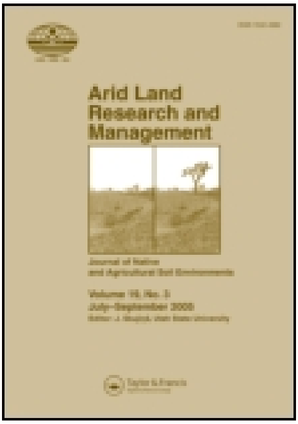

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Estimating Pastoral Productivity of Semiarid Rangeland in Northern Shaanxi Province, China, Using an Environmental Resource Assessment and Management System

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An Environmental Resource Assessment and Management System (ERAMS) has been developed for determining present and potential pastoral productivity of arid and semiarid regions. ERAMS determines productivity of mapped land units on the basis of soil-water availability which is in turn dependent on annual rainfall, slope, soil depth, salinity, and soil physical and chemical constraints. Stock carrying capacity is dependent on soil type and vegetation state or condition (which is based on foliage cover and botanical composition), and nutritive value of the pasture. Physical and biological features are determined by field survey. ERAMS has been used to examine the likely impacts of management strategies that alter the degree of erosion, or vegetation type and state. Comparison of present and potential production indicates the economic benefits of programs designed to increase carrying capacity through improved vegetation cover and land stability.

Keywords carrying capacity, ERAMS, land use planning, rangeland inventory

Land degradation is a widespread phenomenon affecting grazing lands throughout the world. Land degradation was estimated to affect 1,964 million ha of the earth in 1990 (Ghassemi et al., 1995), of which 84% comprised wind and water erosion. Human populations have continued to rise, leading to increased land degradation, reduced environment quality, and an increasing concern for the environment.

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In the semiarid regions of China, pastoral land use is dominated by sheep and goat grazing on unimproved native rangelands, opportunistic cultivation, and semisedentary agriculture. Inappropriate land management and increasing population pressure has lead to increased desertification over large areas of China. In the mid-1990s approximately 79% of the arid, semiarid and dry subhumid areas of China were estimated to be affected by desertification, at an annual increase of 2,460 km^2 (Longjun, 1997).

On the Loess Plateau of northern China, inappropriate land management has lead to dramatic increases in salinization, wind and water erosion, and land degradation over the past 30 years (Fu & Gulinck, 1994), leading to a deterioration in environmental quality, particularly soil and water quality. Encroachment by mobile sand dunes onto areas formerly used for cropping has reduced the area of land available for cultivation, putting greater pressure on remaining farming land. Although research and extension efforts are directed at controlling environmental problems, only limited progress has been achieved.

A major step in land use planning and land management is to determine the present and potential land capability so that land resources are used within their capability. Any system to determine land capability must be relatively efficient, reliable and repeatable. One such methodology is ERAMS (Environmental Resource Assessment and Management System), developed to determine land capability on semiarid lands (Squires et al., 1990; Squires & Thomas, 1990). This article describes the application of that methodology to an area on the northern Loess Plateau of China.

Methods

The Study Area

The study area was located in Shenmu County in northern China. Shenmu County is located approximately 520 km northwest of Beijing in Shaanxi Province (38°49′ N, 110°29′ E; Shenmu). It is bordered to the north by Inner Mongolia and to the south by the Yellow River. The Great Wall separates the aeolian region in the northwest from the hilly loess country to the southeast. In these loess-dominated landscapes, grazing is secondary to cropping as the predominant land use. Shenmu County is typical of a band of semiarid country forming a boundary between the predominantly pastoral country and that devoted to cropping.

The study was centred on the village of Erlintu, approximately 50 km northwest of Shenmu county and covered an area of approximately 530 km^2, varying from 1,000 to 1,400 m above sea level. The area is characterized by a vast undulating plateau dominated by sand dunes (both fixed and drifting), clay depressions and small ephemeral lakes. The soils range from deep, undifferentiated aeolian accumulations on the sandhills and sandplains (Aridisols, Entisols, Psamments), to deep saline clays in the low-lying wetlands and meadows (Mollisols). Loess soils in the area typically contain 7–14% clay, 10–13% fine silt, 48–56% silt and 23–30% sand (Fu & Chen, 2000) with erosion rates up to 16,300 $Mg\,km^{-2}yr^{-1}$ (Zhang et al., 1990). Organic matter levels on the sandy soils are low (< 1.0%), pH averages 7.6, and available nitrogen, phosphorus and potassium are low (32:6:78 $mg\,kg^{-1}$, respectively) (Guo, 1986).

