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APPLICATION OF INDICATOR SYSTEMS FOR MONITORING AND ASSESSMENT OF DESERTIFICATION FROM NATIONAL TO GLOBAL SCALES

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ABSTRACT

This paper suggests how the United Nations Convention to Combat Desertification (UNCCD) community can progressively make use of a flexible framework of analytical approaches that have been recently developed by scientific research. This allows a standardized but flexible use of indicator sets adapted to specific objectives or desertification issues relevant for implementing the Convention. Science has made progress in understanding major issues and proximate causes of dryland degradation such that indicator sets can be accordingly selected from the wealth of existing and documented indicator systems. The selection and combination should be guided according to transparent criteria given by existing indicator frameworks adapted to desertification conceptual frameworks such as the Dryland Development Paradigm and can act as a pragmatic entry point for selecting area- and theme-specific sets of indicators from existing databases. Working on different dryland sub-types through a meaningful stratification is proposed to delimit and characterize affected areas beyond the national level. Such stratification could be achieved by combining existing land use information with additional biophysical and socio-economic data sets, allowing indicator-based monitoring and assessment to be embedded in a framework of specific dryland degradation issues and their impacts on key ecosystem services. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: land degradation/desertification indicators; interpretation frameworks; desertification issues; UNCCD

INTRODUCTION

Since the United Nations Convention to Combat Desertification (UNCCD) opened for signature in 1994, it has endeavoured to coordinate the collection, analysis and exchange of data to describe the nature, extent and location of desertification. It has sought first to identify indicators that help to assess the current situation and the potential impacts of changing climate, changing land uses and agricultural practices, and second, indicators to measure progress on its implementation (Brandt and Geeson, 2008). Clarification of indicators and benchmarks continues to be a priority for the UNCCD as confirmed by the ninth Conference of the Parties, held in Buenos Aires from 21 September to 2 October 2009 (ICCD/COP(9)/18/Add.1). Although numerous initiatives and programmes of UNCCD stakeholders attempted to develop indicators for characterizing the state and trends of desertification, land degradation and drought and actions to combat it, the approaches employed still suffer from limited scientific harmonization. This lack of agreement regarding indicators may have been aggravated by the institutional setup of the UNCCD which has not favoured the most direct flow of information between its implementing bodies and the scientific community (Grainger, 2009a).

Because of its breadth, complexity and dynamism, desertification is difficult to monitor and assess (Eswaran *et al*., 2001). As outlined by Vogt *et al*. (2011), desertification monitoring and assessment approaches at supra-national and global levels have so far been largely empirical and focused primarily on biophysical symptoms. Nevertheless, science has made lots of progress towards understanding major issues and proximate causes of land degradation and desertification. According to Reynolds *et al*. (2007), the major research lesson over the past two decades is that most environmental management and sustainability

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issues cannot be explained or solved by focusing on either the human or the natural elements of the system in isolation. Emphasis has therefore progressively shifted to basing decisions concerning land degradation and desertification on integrated approaches known as 'coupled human–environment or ecological' systems or socio-ecological systems (Lebel *et al*., 2006). To achieve the goal of sustainable resource use, such an integrated approach is essential and has to be reflected in the use of indicators for desertification monitoring and assessment (M&A). In this context, indicator systems should be nested (i.e. at different levels of interest, where each is a subset of a higher one) and the design at each scale should address the needs of decision makers at that scale, but be linked to the other scales by a common theme or goal. According to Reynolds *et al*. (2011) the common themes or goals of the nested approach should be based on variables representing key ecosystem services. Likewise, Vogt *et al*. (2011) outline that decision makers from local to global levels need similar categories of desertification information, but the exact nature of this information differs greatly across the scales and level of operation, as do the methods available for data collection. Broadly, all groups need to know:

- The spatial location, severity and extent of desertification and whether these factors are changing over time. This requires a baseline against which to monitor change, and periodic repetition to determine the direction and rate of change.
- The nature of the prevailing desertification processes, for instance loss of net primary production, wind erosion, soil salinization, bush encroachment, species composition change, etc.
- The causes of desertification and what can be done to counter it. Social, economic, political and environmental drivers need all to be considered (Nkonya *et al*., 2011).
- The risk of desertification occurring in areas currently not affected.
- Financial considerations such as the economic consequences of not taking action and the cost to avoid or reverse the problem (Requier-Desjardins *et al*., 2011).
- The social implications of the current and future situation, in terms of the numbers and wellbeing (health, livelihoods, food security) of the affected people.

These needs are also reflected in the current 10-Year Strategy of the UNCCD (IIWG, 2007), particularly in the strategic objectives and their seven strategic indicators (see Table I).

The nature of these UNCCD strategic objectives and indicators clearly requires integration of biophysical and socio-economic information. It is further essential to perform a precise, spatially and temporally explicit assessment of the extent of the areas affected by desertification. Against this background, in 2009 an international group of experts was commissioned on behalf of the UNCCD secretariat, to propose a minimum set of impact indicators that take account of and build on the seven core indicators listed in Table I. The group made clear that an important missing link in the UNCCD impact assessment process is an agreed methodology by which to define affected areas. They emphasized the importance of a more uniform identification of affected areas at least on a regional basis as a pre-requisite for meaningful implementation of the 10-Year Strategy (Berry *et al*., 2009). This calls for better identification and characterization of affected areas in terms of their extent, dynamics, and trends (positive and negative), as well as of the underlying causes and drivers of land degradation and desertification, with the goal to establish a common baseline for the future implementation of impact assessment of the UNCCD.

This multitude of objectives to be considered in M&A of dryland degradation may have contributed to some confusion when discussing minimum sets of indicators. Partly such a set may have been misunderstood as a universal solution for all aspects of M&A. Therefore, we would like to emphasize that the selection of suitable indicators and their integration or interpretation has to be driven by the objectives stakeholders want to accomplish and the questions that need to be answered. Measuring the impact of the UNCCD against its strategic objectives will definitely require a different set of indicators compared to those required to characterize the areas affected by desertification. Causes and consequences of dryland degradation can have multiple characteristics and vary within space and scale. Hence, the indicator selection needs to accommodate these particularities in order to achieve the objective. Our focus in this paper is to point towards transparent ways to use existing indicator frameworks and databases for selecting and combining indicators for enhancing regular spatially and temporally explicit M&A of desertification problems and solutions, from national to global levels.

