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Edited by
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MONITORING RANGELAND ECOSYSTEMS WITH REMOTE SENSING: AN EXAMPLE FROM KAZAKHSTAN

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Abstract. This paper describes the nature and problems of rangelands in Kazakhstan. A prototype rangeland monitoring program based on an existing monitoring program developed for use in the Soviet Union is described. The monitoring approach has been modified to use the same simulation model, but more modern remotely sensed data is being incorporated into the approach as well. Results from the Balkhash area of Kazakhstan are presented to show progress to date. Current plans are to continue to develop this approach for the study area, and if feasible, apply the approach nationally.

Keywords: Pastureland, desertification, monitoring, modeling of pasture ecosystem, remote sensing, total vegetation index

1. Introduction

Kazakhstan range and pasture lands are semi-natural ecosystems, which have been formed as a result of domestic and wild animal grazing. The total pasture area in Kazakhstan is 187.2 million hectares, including 40% desert

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pasture. Kazakhstan's natural pasture vegetation has been greatly harmed by desertification. Of the main natural factors facilitating desertification of pasturelands, soil salinization and wind erosion are the most evident. Kazakhstan's desert receives more than 6,000 MJ/m^2 of solar radiation and a total of 160–300 mm atmospheric precipitation per year and has a mean annual wind speed of 2–3 m/s. In these conditions, water loss due to evaporation is several times larger than water input. Consequently, in this stressful environment, the main forms of natural desertification, such as soil salinization and wind erosion, progress in the desert zone. The wind causes sand and light sandy soils to be unstable because plant cover takes several centuries to form.

The natural desertification processes in Kazakhstan have become more prevalent because of human activities. Human pressure on pastures, in general, is reflected by pastureland degradation. At the beginning of the 1990s the number of sheep reached 35–36 million in Kazakhstan. Of course the stocking is not uniform, and some regions have very high stocking rates. As a result, changes in the soil and plant cover of the desert zone were observed across more than 60% of Kazakhstan. Such high stocking rates could not be maintained, and by the middle of the 1990s the number of sheep had decreased to 11 million (17 million in 2006). However, the degradation of Kazakhstan's pastures continues, as water points for animals are limited and the sheep are concentrated near human settlements. These pressures result in reduced soil fertility, loss of plant biodiversity and reduced productivity of forage vegetation (Figure 1).

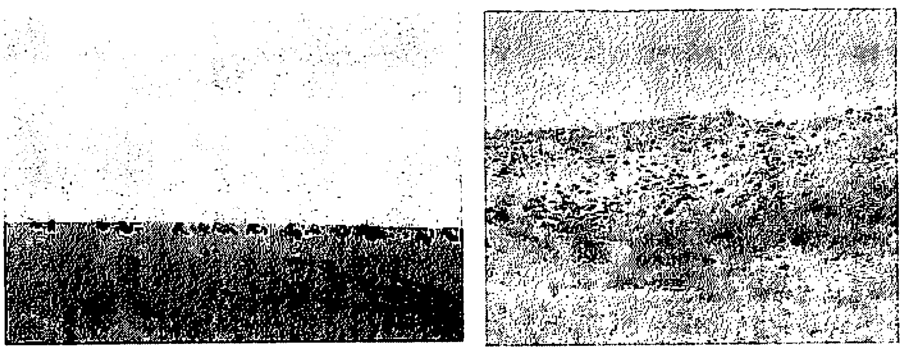

Figure 1. Desert pasture vegetation on plains with clay or sand soils has productivity of 0.2–0.4 t/ha.

