Chapter 1
Introduction

1.1 Introduction

The global demand for food is rising steeply as a result of burgeoning population, shifting dietary preferences, and food wastage, while increasing demands for renewable energy are competing with food production (Hubert et al. 2010). In 2009, the FAO estimated that we must increase the global food production by 70 % to meet demands in 2050 (FAO 2009). But this figure is questioned and may be an underestimate, which further underlines the urgency of global food provisioning (Tilman 2010; Tilman et al. 2002), particularly in the light of the revised World Population Prospects 2012 predicting significantly higher population increase than earlier projections, especially for many countries in sub-Saharan Africa (UN 2013). Further, accelerating climate change is projected to have severe impacts on crop productivity over large parts of the globe (Porter et al. 2014). The combination of increasing water scarcity, as a result of climate warming, and increasing competition across sectors is likely to cause dramatic situations in terms of food and water security in many regions (Strzepek and Boehlert 2010). At the same time "business as usual is not an option." This was the stern message from the International Assessment of Agricultural Science and Technology (IAASTD) when it was presented by its chairman Bob Watson in 2008. By this he meant that agriculture does not deliver what we need—food security for all—instead it undermines the global environment in terms of land degradation; greenhouse gas emissions; pollution of soils, rivers, lakes, and oceans; and reducing biodiversity (Foley et al. 2011). The threat to food security represents a planetary emergency that demands a variety of creative solutions and policies at global, regional, and local levels. One of the most urgent responses to this situation must be measures to stop and reverse land degradation. But such solutions are currently hampered by the lack of reliable data as well as methods for collecting such data. This report is a review of the state of the art of remote sensing techniques for assessing land degradation and improvements.

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1.2 Land Degradation in the UNCCD and GEF

Land degradation has been highlighted as a key development challenge by the UNCCD, the Convention on Biodiversity, the Kyoto Protocol on global climate change, and the Millennium Development Goals (United Nations 2011; UNEP 2007). The GEF was designated a financial mechanism for the UNCCD in 2003; through establishment of its land degradation focal area, the GEF aims to arrest land degradation, especially desertification and deforestation, by supporting sustainable land management (SLM). SLM implements agricultural practices that maintain vegetative cover; build up soil organic matter; make efficient use of inputs such as water, nutrients, and pesticides; and minimize off-site impacts (Bierman et al. 2014).

Both the UNCCD and the GEF use land cover to monitor land degradation and implementation of SLM. Likewise, the trend in land cover is a key indicator of progress in meeting the UNCCD's Strategic Objective 2: to improve the condition of affected ecosystems (UNCCD decision 22/COP.11). For the GEF, achievement of the overall goal of the land degradation focal area is measured through "*change in land productivity*" using, as a proxy, net primary productivity NPP which is estimated through remotely sensed normalized difference vegetation index (NDVI) screened for drought effects using rain-use efficiency RUE. To measure the impact of interventions, GEF-funded SLM projects should report on changes in land cover (GEF 2014). The same approach has also been used to allocate resources from the land degradation focal area of the GEF; other things being equal, countries suffering from serious land degradation, as measured as change in NDVI, are allocated more funds than those with lesser measurable evidence of land degradation.

Recent improvements and the longer time series of the fundamental NDVI dataset call for a review of indicators for measuring the implementation of the Convention and the GEF's allocation of resources to combat land degradation, as well as for measuring the impacts of its SLM projects.

1.3 Concepts, Processes, and Scales of Land Degradation

Land is defined as the "*ensemble of the soil constituents, the biotic components in and on it, as well as its landscape setting and climatic attributes*" (Vlek et al. 2010). Land degradation is a composite concept that has been defined in many and various ways. Indeed, it is a concept as much as a process, defined in various ways by researchers and institutions in this field. This could partly be as a result of the diversity of processes of land degradation in type, scale, time, and extent; the processes are well known but not always fully understood. According to Warren (2002), land degradation is a very contextual phenomenon and cannot "*be judged independently of its spatial, temporal, economic, environmental and cultural context.*" This ambiguity makes it hard to establish measurable indicators, remotely sensed or otherwise.