GENERAL CHARACTERISTICS AND ROLE OF INDICATOR SYSTEMS

In the context of national and supra-national desertification assessments the discussion about the use of indicators has a long history, dating back to early United Nations initiatives in the 1970s (e.g. Enne and Zucca, 2000; Grainger, 2009). According to Mabbutt (1986), desertification indicators should be: (a) as specific as possible to desertification, to avoid confusion with other phenomena; (b) sensitive enough to show the gradual development of desertification in an area; (c) easily quantified by ground observations or remote sensing techniques, or (especially for socio-economic

Table I. UNCCD 10-year strategy science-related strategic objectives and their seven strategic indicators (IIWG, 2007)

Strategic objective 1: To improve the living conditions of affected populations
Indicator S-1: Decrease in numbers of people negatively impacted by the processes of desertification/land degradation and drought.
Indicator S-2: Increase in the proportion of households living above the poverty line in affected areas.
Indicator S-3: Reduction in the proportion of the population below the minimum level of dietary energy consumption in affected areas.
Strategic objective 2: To improve the condition of affected ecosystems
Indicator S-4: Reduction in the total area affected by desertification/land degradation and drought.
Indicator S-5: Increase in net primary productivity in affected areas.
Strategic objective 3: To generate global benefits through effective implementation of the UNCCD
Indicator S-6: Increase in carbon stocks (soil and plant biomass) in affected areas.
Indicator S-7: Areas of forest, agricultural and aquaculture ecosystems under sustainable management.

indicators) available in published statistics; (d) comprehensive enough to be widely applicable to different types of areas; (e) suitable for repeated scanning by ground observation or remote sensing, or capable of periodic updating if obtained from published statistics and (f) recognizable or usable without specialized training. It could also be added that they need to be fairly inexpensive to be measured and monitored on a regular basis.

With reference to recent scientific concepts such as the Dryland Development Paradigm (Reynolds and Stafford Smith, 2002; Reynolds *et al*., 2007) the nature and role of desertification indicators can be characterized as either individual or sets of measurable variables selected to provide a meaningful but easily understood overview of the actual state of the human–environment system with regard to its land degradation status. This remains compatible with more general concepts of state-of-the-art environmental indicator systems such as the environmental indicators of the Organization for Economic Co-operation and Development (OECD, 1997, 2003), which have evolved over recent decades, and which have set out broad principles for defining and selecting indicators that describe complex environmental issues and their socio-economic embedding.

The OECD defines an indicator 'as a parameter, or a value derived from parameters, which points to, provides information about and describes the state of, a phenomenon/environment/area, with a significance extending beyond that directly associated with any given parametric value' (OECD, 2003: p. 5). In the same OECD set of definitions, a parameter is a property that is measured or observed, and an index is a set of aggregated or weighted parameters or indicators. Indicator systems may thus comprise sets of indicators or combine these indicators to give composite indices (Booysen, 2002), allowing different factors to be taken into account, at the same time ideally representing a complex phenomenon in a less synoptic, but simplified and more comprehensible way.

Hence, indicators and indices are expected to simplify the communication process of providing the results of measurements to users. Due to this adaptation to user needs, indicators may not always meet strict scientific demands to demonstrate full detail of causal chains, but clearly have to be based on state-of-the-art scientific know-how. As such, indicators should be regarded as a generalized expression of 'the best knowledge available' (OECD, 2003). Accordingly, no indicator set should necessarily be considered final or exhaustive but should be seen as constantly evolving due to progress in scientific knowledge, data availability or changing objectives and policy concerns. Furthermore, to qualify as 'useful', an indicator should conform to certain criteria, ideally being SMART: Specific, Measurable, Achievable, Relevant, and Time-bound, i.e. specific for a particular time period (OECD, 2001; Brandt and Geeson, 2008). OECD criteria further suggest that indicators should demonstrate policy relevance and utility for users, and analytical soundness as well as measurability. The latter requirement implies features such as a sound scientific and methodological foundation, reference to international standards and consensus on their validity, data availability and quality in terms of continuity, standard protocols/definition, inter-comparability, cost efficiency and others.

The OECD have categorized their environmental indicators into several types of indicator sets, each corresponding to a specific purpose and framework as a function of the addressed environmental problem and audience, which follow a hierarchy of increasing detail and complexity from the supra-national to the sub-national level (OECD, 2003). This is again compatible with the postulate that indicators for M&A should be nested (see above). The same general principles apply when looking at indicators in the UNCCD context. For instance the 7 strategic indicators and the recommended minimum set of 11 impact indicators (Berry *et al*., 2009; Decision 17/COP.9) could be seen as comparable to the structure of OECD Key Environmental Indicators. They are meant to report at the broadest national to supra-national level to high-level decision makers and to the general public, on key environmental issues and trends. Ideally, such a reduced set of indicators (10–15) should be selected from a set of Core Environmental Indicators (CEI) designed for M&A at national level but in an international context. Hence, they should be common to all participating countries or parties. Baseline indicators for improved delineation of affected areas and regular monitoring and assessment of dryland degradation processes would rather correspond to the CEI category, currently comprising as many as around 50 indicators in the OECD system (OECD, 2003). From these extended lists of CEI type indicators, the most suitable indicators would need to be selected for thematic subsets, which may be considered minimum sets, for addressing specific stakeholder objectives.

Against these general criteria, systematic screening of potential indicators for dryland degradation monitoring has already been performed in many research studies, leading to a good understanding of the current capacities and gaps in indicator implementation (see, e.g. Enne and Zucca, 2000; Enne *et al*., 2002; Brandt and Geeson, 2008; Berry *et al*., 2009).

MATCHING INDICATOR SYSTEMS AND CONCEPTUAL DLDD FRAMEWORKS

To define specific indicator sets for the M&A of desertification, we have to match existing environmental indicator systems with conceptual models or frameworks for describing desertification processes. If a set of indicators is to provide an adequate description of a given phenomenon it should be framed within a comprehensive conceptual model of that phenomenon. Employing too simplistic a model will limit the scope of the set, while a set of indicators framed by no model at all will lack coherence. Generally, as summarized by Grainger (2009), such conceptual frameworks will:

(1) identify key variables,
(2) distinguish between (a) observable parameters that characterize the phenomenon and can function as single or aggregate indicators and (b) driving and controlling variables,
(3) cluster similar indicators together under superior headings in the hierarchy,
(4) reveal interconnections between variables, indicators and processes,
(5) prevent duplication and inconsistencies,
(6) show how to synthesize information from indicators to give an integrated overall picture of a phenomenon.