2. Bioecological characteristics of desert vegetation in Kazakhstan

As a result of harsh environmental conditions and natural selection, the deserts of Kazakhstan are host to some 1,200 species of plants. Of these, however, only a few tens of species are dominants or subdominants forming discrete plant communities on pastureland (Bykov, 1978). These species are perennial shrub, dwarf shrub, subshrub and dwarf subshrub species, and perennial and annual forb and grass species. A distinctive group with a short growing period in spring is represented by the ephemerals. Desert plants have developed a degree of resistance to environmental conditions. They are principally mesotrophic and oligotrophic species, plants adapted to poor soils. Deserts, which often have saline soils, are host to many salt-tolerant plants, or halophytes. Sands are home to psammophytes, plants adapted to life in a shifting environment. Depending on their resistance to drought conditions, most plants in desert zones are xerophytes, able to withstand very dry conditions of air and soil. Most of them also withstand high air and soil temperatures and are thus thermophilic plants (Kurochkina, 1978).

Depending on the way they take up moisture, most desert plants may be classified as ombrophytes, trichohydrophytes or phreatophytes (Bedarev, 1968). Ombrophytes are a group of plants whose root system is located in the surface layer of the soil and take up water directly from precipitation. Trichohydrophytes have complex root systems that penetrate fairly deeply into the soil (2–3 m and more) and take up groundwater by means of capillary action. Phreatophytes have thick roots that tap directly into groundwater.

Depending on the time-scale involved, plants may be classified as very early, early, mid-range and late developing species. In the deserts of Kazakhstan, growth of very early and early developing plants starts from late March to early April when the air temperature reaches 3–5°C. Growth ends 1–2 months later after the plants have seeded. Mid-range developing plants stop flowering and produce seeds 2–3 months after the onset of growth. Late developing plants resume growth in the spring when the air temperature reaches 10–12°C, flowering only in midsummer and producing seeds in late summer or in the autumn.

The growing season of desert plants may be divided into a period of active growth, a maintenance period and a period of senescence (Larin, 1969). The period of active growth, which generally begins once the air temperature reaches 10–12°C, is associated with active photosynthesis. Photosynthesis leads to a build-up of organic substances in the form of assimilants and the individual parts of the plant show active growth. In the conditions prevailing in the deserts of Kazakhstan, the period of active growth coincides with the period when the plants are standing and green, but may occasionally also occur in the development phase in an unusually wet year when temperatures have been mild. In such years, the period of active growth is prolonged and ends at seeding. This is the time when the yield of pastureland plants is at its height. After this, growth comes to a halt until seeding has ended. This is the maintenance period.

However, it is much more common for the period of active growth in herbaceous plants to end prematurely when the temperature reaches 18–20°C. Shrubs and sub-shrubs are observed to lose leaves and twigs when the temperature reaches 22–24°C. In such years, the generative phase of desert plant growth does not come to a successful conclusion or is not observed at all. Early withering of plants during the summer results from disruption of their water balance due to inhibition of assimilation caused by high temperatures and insufficient moisture. Biomass fails to increase, although it may be conserved in such a period, only to subsequently wither and fall.

These processes, which are due to the destruction of chlorophyll-containing tissues, may also continue into the cold period of the year. The lengths of the periods of active growth and senescence, which are governed by the biological properties of the plant and by agrometeorological conditions during the year, vary widely. In good years with sufficient moisture, active growth in the very early groups of ephemerals is 50–60 days, while for late-developing plants, the growing period is 120–150 days. In exceptionally dry years, active growth in the spring period lasts no more than 20–30 days for early-developing plants and 50–60 days for late-developing plants. By late summer or early autumn, when the temperature falls to 20–22°C, plant growth interrupted by the summer may resume. Herbaceous plants will start growing again following rain greater than 10 mm (Phedosseev, 1964).

3. Monitoring and modeling pasture ecosystems

Pasture monitoring in Kazakhstan includes:

- Systematic geobotanic field studies on large areas performed by the Republic of Kazakhstan Land Use Agency until 1993 and more limited studies in later years.
- Episodic specialized (geobotanic, soils, agricultural and ecological) observations on limited areas of Research Institute desert research sites.
- Regular point observations by the RSE "Kazhydromet" meteorological station network in dry areas, which are limited by some plant associations.
- Remote sensing and visual observations of vegetation seasonality by RSE Kazakh Research Institute and Ecology and Climate expeditions conducted regularly prior to 1993 and occasionally in later years.