Regional rainfall varies from a mean annual of 300–400 mm, but the long-term average for Erlintu is 330 mm and Shenmu is 395 mm (Longjun, 1997). Rainfall is predominantly summer dominant. Annual temperature varies widely, with summer maxima about 39°C and winter minima of −28°C. Yearly total solar radiation is approximately 591 $kJ\,cm^{-2}yr^{-1}$ and there are about 145 frost-free days each year. Pan evaporation of 2,092 $mm\,yr^{-1}$ is approximately five times the mean annual rainfall. Wind speed averages 2.5 to 25 $m\,sec^{-1}$ with an average of 9.2 dust storms per year (Guo, 1986; Longjun, 1997).

Vegetation

The vegetation in the study area was dominated by the ubiquitous *Artemisia* species including *A. ordosica* Krasch., *A. mongolica* Fisch. ex Bess., *A. sphaerocephala* Krasch., and *A. gmelini* Fisch. ex Bess. *Salix cheilophila* C.K. Schneider and assorted perennial and ephemeral forbs are common on the sandy soils; *Carex duriuscula* C.A. Mey and *Elymus* spp. occur in the low-lying saline meadows. The palatable leguminous browse and forage plants *Astragalus melilotoides* Pall., *Caragana microphylla* Lam., *C. korshinskii* Kom. and *C. leucophloea* Pojark are distributed throughout the study area.

The Field Survey

A reconnaissance field survey was conducted in the Erlintu area in October 1990 and June 1991. Prior to the field work, aerial photography interpretation was undertaken using black-and-white rectified images at a scale of 1:50,000. Twenty-one sites were subsequently selected for detailed measurement of soil and vegetation attributes.

The Vegetation Survey

At each of the 21 sites, the vegetation was assessed using a modified step-pointing procedure (Cunningham, 1975) on three transects totaling about 2,000 m in length. This resulted in approximately 2,000 step points per site. Perennial plants were identified to species level, and ephemerals were pooled according to the ERAMS methodology (Squires et al., 1990). Coverage of bare soil, litter, and cryptogams was also measured.

Step-pointing data were used to calculate projected foliage cover and botanical composition of the vegetation. Vegetation condition at each site was determined using the method of Steeley and others (1986) which characterizes the state (condition) of a site on the basis of the relationship between foliage cover and an index of botanical composition, as well as the presence or absence of juvenile perennial plants. The index of botanical composition (IBC) is defined by the ratio:

$$\mathrm{IBC} = \frac{\text{foliage cover of desirable perennial plants}}{\text{foliage cover of all perennial plants}}.$$

According to the ERAMS methodology, only perennial plants are considered, as these give the best indication of the long-term stable productivity of the rangeland, and they ensure that data collected over different seasons are not confounded by the transitory growth of ephemerals and annuals (Squires et al., 1990). Although we accept that the exclusion of annuals and ephemerals may underestimate pastoral productivity, particularly in good seasons when they are dominant, we believe that the disadvantages are offset by the advantages of having to record only perennial plants. Thus, where the pasture comprises mainly desirable perennials, the index is close to 1.0. Where perennials are predominantly undesirable, that is, toxic or unpalatable to stock, the index is close to zero.

The Soil Survey

In the ERAMS methodology, pastoral productivity, and hence land capability, may be influenced by a number of factors including slope, soil depth, pH, salinity, presence of zones of water accumulation, and the presence of overriding physical constraints such as excessive sandiness or stoniness. Overriding constraints present in the Erlintu study site included highly mobile, deep and shallow sandy soils, and soil salinity levels > 2.4 dS m^{-1}. Where appropriate, soil texture was assessed using the bolus technique (Northcote, 1971), and slope measured using a clinometer. Laboratory analyses of salinity and pH were undertaken, as needed.

Results and Discussion

Land Capability Classes

Using data on rainfall, slope, soil depth, salinity, and the presence or absence of constraints, the 21 sites were assigned to one of 12 Land Capability Classes (LCC) (Table 1) (Squires et al., 1990). The sites differed primarily in relation to soil constraints (presence of deep sands at nine sites), zones of water accumulation, and presence of saline soils (two sites). The slope (2–3%) and rainfall ($330\,\mathrm{mm\,yr^{-1}}$) attributes did not vary substantially among the sites but generally the area was characterized by a system of small dunes and swales. The microtopography was conducive to accentuated patterns of run on and run off.