Single variables or parameters are placed in a system of functional and theme-dependent priorities, reducing the number of measurements and parameters that normally would be needed to give a full scientific presentation of a situation. Consequently, the size of an indicator set and the level of detail contained typically will need to be limited in order to avoid cluttering the overview it should provide with too much detail. Brandt and Geeson (2008) postulate that the best frameworks for organizing indicators are those that provide direct answers to the questions being asked by indicator users, where the range of issues and fundamental information requirements remains similar. However, some users need information at a supra-national to national scale and others at the local scale, both with clear implications for specific data collection and analysis requirements (see also Vogt *et al*., 2011).

For M&A of desertification, this framing of indicator sets typically should consist of two conceptual steps. The first step is the identification of the major critical factors and processes that condition the prevalent land degradation state and trends of a given human–environment system. In line with this, concepts such as 'desertification issues' (Brandt *et al*., 2003, 2006), or similar approaches of classifying documented desertification processes according to their 'proximate causes' (Geist and Lambin, 2004) or 'desertification syndromes' (Schellnhuber, 1997; Lüdeke *et al*., 2004) could be the entry level for a space and theme specific stratification framework for selecting limited but specific indicators sets. This may correspond to a nested set of syndromes of dryland degradation at different scales as proposed by Verstraete *et al*. (2009).

The second step is the actual selection of the most suitable indicators characterizing the key desertification issues using a conceptual model of the cause–effect relationships between environmental and socio-economic components of the observed system. The organization system most often used and referred to in the literature is the DPSIR (Driving force, Pressure, State, Impact, Response) framework. DPSIR is largely derived from the OECD Pressure-State-Response model and was developed by organizations such as the European Environment Agency to organize environmental information and supply causal links for decision makers (Gentile, 1998). The framework helps to explain the relationships between the current state of a landscape and the factors that could exacerbate or reduce the risk of desertification (Brandt and Geeson, 2008). Concerns have been raised that DPSIR may not be best suited to provide an effective representation of desertification and to comply with the Dryland Development Paradigm principles considering fluctuation of and multiplicity of human–environment interactions (Grainger, 2009) as well as the subjectivity and contextuality of the assignment of an indicator to one of the five categories (Zucca *et al*., 2007; Svarstad *et al*., 2008). Nevertheless, it may be considered an acceptable tool for cause–effect based indicator selection until more sophisticated modelling tools, such as Integrated Assessment Models (Reynolds *et al*., 2011) become more familiar to broader user groups.

Following the principles of the approach described above, a number of initiatives have made proposals for core indicator sets serving variable UNCCD objectives. The DESERTLINKS project proposed a set of 140 core indicators, grouped according to sectoral and DPSIR categories (Brandt *et al.*, 2003, 2006). These are broken down to subsets of 11 desertification issues relevant for the Mediterranean Basin and described in standardized fact sheets. All factsheets, issue relational models and indicator sets are stored in the DIS4ME database (Brandt *et al.*, 2006). The DESERTLINKS scheme has been tested and demonstrated in numerous case studies across the Mediterranean region. It considers all scales from local to supra-national levels and suggests tools ranging from participatory stakeholder workshops to regional scale scenario modelling to identify the relevant issues. Therefore, the 'issue framework' approach may in practice be the most compatible with the key implications of the Dryland Development Paradigm for using indicators (Reynolds *et al.*, 2007).

The Land Degradation Assessment in Drylands project (LADA) has adapted the approach to the situation in six LADA pilot study countries,[1] setting-up the DIS4LADA[2] database (Brandt and Geeson, 2008). Similarly, six South American countries[3] have applied these principles and proposed an indicator system for M&A of affected areas in their region (Abraham and Beekman, 2006). This system considers four major factors (abiotic, biophysical, socio-economic and institutional-organizational), which are further deconstructed into nine themes (climate, water, soil, flora and fauna, land use, population, poverty, institutional aspects and social organization). Under this scheme, the countries involved propose 43 national level core indicators and 68 sub-national/local level indicators, each classified according to the DPSIR scheme, for regular M&A activities (Abraham, 2006).

Grainger's (2009) proposal to the UNCCD of an indicator set for a baseline survey of biophysical and socio-economic trends in desertification is also broadly in line with the principles outlined above. He suggests focusing on a working set of 11 biophysical indicators related to vegetation degradation, soil degradation, water resources, integrated with four economic and three social indicators, giving a full rationale for the choice and detailed recommendations for best technical practice of implementation at the national level. This would provide the following pieces of information for a given country in a baseline or common reference year:

- The area of land affected by desertification, classified by degree of degradation.
- The social impacts of desertification, comprising the number of people affected by different degrees of degradation and the distribution of vulnerability among each of these populations.
- The magnitudes of agricultural productivity, production and income in affected areas, representing the economic benefits that offset the environmental and social costs.

However, a systematic collection and compilation of this dedicated baseline data may not be feasible to a majority of UNCCD parties. Efficient implementation would require substantial progress in the improvement of the enabling environment to combat desertification at the institutional level (Akhtar-Schuster *et al.*, 2011) and would crucially benefit from the establishment of a Global Dryland Observation System (GDOS) (Verstraete *et al.*, 2011).

METHODS TO INTEGRATE MULTI-SOURCE INFORMATION LAYERS—TECHNICAL CONSIDERATIONS

The relevant information to be obtained and integrated when implementing indicator sets for assessment may typically vary as a function of the spatial and temporal scale to be addressed. The major aim of linking and integrating information is to provide geographically related representation and documentation and referencing of the state and trends of human induced desertification and land degradation. Explanatory data layers need to have the capacity to reflect changes in and interactions between ecosystem services at all scales. Nested indicator systems with improved harmonization are to be used or built to reinforce this concept. Suitable variables are to be selected in view of the objectives they are meant to meet, which include global strategies, national programmes or local adaptation or mitigation schemes. These objectives are however not only scale- but also perception-dependent. As such, some of the more participatory stakeholder-led approaches can offer additional insight into different perspectives (see Reed *et al.*, 2011; Schwilch *et al.*, 2011). This nevertheless imposes methodological challenges regarding multi-source data integration and the institutional aspects of assuring data continuity and coherence (Verstraete *et al.*, 2011).