The task of pasture monitoring is complemented by modeling the dynamics of natural vegetation over large areas through the use of quantitative data provided by remote sensing. Modeling natural biocenoses, generally a group of plant species each with its individual response to environmental conditions, is a difficult task. The difficulty here is that the model often contains parameters relating to actual plant species and their actual habitats while remote sensing frequently provides only an overall view. This is why in modeling large areas of pastureland the focus has been on relatively simple models based on a small number of parameters and a restricted amount of input information. As a result, these models may, more properly, be considered as applied models. Work with these models is thus often carried out at the level of vegetation zones, most usefully in relation to separate type groups (Tucker, 1980; Lebed and Turbacheva, 1990). The usefulness of this group of models increases when they contain meteorological, soil, and other variables that control the physical processes.

An applied model for estimating the yield of large areas of desert pastureland has been developed in Kazakhstan (Lebed and Belenkova, 1995). The model was officially approved for use in a wide-ranging aerial and space experiment carried out on part of the Priaral (land bordering the Aral Sea) in 1990 and 1993 and has given acceptable results for use in practice.

The present model takes the resumption of growth in the biomass of plants above ground during the year as an overall indicator of the pattern of change in the desert pasture ecosystem as a whole. The results are taken to be the pasture yield, expressed as tons per hectare dry weight. The model relies on digital and video models of spectral reflection from pastures provided by periodic aerial and space surveys. Routine agrometeorological data provided by the station network and cartographic information provided by geobotanical surveys are also used. The model is also used to derive other recognized quantities such as potential and actual yield, as previously determined in relation to agricultural crops (Thoming, 1977).

In the case of pasture ecosystems, the vegetation prevailing at the present time, including species composition, structure and yield, is the direct result of climate, relief, hydrography, soil type, plant pest activity and other environmental factors. Hence, its potential yield is the maximum yield possible given the soil, climate and other natural resources of the locality. At the same time, plants are affected by indirect or redistributive factors, the chief of which are human activity and current weather conditions. Increased human input may bring changes, often of an irreversible nature in the species composition, structure and yield of pasture vegetation (Nechaeva, 1981; Kurochkina, 1978). As a result, most present-day pastures may be termed semi-natural ecological systems (Vinogradov, 1984). Weather is another redistributive factor that determines current seasonal and yearly changes in natural vegetation. However, in contrast to human intervention, such changes are generally reversible in nature. They appear each year as annual changes in the biomass produced above and below ground, in partial shifts in vegetable structure, changes in seed quantity and differences in the amount of new growth in pastures. Weather conditions are associated with what is termed the yield per agrometeorological year. This parameter in its turn is affected by the grazing of stock in different seasons, sometimes for long uninterrupted periods. A portion of the annual yield is lost by withering during senescence. The resultant amount is close to the actual yield of the pasture per agrometeorological year. The actual yield includes the yield from green growth.

Here, the process of quantifying the actual yield of a desert pasture may be described as successive biological and physiological processes associated with the build-up and collapse of plant biomass in the course of the year. In practice, for different species and plant groups, these processes take place at different seasons of the year and last for different lengths of time.

The build-up of plant biomass as a result of growth during the current year is modeled by means of equations of the general type:

$$y_{a\tau} = \frac{y_{pot}}{1 + \left(\frac{y_{pot}}{y_\tau} - 1\right) \exp \int_0^t R \tau dt}, \tag{1}$$

$$R_\tau = R_{\max} \cdot A_\tau, \tag{2}$$

$$A_\tau = f(F, T, W), \tag{3}$$

Where:

$y_{a\tau}$ – yield in the period of active growth during the agrometeorological year (in t/ha)

Y pot – real potential yield (in t/ha)

y_τ – actual yield in the period of senescence (in t/ha)