Stocking and Murnaghan (2000) describe land degradation as a composite term that *has no single readily-identifiable feature, but instead describes how one or more of the land resources (soil, water, vegetation, rocks, air, climate, and relief) has changed for the worse* (Fig. 1.1). Haigh (2002) offers a more utilitarian definition: *the aggregate diminution of the productive potential of the land, including its major uses (rain-fed, arable, irrigated, rangeland, forest), its farming systems (e.g., smallholder subsistence) and its value as an economic resource*. This definition highlights deterioration in the biological productive potential of the land, i.e., the entire geo-ecological system that includes soils, climate, biodiversity, topography, and land use. The key message conveyed by this definition is akin to that conveyed by the Millennium Ecosystem Assessment's definition of land degradation, *the reduction in the capacity of the land to perform ecosystem goods, functions and services that support society and development* (MEA 2005). According to UNEP (2007), *land degradation is the long-term loss of ecosystem function and services, caused by disturbances from which the system cannot recover unaided*. This definition conveys two important messages: the resilient properties of landscapes and their constituent parts and the need for intervention if and when disturbances cause the resilience thresholds to be breached.

Degradation may also be considered in terms of specific components of the land that are affected. For example, vegetation degradation implies reduction in productivity, declining species diversity, and degeneration in the nutritional value of plant populations for the faunal biota. And soil degradation implies deterioration in soil quality and fertility. Such changes may be brought about by many factors (erosion, pollution, deforestation, and others). Again, land degradation may be considered in respect of its physical aspects, referring to changes in the soil composition, especially loss of soil organic matter, and structure, such as compaction or crusting and waterlogging; chemical, pertaining to changes in the soil chemistry's chemical makeup as a result of leaching, salinization, or acidification; and biological degradation referring to reduction of soil biodiversity.

Estimates of the extent and severity of land degradation vary substantially. The only agreement has been that all global estimates have rested on very poor data (Hassan et al. 2005). The Millennium Ecosystem Assessment reported estimates

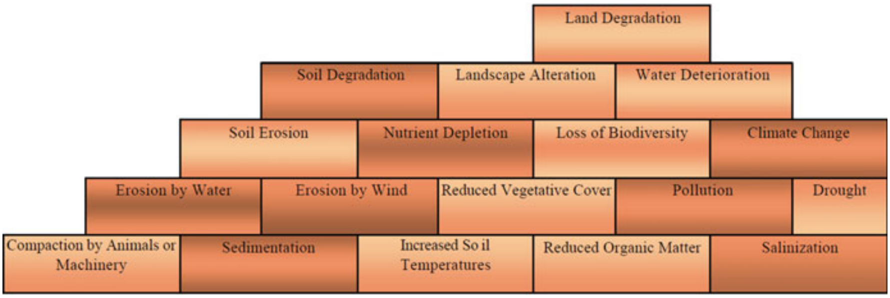

Fig. 1.1 The complexity of processes that constitute land degradation (Stocking and Murnaghan 2000)

between 70 and 10 % of drylands globally being affected by land degradation and concluded with *medium certainty that some 10–20 % of the drylands are suffering from one or more forms of land degradation. And the livelihoods of millions of people … are affected* (Hassan et al. 2005). These figures were, however, not based on a systematic assessment of empirical data.

In order to overcome this uncertainty barrier, GEF/UNEP/FAO initiated the LADA project (Land Degradation in Drylands) which adopted the approach used by Bai and others (Bai et al. 2008). Based on the analysis of a 30-year time series of global NDVI data in combination with gridded climate data, Bai et al. (2008) reported that about 20 % of cultivated land, 30 % of forests, and 10 % of grasslands are degrading. Many studies have reported increasing severity and extent of land degradation in many parts of the world, but estimates tend to be highly method specific (see Annexes 1 and 2).

