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TOWARDS A GLOBAL DRYLANDS OBSERVING SYSTEM: OBSERVATIONAL REQUIREMENTS AND INSTITUTIONAL SOLUTIONS

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ABSTRACT

Quantitative data on dryland changes and their effects on the people living there are required to support policymaking and environmental management at all scales. Data are regularly acquired by international, national or local entities, but presently exhibit specific gaps. Promoting sustainable development in drylands necessitates a much stronger integration, coordination and synthesis of available information. Space-based remote sensing systems continue to play an important role but do not fulfill all needs. Dedicated networks and observing systems, operating over a wide range of scales and resolutions, are needed to address the key issues that concern decision-makers at the scale of local communities, countries and the international community. This requires a mixture of 'bottom–up' and 'top–down' design principles, and multiple ownership of the resultant system. This paper reviews the limitations of current observing systems and suggests establishing a Global Drylands Observing System, which would capitalize on the achievements of systems already established to support the other Rio Conventions. This Global Drylands Observing System would provide an integrated, coherent entry point and user interface to a range of underlying information systems, identify and help generate missing information, propose a set of standards for the acquisition, archiving and distribution of data where these are lacking, evaluate the quality and reliability of these data and promote scientific research in these fields by improving access to data. The paper outlines the principles and main objectives of a Global Drylands Observing System and calls for renewed efforts to invigorate cooperation mechanisms between the many global environmental conventions. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: monitoring; desertification; global change; remote sensing; drylands

INTRODUCTION

Desertification is a serious environmental issue that has hindered the development of arid and semi-arid regions for at least the last 60 years (e.g. Aubréville, 1949; McGinnies *et al*., 1968; UNCOD, 1977; Whitehead *et al*., 1988; Verstraete *et al*., 2008; amongst many others). Since relatively little progress has been achieved by focusing mainly on technical interventions during these decades (e.g. Thomas and Middleton, 1994), emphasis has recently shifted to interdisciplinary and participatory approaches for managing coupled climate–environment–human systems as the key to the sustainable development of drylands (Reynolds *et al*., 2007).

Recent research has stressed the importance of recognizing from the outset the nature and diversity of the processes at work in complex environmental issues such as desertification, and the wide range of spatial and temporal scales at which they operate (Chapin *et al*., 2010). Some of the key processes in drylands occur at broad spatial scales (for example, continental drought, world-wide financial crises and global trade agreements). Other processes—such as changes in the vegetation composition, or loss of soil—affect households and communities at more limited spatial scales. Pragmatic solutions must account for regional or national constraints and are often dependent on actions at the local scale. A similar situation occurs in the time domain: individuals and societies with dryland experience have generally developed strategies to deal with stresses

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lasting from months to years; but persistent stresses of longer duration, or multiple and novel stresses can stretch the climate–environment–human system beyond the limits of its usual resilience and cause it to become trapped in a low-productivity state (Fernández *et al*., 2002). Significant societal efforts, including material and financial investments (usually from above the local scale) are then required to restore the systems back to a productive and sustainable mode of operation. Thus, the slowly changing variables may be the most crucial to track and understand, since they control the rates, directions and magnitudes of key processes underlying the long-term evolution of dryland societies and ecosystems (Stafford Smith *et al*., 2009).

A wide diversity of observing systems, e.g. ground-based weather radar, space-based sensors, manual land monitoring, etc., are already in place to monitor specific aspects of climate change and environmental degradation, both of which have been of great concern for the last decades. For instance, most countries have developed and implemented facilities to monitor the weather (such as meteorological services), the state of natural resources (e.g. hydrological networks and rangeland monitoring sites), the distribution of human and livestock populations (through periodic censuses), etc. A few large-scale networks have also been implemented, such as ACRIS in Australia, ROSELT by the Observatoire du Sahara et du Sahel (OSS), DESURVEY in Europe or LADA at the UN Food and Agriculture Organization (FAO), though these efforts are often targeted at a subset of the issues at hand, and remain limited in scope and capacity, as well as in institutional stability and financial longevity. In addition, national systems and networks tend to operate in isolation, both between agencies within a country and between countries. Space-based remote sensing techniques have made great progress in repeatedly delivering quantitative information on a global scale, but at spatial or temporal resolutions that may not be sufficient for all applications and users. These techniques also most often provide biophysical observables rather than information on social or economic variables. At the other end of the spectrum of scales, field studies, surveys and other methods to collect information locally provide a rich characterization of particular situations but for very limited regions and time periods, and with little standardization. None of these activities have historically been coordinated, either thematically, or in space and time. Even less effort has been expended to develop and recommend common strategies, measurement protocols, archiving standards, quality control procedures, and information sharing.

There is an urgent need for coordination and integration of these various sources of information into a hierarchical, nested, multi-scale system if one is to address an issue as broad as the sustainable development of drylands, which may concern more than one third of the land surface and close to two billion people (Millennium Ecosystem Assessment, 2005; Verstraete *et al*., 2009a; Vogt *et al*., 2011). This effort particularly needs to identify critical variables that have to date rarely been measured, to facilitate access to appropriate information at the most relevant level of detail, and to foster the adoption of data quality and communication standards. To these ends, any approach must encompass a strong engagement with affected countries to ensure their sense of ownership and their preparedness to contribute data from local systems. The resulting system needs to be useful for national and sub-national, as well as supranational, decision making. It should aim to gradually converge on a set of commonly agreed upon standards. Lastly, a coordinated effort to integrate and improve existing observation networks is likely to have a very positive influence on scientific research and our ability to understand and predict the complex processes at work (see Reynolds *et al*., 2011), as well as to estimate the impact of specific decisions and actions.

The sustainable development of drylands shares many features with development in other climate zones of the globe (wet tropical, temperate, etc.). Therefore, creating an entirely new institution, without consideration of existing systems, would not be advisable. Nevertheless, drylands face some specific issues that are not applicable elsewhere, or at least need a special dryland focus. For example, drylands often lack much of the scientific and technical infrastructure available in better-resourced environments (some of the specific data gaps are addressed in the next section). Indeed, the Drylands Development Paradigm (Reynolds *et al*., 2007) suggests that a specific focus on drylands is needed to link social and environmental aspects of desertification, to observe key driving variables and their thresholds of change in a context of high variability, to characterize the multi-scaled nature of dryland function, and to foster the development of local knowledge in changing conditions as a key to good management at all scales. All of these principles must be part of a global observing system aimed at supporting decision-making in drylands (and, it is argued below, are becoming increasingly important for other purposes such as adaptation to climate change).