Integration of Geo-information/Spatial Analysis Tools, Remote Sensing and Terrestrial/In situ Monitoring

According to Safriel (2007), scientific assessment of desertification, especially on a global scale, currently involves three stages—(a) generating numerical data based on ground observations and measurements; (b) transforming the numerical data to map units and (c) extracting statistics by subjecting map units to various analyses. This sequence of steps is the most widespread way used nowadays to capture desertification extent particularly at national, regional (i.e. supra-national), and global levels. Indeed,

[1]Argentina, China, Cuba, Senegal, South Africa, Tunisia; http://www.fao.org/nr/lada/
[2]http://dis-nrd.uniss.it/
[3]Argentina, Bolivia, Brazil, Chile, Ecuador, Peru; http://www.cricyt.edu.ar/ladyot/publicaciones/libro_bid/indice.htm

during the last decades, remote sensing techniques, geographic information systems (GIS) and the global positioning system (GPS) technology development, have provided powerful technical support for the state-of-the-art land degradation monitoring and assessment.

Novel machine learning methods, such as artificial neural networks (Fisher, 2006), evolving graph clustering (Feng and Liu, 2006), or regression tree analysis (Anderson *et al*., 1999) show high level capacities to integrate various data and information layers for spatial effect analysis. However, so far application of these more advanced techniques to multidisciplinary integration and on more feasible methodologies for the dynamic integration of the economic, social and environmental dimensions of development has been embryonic. Displaying this kind of information as discrete maps that can be superimposed in a computer-based Geographical Information System has probably been the most widely used approach (see Buenemann *et al*., 2011). This technology is widely used by institutions and organizations all over the world to develop land degradation and related maps at regional to global scales. Well-known examples are the FAO LADA's global Land Use Systems (LUS), the Desertification Information System for the Mediterranean (DISMED)[4], and several others, mostly performed at the national scale (Enne *et al*., 2004; Enne and Yeroyanni, 2005). Similar frameworks of methods and technical tools were also used to develop approaches to early-warning indicators of desertification trends (e.g. Cheng *et al*., 2004; OSS, 2009) and to identify high-risk areas in order to explore options for their management from sub-national to regional levels (e.g. the Environmentally Sensitive Areas index by Kosmas *et al*., 1999).

Satellite remote sensing can substantially contribute to the identification of affected areas and follow the state of the environment and of available resources through time (see Buenemann *et al*., 2011). Combining remotely sensed geo- and biophysical information with the whole range of meteorological data collected from satellites, as well as satellite derived land use and land use change maps provides unique capacities for linking the natural processes and boundary conditions to the socio-economic framework of desertification (Hill, 2008). However, since biophysical indicators of surface characteristics can be ambiguous and misleading when not interpreted in context, it is crucial to relate the extracted information components to specific causal constraints. The problem here is that the latter might appear as manifold, as drylands differ in their societal, economic and natural settings (Hill, 2008). Therefore, multi-temporal analysis of remote sensing data is increasingly integrated with interpretation schemes based on conceptual models of human–environment systems such as the Desertification Syndromes (Hill *et al*., 2008).

At local level, the assessment of desertification extent is mainly based on ground measurements and *in situ* qualitative monitoring of land degradation (FAO, 2006). However, beyond the sub-national level, there is yet limited capacity of operational and continuous *in situ* monitoring dedicated to land degradation and desertification. The ROSELT/OSS network has conducted long-term environmental surveillance of degradation and desertification (ROSELT/OSS, 2008). It has been addressing the challenge of improving the collective knowledge on desertification, including its interaction with climate change and biodiversity loss. It consists of a cluster of observatories, which span circum-Saharan Africa and share a common focus on desertification. The network of environmental surveillance tools places emphasis on detecting change, assessing its nature and extent, and analysing the mechanisms and effects of natural resource degradation. ROSELT/OSS subsequently provides the relevant biophysical and socio-economic indicators alongside diagnostic and decision-support tools. The network operates as an interdisciplinary platform, which facilitates experience-sharing by promoting and harmonizing concepts and methods for data collection, processing, management and analysis. This requires scientifically sound and reliable indicators, monitoring and early warning methodology that capture resource quality and ecological processes, as well as related human interventions.

In a so far unique effort, China recently finished a national atlas on desertified and sandified land (i.e. land affected by sand encroachment) integrating local detail into a mapping approach at sub-national level. This work is entirely based on ground surveys of 5·02 million plots, as part of a 5-year nationwide monitoring system. A set of easy-operating indicators was established and results were compiled into spatial maps using satellite data as stratifying aid (State Forestry Administration China, 2008).

Integrating Scientific and Contextual Datasets

Dominant scientific models such as the Dryland Development Paradigm acknowledge the statement of Warren (2002) that desertification is contextual and ill-suited to simplistic regional or national generalizations. It has become ethically desirable to promote local participation in all aspects of development, including schemes to control and monitor desertification. Yet recent scientific insights on contextuality show that participation is not just ethically desirable but also practically essential. If assessments made at national scale are not complemented by assessments at smaller scales, especially the local, then a true picture of the status of desertification will not emerge (Grainger, 2009).

[4]EEA (1999), http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=1065

However, scientific methods have matured enough to allow combining interpretative, often more qualitative, approaches with positivist or more quantitative techniques (Reed *et al*., 2011). Derived synthetic models allow for definition of dynamic determining factors and indicators of the human–environment system at various scales. Combination and importance of local and scientific knowledge will differ according to the scale of operation and relevant combined indicators will only be generated by integrating local environmental knowledge and scientific knowledge using geospatial tools (Buenemann *et al*., 2011). The enhanced scientific expressions of the human–environment systems that are obtained determine the indicators to be monitored in a way that they are increasingly adapted to be directly applied into emerging integrated assessment models for analysis (Reynolds *et al*., 2011). FAO LADA designed mapping methods for assessing sustainable land management options at sub-national and national levels integrate local knowledge, through systematic participatory processes developed by the initiative on the World Overview of Conservation Approaches and Technologies (WOCAT, 2007). For instance, building on the LADA/WOCAT activity, scientists and modellers can interact with stakeholders through an iterative process to synthesize the socio-cultural, economic, technological, political and environmental context and drivers of change (Schwilch *et al*., 2011). Similarly, the Australian Collaborative Rangelands Information System (ACRIS) demonstrates some capacity for integrating human–environment interactions into understanding and reporting change in Australia's rangelands (Bastin *et al*., 2009).

