cell of each quality indicators and $Quality\_n_{ij}$ are the calculated values. Four aggregated quality indicators are usually calculated referring respectively to climate, soil, vegetation, and land management.

It is important to highlight that '*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*' (Basso et al., 2000). In these systems the selection of the information layers is also an open process. The choice and the method by which they are obtained are not predefined: alternative 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 environmental (or socio-economic) contexts are considered by introducing appropriate variables. Information layers can be added when there is a requirement to study specific aspects or areas in greater detail, layers can be removed when a first approximation of an Environmental Sensitive Index (ESI) estimate is required and all the desired information is still not available over the investigated area (Ferrara, 2005). As clearly underlined in Basso et al. (2000), this also means that "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 which is 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".

It must be also underlined that establishing a system which requires information that is difficult to obtain, or is expensive to update, even if it is scientifically important, would be severely restrictive and be impractical in complex environments and with continuous monitoring systems in many part of the world and also around the Mediterranean Basin.

3.2 Other quantitative methodologies: some case studies

Following the original analysis on desertification risk (Fig. 2) provided by the National Committee of the UNCCD (see Ceccarelli et al., 2006

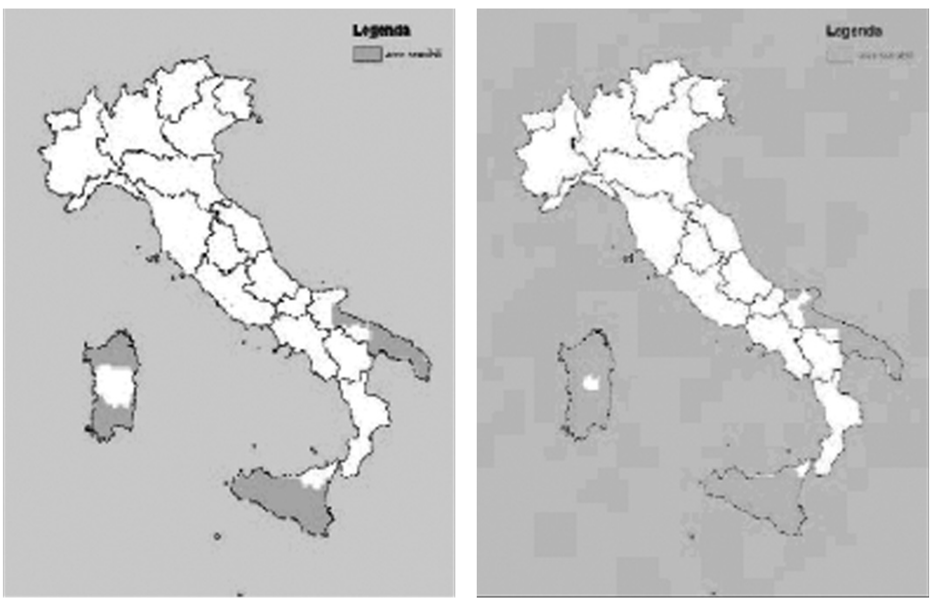

Figure 2. Desertification Risk assessed in 1990 (left) and 2000 by Italian National Committee for Combating Drought and Desertification.

Table 2. Approaches to monitor land sensitivity to degradation in the Mediterranean basin: some case-studies.