Land degradation can be caused by local human activities and biophysical processes as well as by activities and processes that are not tied to the local human or physical landscape (Fig. 1.2). Local activities that contribute to land degradation include mining, unsustainable farming practices, overgrazing, pollution from industrial and nonindustrial sources, and landscape modification. Hoekstra et al. (2005)

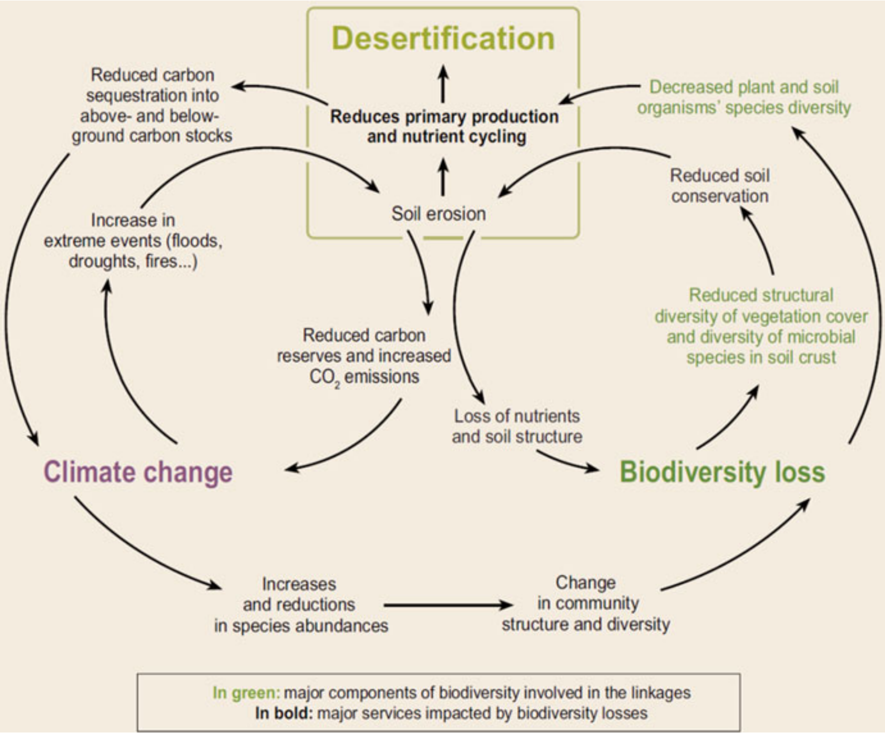

Fig. 1.2 Linkages and feedback loops among desertification, global climate change, and biodiversity loss (MEA 2005)

argue that land degradation resulting from human conversion of natural habitats is most extensive in tropical dry forests (69 % converted in SE Asia), temperate broadleaf and mixed forests, temperate grasslands and savannas (>50 % lost in North America), and Mediterranean forest and scrub. Human activities responsible for land degradation go beyond farming practices, deforestation, and other direct human interactions with the land (Hoekstra et al. 2005). UNEP (2012a) and MEA (2005) see the causes of desertification (nefarious land degradation affecting people in arid and semiarid regions) ranging from international economic activities to unsustainable land-use practices by local communities. It has also been argued that processes such as dryland degradation may be exacerbated by climate change (Cowie et al. 2011).

1.4 Assessment of Resilience of Agroecosystems

No less than land degradation, resilience is an ambiguous term (Thorén and Persson 2014) subject to scientific and political debates (Walker et al. 2004). In his seminal paper in 1973, Holling writes: *Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change of state variable, driving variables, and parameters, and still persist* (Holling 1973). Perrings (1998) offered a more open definition: *in its broadest sense, resilience is a measure of the ability of a system to withstand stresses and shocks—its ability to persist in an uncertain world*, and interdisciplinary scientists interested in coupled social and ecological systems (SESs) have incorporated the idea into their thinking, as expressed by Adger: *The ability of human communities to withstand external shocks or perturbations to their infrastructure, such as environmental variability or social, economic or political upheaval, and to recover from such perturbations* (Adger 2000).