R_τ – plant growth function

R_{max} – value of R_t under optimal environmental conditions

F,T,W – environmental factors (light, heat, moisture) (in MJ/m^2, °C, mm)

τ – time of year (in days, decades, month)

The process of biomass collapse may be expressed by the equation:

$$y_\tau = y_{a\tau} \cdot \exp a_\tau \tag{4}$$

where,

$a\tau$ – rate of biomass collapse

The process of build-up and collapse of biomass is limited by the critical values of the regime factors affecting each species and group of plants. Calculation of biomass is carried out in variable stages of 5, 10 or more days. Here, the mass representing new growth and seeds is not deducted from the total biomass since they represent a relatively small (<10%) part of the total yield and do not significantly affect its measurement.

4. Parameterizing the pasture yield model

In determining the parameters of the pasture yield model, the authors, like other researchers (Kirsta, 1986) have assumed that the response of natural vegetation to change in such environmental factors as weather conditions is fairly consistent. It was also assumed that moderate grazing would not have a noticeable effect on the pattern of plant growth and development arrived at in the course of evolution. At the same time, account was taken of the response of pasture ecosystems to human activity, which could have both beneficial and harmful effects on soil and plant cover. In recent years the effect of human activity on pastureland in Kazakhstan has been associated with marked changes in stocking rates, possible changes in the pasture management system, measures for improvement of pastures and other forms of action.

In this connection, a number of the model parameters reflecting the biological laws governing the development of plants and their response to light, heat and moisture (C_F, C_T, C_W) have been calculated outside the timescale and geographical location of the vegetation modeled. In determining these parameters, the authors used data from observations of pastureland collected over many years at permanent field sites as well as paired agrometeorological observations made at meteorological stations and temporary sites. These observations were carried out directly by the authors of the model and other research workers in the desert zone of Kazakhstan in the period 1960–1980. For example, Table 1 gives the constant parameters of the model for individual plant species in a sandy desert. Similar results have been obtained for the principal dominant plants found in the desert zone of Kazakhstan.

A biological parameter of the model such as potential yield, Y_{pot}, will take on numerical values for each natural region with its own species composition and vegetation structure. It is determined from data giving the actual yield of vegetation in the green state, which may be obtained either by direct field observation or air or space imaging of pastureland during the growing season. A practical example of the results given by calculating Y_{pot} for pastureland in the Priaral from the results given by remote sensing is shown in Table 2. The optimum repetition interval for calculation of the parameter, Ypot, is the same as that for pasture geobotanical surveys, 5–7 years (Vinogradov, 1984).

TABLE 1. Parameters of the model being used for calculation of the yield of individual dominant plants in desert vegetation.

Plant species	Parameters						
	t	R_{max}	ΔW	Cw	ΔT	C_T	a_r
Agropyron sibiricum	4	2.10	0.40	0.40	10	0.50	
	5	2.20	0.60	0.60	7	0.35	0.30
	6	2.10	0.60	0.75	7	0.35	0.70
	7	1.25	0.60	1.00	7	0.35	0.80
	8						0.90
	9						
Artemisia terrae albae	4	1.95	0.40	0.40	10	0.45	
	5	2.15	0.65	0.85	7	0.33	
	6	2.20	0.80	1.00	7	0.33	0.60
	7	1.95	0.80	1.33	7	0.33	0.75
	8	0.70	0.80	1.33	7		0.95
	9	0.70	0.80	1.33	7		0.50

TABLE 2. Potential yield of pasture vegetation (Ypot) in the Northern Priaral calculated for the different geobotanical regions on a map with a scale 1:2,500,000 in 1990.