Procedure	Index	Aggregation method	Source
Environmental Sensitive Areas	Standard ESA index based on four quality indexes (climate, soil, vegetation, management)	Two stages geometric means after variable normalisation	Kosmas et al. (1999) Basso et al. (2000)
Environmental Sensitive Index	Standard ESA index ranging from 0 to 100 (expressed as a percentage of critical score)	Two stages geometric means after variable normalisation	Ferrara (2005)
Environmental Sensitive Areas	A review of modified ESA procedures to account for site-specific, environmental aspects	Various procedures	Ceccarelli et al. (2006)
Environmental Sensitive Areas	Modified ESA index to account for (mainly) human pressure aspects	Two stages geometric means after variable normalisation and weighting	Trisorio-Liuzzi and Hamdy (2002)
Environmental Sensitive Areas	Modified ESA index to account for agricultural aspects	Two stages geometric means after variable normalisation and weighting	Salvati and Zitti (2005)
Environmental Sensitive Areas	Modified ESA index to account for agricultural mechanisation	Two stages geometric means after variable normalisation and weighting	Imbrenda et al. (2008)
Environmental Sensitive Areas	Modified ESA index to account for time-series indicators	Two stages geometric means after variable normalisation and weighting	Salvati and Zitti (2007)
Remote sensing and plant physiology	Desertification Risk Index (DRI)	Arithmetic mean	Feoli et al. (2003), Salleo and Nardini (2003)
Neural Network	Desertification Sensitivity Index (DSI)	Time series analysis	Incerti et al. (2007)
System stability condition analysis	Index describing severity of LD	Analysis output	Ibanez et al. (2008)
Multidimensional Analysis	Land Vulnerability Index (LVI)	Arithmetic mean after variable normalisation and weighting	Salvati et al. (2009)
Multivariate strategy based on land classification	'Risky regions'	Output from Pricipal Component Analysis, Cluster Analysis, and Discriminant Analysis	Salvati and Zitti (submitted)

for a discussion), some original indexes of desertification risk (Tab. 2) were recently introduced by Feoli et al. (2003), Salleo and Nardini (2003), and Incerti et al. (2007). These works prove very useful to monitor the environmental conditions leading to drought and LD in the Mediterranean basin (see also the extensive documentation produced in MEDALUS and DESERTLINKS international projects: for example, Brandt, 2005).

Salvati and Zitti (2007b) proposed a simple index (ISD), composed of three partial indicators, which allows a ranking of LD sensitivity on a municipality basis. It works with both bio-physical and socio-economic indicators and provides results comparable to those obtained with other synthetic indexes. However, the ISD does not completely address the previously discussed structure of ESA and does not evaluate the importance of various underlying factors considered to be determinants of LD.

More recently, Salvati et al. (2009) introduced a time-series multivariate analysis of some environmental indicators grounded in data collected at the municipal level and preliminarily applied over a restricted area. The procedure, applied to various spatial scales and tested for robustness by using different datasets, has the advantage of working with a potentially larger number of variables. In fact, the standard ESA model could underestimate the importance of some factors (e.g. climate variability and rainfall concentration, available water capacity of the soil, demographic variables) that may be crucial in the evaluation of land vulnerability.

3.3 A framework proposal

Experimental studies on LD investigations are quite abundant and well documented, but there is often an insufficient understanding of causes, effects and processes. In some cases there is even disagreement to set indicators and, generally speaking, causes appear difficult to recognise and quantify. Due to heterogeneity of cause-effects relationships relatively few studies attempted to evaluate the potential impact of the various bio-physical and human drivers on landscape quality and thus on LD (Mairota et al., 1998). Recently, Gisladottir and Stocking (2005) proposed the use of Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework to the study of LD and desertification matters. DPSIR is widely adopted to interpret a large number of environmental processes including desertification. The framework assumes a causal sequence among each element where determinants (e.g., human behaviour consequents to economic processes, production and consumption) generate pressures (e.g., polluting emissions, overexploitation of resources) that, producing environmental changes, in turn generate a negative impact on living conditions. The economic system reacts through responses including incentives/disincentive policies, environmental legislation, geared towards all the other elements of the sequence.

Despite a theoretically unambiguous interpretation of environmental phenomena made provided by the DPSIR framework, there is a high degree of subjectivity in its practical implementation. For example many indicators can be considered at the same time as determinants, pressures or impacts. Moreover, in some cases, responses are difficult to define and quantify through indicators. Nevertheless the simplicity of the scheme, its widest application and easy understanding still supports its adoption also in the context of LD assessment.

