The Current Status of Desertification Issues with Special Reference to Sustainable Provision of Ecosystem Services in Northeast Asia

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Abstract

People's livelihoods in drylands rely highly on ecosystem services to provide their basic needs. Dryland ecosystems, however, are extremely vulnerable to over-exploitation and inappropriate land use. Poverty, political instability, deforestation, overgrazing and bad irrigation practices can all undermine land productivity. Recently it has been also emphasized that desertification is deeply associated with biodiversity loss and contributes to global climate change. As the causes, effects and possible policies are strongly interlinked among those issues, multiple benefits could be obtained with increased effectiveness through joint implementation of the three Rio Conventions and further strengthening of synergies based on environmental management approaches. One of the key findings of the Millennium ecosystem assessment scenarios was the importance of a proactive management approach to coping with desertification. Applying desertification early warning systems based on land vulnerability assessments may be one of the most effective preventive actions at both fine and broad scales. However, at degraded sites where land conditions have already shifted to alternate states, it will still be necessary to apply rehabilitative measures and promote restoration processes as a reactive approach. Recent studies have tried to develop methodologies to support decisions of local people on their "best choice" of most effective restoration measures based on both scientific evidence of restoration processes and careful consideration to re-construction of future sustainable land use, especially in Northeast Asia.

Key words: biodiversity, early warning, ecosystem service, global climate change, non-equilibrium, restoration

1. Introduction

Desertification is potentially the most threatening ecosystem change impacting livelihoods of the world's poorest, most marginalized and politically weak citizens living in drylands. Desertification also has strong adverse impacts on non-drylands as well through dust storms, downstream flooding, impairment of global carbon sequestration capacity and regional and global climate change. Specifically in Northeast Asia, recent increases in livestock numbers, changes in socio-economic systems and the collapse of traditional sustainable land use systems have resulted in serious land degradation, which could affect both dryland and non-dryland countries across the whole region. Therefore, combating desertification and promoting sustainable development in drylands are regarded as among the most important environmental issues needing to be solved by international society. Since the United Nations Conference on Desertification (UNCOD) was held in 1977, the international community has recognized the importance of combating desertification. The United Nations Convention to Combat Desertification (UNCCD) adopted in 1994 has also been expected to play a key role in this issue. In spite of these massive efforts, desertification still persists on a global scale. However, recent scientific and technological progress has inspired new perspectives in the desertification issue, which could provide good opportunities for promoting rehabilitation and restoration of desertified land and human well-being in drylands.

In this paper I take an overview of the current status of combating desertification, specifically from the viewpoint of sustainable use of ecosystem services, linkage with global climate change and biodiversity and the desertification counter-paradigm, which is related to the non-equilibrium concept. I also introduce new research approaches to a desertification early warning system and restoration of ecosystem services as conducted in Northeast Asia.

2. Ecosystem Services and Their Vulnerabilities in Drylands

Dryland ecosystems cover over 40% of the world's land area, and one third of the global population is living there. The total area affected by desertification is estimated to be between 6 million and 12 million square kilometers (Millennium Ecosystem Assessment; MA, 2005a; 2005b). UNCCD also reports that over 250 million people are directly affected by desertification, and about one billion people in over one hundred countries are at risk (United Nations, 1994). These people include many of the world's poorest, most marginalized and politically weak citizens. Based on these estimations, desertification could be regarded as one of the greatest contemporary environmental problems.

People's livelihoods in drylands rely highly on biological productivity. In other words, more people in drylands depend on ecosystem services (provisioning, regulating, cultural and supporting services) for their basic needs than in any other ecosystem (MA, 2005b).

Crop and livestock production is one of the most important provisioning services, contributing significantly to the domestic consumption and trade in drylands. Dryland vegetation provides wood-derived fuels which are used predominantly for cooking and heating, and constitute a considerable amount of the energy consumed in many dryland countries. Various plant species are used for medical and cosmetic purposes and as biochemicals to develop novel medicines such as anti-cancer and anti-malarial compounds, and these are supported by dryland biodiversity.