In view of these gaps in existing arrangements for the observation of key variables in drylands and the great need for coordination in this area, we advocate the creation of a Global Drylands Observing System (GDOS), which will integrate with the other relevant observing systems, adding only what is necessary to satisfy the additional needs of dryland users. Such a system would build and capitalize upon existing efforts and projects, providing the necessary coordination and integration, as well as the long-term institutional and financial stability required to address such complex issues over the coming decades. Current and prospective users of information on drylands would benefit

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from a dedicated interface that would serve as a unified entry point to provide comprehensive, coordinated, pragmatic information on the various aspects of land degradation, at spatial and temporal scales of relevance to the decision makers, managers or stakeholders. This same system should also help identify gaps and have the means to help address such limitations. In this paper we attempt to shed light on these issues and suggest concrete steps to progress towards a practical solution for the acquisition, archiving and distribution of information on drylands.

The remainder of the paper is structured around two main sections, which provide an overview of existing observing systems and data gaps and outline the principles of a Global Drylands Observing System, respectively.

EXISTING OBSERVING SYSTEMS AND DATA GAPS

Three major global environmental issues were recognized at the United Nations Conference on Environment and Development (UNCED) that took place in Rio de Janeiro in 1992: climate change, biodiversity and desertification. Each became the subject of a specific international convention: the UN Framework Convention on Climate Change (UNFCCC), the UN Convention on Biological Diversity (UNCBD) and the UN Convention to Combat Desertification (UNCCD), respectively. The UNFCCC is supported by the Global Climate Observing System (GCOS), in existence for 15 years. Recently, the Group on Earth Observations Biodiversity Observation Network has been established to help coordinate the many biodiversity observation systems. In addition, the UNFCCC also benefited from the scientific advice and support of the Intergovernmental Panel on Climate Change (IPCC), which has been regularly issuing assessment reports on the state and evolution of the climate system, and the UNCBD now has a similar body, the International Platform of Biodiversity and Ecosystem Services (IPBES). The UNCCD, in contrast, currently has neither a dedicated observing system nor a stable, long-term scientific advising body to provide relevant, reliable, accurate and timely information to the various decision makers, managers and stakeholders committed to the sustainable development of drylands (see Akhtar-Schuster *et al.*, 2011).

Limitations of Existing Observing Systems

Although considerable amounts of data are now being collected at a range of spatial and temporal scales, there are significant gaps and deficiencies in our ability to monitor drylands (Verstraete *et al.*, 2009a). Some of the most glaring deficiencies of existing observing systems include:

- The spatial density of *in situ* observation networks is often inadequate to characterize (and thus understand) the state and evolution of drylands, or to evaluate the performance of satellite-based products in these regions.
- When available, data coverage is often limited to relatively short, discontinuous time periods.
- The number, type and quality of existing data is often insufficient and/or biased towards those variables that are easier to assess rather than those that are most relevant for drylands. This is particularly pertinent for social and economic variables.
- In general, geophysical data are much more prevalent than biological or ecological data, and these in turn are more plentiful and accessible than data on the human dimensions of drylands.
- A wide range of environmental variables are routinely derived from space-based measurements, but many social, political or economic variables are needed that cannot easily be acquired with such techniques.
- Although satellite instruments have systematically acquired global data since the mid-eighties, the early records are available only at relatively coarse spatial resolutions (e.g. AVHRR Global Area Coverage (GAC) data). High-resolution observations, such as Landsat MSS and TM data acquisitions, are infrequent or largely missing, for instance over Africa prior to 1983 and during the decade 1989–1998 (Roy *et al.*, 2010).
- Long-term trends in vegetation cover and land use can serve as indicators of both past changes and management effectiveness. It is crucial to both reprocess existing data archives to provide a more comprehensive historical context to current changes and to maintain or improve an adequate monitoring capacity to support planning and sustainable management. Both of these activities should be given a high priority and take full advantage of recent scientific developments, for instance by implementing the best scientific approaches available.
- The integration of data from sources as diverse as remote sensing instruments on space-based platforms and local surveys into a single information processing system remains a major scientific and technical challenge. Although progress in this direction will be very useful in many other areas, advances in the drylands are expected to be particularly relevant in promoting sustainable development because of the tight coupling between human and environmental processes in these regions.
- Data are not always properly archived or made available and accessible to the users who need them the most. In some cases, key records and archives have been lost through physical degradation, war or other causes.
- Historical data of great relevance are sometimes located in former colonial powers but need to be digitized, archived and made available.
- Availability of and access to data and information often remains a critical issue, especially with regards to

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the management of water. Significant efforts are urgently required to address the reasonable claims to ownership and intellectual rights but also to improve transfer rights and open access to observations, measurements, records or statistics that have significant implications for the livelihood of local residents or the management of resources.

- Standards, best practices, common units of measurement, benchmarking protocols and quality control procedures, universal formats, and clear data policies are often lacking, thereby preventing the exchange, interpretation, validation and exploitation of these data and products, not to mention hindering research.

Data Gaps and Needs

Existing observing systems in drylands have usually been designed for specific purposes, without much concern for integration or interoperability with other structures; in some cases, they may have been implemented by transferring practices or structures developed or adapted for different environments. As a result, variables of great importance for drylands are not always adequately monitored. The following cases, selected from thematic areas of great importance for these regions (water availability and accessibility, vegetation state and changes, soil properties and erosion, etc.), provide a few specific examples:

Water cycle

Drylands are defined by the limited availability of water during part or all of the year to support plant growth, human requirements, and animal needs. Water cycle observations are therefore needed to contextualize most other biophysical variables (e.g. Bastin *et al*., 2009); changes in water availability also matter in their own right for agricultural productivity, water supply management and conservation. Measures are needed not only at the local scale but also at the national and global scales to provide early-warning of emerging regional problems.

Water availability depends on the seasonally and interannually varying balance between inputs (in the form of rain, fog and snow) and losses (primarily due to evaporation and transpiration, but also runoff, drainage and extraction for human uses). The balance is conditioned by the storage capacity of the system, in particular in the soil profile and aquifers. Small water bodies often play a critical role in agricultural and pastoral activities in drylands, in particular in the Sahel, though these essential resources are not operationally monitored.