Division and vegetation	t/ha
Artemisia spp. and Halophytic with ephemerals on brown clay soils on hummocky flatlands *(Artemisia terrae albae, Anabasis salsa)*	2.66
Halophytic and Artemisia spp.with ephemerals on clayey saline soils on undulating flatlands *(Atriplixae capae, Anabasis salsa, Artemisia terrae albae)*	0.90
Halophytic and Artemisia spp. on clayey saline soils and sandy soils on undulating flatland *(Kochia prostrata, Anabasis salsa, Artemisia terrae albae)*	2.71
Artemisia spp. and grasses with Halophytic and ephemerals on clay and sandy loam soils on pre-sandy undulating flatland *(Artemisia terrae albae, Agropyron sibiricum, Poa bulbosa)*	1.41
Artemisia spp. and grasses with Halophytic and shrub on clay soils *(Artemisia terrae albae, Kochia prostrata)*	1.03
Shrub and Artemrsia spp. and grasses on the hilly ridged sands *(Artemisia terrae albae, Agropyron sibiricum, Calligonum)*	2.50

The model makes it possible to calculate the yield of pasture vegetation at different sites ranging from a few acres hosting specific plant communities to hundreds or thousands of hectares representing specific geographical landscape types or geobotanical vegetation regions. The outcome is a series of curves representing changes in the biomass of vegetation of the current year's growth throughout the growing season, in the fodder stocks on pastureland at different seasons in the bioclimatic potential and bioecological condition of pasturelands, and in other indicators.

A working variant of the model can be used under different regimes, including operational studies for forecasting yields during the growing season (Figure 2) over a complete year and retrospective studies to calculate pastureland yields from agroclimatic data. The usefulness of the initial results given by the model is increased if they are further processed to give a map of fodder yields or biological productivity.

Information on pasture yields is of practical use in moving stock on pastures and improving stocking rates on areas of ecologically poor pastureland. It can also be used in decision-making on agricultural and ecological issues with a bearing on evaluation of the country's natural resources and preparation of socioeconomic development programs for desert regions and ecological programs. Pasture monitoring and modeling can be used as practical tools made possible by modern remote sensing systems and algorithms for the analysis of geospatial information.

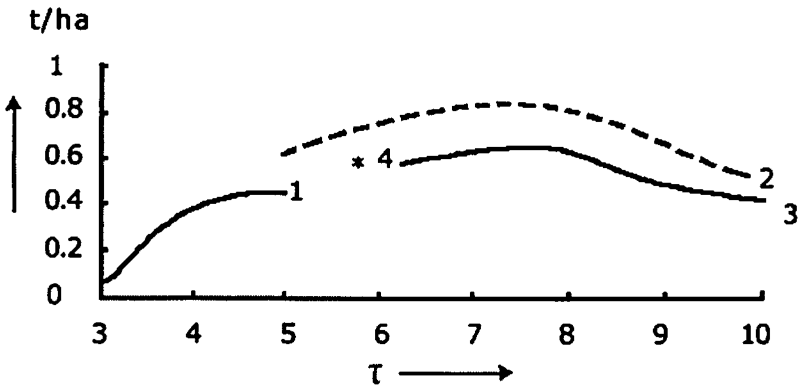

Figure 2. Forecast yield (t/ha) of *Artemisia* spp. and salines on clay-soils on flatland in the Northern Priaral throughout the 1993 growing season (Lebed and Belenkova, 1995). Calculations made on 10 May (1), 10 June (2), 10 July (3) result of aerial survey (4).

5. Current research and preliminary results

We are currently developing a prototype modern rangeland monitoring program based on a simulation model as well as field and remotely sensed data. Figure 3 shows the flow of information in the processing steps undertaken by the International Science – Technology Center Project funded by the United States Department of Agriculture to collaborate on research to improve the monitoring and modeling of rangeland vegetation in Kazakhstan. Recent research in the southwestern United States has shown that it is possible to quantify grassland cover, height and biomass even when the grasses are senescent using Landsat 7 imagery (Qi et al., 2002). The approach uses field measurement of key parameters to estimate a soil adjusted total vegetation index (SATVI), which is in turn used to estimate cover using an empirical relationship from the field data. Grass height is estimated empirically using an empirical relationship to the NIR band. Biomass is then calculated using the product of the cover and height and an empirical correction factor. Preliminary research indicates that the same approach can be used in parts of Afghanistan and China. A map of estimated 2006 biomass for rangelands in the Balkhash area in Kazakhstan is shown in Figure 4.

