Application of Ecological Theory to Management of Arid Drylands: An Example from China

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Abstract. Rangeland ecosystems shift across dynamic thresholds between different ecological states in response to natural or human-induced factors. These different ecological states are the result of interactions among climate, soils, grazing history, and management practices. The notion of a single ‘‘pristine’’ final state is only conceptual in nature, and because of this, dynamic thresholds and the effects of various processes on ecosystem structure and function must be incorporated into decision-making. Rangeland managers should have a working knowledge of the key ecological processes in each state, and the processes that drive a system across a dynamic threshold from one state to another. To do this they need indicators for critical decision-making points. It is essential to identify the thresholds of an ecological transition state and ecological indicators of these states. The criteria of these ecological indicators might be measurable, sensitive to stress on the system, have a known response to disturbance and easy to measure. The state and transition approach may offer an appropriate framework as an aid for decision making and can be used to highlight ‘‘management windows’’ where opportunities can be seized and hazards avoided. China’s vast drylands are used as a case study and the potential to apply these principles is discussed.

Keywords: Ecosystem indicators, Threshold, Vegetation dynamic, Drought.

Introduction

Among the mainstream practitioners of rangeland management in North and South America, southern Africa and Australia there is a general recognition that many arid systems are non-equilibrial and that the successional path leading to a specific climax ecosystem is unlikely. Natural ecosystems shift between different ecological states through ecological transition zones Anand and Li (2001) in response to natural or human-induced factors rather than follow a prescribed successional path Friedel (1991). Multiple stable states exist as a result of interactions among climate, soils, grazing history, and management practices Westoby *et al.* (1989). Plant cover in arid environment shifts across dynamic thresholds between different ecological states in response to disturbance such as grazing, drought and fire. In severe cases in dryland regions this is manifest as desertification. Desertification processes have been intensively studied and the factors affecting the initiation and the rate of progression are now better understood.

Rangeland managers need a workable framework that will underpin their decision making. The state and transition approach of Westoby *et al.* (1989) may offer an appropriate framework and can be used to highlight ‘‘management windows’’ where opportunities can be seized and hazards avoided. Natural resource managers should have a working knowledge of key ecological processes in each state, but they need indicators for critical decision-making points to serve as the basis for developing and interpreting natural ecosystems.

Rangeland ecosystems shift across dynamic thresholds between different ecological states in response to disturbance factors. These different states are stable and each state is a result of interactions among climate, soils, grazing history, and management practices Westoby *et al.* (1989). The notion of a single ‘‘pristine’’ final state is only conceptual in nature, and because of this, dynamic thresholds and the effects of various processes on ecosystem structure and function must be incorporated in decision-making Eiswerth and Haney (2001).

The question of what constitutes an indicator of threshold, and how to measure it, is important for ecosystem management. What attributes are to be measured, how are they to be measured, and how the measurements to be interpreted are, are the subject of continuing debate Andreasen *et al.* (2001). Rangeland ecologists need to be able to explore spatial relationships of many species over many environmental features in relation to grazing effect. Whilst the measurement of vegetation composition is important in the assessment of vegetation condition, other attributes are required in order to understand better vegetation dynamics. If only vegetation is monitored, it will not be clear whether any changes in composition are due to interactions between gazing and vegetation alone, or whether the soil, as a habitat for native plants, has been degraded. Tongway and Hindley, (2000) have suggested that attributes of the soil-surface condition (soil cover, soil texture, cryptogam cover) may be combined in various ways to provide useful indicators of landscape function such as stability, infiltration or nutrient cycling.

The effects of nonlinear processes on ecosystem structure and function and the nature of dynamic thresholds are rarely considered sufficiently and to date their incorporation in decision-making is inadequate Eiswerth and Haney (2001). This is particularly so in China where the newer thinking in ecology has not yet been widely promulgated and where assumptions based on equilibrial theories prevail.

Dry lands of China

We define rangelands as “uncultivated land that will provide the necessities of life for grazing and browsing animals and the herder families that depend on them. Therefore it includes deserts, forests and natural grasslands and shrublands.” The area of arid and semi arid rangeland (sometimes referred to as the “grasslands”) in China is about 186 million ha, the exact amount depends on whether the classification is based on climate, soils, drainage-effectiveness, or vegetation.

The arid, semi-arid and dry sub-humid areas in China are widely distributed over parts of 471 counties of Xinjiang Uygur Autonomous Region, Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region and Tibet Autonomous Region, the provinces of Qinghai, Gansu, Hebei, Shaanxi, and Shanxi extending over several thousand kilometres from east to west. The rangelands of China are characterised by high year-to-year variability in precipitation. This in turn results in (1) variability in plant growth (2) uneven provision of nutrition for cattle, sheep, goats, camels, horses and other herbivores (e.g. wildlife) and (3) limited potential to carry out necessary plant management options such as rest and rotational grazing.