The application of DPSIR to the study of LD processes implies, *in primis*, the identification of each element of the model and, subsequently, the development of a procedure to derive a synthetic index. Starting from the previous assumptions and definitions on LD and environmental vulnerability, we identified six degradation systems. Each of them is interacting with the others although the systems are analysed separately in accordance with the framework DPSIR, including (i) climate and climate change, (ii) soil sealing/urbanisation, (iii) soil salinisation, (iv) soil erosion, (v) soil pollution, and (vi) agricultural impacts. For each of the above mentioned systems a number of indicators may be selected which describe the corresponding process of degradation. Some indicators could be related to more than one degradation system. However, in order to avoid redundancy in information, univocal attribution should be conducted. A particular aspect, related to the indicator choice, concerns the integration of information by different data sources because, in consideration of different formats, spatial resolution, units of measurements, arose the necessity to overcome data heterogeneity. In this respect useful approaches to develop synthetic indexes envisages the application of objective methods as multidimensional analysis. Such methodology are generally useful to reduce the complexity of data array, providing an implicit assessment of the quantitative importance of each variable considered (Salvati and Zitti, 2005). It is also advisable to elaborate separately socio-economic indicators and bio-physical indicators in relation to their different nature and information content. Perini et al. (2009) apply the DPSIR framework in Italy by following indications from the existing literature (see Ceccarelli et al., 2006 for a review). The authors selected 73 indicators covering all degradation systems (including 18 for climate change, 5 for soil sealing/urbanisation, 5 for soil salinisation, 23 for soil erosion, 4 for soil pollution, and 18 for agriculture). The relationship between each indicator and its (positive or negative) impact in each degradation process was finally established and contributes to delineate a composite index based on a selection of the indicator set (Tab. 3).

3.4 Regional assessment of aridity trends as a tool for LD monitoring

The elaboration of multi-temporal maps of the Aridity Index provides indications on the dynamic evolution of the surface area vulnerable to desertification. The identification of changes in

Table 3. The standard DPSIR framework proposed by Perini and coworkers (2009) for the study of LD in Italy.

Driving Forces	Pressures	State		Impacts	Responses
climate change	precipitation temperature	rainfall evapotranspiration drought run-off aridity		soil moisture depletion, soil erosion	irrigation, land amelioration
climate change, agriculture	climate aggressiveness, grazing, fire, soil management	soil characteristics	soil depth soil texture AWC soil parent material stoniness soil drainage organic carbon content	soil erosion	agro-enviromental policies, agronomic techniques, sustainable crop production
			Land cover		
		human activities	over-grazing forest fires soil compaction		protected areas
agriculture	water over-exploitation	groundwater use for irrigation		soil salinisation	irrigation source/ system diversification
		Unsustainable irrigation systems			
		land use	crop intensification Rural settlements crop suitability	loss of cultivable land	sustainable agriculture
	intensification / marginalisation of agriculture	farm management strategies	type of farm management farms granted in leasing Economic diversification of farmer activities	crop diversification	diffusion of integrative economic acivities (e.g., rural hospitality)
		socio-economic system	people employed in agriculture farmers ageing farm marginalisation	agricultural efficiency	policies for young farmers
population growth	urbanisation	population density characters of human settlement tourism concentration		soil sealing	sustainable urban planning
economic development	pollution	quantity of pollutant emission mining		excess of wastewater	limitation to polluting

LD indicators over time is a requisite for improving the understanding of ongoing trends and possible impacts on vulnerable lands. The extension of territories in different Aridity Index classes (see Tab. 4) may be regarded as a desertification-relevant indicator that can be used to produce maps for the increase/decrease of dry lands areas over thirty years (or longer) time period.