Precipitation is routinely measured by *in situ* instruments, but in drylands these tend to be too sparsely distributed to properly represent the spatial variability of rainfall. Remote sensing can help to fill the gaps, with either ground-based radar or space-based sensors. The physical drivers of evaporation and transpiration—air temperature and humidity, wind speed and net radiation—are well understood, and in principle easily measured *in situ*, but in practice, reliable observations of these variables are even sparser than precipitation measurements. Again, remote sensing can assist in filling the missing areas, but the space-based measurements are mostly indirect and thus require a few well-functioning ground networks for calibration.

In drylands there is a high dependency by people, livestock and agriculture on groundwater resources. The partitioning of precipitation into surface runoff, aquifer recharge or transpiration is strongly controlled by local processes: the type of soil; the state of its surface (e.g. soil crusts); the nature and properties of the plant cover, species composition, etc. The widespread tendency is for extraction from aquifers to exceed recharge, resulting in a falling water level and rising salinization in groundwater reserves. Measuring the depth to the water table is relatively straightforward and widely done, but synoptic views are hard to come by, and these data are often not shared across international or jurisdictional boundaries, even when the aquifer is continuous. Measurement of the current status, water quality and rate of groundwater extraction will for the foreseeable future rely on *in situ* systems. Satellite-based communications could help in gathering and sharing the information, and air- or space-borne sensors can help to some extent in delineating the extent of aquifers.

Effective and equitable access to water raises a range of economic, social and political issues, which go beyond the scope of this paper. However, these topics have been extensively addressed in UN publications (e.g. by the World Bank and the UN World Water Assessment Programme, including the World Water Development Report) and by the Global Water Partnership, as well as in the literature (see, in particular, Saleh and Dinar, 2004 or Mollinga and Bolding, 2004).

Vegetation

The extent of ground cover by vegetation is one of the most fundamental of dryland variables. In addition, the nature of the plant cover (annual or perennial, grass or woody, palatable or unpalatable, etc.) is usually critical in determining its value to humans. Plant cover is a key controlling variable of the hydrological cycle and soil stability. Primary production by plants underpins many ecosystem services, including those based on animal production, typically the economic mainstay in drylands. This information is crucial, not only for the local management of resources but also to link productivity changes to potentially damaging social, economic and policy factors (see Nkonya *et al*., 2011) and to allow corrective decisions and actions at the national or global level.

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The concept of vegetation cover is conceptually easy to grasp but notoriously difficult to measure because of its extreme variability in space and time: the values reported depend strongly on the method of measurement and the (often implicit) assumptions implied by the observation protocol. The relatively cloud-free nature of drylands, and the fairly open canopy, should nevertheless make this a variable ideally suited to estimation by remote sensing techniques, and indeed, many applications have been developed. Often, at the sparsely vegetated end of the continuum where concerns about desertification are most acute, the methods used are at the limit of their sensitivity, and spurious trends may be erroneously reported if the interpretation of values that are numerically low does not take into account the relatively large effect of the inevitable errors of measurements. Current practice is far from realizing the technical potential in this field.

Moderate spatial resolution (100–300 m), frequent (daily to weekly), sensitive and unbiased observations of live plant cover properties such as the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR, e.g. Gobron *et al*., 2009) or Leaf Area Index (LAI) are fundamental measurements and have already been recognized as 'Essential Climate Variables' by the Global Climate Observing System (GCOS, 2004). These products provide a firm quantitative basis for environmental assessments; they replace dimensionless indices such as the Normalized Difference Vegetation Index, which has been widely criticized because of its sensitivity to a wide range of perturbing effects unrelated to plants (e.g. atmospheric composition, soil moisture, surface anisotropy, etc. see, e.g. Meyer *et al*., 1995 and Turner, 2003) and non-optimal relations to vegetation properties. Measurements of dead plant cover are also critical—for instance, through observations of woody biomass and the cellulose index. 'Bare ground' is a measure of what can be observed in the spaces between live and dead plant cover, and is an important hydrological predictor.

'Greenness' measures by themselves provide little information about the quality or composition of the cover. Traditionally, this is provided by *in situ* range assessments, which are time-consuming. To be representative, such assessments require thousands of plots per vegetation type. Much on-the-ground activity is directed toward these measures in many countries, but the data are neither shared nor standardized, and for most of the dryland extent, are wholly inadequate for the early detection and tracking of trends. Airborne and satellite-based remote sensing of vegetation composition shows some promise (for instance, through hyperspectral, phenometric or structural information) but these techniques are still not in routine application. These more sophisticated remotely-sensed measurements will still need to be complemented by *in situ* observations and local and indigenous knowledge to help convert raw data on vegetation cover into useful information on actual productivity, or on the type of plant use (whether for forage, for bush medicine, or touristic value). An integrated, multiscale, hierarchical system capable of ingesting, processing and analyzing such diverse sources of data would generate much more useful information at the scales and resolutions required by the users (e.g. Bastin *et al*., 2009).

The key vegetation process is primary production. In principle, it can be estimated from near-continuous FAPAR and solar irradiance records, modulated by measurements or estimates of the soil water status (e.g. Jung *et al*., 2008). Robust, tested and generally applicable observational products are not yet systematically available to document the primary productivity of drylands. It is likely that their implementation is feasible, but dependent on simultaneous soil moisture and vegetation composition observations.

The main disturbances affecting vegetation cover and processes in drylands are clearing and tilling for crop agriculture, grazing and browsing by herbivores, tree harvesting (mainly for fuelwood) and wild fires. The extent and intensity of fires can now be accurately and routinely monitored from space (e.g. Giglio *et al*., 2006; Roy *et al*., 2008). Continuity of these research domain products is an issue, as is their dissemination to local users. Livestock and wild herbivore biomass is likely to be dependent on census (often by air) for the foreseeable future. Some international systems exist to collate these data (e.g. by the Food and Agriculture Organization (FAO) of the United Nations and the Consultative Group on International Agricultural Research (CGIAR)); they are typically somewhat out-of-date and of patchy reliability, but nonetheless require incorporating into any system that aims to attribute causal relationships between human use and productivity changes.

Land cover, land use and their changes

'Land cover' is a key observation, both for resource determination and for change detection. The broad classes ('rangeland', 'forest', 'cropland', 'settlement', etc.) can now be routinely and reasonably accurately determined from satellite observations, but distinguishing the crucial cover type subcategories (e.g. shrublands, savannas, degraded lands, etc.) remains problematic. Methodological instability has thus far limited the capacity to perform reliable change detection. Classifications remain largely dependent on the sources of data used and the analysis method applied. Different scientific communities implement different approaches and consider processes at different spatial and temporal scales. The lack of common methodological agreement hinders dialogues, exchanges and assessments. Nevertheless, once a methodology has been tested and approved to categorize land cover types, repeated application of this technique to data at different times can in principle help document land cover changes.