Dryland people's lives are also guaranteed by regulating service and supporting services as well. Water regulation is regarded as of major significance since water is closely related to various other services such as maintaining soil moisture and primary production, providing irrigation, livestock watering and domestic uses, and controlling surface runoff and soil erosion. Vegetation cover could also contribute to regulation of the global climate through carbon sequestration. Although the plant biomass in drylands is relatively low, the large surface area of drylands plays an important role in global carbon sequestration. Total dryland soil organic and inorganic carbon reserves are estimated to comprise 27% and 97% of the global soil organic and global carbon reserves, respectively (MA, 2005a).

Drylands also have high cultural identity and diversity, with nomadic cultures, for example, that have historically played a key role in the development of dryland farming systems and have co-evolved unique traditional knowledge such as water harvesting, cultivation practices, climate forecasting and the use of local plant resources. "Cultural landscapes" which have been formed through people's striving to conquer the desert or aspiring to live with the desert are now recognized to have high heritage values. Orkhon Valley in Mongolia and the Mogao Caves in China are outstanding examples in Northeast Asia, which were inscribed in UNESCO's list of World Heritage Sites.

The above-mentioned ecosystem services are all provided by dryland biodiversity. Individual species which provide single services such as genetic resources are a clear example indicating the relationship between biodiversity and ecosystem services. There are also many dryland species which are involved in providing a range of ecosystem services. One such example in Northeast Asia is *Achnatherum splendens*, a perennial tussock grass called Jiji-sao in China and Tsagaan Ders in Mongolia, which grows mainly in lowlands with ground water close to the surface. Although it grows tough leaves and stems and is rather avoided by livestock, it plays a key role in forage provision during harsh periods such as winter and droughts. Its dense clumps also form "islands of fertility" by holding litter and dung, facilitate the growth of other young plants by forming favorable conditions and provide shelter for livestock from cold winds (Manibazar & Sanchir, 2008). While plant species which provide food for frugivores during periods of scarcity are regarded as "keystone plant resources" in tropical forest ecosystems (Terborgh, 1986), *A. splendens* could be called dryland keystone plant resource for livestock and nomadic people.

Figure 1 shows the interrelationship among major ecosystem services, biodiversity and livelihoods (MA, 2005a). The functioning of biodiversity contributing to livelihoods has two aspects: species diversity and structural diversity. While the former sustains pastoral livelihoods through forage provision, which depends on primary production and increases options for alternative livelihoods by providing biochemicals and fuelwood, the latter is strongly related to water regulation and maintaining dryland farming through water provision. Those linkages also indicate that ecosystem services derived from biodiversity support not only livelihoods in drylands, but also the well-being of people living outside the drylands by providing biological and cultural resources and regulating the global climate.

Dryland ecosystems, however, are extremely vulnerable to over-exploitation and inappropriate land use. Poverty, political instability, deforestation, overgrazing and bad irrigation practices can all undermine the productivity of the land.

3. Drivers and Processes of Desertification in Northeast Asia

The UNCCD defined "desertification" as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Land degradation is also defined as reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest or woodlands resulting from land uses or from processes arising from human activities and habitation patterns (United Nations, 1994).

Climatic variations are caused by various factors with different time scales, ranging from the glacial-interglacial