Addressing Temporal Inconsistencies of Data Sets—The Need for Multi-temporal Information

In addition to integrating scientific and contextual datasets, strategies are needed to reliably integrate datasets collected with different timings and frequencies of data collection. This is vital in order to account for intrinsic natural fluctuations of dryland ecosystems, which means that the human–environment systems constantly change and driven by their coupled and co-adaptive dynamics, they are rather fluctuating than undergoing steady linear changes. This makes it difficult, for example, to: (a) link the present status of vegetation to benchmark values in order to assess the degree of degradation; (b) decide which year should be the baseline for long-term monitoring and (c) even identify the benchmarks themselves (Grainger, 2009). The problem arises when, for example, a selected baseline year would fall into a period of extended drought and hence, reduced vegetation biomass, which would distort the assessment of the extent and severity of degradation against this baseline. Another important aspect is that multi-temporal information is needed to understand how desertification has happened in the past. This knowledge is essential input to current methods of modelling and assessing predicted desertification risk (e.g. Kosmas *et al*., 2003, 2006) in support to planning action for prevention and mitigation.

Consequently, the status and development of drylands cannot be assessed by measurements or sets of observations at a single point in time or during a short reference period. Instead, it needs to be evaluated within a longer time frame. Hence, it is crucial that longer time periods are considered when defining baselines for monitoring and action planning.

Taking into account the availability of historical remote sensing data archives and the increase in thematic supra-national and global data layers of fundamental bio-physical and socio-economic variables since the start of the UNCCD, a 10–15 year period converging in a reference year, e.g. the year 2010, might be a feasible time frame for establishing an initial global scale baseline situation for M&A of land degradation, desertification and drought, that can be relevant to the implementation of the 10-Year Strategy (Zucca *et al*., 2011).

A PRAGMATIC IMPLEMENTATION SCHEME FOR SELECTION AND INTEGRATION OF INDICATORS AT GLOBAL SCALE

We suggested that indicator sets are variable and conditioned by the questions they have to answer, and that many options are available for their integration. To consolidate these findings we now formulate an implementation framework aimed at harmonizing indicator selection and integration procedures for monitoring and assessment of degradation issues at a global scale, based on existing data and M&A initiatives.

General Implementation Principles

Desertification issues inventoried in a spatial stratification drive the selection of the indicators needed in relation to the specific M&A objective or priority for the respective human–environment system. The actual selection is then guided by a cause–effect relational framework, such as DPSIR. Obviously, assignments of indicators of, say, Drivers or State will vary when responding to distinct objectives. A resulting minimum set of indicators may provide feedback to eventually adapt data collection and monitoring systems to modified monitoring needs. Evaluation or further integration of indicators leads to the final assessment in response to the objective. Progress or restrictions for monitoring, as well as the outcome of the assessment, can influence the priority of objectives in follow-up M&A activities. This feedback, reflecting the variable character of changing human–environment systems, might in turn modify the requirements for indicators as well, as sketched in Figure 1.

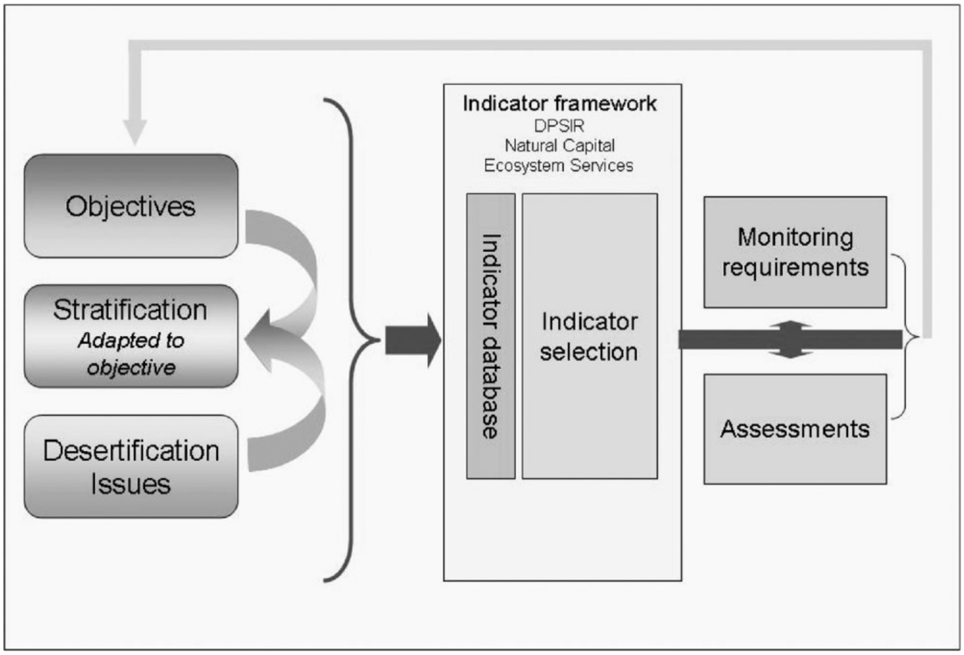

Figure 1. Flowchart of main elements and principal pathway for selecting adapted indicator sets.

First Steps to Practical Application of the Framework

The Millennium Ecosystem Assessment (2005) evaluates the capacity for ecosystems to provide services as a robust way to quantify land degradation. The mapping and assessment of the state and extent of desertification, preset as the main objective, can be based on the analysis of ecosystem services. Conforming to the concept of human–environment systems, it is human activity that places demands on ecosystem services. Changing anthropogenic requirements and related impacts will define the trends and current status of the supply of ecosystem services. Land use is the reference to ecosystem exploitation, as it can be defined as the sequence of operations carried out with the purpose to obtain goods and services (Nachtergaele and Petri, 2008). Further to the biophysical potential, land use is conditioned by a number of human factors, such as demographic or economic aspects. Land use is accepted to be a prime driver of land degradation. Hence, land use stratification will be the entry level for selecting the space and problem-specific set of indicators. The FAO LADA global Land Use Systems map (LUS) combines more than 10 global biophysical and societal datasets (Nachtergaele and Petri, 2008). These unique combinations of human aspects along with land use for various ecosystems are considered a valid stratification as proxy for ecosystem exploitation. The combination of biophysical and socio-economic aspects into ‘land use systems’ is useful at global scales, as it aggregates detailed, and at times, scattered, land uses into thematic meaningful and spatial usable strata.