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'Land use' is a much more problematic concept to measure from space, as it refers more to human aspects of land exploitation than to the intrinsic biophysical properties of the environment. A single land cover can have multiple land uses, simultaneously or sequentially. Relevant information on land use and related variables is typically collected through field campaigns (see the subsection on human dimensions below). This field would however greatly benefit from standardization of methods, reporting mechanisms and other tools to guarantee the accuracy and comparability of the results, and continuing support over time is required to provide information on changes. Often this survey work is conducted by the same mechanisms used for population and livestock.

Soils

Knowledge of soil properties and distributions is essential for understanding ecosystem processes, hydrological phenomena, land use changes, land-atmosphere interactions, and so forth. Soil properties can vary on a scale of a few tens of metres and in the extensive drylands of the world are currently poorly characterized. Nonetheless, much more *in situ* soil data have been collected than are available to users in a useful form—a concerted effort in data sharing and digitization would make a big difference. Reliable maps of the soil water storage capacity are crucial to the monitoring of soil moisture status. Satellite-based measurements of soil moisture show promise, particularly in drylands, but direct observation penetrating deeper than a few centimeters into the soil are currently not feasible. Yet, it is generally the water contained in deeper soil layers that is crucial for ensuring sustained plant production in drylands. Inversion of soil–plant–atmosphere models could provide this information, provided that data from several sources could be integrated.

Soil erosion processes

The thickness, nutrient content, water-holding capacity and surface state of the soil underpin long-term changes in primary productivity in many drylands. Soil loss generates undesirable impacts off-site, for instance through dust transport and sediment accumulation in dams and waterways. Regular measures of selected biological, physical and chemical properties of the environment are needed locally to forewarn of productivity changes for management, and for investment choices at national and global scales.

Two main meteorological variables are important for soil erosion processes: precipitation and wind. As mentioned previously, these parameters are often scarcely measured in drylands, and when such measurements are available, they are often averaged or accumulated values on a daily basis, which may not be adequate for the purpose of estimating the actual effect of soil erosion.

Precipitation can lead to soil erosion by rain-splash or through the creation of rills and gullies. However, the direct erosive impact of raindrops is more directly connected to rain intensity than to precipitation amount (e.g. Desir and Marína, 2007; Weia *et al*., 2010), so measuring the former is much more important than the latter when developing relationships between other indicators and soil condition change, as even synoptic observations of precipitation accumulation every 6 h may not be sufficient. Soil erosion is of course highly dependent on topography as well as land use and land management practices, which should also be monitored at appropriate spatial and temporal scales.

Regarding erosion by wind, measuring average daily wind speed is less important than observing extreme events, since the mobilization of soil particles is proportional to the cube of the wind speed: wind gusts, dust devils and dust storms carry considerably more soil materials over much longer distances than a stable average wind (e.g. Stout and Zobeck, 1997). Dry soils are more erodible than wetter ones, so soil moisture measurements are essential to predict or assess soil losses, especially during dry spells or droughts (e.g. Merrill *et al*., 1999).

As in the case of water erosion, land use and management practices can help mitigate (e.g. by maintaining some vegetation cover or at least plant stubs in the fields, or terracing to limit the effect of slope) or enhance (e.g. through tillage) erosion processes (e.g. Thornes, 1990). These risks increase further when agriculture expands in marginal areas or on steeper slopes.

Studies are often lacking to document the ecological and economic impact of soil erosion, by water or by wind, beyond the obvious soil degradation effects, and especially in regions downstream or downwind of the areas affected.

Human dimensions

Use of the natural resources by people and their livestock constitutes the primary driver of change in drylands, where economic opportunities are typically very limited, most inhabitants often live near or below the poverty line, and natural resources are often exploited beyond their natural regeneration capacity (e.g. UNCOD, 1977 and Geist and Lambin, 2004). Changes in social, economic and political variables must be documented at the relevant scales to understand the processes at work, predict upcoming situations and support measures to mitigate the problem or adapt to its consequences (see, e.g. Nkonya *et al*., 2011). The resulting flow of information and accumulation of expertise will contribute to decision-makers recognizing that pressures on the land may be caused by external drivers and institutions (such as globalization and trade agreements) as well as endogenous effects (such as population growth, migration and national policies).

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Monitoring social, economic and political variables (such as demographic changes, household economics, or the quality of local institutions and decision-making processes) in ways that are compatible with the biophysical data is challenging. This is due to the inadequacy of remote sensing techniques for many of these variables, and the fact that they are usually sampled on very different spatial units to those applied to biophysical measurements (e.g. local government areas or villages instead of vegetation communities or catchments). These factors, amongst others, complicate the analysis of time-series and mean that the spatial and temporal resolution of social data is rarely commensurate with biophysical data. Nonetheless a great deal of data is collected already, and difficulties in accessing and comparing data are lessened if a single coordinating organization or public agency is in charge of collecting, archiving, harmonizing and analyzing data such as demographics, education, aggregated household economics and other social measures over a period of multiple years. Macroeconomic policies are also of interest, since they directly affect the exploitation of natural resources and therefore the adequacy of drylands management practices. All these aspects are relevant to shape decisions over a wide range of scales, from the national to the local level.

The analysis of data and the provision of useful information to decision makers is increasingly constrained as observations are procured at finer spatial resolutions. Research projects typically collect site-specific data but these are rarely made available for analysis outside of the project or for comparison with results obtained by other initiatives. This makes data compilation a cumbersome, expensive and time-consuming operation.

In addition, socio-economic surveys in degraded lands usually focus on scarcity and collapse or on poverty assessments—a bias introduced by the intention of establishing development projects. Indicators recorded from questionnaires and interviews are typically linked to local perceptions and addressed to the stakeholders. The main limitations of this approach include:

- a narrow thematic focus (agriculture, water, livestock breeding, migrations, etc.),
- an inadequate assessment of the real economic value of ecosystem services,
- the survey methods used can range from participatory approaches such as Rapid Rural Appraisal to quantitative assessment of variables such as income, expense, social dynamics, production, land tenure, trends in vegetation or agriculture, etc.; the accuracy of the method is frequently undocumented,
- a lack of temporal continuity in monitoring, which prevents projections into the future,
- the infrequent use of formal relational databases to archive and analyze socio-economic data, which hampers their subsequent exploitation, and
- the absence of analysis of such data in the context of broader interdisciplinary studies involving climatic and environmental processes to provide a sound context for their interpretation.