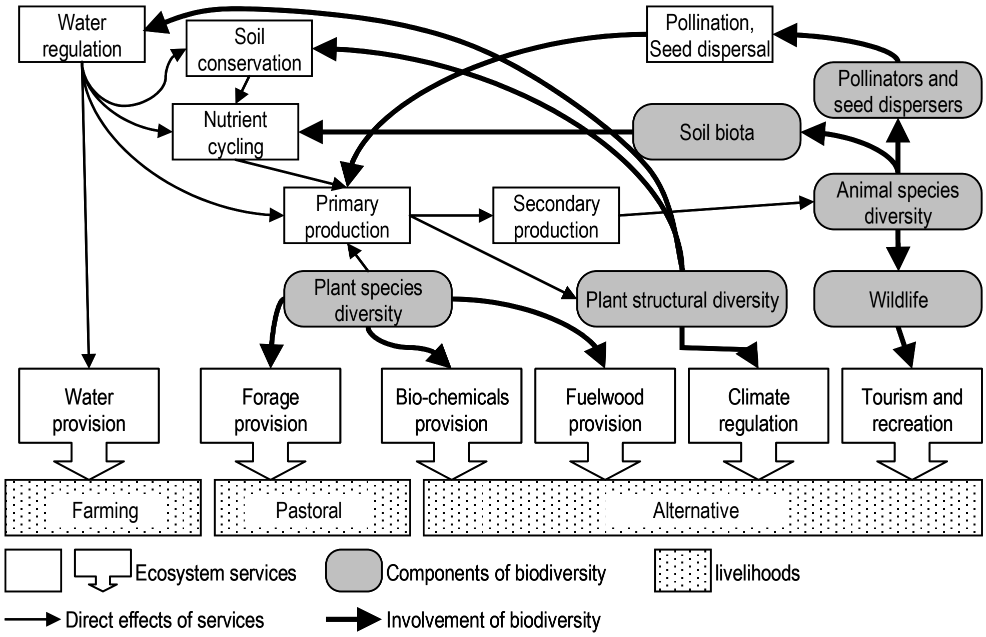

Fig. 1 Linkages between ecosystem services, biodiversity and livelihoods in drylands. (MA, 2005a)

cycle to the solar activity cycle, atmospheric circulation and fluctuations of sea-level temperatures. Moreover, high fluctuation in climatic variables such as precipitation may be an important bioclimatic driver. It is caused by large inter-annual and seasonal climatic variation and is enhanced by increasing aridity. These variations also cause fluctuations in ecosystem services such as crops, forage and water yields.

Human activities are major drivers of degradation in drylands. Overgrazing is an activity in which intense grazing pressure on rangeland exceeds its carrying capacity (the number of livestock that can be maintained without degrading vegetation), and is caused by several indirect drivers such as growing numbers of livestock for market demand and concentration of livestock by sedentarization policies. In the steppes of northeastern China, for example, a rapid increase in the number of livestock during the first 30 years after the end of World War II had reduced the area of grassland per sheep to less than one-fifth by the early 1980s. Increased livestock numbers accelerate desertification not only by leading healthy grasslands to degradation but also by expanding their grazing activity to marginal lands, which were regarded as unfit in the past.

Agricultural activities are another important anthropogenic driver. Inappropriate agriculture includes shortening of the fallow period/crop interval, reclamation of less-favored areas, introduction of the wrong sorts of crops, absence of anti-erosion measures, insufficient or excessive use of fertilizers, improper use of irrigation water, poor drainage, etc. Specifically in the case of Inner Mongolia, China, recent excessive use of water resources to expand maize production caused water reservoirs to dry up (Zhao *et al*., 2010). In semi-arid regions of Mongolia, crop abandonment has increased since the early 1990s after intensive cultivation, and vegetation recovery has been seriously inhibited in the abandoned fields even decades after their abandonment, because of altered physico-chemical soil properties (Hoshino *et al*., 2009; Hoshino, 2010)

Over-exploitation of vegetation is also regarded as a major driver in desertification. The problem arises mainly from an increased demand for fuel wood. Trees are cut down repeatedly at a rate exceeding their reproductive ability in forests around growing cities and communities, leading to the depletion of wood resources as well as the onset of desertification.

Combination of two land uses which often become driving forces, pastoral rangeland and cultivated land, sometimes leads to synergistic interaction and enhances the degradation. It has also been pointed out that conversion of rangeland and sylvo-pastoral dryland systems to croplands increases the risk of desertification due to increased pressure on the remaining rangelands (MA, 2005a). In Inner Mongolia, China, sand fixation measures and subsequent transformation from rangeland to cropland were implemented from the early 1980s mainly in a central village zone along the main roads, forcing livestock to move into marginal, more fragile areas, which caused another sand dune remobilization (Fukuhara and Imagawa, 2000). This example suggests that desertification is caused by not only single factors but also combinations of several factors. Those man-made factors also work in tandem with natural factors such as climate change in the desertification process, as mentioned later. It underscores the need for a true understanding of the effects of both climatic and human factors if we are to gauge the current state of desertification.