At this point we need to enhance the selection criteria by integrating knowledge on the prevalent or potential desertification and land degradation problems for the various strata. Zucca *et al*. (2011) performed an analysis and overview of global desertification issues. The result of this extensive review is a listing, summarized in Table II, of

Table II. List of important regional to global desertification issues and related problems derived from Zucca *et al*. (2011)

Major desertification and land degradation issues
A. Overuse of agricultural land, intensification, inappropriate agricultural practices/non-SLM, increased soil erosion
B. Increase in intensive irrigation, overuse of water resources, salinization
C. Grazing mismanagement, overgrazing and decreasing NPP in rangelands, soil degradation, sand encroachment
D. Deforestation
E. Increased aridity or drought
F. Socio-economic issues, changes in population distribution and density, rural migration/land abandonment, urban sprawl, littoralization
G. Uncontrolled expansion of mineral mining and industrial activities, extensive air and water pollution by waste materials, soil loss by contamination

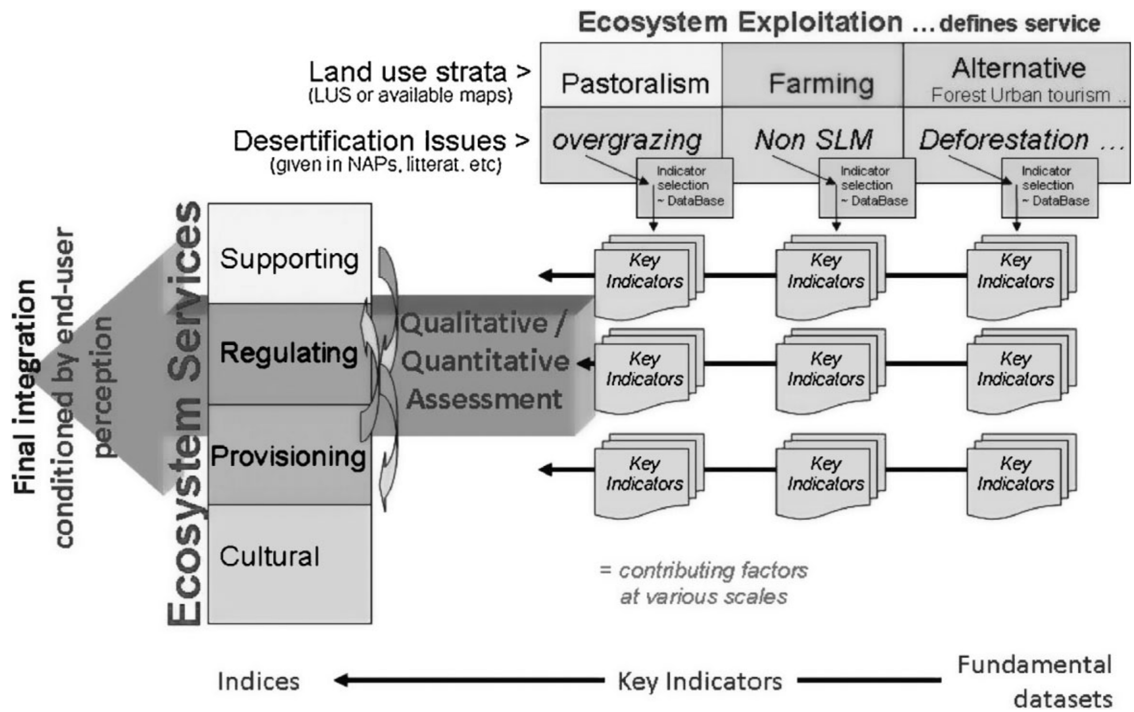

Figure 2. Schematic and simplified overview of the general concept for selecting, using and integrating key indicators, being contributive factors of DLDD, into combined indices useful for evaluating related ecosystem services (Cherlet and Sommer, 2009). SLM = sustainable land management.

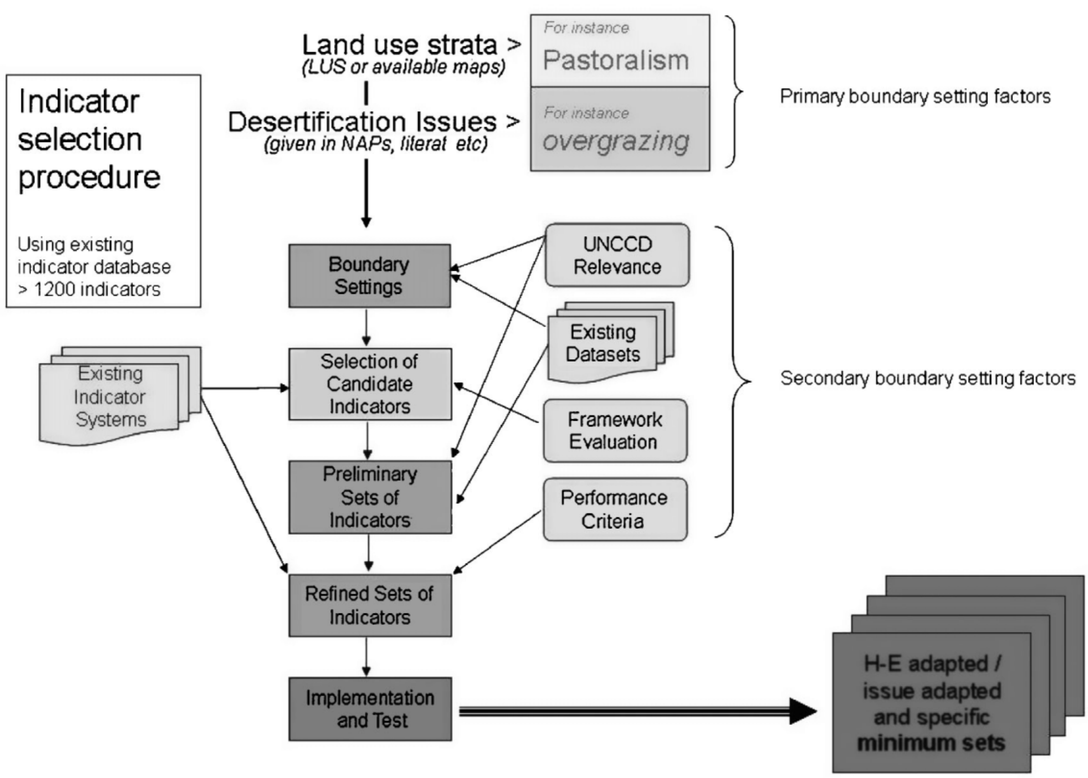

Figure 3. Flowchart of selecting global scale indicators (after Zucca *et al.*, 2011). H–E = human–environment.

desertification issues most widely reported by affected countries and stakeholders (such as overgrazing, rural migration, etc.). These issues are considered comprehensive sets of generic information reflecting the main interactive dynamics of a human–environment system that lead to land degradation. Global mapping of potential occurrences of these issues is currently being undertaken and will be spatially linked with the global land use systems (Cherlet and Sommer, 2009).