The 21 study sites comprised five Land Capability Classes. Six sites were automatically assigned to LCC 12 due to the overriding constraint of deep immobile sands. Three sites were assigned to LCC 10 due to a greater proportion of the area occupied by sinks at the margins of the dunes. The presence of these sinks is expected to increase the overall available moisture in that land class. The low, stable dunes and plains with moderately dense *Artemisia* spp., *Cynanchum* spp., *Salix* spp. and perennial grasses were assigned to LCC 3. Finally, the two sites on low-lying wetlands were assigned to LCC 5 because of soil salinity levels ($8\text{–}16\,\mathrm{cm^{-1}}$).

Vegetation States

Four major vegetation associations occur in the Erlintu area. The dunefields and sandy soils support *Artemisia* spp. while *Salix* spp. occur at the dune margins. Low-lying depressions and wetlands are dominated by *Carex* spp. and *Elymus* spp. communities. Nineteen of the 21 sites were dominated by *Artemisia* spp. For the *Artemisia* (and *Salix*) sites where we had sufficient data, we plotted the relationships

TABLE 1 Total Annual Dry Matter Production and the Dry Matter Production per mm Available Moisture on Land Capability Classes 1–12

	Available moisture (AM)				Total annual dry matter production (TADM) $2.33\ \mathrm{AM}^{1.22}$	
	AM		$\mathrm{AM}^{1.22}$			
Land Capability Class	Range (mm)	Mean (mm)	Range (mm)	Mean (mm)	Mean ($\mathrm{kg\,ha^{-1}\,yr^{-1}}$)	Mean ($\mathrm{kg\,ha^{-1}\,yr^{-1}\,mm^{-1}}$)
1	> 461	487	> 1,777	1,900	4,427	9.09
2	408–461	434	1,530–1,777	1,654	3,853	8.88
3	354–408	381	1,288–1,530	1,409	3,283	8.62
4	299–354	327	1,048–1,288	1,168	2,721	8.32
5	258–299	279	875–1,048	962	2,241	8.03
6	216–258	237	705–875	790	1,841	7.77
7	173–216	194	538–705	622	1,449	7.47
8	129–173	151	376–538	457	1,065	7.05
9	99–129	114	272–376	324	755	6.62
10	68–99	84	172–272	172	401	4.77
11	36–68	53	80–172	126	294	5.55
12	0–36	19	0–80	40	93	4.89

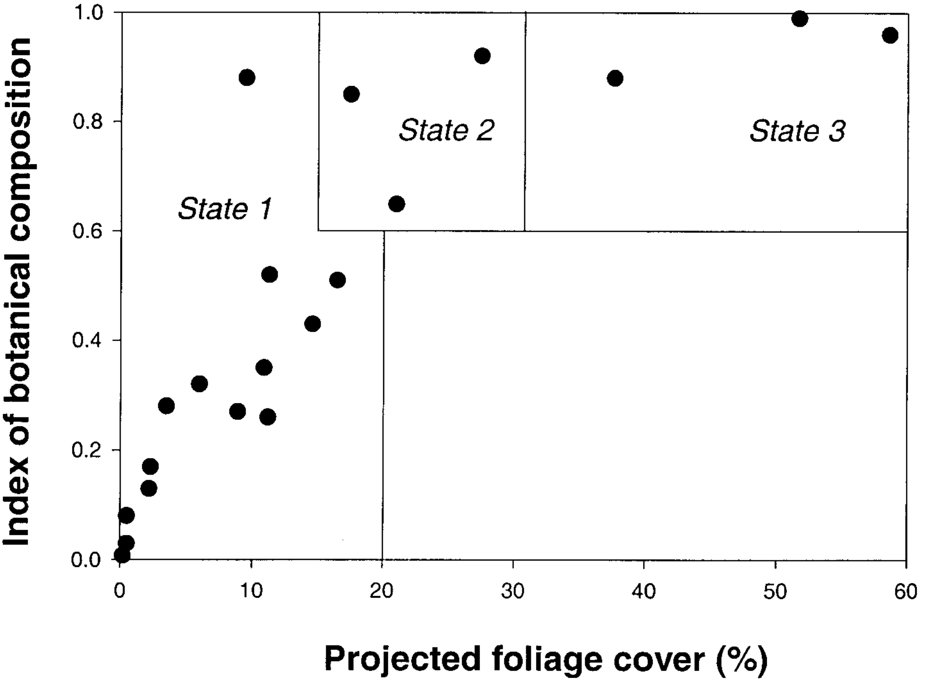

FIGURE 1 The relationship between projected foliage cover and an index of botanical composition (IBC) based on the proportion of the perennials *Artemisia* (and *Carex*) in the plant community.

between foliage cover and botanical composition according to the ERAMS methodology (Steeley et al., 1986) in order to assign the sites to one of four condition states. Insufficient data precluded us from deriving meaningful data for the *Carex* spp. associations because they were restricted in areal extent.