Processes of land degradation in drylands include erosion by water and wind. In the case of China, the erosion process reflects environmental gradients. In the middle and southern parts, water erosion is the predominant process and also affects downstream areas, for example, through destructive floods. The northern drier regions are susceptible to wind erosion. Dust and sandstorms (DSS) are among the most serious wind erosion events in this region. DSS has long been understood as a natural phenomenon in which the wind carries dust from the Yellow River basin, deserts, etc. Recently however, their frequency and intensity have been increasing, suggesting DSS's relation to soil degradation caused by rapidly expanding overgrazing and to the increasing conversion of land to agricultural use (Ministry of Environment, 2008; Wang and Xue, 2010). DSS not only damages agricultural production and living conditions in the source area but also has adverse impacts on non-drylands such as through the transport of anthropogenic atmospheric pollutants which cause respiratory diseases in eastern Asian countries. At a global scale, DSS is thought to affect the global climate by forming clouds and affecting rainfall patterns, the global carbon cycle and the oceanic ecosystem.

The degradation process also includes deterioration of the physical, chemical and biological or economic properties of soil. Long-term loss of natural vegetation involves not only reduced biomass, but also species replacement from perennial grasses to unpalatable and nutrient poor species (Koizumi *et al*. 2000).

4. Linkage with Global Climate Change and Biodiversity Loss

Since the United Nations Conference on Desertification (UNCOD), which was held in Nairobi, Kenya, in 1977, the international community has promoted numerous research activities on desertification processes and preventive measures, along with emergency aid for food and refugee relief. The United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992, also known as the Earth Summit, moved the international effort against desertification to a new level, which led to the adoption of the UNCCD in 1994. Combating desertification is also recognized as an important factor in achieving the Millennium Development Goals (MDGs). Discussions on combating desertification, however, have made little progress compared with those of the other "Rio Conventions," the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD).

Recently it has been emphasized that desertification is deeply associated with biodiversity loss and contributes to global climate change. Figure 2 shows linkages and feedback loops among desertification, global climate change and biodiversity loss (MA, 2005b). Desertification affects global climate change because soil and vegetation losses may cause the release of a major fraction of their carbon stores to the atmosphere, with significant feedback consequences to the global climate system. Global warming may also adversely affect biodiversity and community structures due to increased evapotranspiration.

Although these three issues have been tackled separately in many countries and regions, it is clear that the causes, effects and possible policies are strongly interlinked. Therefore, joint implementation of the three Rio Conventions and further strengthening of synergies based on environmental management approaches could bring multiple benefits with increased effectiveness.