Table 1. Grasslands of Selected Provinces.Regions of China (Million ha).

Province.Regio	Total Area	Provincial Grassland Resource	
		Area (% of Province)	% of China’s Grassland Area
Tibet	122.8	82.0 (66.8)	20.8
Inner Mongolia	118.3	78.8 (66.6)	20.0
Xinjiang	166.0	57.3 (34.5)	14.6
Qinghai	72.1	36.4 (50.5)	9.3
Sichuan	56.7	22.5 (39.7)	5.7
Gansu	45.4	17.9 (39.4)	4.6
Yunnan	38.3	15.3 (39.9)	3.9
Heilongjong	45.3	7.5 (16.5)	1.9
Ningxia	5.2	3.0 (57.7)	0.7
Liaoning	14.6	2.0 (13.7)	0.5
Jilin	18.7	1.9 (10.2)	0.4
Other provinces	366.8	68.8	17.6
Total	960.3	392.8	100.0

Source: Ministry of Agriculture, April 1999.

The degradation cycle commences with the aftermath of drought and/or excessive grazing pressure causing an increase in the proportion of bare ground and of plants with low palatability or forage value. This situation leads to increased run-off or wind erosion and soil loss. The resulting erosion leads to reduction in infiltration rate and a further loss of productivity and so the downward spiral of degradation sets in. The patterns of degradation in China are complex and diverse because of altitude and substrate and the patterns of land use imposed over the past decades. Almost 80% of the arid, semi-arid and dry sub-humid areas are affected by degradation to a greater or lesser extent. Rangeland degradation is as high as 56% overall but in some areas it is worse. For example, a remote sensing survey of Inner Mongolia in 1983, showed the area of the degraded rangeland was 21.34 million ha, accounting for 35.6% of the total area of rangeland. By 1995, however, the area of the degraded rangeland had increased to 38.69 million ha. A net increase of 1.74 million ha in twelve years. The annual increase of degraded rangeland is approximately 2%. For practical purposes, most of the of China “Three North regions” (north west, north and north east) is arid rangeland of which 105 million ha is classified as degraded, to a greater or lesser extent.

Some key issues in relation to measuring desertification are (i) separating long-term trends from short-term variation. Measurements must be able to determine when a genuine trend emerges from the noise driven by inter-annual and inter-decadal variability. This is closely related to understanding the causes of different forms of change both from the point of view of considering how to treat problems, and to help refine conceptual models. Specifically, to detect when a trend signal emerges from short-term noise. It is important to know which components of the factors are affected by physical drivers as opposed to human impacts or their interactions.

(ii) The reduction in vegetation cover and vegetation quality (eg. through changes in species composition) in dry areas is an essential element of desertification. We must take full account of spatio-temporal trends in vegetation cover and land use as modified by human impact and climate change. Research to identify generic land use change processes in dry areas can build upon similar work in the humid tropics Grainger (1992).

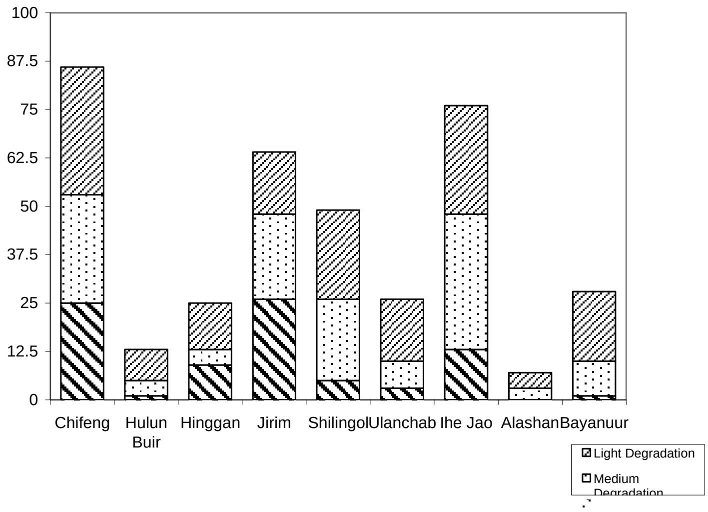

Fig. 1. Percentage of Rangeland Considered to be degraded in Selected Local Government Areas of Inner Mongolia Adapted from: Humphrey and Sneath (1999).

The results will lead to a better assessment of the economic linkages between land degradation, its impacts on global climate, biodiversity, food production and human welfare, so that governments can make a more realistic cost-benefit analysis of future actions to combat desertification. Vegetation degradation, in the drylands and elsewhere, remains so poorly studied that it is a major source of uncertainty in our knowledge of the global carbon cycle and the links between desertification and climate change Williams and Balling (1995).