This approach, tested for Sicily (Sciortino et al., 2005), indicated that semiarid zones increased by 4.478 km^2 (17,6%) over the two periods 1931-1960 to 1971-2000 reaching at the end of the period nearly 23% of the whole region (Fig. 3). In the same period dry sub-humid zones increased by 2.144 km^2 (+8,4%) amounting to 47% of the regional surface. The humid zones decreased consequently by 6.622 km^2 (-26%) from 56% to 30% (Tab. 4). By considering the period encompassing 1971-2000, 69% (17.769 km^2) of the regional territory is below the aridity index threshold of 0.65 and can be considered, according to the UNCCD definition, vulnerable to desertification. The progressive aridity which affected Sicily in the last years involves especially the interior lands (nearly

Table 4. Aridity Index classes.

Hyper- Arid	IA ≤ 0.05
Arid	0.05 < IA ≤ 0.2
Semi Arid	0.2 < IA ≤ 0.5
Dry sub humid	0.5 < IA ≤ 0.65
Humid	0.65 < IA

30% of these lands changed to a drier climate class). The assessment made for the Sicilian region can be easily conducted in other regions where high resolution climatic data are available.

4. Economics and integrated assessment

4.1 Estimating costs of Land Degradation

The literature about land degradation and desertification has a lot in common with other scientific fields, in particular natural resources management (land and water) and climate change. Therefore, when exploring methods for the assessment and economic evaluation of LD phenomena and policies, a wealth of references are available. On the other hand, it is also evident that the literature about LD and desertification usually does not make a distinction between mitigation and adaptation, preferring to focus more generally on strategies to combat those phenomena. Worth to mention is also the fact that in the case of LD, more than for climate change, the drivers of pressure are the results of strictly interrelated natural and human factors, with a tendency of human factors to prevail in terms of impact magnitude.

The literature about climate change adaptation is particularly close and rich of methodological proposals for the economic valuation of the costs of inaction and costs of adaptation, which can be brought to the field of land degradation. Moreover, the evolution of climate drivers, is affecting and thus climate change and land conservation policies are often not easily separated, this support the idea that similar assessment methods could be used.

The concept of cost of inaction is indeed close to the estimation of the economic impacts of LD, while the cost of adaptation is clearly related to the monetary estimation of the proactive efforts (either public or private) to combat ongoing land degradation processes. With regards to the analysis of the costs of inaction, both the direct impacts in terms of reduced services offered by degraded lands, and the indirect impacts (e.g. unemployment and migrations, but also loss of biodiversity) should be assessed, thus raising challenging methodological issues. Moreover, in different contexts, various aims could support the evaluation effort, thus requiring to focus on the assessment of various aspects, such as costs, benefits, effectiveness, distributional effects, etc. What is generally valid is the need to combine multi-disciplinary analyses, in what is usually defined as integrated assessment and, more specifically, given the relevant dynamics of the phenomena, integrated assessment modelling.

The assessment of the costs of LD includes the costs of interventions to combat the ongoing phenomena all together with the residual impacts. In case no actions are put in place to combat LD, the costs of impacts can be defined as inaction costs, which are usually compared with the costs and benefits of alternative strategies to identify optimal solutions. In general, whenever the net total benefits of proposed actions show positive values, it is worth to implement the proposed strategies, instead than opting for inaction. Critical methodological issues in this context include the identification of reference scenarios (ante-post) for inaction assessment, the management of spatial and temporal (e.g. discount rate) dimension, management of uncertainty, the identification of irreversible impacts, and last but not least the costs of various forms and degrees of degradation.

There are many possible options for economic evaluation of LD and actions to combat it and they could be grouped in three main categories: Cost-Benefit Analysis (CBA), Cost-effectiveness Analysis (CEA) and Multi-Criteria Analysis (MCA) (for more details about methods and possible applications in similar context see for instance Hein, 2002; Belton and Stewart, 2002; World Bank, 2006a, 2006b). The first providing full monetary valuation of costs and benefits of interventions as briefly described above, the second comparing instead costs with a predefined objective of the actions, thus identifying the less expensive alternative, the third providing instead a very broad set of methods aimed at supporting the identification of preferred solutions within a defined set of alternatives evaluated with regards to a predefined list of eval-