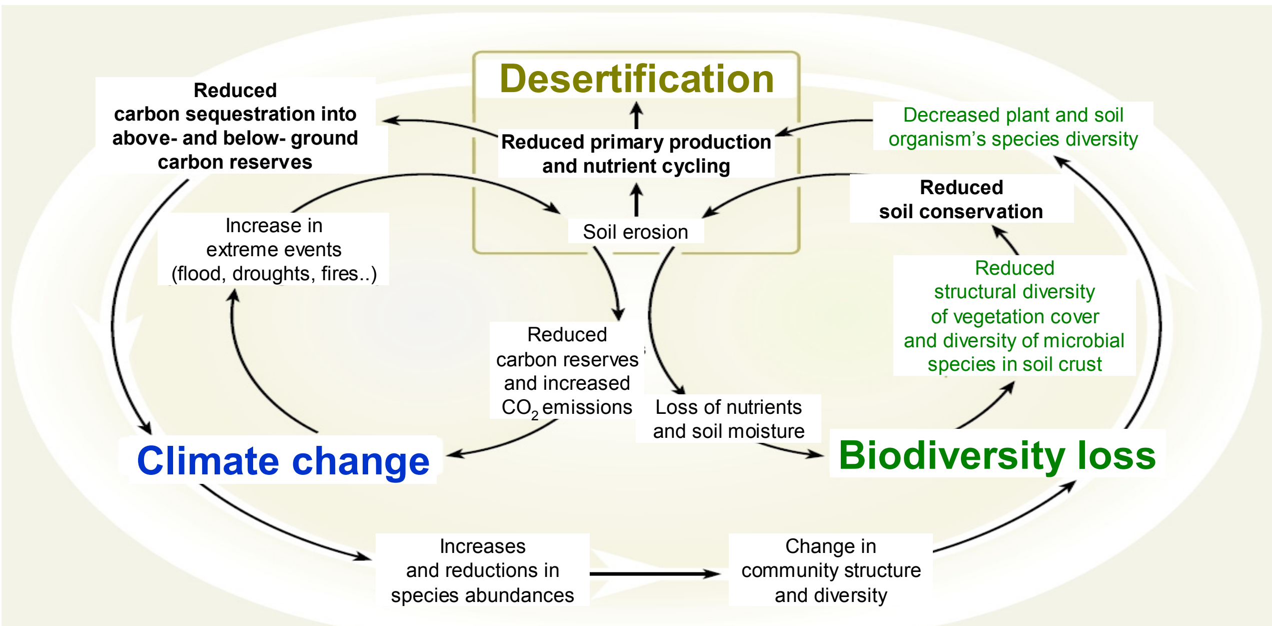

Fig. 2 Linkages and feedback loops among desertification, global climate change and biodiversity loss. The major components of biodiversity loss (in green) directly affect major dryland services (in bold). (MA, 2005b)

5. Counter-paradigm to Desertification

As mentioned earlier, desertification is defined as a persistent reduction or loss of the provision of ecosystem services. Until the 1970s, the desertification concept had consisted of an equilibrium model which assumed that internal ecosystem regulation was achieved through negative feedback mechanisms that moved the system towards stability. In this model, degradation was located along a liner trajectory from poor to excellent states and could be measured as the distance from a theoretical natural stable state. It also provided conventional land management policies and recommendations according to estimated carrying capacities (Leach *et al.*, 1999).

However, this “desertification paradigm” (MA, 2005a) based on the notion of the “balance of nature” has been challenged in the last two decades (Sullivan & Rohde, 2002; Briske *et al.*, 2003). A number of studies have shown that dryland systems could be far better described by a non-equilibrium model in highly variable and less predictable environments in space and time (Ellis & Swift, 1988; Leach *et al.*, 1999), which have led to the development of an alternative “counter-paradigm” (MA, 2005a) concerning dryland systems. The non-equilibrium model, compared to the “flux of nature,” holds that internal regulation is limited (Briske *et al.*, 2003) and land/vegetation dynamics are driven by periodic and stochastic climatic events, which result in discontinuous and possibly non-reversible changes (Hermann & Hutchinson, 2005). There is much evidence that negative feedback may occur but is not inevitable. Rather, several case studies have revealed that it is possible for dryland people to overcome desertification by intensifying their agricultural activities and pastoral mobility in a sustainable manner (*e.g.*, Mortimore & Harris, 2004; Niemeijer & Mazzucato, 2002).

The key message of the counter-paradigm is that the interaction between direct and indirect drivers combined with the local situation can create a wide range of consequences and that understanding the location-specific interaction of socioeconomic and biophysical processes is critical (MA, 2005a; 2005b). Figure 3 gives a schematic description of the two paradigms and their interrelationship (MA, 2005a). Whereas the conventional desertification paradigm focuses only on negative interaction (a downward spiral leading to desertification), the counter-paradigm considers both negative and positive interactions (ways out to avoid desertification). Therefore, the counter-paradigm makes responses much more flexible by taking into account multiple sustainable development pathways rather than imposing a single, intervention-based development model.