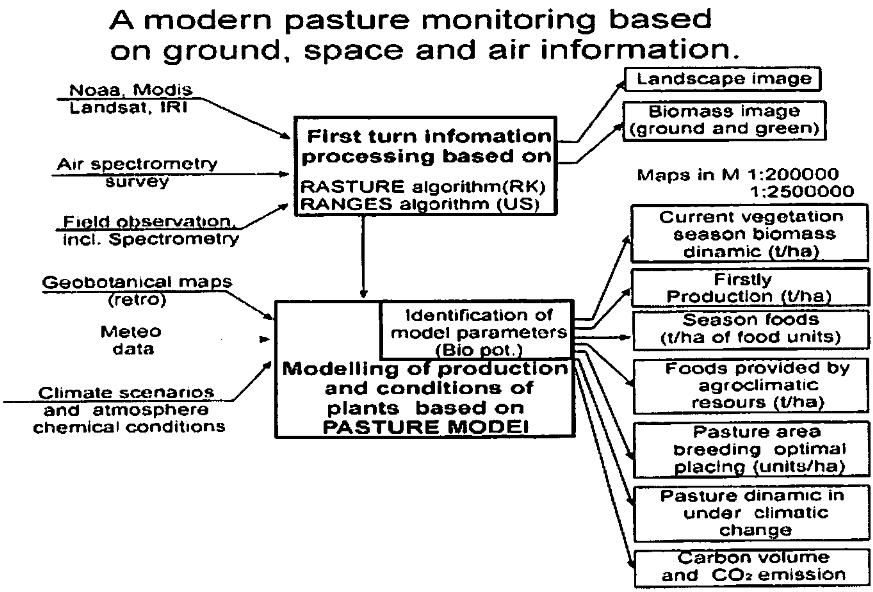

Figure 3. Flow of rangeland monitoring processes.

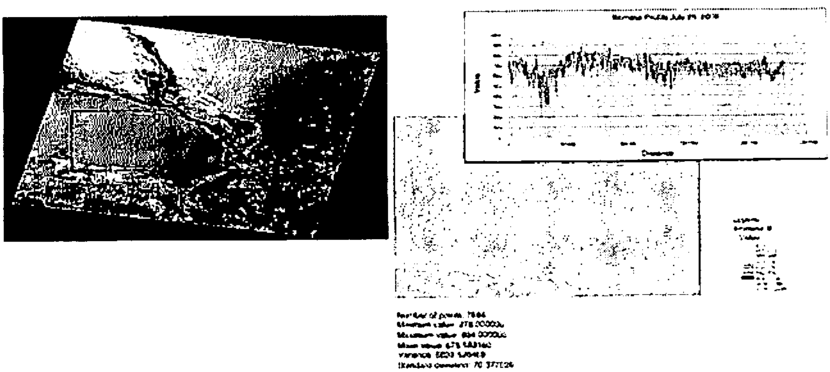

Figure 4. Preliminary results of the Landsat image processing.

6. Future research

Rangelands are an extensive but critical resource. Modern tools such as remote sensing and simulation modeling, in addition to field data collection and geospatial databases, should harness information from all sources to provide better information about spatially distributed patterns of plant production for decision making. Remote sensing and modeling imply a simplification of complex ecological interactions. The benefit of that simplification is that conditions over very large areas can be studied without excessive labor costs.

Future research will focus on rangeland model parameter identification based on modern sensors (Landsat, MODIS), as well as other sources of remotely sensed and field data on the conditions of Kazakhstan's rangelands and local agroclimatic resources. We also expect to assess the possibility of impacts under climate change and modifications of atmospheric chemistry and carbon balance on rangelands. If current efforts with this approach are able to demonstrate feasibility, and funding is available, the approach will be expanded to a national effort to monitor rangelands across Kazakhstan.

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