The selection of indicators is based on the characteristics that allow best available representation of the land use and the potential desertification and land degradation proximate causes or issues, combinations of which, in our example, can address the objective of global mapping of state and extent of desertification. The procedure for selecting indicators is driven by a database containing indicator meta-information linking them to land use, desertification issues, data availability, an evaluation framework, etc. Zucca *et al.* (2011) prepared and described such a database containing more than 1200 existing indicator descriptions, including fundamental variables that may feed into the integrated assessment schemes or complex high level indices. Sets of indicators that are selected, conditioned by the spatially framed specific land-use and issue combination, may be called 'key indicators'. Figure 2 shows a schematic overview of the overall pathway 'land use–issue–indicators–ecosystem service' and Figure 3 outlines the database selection procedure. It should nevertheless be noted that this represents just one pragmatic implementation scheme at global level. Linkages to other, more participatory and multi-stakeholder oriented approaches (see Reed *et al.*, 2011; Schwilch *et al.*, 2011) also need to be developed to assure coherence of M&A through different levels of scale.

Optional Fundamental Datasets and Integration to Key Indicators

Key indicators and more complex indices of land degradation and desertification typically have to be derived from already existing fundamental datasets. Such fundamental datasets are mostly collected through discipline-based observatories and data collection centres that provide representative information for their immediate environment, which may not primarily correspond to our specific M&A objectives. Figure 4 outlines a concrete set of fundamental parameters, identified by an international expert group in the context of preparing a new World Atlas of Desertification

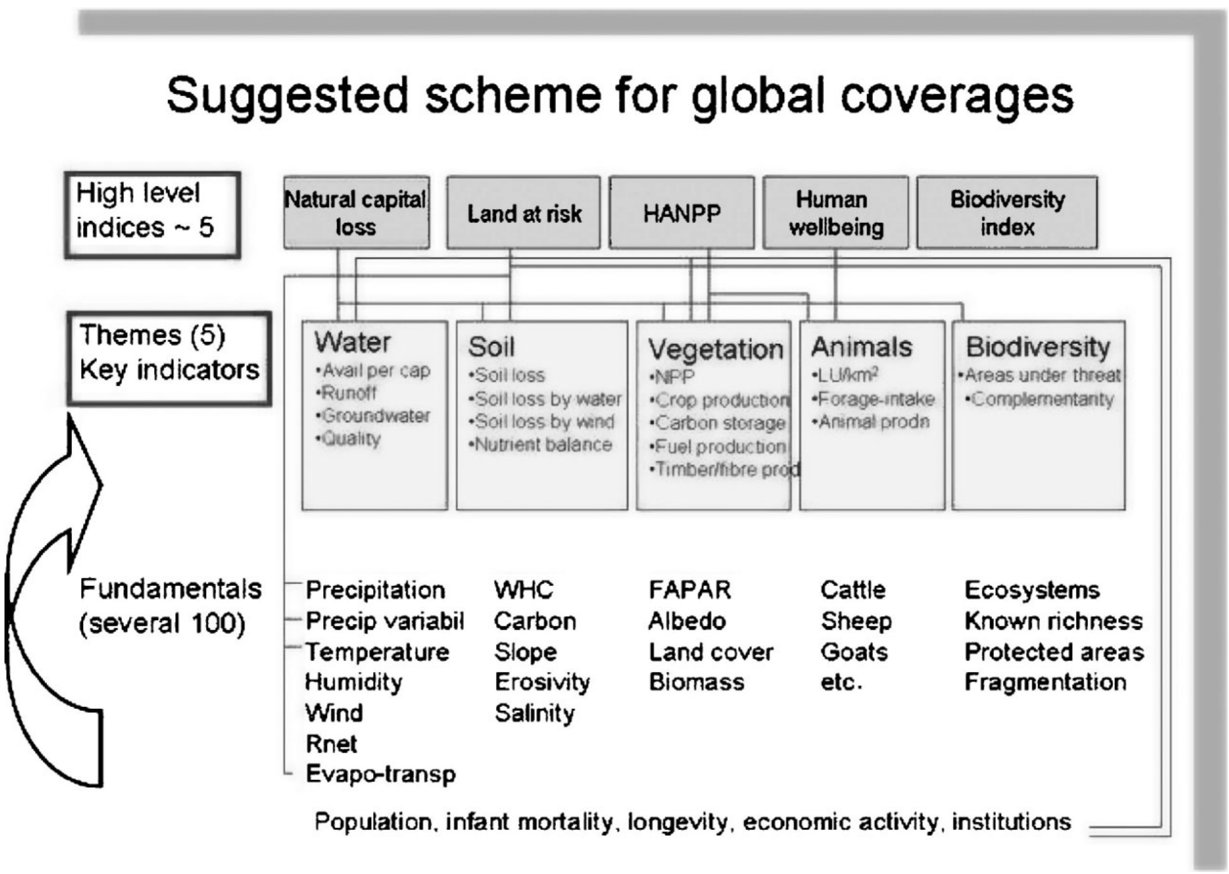

Figure 4. Data scheme for global scale key indicators and indices for desertification M&A as suggested by the WAD expert group (Cherlet and Sommer, 2009).

(WAD; Cherlet and Sommer, 2009) and the hierarchy under which they need to be further aggregated to key indicators. It also considers complex indices for global M&A of land degradation and desertification extent.

Currently such fundamental datasets are available in a variety of formats but still need to be compiled into consistent global datasets (Zucca *et al*., 2011) and important gaps still exist (Verstraete *et al*., 2009, 2011). Many data sets, such as aridity maps, land use change, migration, etc., were found to be thematically adapted but of limited use for global integration due to quality constraints. The UNCCD-commissioned review of impact indicators also stressed data availability as a constraint (Berry *et al*., 2009).

Multi-temporal remote sensing data provide additional crucial spatial data layers to derive state and trends of biophysical processes (Buenemann *et al*., 2011). However, statistical processing of time series does not always follow and sometimes even violates rigorous statistical rules (Ivits *et al*., 2008). It may therefore give different results from the same datasets (Herrmann *et al*., 2005; Vlek *et al*., 2008). Implementation of standards and criteria for data processing and information harmonization at source is crucial and needs to be coordinated at the international level. Scientific teams could link up into a network of networks and perform this coordinating role on data aspects and harmonization of monitoring. The GDOS platform as proposed by Verstraete *et al*. (2011) appears to provide a sound-enabling framework and would be urgently needed to assure the necessary progress.