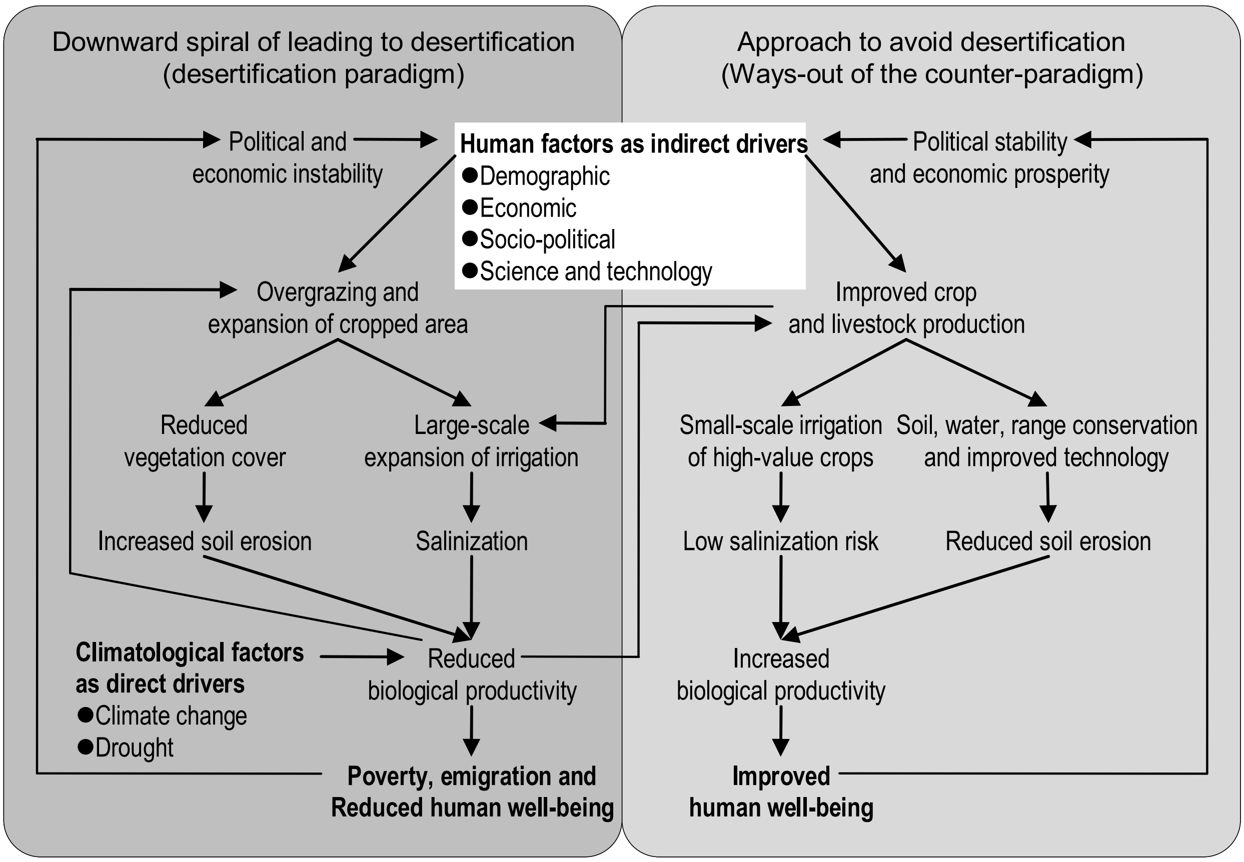

Fig. 3 Desertification paradigm and counter-paradigm. The desertification paradigm (left side) focuses only on the negative interactions, leading to a downward spiral of desertification. The counter-paradigm (right side) involves developments that can help avoid or reduce desertification. In the counter-paradigm, land users respond to stresses by improving their agricultural practices on currently used land. (MA, 2005a; 2005b)

6. Importance of Detecting Thresholds in Desertification Processes

Although a downward spiral of degradation does not always occur in a non-equilibrium system, excessive use pushed by human activities combined with climatic variables could induce a negative feedback leading to desertification. A threshold model is one version of non-equilibrium paradigm, assuming that dryland ecosystems undergo a shift into an irreversible process if major disruptions exceeding the threshold of their resilience persist (Holling, 1973; Schlesinger *et al*., 1990), such as so-called "shrub encroachment." Those phenomena have also been observed in the Asian steppe regions (*e.g*., Christensen *et al*., 2003). Therefore, to detect "thresholds" is essential not only for an understanding of the desertification process, but is also important in proactive management practice for sustainable resource use, as mentioned later.

Several international cooperative research projects including the Global Environmental Research Fund by the Ministry of the Environment Japan (GERF) have been conducted focusing on detecting thresholds in Northeast Asia. The following example is a case study in the Horqin Sandy Land, Inner Mongolia, China (Ohkuro & Nemoto, 1996; Okuro *et al*., 2006; Zhao *et al*., 2004). The Sandy Land is an extensive field of sand dunes which are bio-climatically covered with vegetation. The Quaternary surface sandy deposits are fixed by perennial grasses and shrubs. However, an increase in human activity has caused sand dune remobilization. The results of a grazing experiment conducted for five years showed two types of degradation processes, one involving soil compaction and the other caused by wind erosion. The former process was regarded as a relatively moderate one, compared with the latter, which was a more serious process highly susceptible to accelerated sand dune remobilization. Micro-landform conditions were also found to be the determining factor of the differences in effects of grazing on land and vegetation degradation. Those results indicated that sustainable grazing requires the utilization of rangeland based on local differences in the processes of degradation and recovery and a level of grazing pressure below the threshold which triggers non-linear changes such as "accelerated soil erosion."