It is useful, when assessing rangeland degradation, to distinguish between ‘‘deteriorated’’ which is judged to be reversible and ‘‘degraded’’ which is not economically reversible. However, it should be noted that the definitive discrimination in terms of ‘‘reversible’’ and ‘‘non-reversible’’ is apparent only with the benefit of hindsight. Rigid attempts to define ‘‘degradation’ obscures the fact that degradation and the associated loss of productivity occur on timescales from years to decades (and beyond). In this report we have used the term ‘‘degradation’’ in the general sense to embrace both reversible and non-reversible aspects of resource damage.

Both the terms ‘‘deterioration’’ and ‘‘degradation’’ describe a more fundamental change in rangelands, namely a loss of landscape function Ludwig *et al.* (1997). Deteriorated and degraded rangeland environments are characterised by a reduced capacity to absorb rainfall and increased runoff, greater surface disturbance and greater patchiness, loss of surface soil nutrients and overall poorer nutrient availability. There will always be periods of deterioration resulting from seasonal and unpredictable annual fluctuations of climate. Differing levels of resilience in the resource to perturbations in different systems lead to different manifestations of ecosystem instability stocking (2005).

The Chinese response to these changed ecological conditions in the grazed drylands was to implement the Grassland Law that was predicated on the notion that if herders are given some security of tenure over a particular piece of rangeland that their stewardship would be more effective than that which applied under common use grazing systems that had prevailed in the past. (Box1).

Box 1. The Grassland Responsibility System

The payable use of grassland responsible system clarifies property rights and use rights for herders. Herder's contract with local governments for use of grasslands and the contract specify the grassland type, area, estimated yield and theoretical carrying capacity, contract period and fees payable in return for the rights. The contract period is usually more than 30 years and the fees are determined by the grassland area and livestock numbers.

The system was developed in three stages: at the initial stage (1980-1982) the contract only defined and assessed a fee based on livestock numbers; during the second stage (1983-1986) the contract defined and assessed a fee based on livestock numbers and defined a grassland area without an attached fee; the third stage (post-1987) separated the use right and the property right by charging the grassland use fee.

Up to the end of 1999, 113 million hectares of grassland (36% of total usable grassland) has been contracted to herders across the country with most progress having been made in Inner Mongolia Autonomy Region which has contracted 82% (93 million hectares) of its usable grassland.

It is generally considered that this system has improved the quality and sustainability of grassland management although it needs further improvement (enforcement of grassland use and carrying capacity is apparently weak, there is a need to develop management approaches which provide a venue for all relevant stakeholders – herders, relevant experts, government officials – to make informed management decisions regarding technical, environmental and other issues.

Total grazing bans have been applied in some areas where the government favours sedenterization of herders and the implementation of more intensive production systems based on feedlots and ‘‘cut and carry’’. The *Grassland Law* is seriously flawed in that it is based on notions of ecological succession (equilibrial) and upon the idea that the carrying capacity should be set at a level more appropriate to maximizing animal production per head of animal. Herders reject the carrying capacity assessments based on criteria more appropriate to commercial ranches. In practice the herders see production per unit area as the key objective and many are operating at a more subsistence level where conventional calculations of carrying capacity are all but meaningless.

Confining a fixed number of animals on a fixed area in an environment that experiences wide variation in seasonal conditions and a highly variable pattern of precipitation from year to year has proven to a major factor in accelerating desertification (Williams). The present system is not working (US) it is most likely that any form of grazing by livestock will effect a change in botanical composition. Because rangelands are variable in both space and time, mobility of herds is often the only way to cope with the sharp fluctuations in quantity and quality of forage. However, this semi-nomadic life style is discouraged (or even outlawed) in favour of a sedentary lifestyle.

The role of rangeland management, by both the herders who use the land and by the officials who administer it, in either maintaining or restoring rangeland ecosystem needs to be seriously thought about. Quantifying the link between rangeland condition and livestock performance will be an important step in improving the adoption of more sustainable grazing practices in rangeland environments. The combined assessment of vegetation and soil features could provide more comprehensive understanding of disturbance affects, such as grazing, and could be a sound basis for management of a particular area. It will help to aim at sustainable utilization of the plant community with regard to full ecological understanding of vegetation condition. Even within the constraints imposed by the Grassland Law and its implementation, it could be argued that applying a more opportunistic approach would be worthwhile. The state and transition approach of Westoby *et al.* (1989) may offer a more appropriate framework as an aid for decision making and can be used to highlight ‘‘management windows’’ where opportunities (such as abundant forage and drinking water in the desert fringe) can be seized and hazards (such as drought and extreme winter weather) avoided.