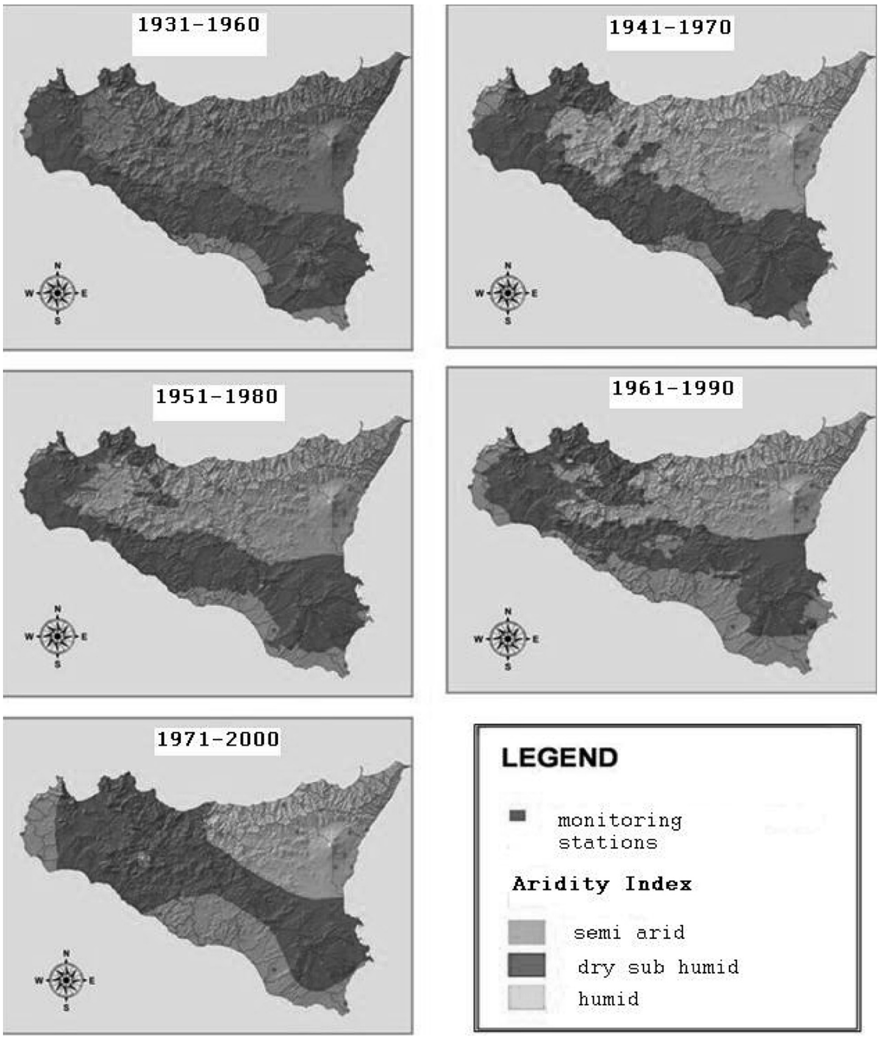

Figure 3. Aridity Index areas in Sicily, southern Italy.

uation criteria or objectives, not necessarily measured in monetary terms.

4.2 Integrated approach to land degradation assessment

The previous sections of the paper present and discuss the theoretical framework and methodological approaches for analysis and monitoring of LD, with a focus on the Italian peninsula. We move now to the preliminary development of a proposal for designing and implementing an integrated assessment of LD in Italy.

The first evidence from the international literature, is the need to avoid a segmented sectoral and disciplinary approach to the problem, preferring instead a full integration of bio-physical and economic analyses. In order to do that a shared conceptual framework is needed. As mentioned before, many official documents (Enne and Luise, 2006) and research papers (Povellato et al., 2007) refer to the DPSIR scheme as a framework for approaching the integrated assessment of the relationships between humans and the environment, and also for LD problems (see section 3.3), and in particular for supporting the development of effective strategies to combat land degradation. Figure 4 illustrates a conceptual framework in which the DPSIR scheme fits within a wider process of policy implementation and evaluation, built upon the framework defined by the EEA (2001) within the REM Project (Reporting about Environmental Measures).