7. Desertification Early Warning Systems as A Proactive Management Approach

One of the key findings from the Millennium ecosystem assessment scenarios was the importance of a proactive management approach in coping with desertification (MA, 2005b). At a local scale, scientific evidence concerning thresholds discovered through detailed field investigations would help land managers prevent the occurrence of undesirable states and promote the occurrence of desirable states, which could contribute to proactive management practices. Applying desertification early warning systems (EWS) based on land vulnerability assessments could also be one of the most effective preventive actions at both fine and broad scales. A pilot study on developing EWS in Northeast Asia funded by GERF was recently carried out (Takeuchi and Okayasu, 2005). This project integrated the observation of desertification indicators at a broad scale and desertification processes in relation to man-induced disturbances in various geographical conditions, by building models for long-term trend assessment and scenario assessment. The most important point in this project was that the integrated model made it possible to use land vulnerability as an indicator which could be estimated by detecting thresholds of vegetation change and by calculating corresponding benchmarks of grazing pressure and soil erosion rates. Thus the results of trend and scenario assessments could be used to create concrete land use policies and contribute to supporting decision makers and land managers.

8. Toward Restoration and Sustainable Use of Ecosystem Services in Drylands

At degraded sites where land conditions have already shifted to alternate states, however, applying rehabilitation measures and promoting restoration processes are still needed as reactive approaches. It is well-known that the restoration pathway is not always the same as the degradation path. In our research project funded by GERF, we focused on key processes which are important for the restoration of ecosystem services, and key species which play important roles as engineers in terms of facilitating restoration processes. This study aimed to provide a guideline for ecosystem restoration and sustainable resource use in the rangelands of Northeast Asia. To achieve this purpose, we have been pursuing answers to the following questions using remote sensing, laboratory experiments and field investigations: (1) How is land with different restoration potentials spatially arranged? (2) How do key species which play major roles in restoration processes adapt to harsh environments? (3) How do revegetation technologies promote restoration processes? Although we are now in the process of synthesizing the results, several outcomes from the project are being announced in this special issue (Hoshino, 2010; Okayasu *et al*., 2010; Sasaki, 2010; Shimizu *et al*., 2010; Yoshihara, 2010; Yoshikawa, 2010). The goals of this project are to develop ecosystem restoration prediction models by integrating those results, predict the effectiveness and applicability of various countermeasures and provide scientific evidence regarding where and which combination of countermeasures could achieve the most effective restoration and sustainable land management (Fig.4). Those tools could support the decisions of local people on the "best choice" of the most effective restoration measures in the future.