There are, however, commonalities in data and information requirements in the human dimension that need to be monitored in order to design sound national or sub-national policies and programs, as detailed in the following subsections. While these challenges remain, steps are being taken towards integrating different types of social and economic data, increasingly through the use of participatory, interdisciplinary and multi-stakeholder approaches (Schwilch *et al*., 2011; Reed *et al*., 2011).

Social variables

Essential demographic characteristics of populations in drylands can be derived from the national censuses, if they exist, though data are rarely reported for those regions, except where these happen to coincide with administrative boundaries. Variables such as population density, by gender and age groups, access to schools (private, public, and boarding), level of education and literacy rates are important to monitor as they affect (1) how to optimally exchange information with these populations about their changing environment as well as possible impacts on their livelihood, or (2) how to leverage the nature and extent of their local knowledge for the benefit of other populations in similar circumstances.

Birth and death rates, life expectancy, which may be further diminished by the prevalence of HIV/AIDS in some regions, as well as emigration and immigration fluxes are necessary for population forecasts. Some drylands of the world suffer from abandonment due to the poor economic and environmental conditions, while others may be subject to immigration or local population growth. Underdevelopment and lack of resources remain an issue in either case.

The cultural, political and economic stance of different ethnic groups of any particular region is also important in understanding their respective livelihoods, the degree to which they are dependent on land resources, access to governmental subsidies, resource sharing within the community and ultimately their respective vulnerability.

Limited access to clean water for human consumption remains one of the defining aspects of xeric environments, and this has detrimental impacts on the health of individuals. Drylands (excluding hyper-arid regions such as the Sahara, Gobi and Atacama deserts) do receive seasonal precipitations that, in turn, can bring other public health issues such as water- and insect-borne diseases, especially when access to healthcare is limited. Respiratory diseases linked to air dryness and heavy aerosol loads (as well as the indoor burning of fuel without proper stoves and ventilation) is a

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significant health issue. An important integrative variable for human health is the expected longevity at birth. Childhood mortality (i.e. before 6 years of age) is a sensitive indicator of disease exposure, and so is weight-for-height stunting for nutritional inadequacy. Additional detail, such as the morbidity rates associated with key diseases (e.g. respiratory ailments, diarrhea) can play an important role in planning and implementing public health investments.

Populations and societies that have been living in drylands for prolonged periods of time (centuries or more) have typically accumulated extensive experience and expertise about how to best deal with the limitations of xeric environments, including ways to gather, conserve and use water efficiently, develop agriculture and animal husbandry, as well as a specific understanding of the role of biodiversity. Their findings, often obtained from generations of trials and rejection of errors, can be extremely beneficial for other individuals and groups who may face new threats due to climate changes, for instance. Moreover, understanding traditional knowledge systems is vital for designing programs to improve management that are congruent with local understanding and practice. This emphasizes the need to involve local stakeholders in monitoring activities (see Reed *et al*., 2011).

Economic variables, including natural and social capital

Given that income in drylands is usually inadequate to satisfy a household's needs, it is necessary to compute family income by including 'autonomous' income (such as sales of products, salaries, independent jobs, and pensions), remittances from migrants, and transfers from the government (such as subsidies). Accordingly, it is important to monitor the amount and sources of on- and off-farm income. Research and development projects usually calculate the extent to which populations rely on local agricultural production and the proportion of domestic production used in household consumption. Official statistics may inform on indigence levels such as the percentage of the population living below the poverty line; the economically active population; dependence on social grants; and some measure of the local economic activity (i.e. gross local product), coarsely disaggregated spatially and by sector.

Dryland dwellers face another set of limitations, related to the opportunities for access to and integration in local markets. This is especially true in remote locations, with poor transportation infrastructure. Thus, it is important to register the evolution of prices of the main staple foods and agricultural inputs, as well as the availability of agricultural credit, technology transfer, and technical assistance, and actual use of technology such as drip-irrigation, agrochemicals, or greenhouses.

Whilst these datasets provide insights on the economic opportunities faced by the population, development work over the past three decades has emphasized that households in drylands, as elsewhere, depend on a range of social, human and physical capitals in addition to the environmental and economic capitals addressed here so far. This has been expounded as the sustainable livelihoods approach (e.g. see Chambers and Conway 1992; UK DFID, 1999–2001). To paint a full picture of drivers of change, measures of social (e.g. social networks, institutional arrangements and functionality), human (e.g. education and health) and physical (e.g. status of irrigation infrastructure, road and telecommunications networks) will also often be needed. Lastly, economic development and resource conservation are often viewed as conflicting goals but they need not be (Dixon *et al*., 1989), which is a key consideration in the Drylands Development Paradigm (DDP) (Reynolds *et al*., 2007).

Political variables

The access by households to key resources such as land and water is important to monitor. Resource access rights, including tenure arrangements play a critical role in the use and management of drylands (León, 2009).

A normal practice in governments that influences how drylands are managed, is the design and implementation of economic instruments such as subsidies (e.g. on- and off-farm irrigation infrastructure, agricultural production, hand labor employment, drought aid, reforestation, etc.) and taxes, and other incentives imbedded within public policies.

The existence and effectiveness of diverse institutions such as public agencies, protected areas, as well as traditional, non-governmental and community organizations in combating desertification, and the availability of funds and resources for this task constitute important contextual data.

International Institutional Limitations

Synergies, or complementary objectives, that might exist among the Rio Conventions (UNFCCC, UNCBD, and UNCCD) were understood from the outset. Specifically, the need to exploit the potential inter-linkages among the conventions was made explicit in the UNCCD (UNFCCC, 2004: p. 4):

> A number of elements of the texts of the three conventions imply inter-linkages with the objectives of the other conventions. In the case of the UNCCD, encouragement to coordinate activities among the three conventions is built in to the text of the Convention itself (Article 8·1). In addition, the three conventions share a number of cross-sectoral themes, such as those relating to research and monitoring, information exchange, technology transfer, capacity-building, financial resources, and public awareness.

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The Conference of the Parties of the UNCCD has worked for years to exploit these synergies between the conventions (COP, 1999, 2001a, 2003a, 2003b, 2005), and cooperation between the three conventions is facilitated by a Joint Liaison Group (JLG), established in 2001 (SBSTA, 2002).