The conceptual framework (Povellato et al., 2007) clearly shows that policy measures to contrast LD should be defined according to clear-

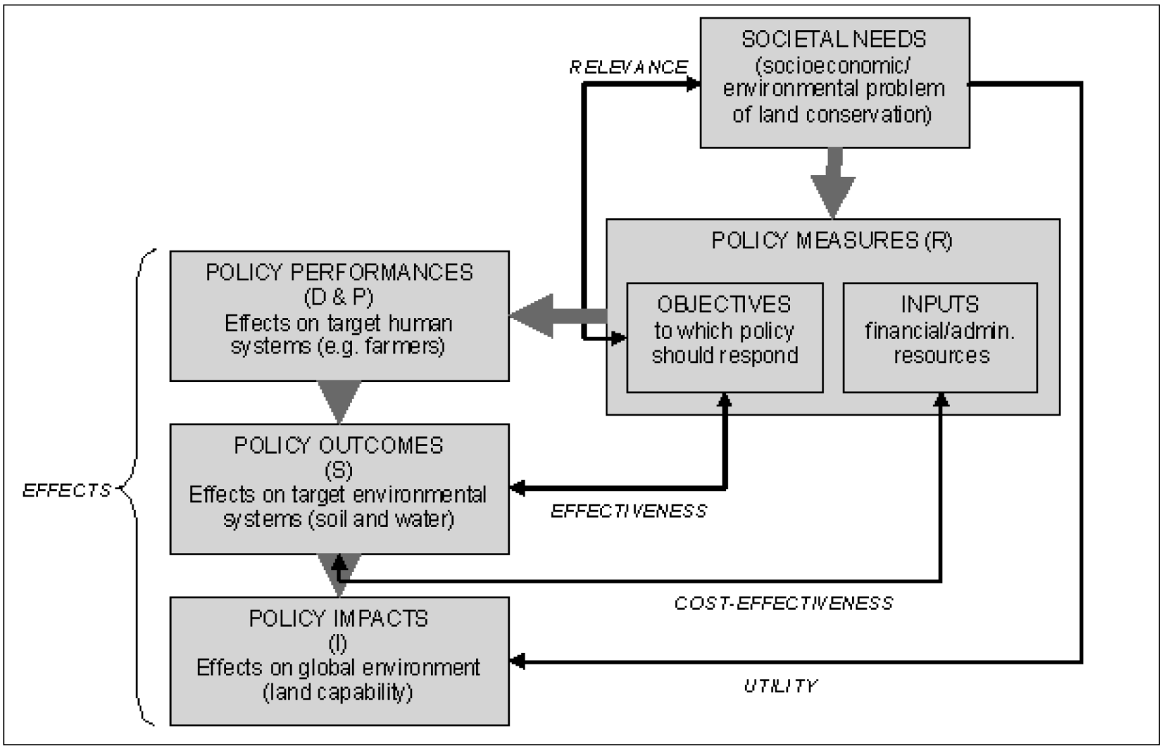

Figure 4. Policy evaluation framework and DPSIR cause-effect links for the evaluation of policy measures to combat land degradation: see text for acronyms explanation (redrawn from Povellato et al., 2007).