For the *Artemisia*-dominant vegetation community, four vegetation states were defined ranging from sites near ecological potential to severely degraded sites (Squires et al., 1990). State 0 was defined as being at ecological potential and contained both adult and juvenile plants. State 1 contained adults and juvenile plants but produced at only 80% ecological potential. State 2 was defined as having a foliage cover from 15–30% and IBC > 0.60 and produces at 33% of ecological potential. State 3 included all sites where foliage cover is < 15% or where foliage cover is up to 20% and where IBC < 0.60 (Figure 1). State 3 produced at 10% of its ecological potential.

Estimation of Total Annual Dry Matter (TADM)

An essential step in the ERAMS method is the estimation of the total annual dry matter production. The growth of vegetation in semiarid areas is governed primarily by available moisture (Thomas & Squires, 1991). Available moisture is in turn dependent upon annual precipitation, but also, in a more simplistic sense, on factors such as slope, soil depth, soil texture, salinity, and the presence of areas of rainfall accumulation such as run-on zones.

Each of the vegetation associations (*Artemisia, Salix, Carex-Elymus*) has a characteristic potential annual dry matter (TADM) production. Total dry matter production is related to available moisture by the equation:

$$\mathrm{TADM} = k\,\mathrm{AM}^{\mathrm{X}}, \tag{1}$$

where AM is the available soil moisture (as determined by rainfall, soil, and slope characteristics), k is a constant, and the X is a multiplier.

Linear regression relationships between rainfall and annual dry matter production have been reported for semiarid Kenya (van Wijngaarden, 1985), China (Ting-Cheng et al., 1983) and Australia (Thomas & Squires, 1991). Curvilinear relationships have been determined for the North African steppe (Le Houérou & Hoste, 1977) and more complex, process-based models are currently being used which are based on water balance and plant growth calculations. However, more complex models are extremely data demanding, and in many areas of the world's rangelands, the unavailability of detailed datasets precludes the use of anything but simple models. Ideally, data from which estimates of TADM are derived should be obtained from sites in good condition and preferably from ungrazed or lightly grazed sites. Alternatively as many sites as possible should be used to calculate TADM in order to reduce bias from sites which may be producing below ecological potential.

We used productivity data collected in 1983 from 37 range sites in the Erlintu area (Guo, 1986) to determine the relationship between TADM and AM. For the *Artemisia* and *Salix* associations the multiplier was 1.22, and 1.36 for the mixed perennial pastures.

Thus, for the *Artemisia* and *Salix* associations,

$$\mathrm{TADM} = 2.33\,\mathrm{AM}^{1.22}, \tag{2}$$

and for other perennials,

$$\mathrm{TADM} = 2.33\,\mathrm{AM}^{1.36}. \tag{3}$$

Available moisture $\mathrm{AM}^{1.22}$ has been determined for the 12 Land Capability Classes derived from all possible combinations of rainfall, slope, soil depth, and salinity (Table 1). Total dry matter has then been calculated using Equation 2. Table 1 lists dry matter production for all land classes and demonstrates that total dry matter production for the 12 possible land classes ranges from about 93 kg $\mathrm{ha^{-1}\,yr^{-1}}$ on LCC 12 to 4,427 kg $\mathrm{ha^{-1}\,yr^{-1}}$ on LCC 1. This gives a range of production from 4.9 kg $\mathrm{ha^{-1}\,yr^{-1}\,mm^{-1}}$ to 9.1 kg $\mathrm{ha^{-1}\,yr^{-1}\,mm^{-1}}$ or an average of 7.3 kg of pasture produced per hectare per year for every mm of available moisture. These values are slightly higher than those from the Mediterranean basin (4 kg; Le Houérou, 1984) and rangelands in Australia (2–8 kg; Squires et al., 1990). A peculiar feature of the sites was that the water table was high, as evidenced by the presence of small freshwater ponds and lakes among the dunes.

However, only a part of total production can be safely utilized for grazing. In commercial livestock systems a realistic level of utilization is somewhere between 40 and 60% of total dry matter production (Le Houérou & Hoste, 1977). In more traditional pastoral systems, especially those that are nonequilibrium, the level of utilization often exceeds 80% (Westoby et al., 1989). Sufficient aboveground production needs to be retained in any pastoral system to ensure that ecological processes such as flowering and seed set are not adversely affected. Similarly it is essential to preserve an extensive root system in order to maximize essential metabolic processes such as respiration (Chapin et al., 1990), and to ensure that perennial plants capture both water stored at depth and moisture retained in the upper soil horizons (Hodgkinson & Freudenberger, 1997). An acceptable safe limit of utilization varies among species and needs to be adjusted accordingly. For the present study, the acceptable level of utilization of perennial shrubs in the Erlintu area is set at 75% of total production in line with studies from other traditional pastoral systems in semiarid regions (Behnke & Scoones, 1993). This high level of utilization is in marked contrast to the levels reported for commercial ranches in North America and Australia (Galt et al., 2000).