A Joint Work Program between the UNCCD and the UNCBD has existed since 2004 (COP, 2001b; Zeidler and Mulongoy, 2003). Yet the Parties to the UNFCCC rebuffed proposals for closer cooperation with the UNCCD made by the Joint Liaison Group in a Scoping Paper requested by its Subsidiary Body for Scientific and Technological Advice (SBSTA, 2004). Various reasons were proposed to justify this (SBSTA, 2006), but the UNFCCC's reservations may have reflected concern about the UNCCD's weak science base. Most recently, creation of focal points in each convention to inform on the status of assessments (JLG, 2007) does not appear to have been particularly effective. This was disappointing, in view of strong scientific arguments for the presence of overlaps between the two fields (Grainger *et al*., 2000).

However, divergences may also have arisen from the different nature of the problem that UNFCC has mainly been tackling in the past, in an effort to establish top-down measures to mitigate climate change. As attention turns to adaptation instead, observing systems for UNFCCC are beginning to tackle the question of data collection for concrete actions that are generally more regional to local in nature and requiring strong ownership at these scales while maintaining some global consistency. This is much more similar to responding to desertification, which is also mostly a local affair, albeit embedded within broader national and global policies (e.g. trade, etc.), for which a nested architecture is required. Establishing an effective way of delivering to both global and local needs is thus an enterprise of great importance, which GDOS can (of necessity) contribute to greatly, and through which a more constructive collaboration with UNFCCC may emerge.

In any case, improved monitoring would help to overcome these reservations, not least by leading to better estimates of changes in drylands that have climate system consequences such as in albedos and carbon stocks and fluxes. Ensuring that vegetation degradation indicators include a carbon component would be particularly relevant. The UNCBD is still in the early stages of developing its own suite of indicators, with an initial set having been chosen to monitor compliance with the UNCBD's '2010 Target' of achieving a 'significant reduction in the current rate of biodiversity loss' by that year (Balmford *et al*., 2005). Incorporating a biodiversity component in the vegetation degradation indicators of the UNCCD would contribute to the development of better indicators for the UNCBD, but would be more scientifically and institutionally demanding than for the corresponding carbon indicators.

In addition to the Rio Conventions, there are other conventions and agreements that have a direct bearing on the objectives of UNCCD, and that have complementary interests. Over the past 5 years, UNCCD has established relationships with each of these (UNCCD, 2007):

- Ramsar Convention on Wetlands http://www.ramsar.org/
- World Heritage Centre http://whc.unesco.org/
- Convention on Migratory Species http://www.cms.int/
- Collaborative Partnership on Forests http://www.fao.org/forestry/cpf/en/
- United Nations Forum on Forest (UNFF) http://www.un.org/esa/forests/
- Common Fund for Commodities (CFC) http://www.common-fund.org/
- International Crops Research Institute for Semiarid Tropics (ICRISAT) http://www.icrisat.org/
- United Nations International Strategy for Disaster Reduction (UN-ISDR) http://www.unisdr.org/

As pointed out above, a number of efforts have been launched recently to coordinate global environmental observations with an eye toward enhancing efficiency. Yet, the well-documented institutional synergies that might be achieved through coordination among the Rio Conventions and other environmental agreements, and the agreements and mechanisms that have been enacted to tap on them have yielded little demonstrable progress in achieving such synergies.

Perhaps more to the point of effecting change, most of the discussion described above has been directed toward 'horizontal' integration of efforts across international organizations, often restricted just to the conventions themselves. Given the lack of such integration, this clearly is not an easy task. However, even assuming that horizontal integration is achieved, very little attention has been paid to 'vertical' integration. It is pointed out that the conventions are just one of a number of potential stakeholders and that far more impact might be achieved through the engagement of regional, national, and sub-national interests. These issues are discussed at greater length in Chasek *et al*. (2011).

There is considerable potential benefit in making the information contained in assessments available to 'downstream' organizations that might use it to develop, implement, and monitor interventions on the ground. Thus, it would appear that in the effort to realize synergies among assessment efforts—both horizontal and vertical—a great deal remains to be achieved. In this context, the movement downstream towards managers (as opposed to policy makers) brings with it the intertwined issues of data or information latency (i.e. the lag between data acquisition and data delivery) and cost: as latency decreases both the value and cost of information increase.

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THE GLOBAL DRYLANDS OBSERVING SYSTEM (GDOS)

The opportunities for synergy between the Rio Conventions, but also between observing systems, have long been recognized though little progress has been made in bringing these disparate efforts together (see also Cowie *et al*., 2011 and Chasek *et al*., 2011). Considering the state of our global environment, the efficiencies that might result from exploiting these synergies are immediate and overwhelming, and they must be pursued (Verstraete *et al*., 2009a).

Adequate mechanisms appear to be at-hand to facilitate collaboration or at least coordination. Unhappily, there are apparently no incentives to achieve this and no disincentives to discourage lack of cooperation, and, as a consequence, there has been very little action beyond meetings and expressions of good intentions.

In light of this impasse, other avenues to achieve coordinated assessments have been put forward that are intended to circumvent these obstacles. For instance, UNEP has suggested several alternatives that might be pursued for their global assessments (UNEP, 2009), but potential linkages to the assessments conducted or required by the conventions are not discussed.

A more tailored approach that is UNCCD-specific is put forward here. Based on the history of collaboration to-date among conventions, we recommend establishing a Global Drylands Observing System (GDOS) that should emulate the other coordinating models for terrestrial and climate observing systems and provide an institutional mechanism to facilitate collaboration among the Rio Conventions. GDOS should also reinforce relationships that have been established with other global environmental conventions (e.g. Ramsar, World Heritage Centre, Migratory Species, Collaborative Partnership on Forests, etc.).

The Architecture of GDOS

A wide variety of climatic, environmental and socio-economic variables are already routinely recorded, over a range of spatial and temporal scales, by national, regional and international networks and systems. Therefore, we believe it is not necessary to build a new observing system from scratch but, rather, to develop an integrated interface and coordinating mechanism that will facilitate access to those data and information already existing, stimulate the acquisition, archiving and distribution of the missing elements, and promote the standards of measurement, quality assurance, and formatting that will facilitate exchanges and interactions between actors at all relevant scales and levels. Wherever and whenever critical data and information are not being collected or made available, the GDOS system would also help fill these gaps and promote further monitoring and information sharing. This approach is entirely consistent with the Group on Earth Observations (an alliance of over eighty countries and more than 120 organizations at the time of writing) concept of a 'Global Earth Observation System of Systems' (GEOSS http://www.earthobservations.org).