Renschler et al. (2010) have argued that environmental and ecosystem resources might be used as indicators of ability of the ecological system to return to or near pre-shock or pre-event states. The strong correlation of NDVI with aboveground NPP makes it a useful indicator of ecosystem resilience. In a study exploring the concepts and application of theories of general resilience, Walker et al. (2014) identified twelve components of general resilience in five catchments in south eastern Australia. These components include diversity (which may be identified and measured by processes including vegetation clearing, forest fires, floods, and drought), and connectivity, modularity, and reserves in ecological systems (Walker et al. 2014) which can be identified and measured by earth observation methods, including land-use and land-cover change assessments. In the context of monitoring land degradation using remotely sensed data, we would prefer a more precise definition of resilience that can be operationalized by something measurable. A central concept in ecological resilience is a system's ability to absorb and recover from disturbance or stress; this may be depicted by a hysteresis curve (Kinzig et al. 2006) (Fig. 1.3).

A resilient system subject to stress, such as drought, may reduce its productivity as long as the stress persists but, then, return to its prestress productivity. If the system is not sufficiently resilient, it will not regain its prestress productivity. The Sahel is an example of resilience at a grand scale. Since the 1980s, long time series of NDVI data have been used extensively in the study of land degradation in the Sahel (Fensholt et al. 2013; Anyamba and Tucker 2005; Hickler et al. 2005; Prince et al. 1998), confirming a general pattern of recovering vegetation.

The interpretation of the recovery of vegetation vis-à-vis the resilience of such systems must, however, be approached with caution. This is because the state of an ecosystem is not defined solely by its overall bio-productivity, but also, by the vegetation composition as well as the ecosystem services it offers. It therefore follows that the stability of positive trends in bio-productivity (an aspect of ecosystem dynamics that can be captured by the time-series analysis of NDVI data) may not necessarily report the resilience of such systems. Recent studies relating long-term NDVI trends to ground observations in Senegal show that positive NDVI trends do not systematically indicate positive developments, neither in terms of the composition of the vegetation cover, which showed impoverishment even in the greening areas (Herrmann and Tappan 2013), nor in terms of human well-being (Herrmann et al. 2014).

NDVI is proposed as a measure of *land-cover status*—one of the eleven impact indicators recommended in the UNCCD "Minimum set of Impact Indicators"; its purpose (Orr 2011) is to *monitor land degradation in terms of long-term loss of ecosystem primary productivity and taking into account effects of rainfall on NPP*.

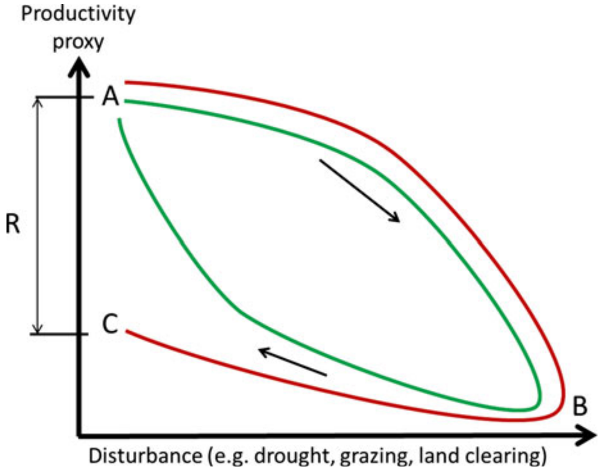

Fig. 1.3 The principle of hysteresis. At point *A*, before the stress, productivity is high. As the stress increases, productivity declines to a point *B* where the stress is reduced. As the stress is reduced, productivity increases. A fully resilient system (*green curve*) will spring back to its original state (*A*). A less-resilient system (*red curve*) will only recover to point *C*. The resilience of the system, *R*, is related to the distance between *A* and *C*; the lower the value, the higher the resilience

DPSIR (Driving Force, Pressure, State, Impact, Response) is a general framework for organizing information and reporting about state of the environment. First developed by the Organization for Economic Cooperation and Development (OECD) in the 1980s, this framework is currently being applied in a range of fields and projects, including those of the UNCCD and GEF (Orr 2011). DPSIR is also the methodological framework used by UNEP in its Global Environment Outlook (GEO) reports at global, regional, and national levels (UNEP 2012a). The state variables are pointers to the condition of the system (including biophysical factors/processes), as well as trends (environmental changes) which may be naturally or human induced (Vacik et al. 2007; Orr 2011). NDVI can be useful in the evaluation of vegetation cover, carbon stocks, and land condition (Orr 2014) which may provide resilience indicators.