Rationale for Using Recent Ecological Theory to Better Manage China’s Drylands

If a system shifts across a dynamic threshold from a stable, productive, undisturbed (defined as “healthy”) state to a less healthy state, if would be valuable to have a set of indicators to (i) give an early warning of such change, and to (ii) facilitate the recovery of the system. The U.S. National Research Council (1994) and Andreasen *et al.* (2001) pointed out the need for an early warning phase between “healthy” and “at risk” states and the need to identify thresholds between “at risk” and “unhealthy” states. Such ecological indicators must be workable and measurable and Dale and Beyeler (2001) proposed the following criteria: easily measured, sensitive to stresses on the system, respond to stress in a predictable manner, be anticipatory, predict changes that can be averted by management actions, be integrative, have a known response to disturbances, anthropogenic stresses, and changes over time, and have low variability in response. However, caution must be exercised with indicators that are highly sensitive to change because they may also be highly sensitive to natural variability and may not be useful Andreasen *et al*. (2001).

Understanding the role of plants as indicators has important implications for sustainable rangeland management, and for the rehabilitation of areas that are already degraded Heshmati *et al.* (1998). The threshold concept describes unidirectional changes in ecosystem structure and ecosystem functional processes. The state-and-transition model Westoby *et al.* (1989) implies that plant community composition makes dramatic changes only during times of unusual environmental influences. Furthermore, the species composition of differing plant communities in particular states, on a particular ecological site, fluctuate within defined limits, which can also be expressed as several domains of attraction (West and Yorks 2002) or threshold Friedel (1991) or ecological transition zones Anand and Li (2001) depending on the degree of responses to disturbance. Whenthese thresholds are crossed, recovery to the original ecosystem.

Another important factor is to develop a set of threshold values that will signal the onset of a major change in rangeland ecosystems before it becomes irreversible. Even if thresholds could be an established and reliable indicator found, it is still not clear whether the rangeland manager under the present system of land tenure can adjust stocking rates, or patterns of grazing in a way that can make any difference. Rangeland managers should have a working knowledge of the key ecological processes in each state, the processes that drive a system across a dynamic threshold from one state to another. Appropriate indicators need to be developed for critical decision-making points to ensure a more sustainable use of these vast and valuable natural resources.

Conclusions

Drylands are “non-equilibrium ecosystems’’ meaning that they regularly and normally change between different ecological states, making it difficult if not impossible to define a stable equilibrium. There are, however, patterns and cycles in such change. The degree of predictability is low, but traditional users have learnt to detect and sustainably utilize these cycles and changes. Dryland ecosystems are also ecologically resilient, in fact much more so than usually believed. The scale and magnitude of persistent ecological damage has been over-estimated, with “overgrazing” used as a convenient scapegoat for many other causes. Serious land degradation and desertification are evident around permanent settlements and water points, where livestock mobility is reduced, but much less so in open rangelands under extensive production systems. If anything, over-cultivation is the single most serious threat to drylands and rangelands. Root causes are policies and laws that favour cultivation over livestock production, sedenterization programmes and inappropriate service investments.

Local pastoral systems are highly heterogeneous, ranging from agro-astoral systems to fully nomadic systems. They have one feature in common: mobility of livestock. Mobility has been shown to be an appropriate mechanism for adaptive management of non-equilibrium ecosystems. Where it continues unhampered, it has resulted in increased biodiversity conservation and sustainable land management. Where it is constrained by land use and land tenure changes, and policy disincentives, it has led to serious over-grazing and land degradation. Dryland landscapes have been shaped over centuries by knowledge-intensive and highly flexible pastoral strategies and custodianship. Mobile, extensive, pastoral systems in drylands produce more economic gains per hectare, than sedentary, intensive, production systems.

Despite the emergence of individualistic behaviors, most pastoral groups continue to share a sense of community. Their social capita-indigenous knowledge, customary leadership patterns, reciprocity and interdependence rules, political alliances, social "symbiotic" relationships and conflict resolution mechanisms-is very high. Such social capital contributes to powerful adaptive rangeland management strategies, which still have to be fully recognised in their role for sustainable land management.

Mobile pastoralism is ecologically, economically and socially crucial for sustainable development in dryland ecosystems. But despite several decades of inter-disciplinary scientific research and evidence supporting the appropriateness of transhumant and pastoral systems for dryland sustainable management, most countries continue to treat herders as second-class citizens. Most policies are biased towards sedentary populations (agricultural subsidies, service delivery, and land tenure). Very few attempts have been made to develop innovative models and identify best practices for enabling pastoral mobility within the current context of globalization, communications revolution, and democratisation. This is the challenge for researchers in China.

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