This goal requires a clear vision of a nested architecture, some initial proposals for a set of 'expandable' data collection themes which are relevant to decision making at multiple scales, and a strong process for engaging with a substantial proportion of the UNCCD signatories towards an eventually consistent data system. Recognizing this will not be achieved immediately, it is important to design a flexible evolutionary pathway for the system, and ensure that nations get benefits from the system early on so as to continue to support its evolution.

We suggest the GDOS architecture involves the following basic elements:

- agreement on an initial set of decisions that need informing at different scales,
- consequently a small set of data themes that are specifically chosen to allow nesting of interpreted data elements relevant to decision-making (and improving scientific understanding) at different scales, and which potentially encompass local data collection as well as national and global dryland datasets from different sources,
- a process for engaging participating countries in a consistent system, and in a distributed data management and analysis capability for accessing data that may continue to be held in source countries.

This process would initially envisage supporting decisions at a few key scales below global:

- supra-national (regional) decisions about cross-border allocation and management of dryland resources,
- national decisions about managing dryland degradation within their own country, especially if used in conjunction with more bottom–up approaches (see e.g. Schwilch *et al*., 2011), and the provision of consistent reporting by member countries to the various conventions,
- some elements of local decisions about land management and their success over time.

Local resolution and relevance is a lot to ask of a global system, but much on-ground data is gathered at this scale and will need to be integrated into the system if it is to provide relevant and accurate information at broader scales. The local case studies are important at higher scales, and many local users already take advantage of global climate and land surface products. Table I outlines possible examples of such decisions and the corresponding information needs.

Table II suggests how elements of a GDOS could be organized along data themes and scales, to highlight 'slow variables' in the climate–environment–human system and

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Table I. Some examples of the potential information needs of decision makers at different spatial scales and their implications for a GDOS

Characteristic scale	Type of decision or issue	Likely concerns of decision makers	Implications for GDOS
A. Global (Governments, donors and NGOs)	Development investments to meet the Millennium Development Goals (MDGs and other goals) in dryland countries	Which countries are most vulnerable?[a]	International cooperation with other Global Observing Systems
		Are past investments working? Are global treaties (e.g. World Trade arrangements) helping the MDGs?	Track interventions
	Offsite effects of drylands processes on the Earth System as a whole (e.g. dust production on climate or livelihood losses on migration and conflict)	What impacts are dryland conditions having on environmental and social stability elsewhere in the world?	Monitor dust export, carbon storage, drivers of population migration, etc.
			Have widespread credibility and ownership by member countries
B. Supra-national	Negotiating cross-border allocation and management of dryland resources	Access to and fair use of water resources; or of other land resources in the case of nomadic populations, for instance	Credible and transparent monitoring of water allocations in shared basins, etc.
			Agreement on common measures, best practices, sharing observations and agreeing on quality standards
C. National	National investment in local dryland development and managing dryland degradation within the country	Who is most vulnerable? Where are the highest risks? Are investments working? What are the pressures for urban migration?	National ownership is needed, both to provide national data and accept global contextual data into national decision-making[b]
D. Local[c]	Support for improving land management techniques over time, and for avoiding thresholds of collapse in local livelihoods	What are the local land uses of relevance?	Data on land degradation will be very specific to the land uses in the locale, and hence needs to be summarized under key data themes to scale[d]
		What measures will help these, or contribute legitimately to evaluating them?	Data at this scale are often vital for ground-truthing remote sensing

[a]We acknowledge, of course, that there will be geopolitical reasons behind these investments as well, but, inasmuch as the investments are made on grounds of need, these would be the criteria of concern.
[b]These data (e.g. global land cover or NPP satellite data) must be seen to provide benefits to the nation concerned.
[c]This level of detail may be too fine for a global system but much on-ground data will be gathered at this scale and needs to be integrated into the system.
[d]Many locally tailored data collection systems require some harmonization whilst remaining locally relevant, some of them with short donor-based lifetimes, but others are long-lived (e.g. LADA).

their thresholds, as well as 'fast variables' that are known to be good indicators (for discussion of slow and fast variables in drylands, see Reynolds *et al*., 2007 and Stafford Smith *et al*., 2007). These elements should aim at answering the questions of decision-makers, and improving the scientific understanding of the system, such that better or more reliable answers can be provided in the future.

For instance, global datasets would include soil type and condition, aerosol properties and dust transport, dry spells and droughts, land cover and productivity, as measured by the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), or household income, equality, migration or access to electrical energy. Whenever data are acquired directly at one scale and not collated or aggregated from observations at a finer scale, such information should be made available at the lower scales. Hence, data obtained from remote sensing or censuses by Space Agencies or international organizations should be accessible at the national, regional or local levels through appropriate mechanisms and in understandable form.

These elements should be supported by an institutional architecture which is agreed upon by a reasonable initial proportion of UNCCD countries, and which facilitates the negotiation of the set of themes and measures, as well as

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Table II. Some examples of how 'slow' variables expected from a GDOS could respond to decision-maker issues and be nested across spatial scales for some data themes: a complete initial set of these needs to be postulated by experts and then negotiated among partners

Scale/Date theme	Soil	Water cycle	Vegetation	Household well being	Institutional functionality
A. Global: (1) Effects of interventions on MDGs in drylands	Total loss of soils (for whether investments are reducing natural capital)	Changes in per capita water availability (effects of investments on this MDG)	Changes in productivity as summary measures (effects of investments on food security)	Changes in global poverty (effects of investments on MDG)	Trade arrangements (effects of these on MDG achievements)
(2) Effects of drylands on Earth system	Total dust movements from drylands (for impacts on climate)	Transfers of embedded water (dryland inputs to global water use)	Changes in global land cover (effects on climate)	Net levels of migration (effects on global security)	National engagement in global monitoring institutions (credibility and effectiveness)
B. Supra-national: cross-border water basin management	Soil degradation across basin (effects of water allocation on degradation)	Basin-wide water allocations (equity of allocation)	Changes in productivity by key land uses across basin (effects of water allocation on food)	Mean and variance of household incomes (implications of water allocations for conflict)	Functionality of water sharing institutions (potential for regional conflict)
C. National	Soil degradation levels across the nation (direct investments in land management)	Water access per capita across nation (direct and assess investments in water infrastructure)	Net dryland agricultural production and trends (locale-sensitive investments to avoid food insecurity)	Dryland province average household income and savings, distribution and trends (investments in avoiding conflicts)	Education levels attained, processes to exchange local knowledge (likely future management quality in the face of change)
D. Local	Local dust watch and soil carbon storage measures (potential for carbon credits)	Trends in mean and distribution of water supply per household or enterprise (poverty alleviation)	Trends in locally-relevant measures of productivity of agriculture and other key harvest species (prospects for food security)	Household income and capital savings, frequency of food shortages (household vulnerability)	

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their gradual evolution over time. These institutional arrangements must also manage access to data that may be distributed or centralized. National and local data are likely to remain with their respective owners, with agreements to allow their synthesis or reinterpretation to inform the scaled up measures in each theme. Some data, such as global remote sensing datasets, are likely to be collected and stored centrally from the start. All these data must clearly be available to partner nations for an efficient contextual analysis of their own datasets. These coordination and collaborative tasks form an integral part of the incentive to contribute to GDOS overall.