Sheep Carrying Capacity

The pastoral potential of any piece of land, and therefore the potential carrying capacity, can be determined by considering total utilizable dry matter (UDM), and vegetation type and condition. Vegetation in State 1 produces at 80% of ecological potential. Therefore a site with vegetation in State 1 and Land Capability Class 3 would currently produce 2,626 kg dry matter $ha^{-1} yr^{-1}$ (80% of 3,283 kg; see Table 1). Sites in Land Class 12 (the sand dune areas) with *Artemisia* in vegetation State 3 would produce 9.3 kg dry matter $ha^{-1} yr^{-1}$ of *Artemisia.* Notwithstanding the above, some areas in Land Class 12 and vegetation State 3 would produce only 9.3 kg dry matter $ha^{-1} yr^{-1}$, but generally this is the average for the land class as a whole.

Feed quality is another factor that needs to be considered along with utilizable dry matter. As botanical composition declines from State 1 to State 3, so does the nutritive value of the pasture, as the more nutritious and palatable species are removed by grazing. Thus 1 kg of dry feed in vegetation State 1 will have a higher nutritional value than the same quantity of dry feed from State 3.

In the Erlintu area, the daily intake of usable dry matter for a 40 kg sheep is estimated at 2.0 kg sheep $unit^{-1} day^{-1}$ (730 kg UDM $sheep^{-1} yr^{-1}$). Research is currently underway to determine the nutritive value of vegetation, in terms of metabolizable energy, for various vegetation states. Once this is known for *Artemisia, Carex* and mixed perennial pastures, then the total carrying capacity of the Erlintu area can be determined.

Options for Increasing Carrying Capacity

The two principal methods for increasing the current carrying capacity are: firstly, to introduce pasture species with a higher dry matter production or nutritive value or both, and secondly, to improve vegetation state by manipulating grazing rates or using rangeland reclamation. Species such as *Artemisia ordosica* and *A. sphaerocephala* have been successfully introduced onto unstable sandy soils, and in the wetland areas *Melilotus suaveolens* Ledeb. has proved promising. Aerial seeding trials with *Artemisia* spp. and *Astragalus* spp. have proved successful on some sandy soils (P. Guo, Shenmu Grassland Station, personal communication, 1995).

Destocking and rotational grazing may be necessary to ensure the success of rangeland reclamation programs. Evidence from Erlintu is that high foliage cover (> 60%) can be achieved after only five to seven years of destocking. Destocking may be assisted by supplementary feeding of crop residues to livestock so that pressure can be reduced on the rangelands. In Erlintu there are 2,400 ha of cropped land. Straw and by-products of crops totaling about 1.95 Mg ha^{-1} can be utilized but there is shortfall in the forage required to support the burgeoning flocks and herds.

Conclusions

ERAMS is a relatively rapid and cost-effective method for estimate calculating of potential and current carrying capacity of semiarid rangeland. The ERAMS methodology is based on the fact that there is a strong correlation between pasture productivity and available moisture in semiarid regions. Simple measurements of soil depth, slope, salinity, rainfall, and vegetation type and condition can be used to determine total dry matter production for semiarid areas. The nutritional value of the pasture can then be used to determine the maximum carrying capacity. Compared to high quality forage (e.g., higher digestibility, higher nitrogen), a greater amount of poor quality forage is required to support one livestock unit. The aim of rangeland improvement must be to provide a higher level of animal nutrition and still ensure adequate soil protection.

The ERAMS methodology can be used to examine the likely impacts of management strategies that alter vegetation type, vegetation state, or the degree of erosion. By comparing the current productivity with potential productivity, land managers can examine the economics of undertaking reclamation measures designed to improve land stability.

The ERAMS system is a quantitative system of land and vegetation capability classification, and provides a framework within which the consequences of continual overuse of the rangelands can be assessed. It was designed as a reconnaissance approach to collect data over large areas. The emphasis is on ease of measuring and processing. The actual field measurements for soil, topographic, and vegetation parameters are relatively simple and straightforward, especially in those regions of the globe where no rangeland surveys have been conducted and where the balance between stocking rate and forage availability is, at best, tenuous.

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