ly stated *needs* related to a wide range of issues (social, economic, environmental), thus requiring the adoption of integrated assessment approaches. In this case, according to the land conservation objectives of the *measures*, *inputs* should be provided in terms of resources dedicated to the design and implementation of the specific measures, from which we expect tangible results by target groups of social actors (*performance*). The effect of these behavioural changes on environment can be defined as the *outcomes* of the measure (i.e. its tangible results) and, on a more global scale, the ultimate effect (on the environment and therefore on human health) is identified as the *impact* of the policy. The links between the various boxes of Figure 3 highlight the various assessment paths from the social, economic, and environmental viewpoints. In parallel to the REM structure for the assessment of policy effectiveness, the DPSIR nodes allocated to the various boxes facilitate the interpretation of the flow chart in terms of human behaviour and its consequences for the bio-physical environment (outcomes/impacts). It also emphasises the importance of tracing through the causality of effects, thus linking the effects of a driving force (e.g. agricultural activities) to a certain pressure (e.g. soil erosion) to a change in the state of the natural resource (i.e. soil degradation) to a final impact (i.e. reduced land suitability for agricultural production). Policy measures are thus formalised in terms of responses, from which we expect to obtain specific positive impacts on the problem in question.

According to the proposed policy evaluation framework, the integration between bio-physical and economic analyses should be based, as discussed also above, on a comprehensive set of indicators describing the current state of the environment and human activities (the so called socio-ecosystem). The current values of indicators should derive from targeted monitoring and mapping activities but, in order to support the identification of preferred strategies, they should also be projected into the possible futures, by means of simulation models. The comparison of multiple future scenarios either determined by the combination of drivers, which could be endogenous only (i.e. the proposed strategies and their expected effects) or also exogenous (e.g. climate change) allows to assess the effectiveness of policies and their costs. Typically, a BAU scenario (*Business As Usual*, i.e. without policy implementation) provides data for the estimation of costs of inaction, to be compared with the costs and benefits of alternative policies. Those assessments can be carried out with regards to one degradation system at the time (i.e. soil erosion; deposition; urbanisation; salinisation; and aridity), to multiple systems or with an holistic approach.

The need for adequate modelling tools must be stressed, otherwise projections are simply impossible. At this regard the preferred option is evidently the combination of mechanistic mathematical models within a comprehensive Integrated Assessment and Modelling (IAM) framework. Integration is indeed needed for the analysis of both the environmental and the social dimension of the phenomena, but not necessarily all models or modules should be mechanistic and formalised in mathematical terms. In many cases simpler quantitative or even qualitative models either empirical ones or derived from the elicitation of expert knowledge with adequate techniques can provide the needed simulation framework.

Worth to mention is the fact that the basis for the economic valuation is provided by the quantification of the services provided by the studied ecosystems (Millennium Ecosystem Assessment, 2005) and the comparison of alternative scenarios provides the deltas to be quantified in monetary terms. Variation of land capability to provide agricultural production is clearly the first service to be considered, but not the only one, others being the conservation of biodiversity, the effects on the water cycle, and others.

5. Concluding remarks

LD could dramatically affect the ecosystem services related to the capability of the land of provisioning food in many areas around the Mediterranean Basin, including southern Italy. Targeted policies are needed to cope with the risk of LD and the scientific approaches supporting the development of such policies should integrate methods coming from both bio-physical, and economic disciplines. At this regard, the analyses reported in the previous sections of this paper allows to identify a series of actions that should be implemented in the Italian situation:

(i) to clarify the institutional setting and the competences for the various dimensions of LD;
(ii) to identify a menu of possible strategies and related measures for specific sets of phenomena and objectives, within an overall IAM approach;
(iii) to integrate available studies on physical vulnerability within a broader concept which includes also the social and economic dimensions;
(iv) to integrated the studies focused on land degradation within the literature of global change;
(v) to downscale to sub-national contexts the reference scenarios available at the global or continental scale in order to identify the main drivers and pressures on Italian socio-ecosystems;
(vi) to invest efforts on systematic studies on the costs and effectiveness of the various available strategies in the national context;
(vii) to develop local case studies with comparison of alternative evaluation techniques and in particular: Cost Benefit Analysis, Cost Effectiveness Analysis and Multi-Criteria Analysis;
(viii) to implement pilot studies in which the application of alternative strategies is explored, thus supporting the implementation of an adaptive approach towards combating LD in Italy.

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