We acknowledge that the principles of participatory engagement to assure ownership means that these details must be debated by partner countries; however, there is sufficient experience and analysis around the world to be confident that the outline above will be a good foundation to work from, and that there is no need to start from scratch.

Institutional Arrangements and Functions of GDOS

Coordination and integration

GDOS should establish and nurture full collaborations with existing international and national bodies that are already collecting relevant data, paying special attention to the acquisition of information not covered by these systems and to the effective and transparent integration of these diverse sources on behalf of the users and stakeholders.

Diagnosis

GDOS should document the nature, scope and severity of the issues affecting or impeding the sustainable development of drylands, paying special attention to the spatial distribution and temporal evolution of relevant variables.

Evaluation

GDOS should help establish and verify the impact, efficiency and effectiveness of adopted policies and measures to combat desertification and promote the holistic development of drylands.

Early warning

GDOS should provide effective mechanisms to alert authorities and communities about the unexpected or unintended (especially time-lagged) consequences of policies or management decisions, and monitor unforeseen events that may compromise the habitability and long-term development of drylands due to external factors such as climate change, an international financial crisis, etc.

Foster research

GDOS should promote a better understanding of the processes at hand, providing the data required to benchmark and upgrade integrated models, and elaborate a long-term perspective on the prospects for the concerned populations and their natural environment.

In the process of fulfilling these roles, GDOS should also perform the following functions.

Standardization

Establish a list of Essential Drylands Variables, some of which may already be covered by existing systems such as the Global Climate Observing System in the climate area; develop, evaluate and deploy common algorithms to generate the required information when it is missing; define and promote the use of common units and data requirements, in particular regarding the recommended spatial and temporal sampling of each variable.

Quality control

Stimulate and encourage the calibration, validation, and benchmarking of all tools and products within its scope to ensure the accuracy and reliability of the information generated; propose monitoring principles and recommended measurement protocols or procedures in areas not covered by sister organizations.

Coordination

Foster collaborations, exchanges of information and integration of methods and procedures across disciplines (especially between natural and social sciences), across national and international institutions (in particular with the Global Climate Observing System, the Global Terrestrial Observing System, etc.), across approaches (e.g. remote sensing vs. field data acquisitions), as well as across stakeholder groups.

Communications

Facilitate data and information usage and exchange, in particular through the definition of formats, protocols and data policy (access and exchange); recommended procedures for the long-term archiving of critical data, taking into account the rapid evolution of concerned technologies; and the timely presentation of information in a form usable by stakeholders. Capacity building and training of qualified personnel to achieve these goals should also be given high priority but at the same time, efforts to utilize local and traditional knowledge should be made.

In summary, GDOS is envisaged to support directly the UNCCD Secretariat, the Committee on Science and Technology of the UNCCD Conference of the Parties, as well as the Offices and Departments responsible for the drafting and implementation of National Action Plans to Combat Desertification (NAP). Specifically, GDOS should provide the framework and mechanisms to archive and exploit data from various sources, at different scales and resolutions,

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for policymaking as well as environmental management. GDOS does not replace existing systems but helps capitalize on and complement them by providing tools and techniques to integrate, benchmark, analyze and exploit the available data, as well as promote new data acquisition, and the standardization and sharing of these resources (Verstraete *et al*., 2009b).

Beyond providing essential operational services and supporting these institutional users, it is expected that the GDOS will also prove useful for non-governmental organizations and other actors involved in drylands. Last but not least, the availability of a common, comprehensive, integrated observing system should stimulate scientific research; indeed serve as a new catalyst to promote interdisciplinary investigations. The history of science is rife with examples where major advances in observation, whether through dedicated instruments (e.g. the microscope, the telescope, etc.) or analysis techniques (e.g. remote sensing) have revolutionized the state of the art and brought new understanding of the processes at work. A similar quantum leap in scientific activity could occur if GDOS can become part of a growing network of global environmental observatories (Grainger, 2009).

SUMMARY AND CONCLUSIONS

Desertification has proven to be an environmental and human problem that is particularly hard to solve. Although Reynolds *et al*. (2007) note that advances in many areas of science relevant to drylands and community development practices in recent years suggest a common framework for managing dryland systems, little concrete progress has been achieved in the last 60 years, despite large investments and substantial personal, institutional and material efforts. This state of affairs has multiple causes, but one critical issue has been the continuing schism between policymaking and the scientific world. The situation is likely to evolve as a result of growing dissatisfaction from the donor countries and organizations, renewed interest in implementing a more holistic approach to the problems, and recent scientific advances.

Specifically, new concepts and innovative approaches have emerged, such as Ecosystem Services (e.g. as reviewed by Carpenter *et al*., 2009), Human–Environment coupled systems (Liu *et al*., 2007) and the Drylands Development Paradigm (Reynolds *et al*., 2007). They provide the conceptual basis to apprehend such a complex issue and open new vistas on the sustainable development of drylands through adaptive resource management approaches. The latter, however, require integrated models and a monitoring system to report on issues, evaluate progress, warn of new dangers and promote a better understanding of the processes at hand.

The establishment of a Global Drylands Observing System (GDOS) is thus timely and necessary to capitalize on these developments. This paper has sought to justify the need for GDOS and to briefly outline how it could operate. Once the principles and main goals of such a system are understood and approved, its implementation could start by expanding or building on existing efforts to demonstrate, on a limited scale initially, the benefits that can be expected to accrue. The worth of the system will be realized when it is adopted by most concerned countries, as it will not only effectively promote the sustainable development of drylands but also stimulate further research and the sharing or expertise. The adoption of such approach by the main donors would also greatly speed up its implementation.

In the long run, GDOS will leave an invaluable legacy in the form of much improved understanding of drylands, large databases characterizing the environmental and human aspects of arid and semi-arid zones, improved living conditions for the inhabitants of these regions and above all clearer prospects about what can really be expected and achieved in these harsh conditions.

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