Inherent to the proposed framework, specified key indicators ideally reflect human–environment interactions and the associated ecosystem exploitation; hence their variation can be directly related to core ecosystem services. However, in most cases assessment of a specific ecosystem service will be a function of the combination and/or integration of key indicators. For instance, Net Primary Production (NPP) is a core 'supporting service' that can be calculated at global scales from satellite based vegetation products, such as the Normalized Difference Vegetation Index (NDVI) or preferably the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR). Satellite derived NPP information can be further enhanced by derived phenological metrics; e.g. to better understand rangeland or agriculture specific interaction of canopy structural variation and productivity (Hill *et al*., 2008; Ivits *et al*., 2009). High-level indices can be computed by integrating effects and changes of ecosystem services as obtained through key-indicator evaluation. For example, the Human Appropriation of Net Primary Production (HANPP), listed in Figure 4, represents the amount of carbon required to derive food and fibre products consumed by humans including organic matter that is lost during harvesting and processing. Such an index is calculated globally and found to be useful to elucidate on NPP supply and demand rate balances that are important issues for conservation policy and food security decision making (Imhoff *et al*., 2004; Imhoff and Bounoua, 2006).

The Australian Collaborative Rangelands Information System (ACRIS) has demonstrated that the outlined concept of integrating multi-source data sets with limited degree of standardization can work. For national rangelands, meta-analysis of often disparate monitoring datasets provided higher-order understanding of change allowing sub-national scale information to be synthesized to national scale (Bastin *et al*., 2009). For example, an index of 'seasonal quality' identified where vegetation change was within, or beyond, that expected for the climatic variability experienced. In many areas, vegetation change counter to seasonal expectations was then attributable to grazing management.

Immediate Possibilities for Harmonizing Indicator Approaches

The approach outlined above can be performed at multiple scales. Intrinsic to the detail of the information used at various scales, it addresses the different complexities that are scale dependent. There is sufficient scientific potential and capacity to compile the required products and information that need to populate such system.

The described concept suits an implementation structure that builds on initiatives such as LADA, the Chinese monitoring system, ACRIS and others. All these initiatives have demonstrated various levels of success in compiling information about land degradation (or condition) at local to national scale.

The ACRIS system demonstrates that considering logical relationships amongst contributing factors with adapted stratifications provides clarity for improved monitoring, assessment and reporting (Bastin *et al*., 2009). ACRIS could further provide useful lessons in a first step towards compiling available, albeit likely disparate, datasets into a supra-national or global assessment of desertification/land degradation.

The FAO LADA project adopted a pragmatic and participatory approach for integrating data and information at national level. Using a standardized template of criteria, a group of experts reaches a consensus on land degradation for the various polygons of the global Land Use System Map, the borders of which are eventually adapted to better represent national situations. Ancillary spatial data and information is at disposal and evaluated in support of the assessment (McDonagh *et al*., 2009).

For climate and water related issues, regional initiatives, such as the Latin American map of arid zones and the on-going drought atlas project coordinated by CAZALAC,[5] are

[5]Centro del Agua para Zonas Aridas y Semiaridas de America Latina y el Caribe; http://www.cazalac.org

now setting standards that can be adapted and applied by other regions.

The World Atlas of Desertification initiative can foster the required scientific networks to contribute to this. *The Atlas* initiative is a first step towards applying the concepts mentioned above in a structured way. A core expert group deliberated on the practical aspects and on the main indices to provide baseline information for the revision (see also Figure 4). *The Atlas* is also planned to be a living digital platform that will back-up direct and timely data updates and thus support the possibility for regular updates of assessments on the state of global desertification/land degradation. The first baseline information is being compiled for the year 2010, and the next reporting period could suitably be 2015. Realizing a structure building on regional scientific teams, such as proposed under GDOS (Verstraete *et al*., 2011) is a crucial step to ensure data harmonization and dissemination if regular updates to global land degradation and desertification assessment are planned.

CONCLUSIONS

The multitude of objectives to be considered in M&A of desertification often leads to irritation when discussing so-called minimum sets of indicators. Selection of suitable indicators and their integration or interpretation for the M&A of desertification has to be driven by the specific objectives stakeholders want to accomplish and the questions that need to be answered. Measuring the impact of the UNCCD against the strategic objectives will require different sets of indicators to characterizing the areas affected by desertification. Causes and consequences of dryland degradation and desertification can have multiple characteristics and vary within space and scale. Hence, indicator selection needs to accommodate these particularities in order to achieve the objective.

The main goal of the discussed indicator selection framework is to provide enhanced indicator sets for regular, spatially and temporally explicit assessments coherent at all relevant spatial scales for addressing national to global level land degradation issues. Such assessments need to better inform on the extent, intensity, and dynamics of land degradation and desertification in the identified affected areas, as well as provide information on their underlying causes and drivers. A high level objective should be to establish a scientifically sound baseline against which the future implementation of impact assessments of the Convention could be compared.

Science has made considerable progress in understanding major issues and proximate causes of land degradation such that the necessary indicator sets can be consistently selected from the wealth of already existing and documented indicator systems. The selection and combination of supra-national to global level indicators should be guided according to tolerably transparent criteria given by established cause–effect frameworks (e.g. DPSIR, Ecosystem Services, Capitals) in a spatial and thematic stratification approach. Thematic concepts such as desertification issues or desertification syndromes then could be the entry level for selecting space- and theme-specific sets of indicators from existing well documented indicator databases. These can be validated according to local conditions following approaches developed by international initiatives such as DESIRE, FAO LADA, WOCAT (Reed *et al*., 2011; Schwilch *et al*., 2011) and advanced national activities e.g. ACRIS.

These recent achievements provide a promising starting point to generate supra-national to global scale baseline information to serve regular and coherent M&A in a stratified way e.g. according to specific dryland sub-types characterized by combined information on land use systems and associated conceptual models of prevalent desertification issues. Despite known constraints of data quality and availability, the latter approach can be already tackled to some extent with existing and accessible regional and global data sets. However, a more systematic collection and compilation of dedicated baseline data at national levels would be needed, but may currently not be feasible for a majority of UNCCD parties. Consequently, more efficient implementation of M&A baseline data compilation would call for substantial efforts in the improvement of the enabling environment at the institutional level of the UNCCD implementation process (Akhtar-Schuster *et al*., 2011) and would crucially benefit from the establishment of a Global Dryland Observation System (GDOS) (Verstraete *et al*., 2011). The World Atlas of Desertification initiative, the application of the described indicator concept at regional to global scale, encourages scientific and institutional networks to contribute and will itself, contribute towards implementing the proposed GDOS.

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