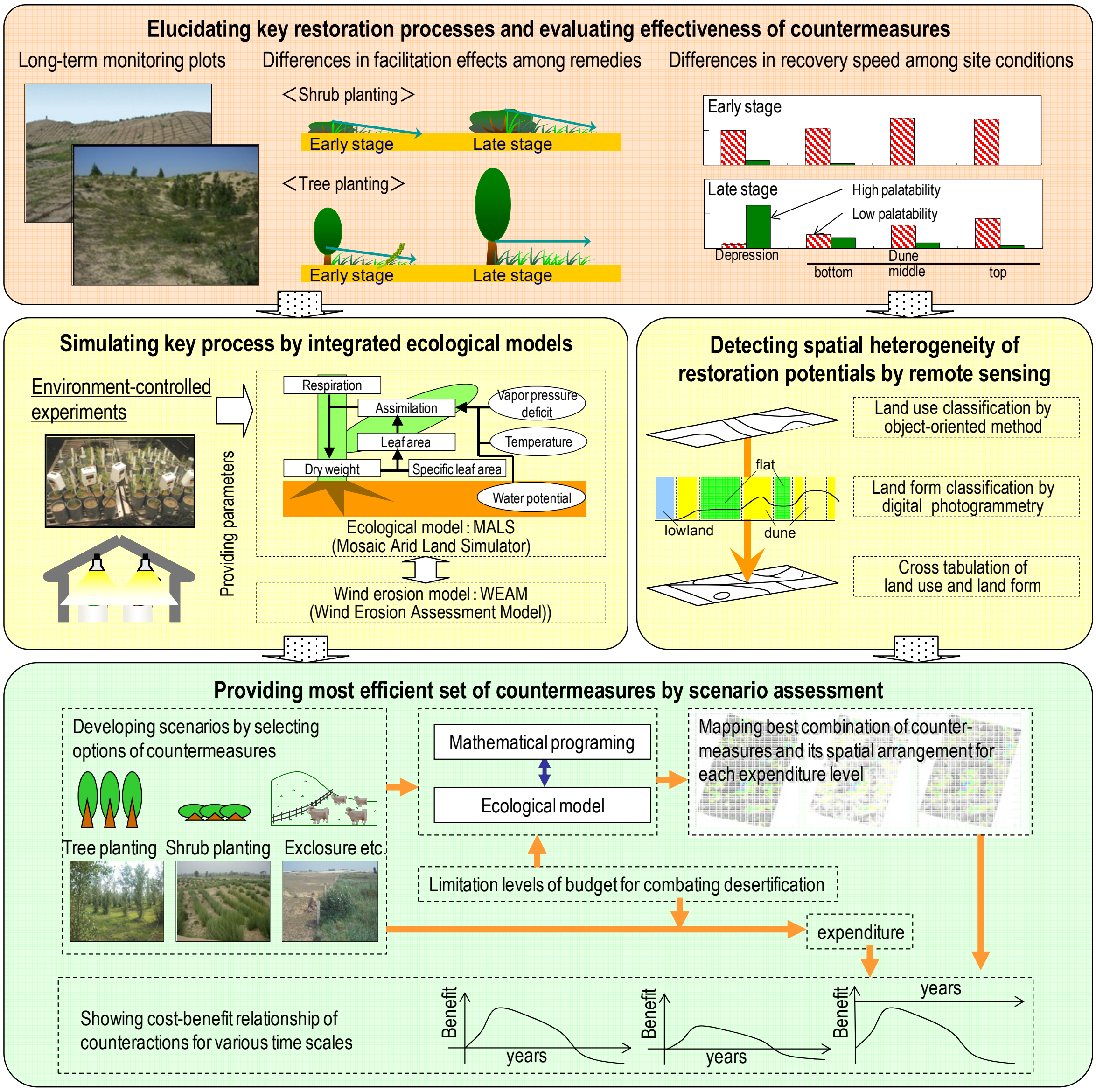

Fig. 4 Framework of a new approach to researches on desertification control and restoration of ecosystem services in grassland regions of Northeast Asia.

9. Conclusion

Advances in desertification research and policy challenges during the past two decades have provided new perspectives in managing dryland ecosystems, and have suggested a new synthetic framework, the Dryland Development Paradigm (DDP). The DDP responds to recent research and policy trends which link ecosystem management with human livelihoods in order best to support the large and rapidly expanding populations in drylands (Reynolds *et al*., 2007). The following recommendations emphasized in this paper are *inter alia* important in the promotion of the DDP: (1) strengthening synergies among three Rio Conventions-UNCCD, UNFCCC and the CBD, (2) establishing and disseminating desertification early warning systems as a proactive management tool, (3) developing integrated technologies to promote ecosystem restoration and sustainable resource use in drylands.

Acknowledgments

I would like to thank Dr. Hideyuki Shimizu of National Institute for Environmental Studies, Dr. Tomoo Okayasu, Mr. Takafumi Miyasaka and Ms. Eriko Miyamori of the University of Tokyo for providing figures. This study was supported by the Global Environment Research Fund, Ministry of the Environment Japan entitled "Desertification Control and Restoration of Ecosystem Services in Grassland Regions of North-East Asia (G-071)" and by the Global Center of Excellence Program of the Japan Society for the Promotion of Science of the Ministry of Education, Culture, Sports, Science and Technology of Japan: "Center of Excellence for Asian Conservation Ecology as a Basis of Human-Nature Mutualism."

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(Received 10 April 2010, Accepted 9 June 2010)