Real-time monitoring of grass and animal for steppe management in Inner Mongolia, China

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Abstract: Steppe grasslands in Inner Mongolia have been utilized for livestock farming by nomadic people over several centuries. At the same time, grassland was conserved as an invaluable ecosystem. However, in recent years, desertification of grassland is encroaching mainly because overgrazing by animals. Grassland condition will be decided with the balance of grass production and herbage intake by animal. The field experiment was conducted under the collaboration of Institute of Botany, in Chinese Academy of Sciences from 1997 to 2004 in order to make real-time monitoring system. The study site is in Xilingol steppe, Inner Mongolia. As the results, satellite remote sensing using NOAA/AVHRR and Terra/MODIS data revealed seasonal changes of grassland biomass and herbage quality. Estimated aboveground biomass in August (2001) decreased nearly 40 % comparing with that of 14 years ago in Xilingol steppe. Biomass fluctuated year by year, affected by climate conditions. NDVI of grassland could be expressed by rainfall and air-temperature of the previous month. In addition, progresses in IT such as GPS and GIS technologies clarified animal behavior on grassland. Jaw sensor could record jaw movement of grazing sheep. Such information offered us the location, behavior and spending time of animal on grassland, which is capable to calculate grazing intensity. It might be useful to determine carrying capacity of the site under the specific land and climate conditions.
Keywords: Biomass, GIS, GPS, Herbage quality, Real-time monitoring, Remote sensing, Xilingol steppe.

1. Introduction

Steppe grassland in Inner Mongolia, China, has been threatened by desertification mainly because overgrazing by animals. Grassland production changes year after year, place to place affected by climate conditions and grazing intensity. The questions we addressed are development of the new real-time monitoring system to conserve the precious ecosystem, at the same time, to achieve sustainable livestock farming. Grassland conditions will be decided by balance of grass production (GP) and herbage intake by animal (HI). When HI superiors to GP, grassland will be degraded, and when GP exceeds HI, it will be conserved and recovered (Fig.1). The rate of GP is decided by climate, soil and so on, while HI is decided by grazing intensity including stocking rate, animal species, palatability and so on. Our system aims real-time monitoring of GP and HI using satellite data, GPS, GIS and mathematical models [1].

Entering in this century, satellite sensors had made remarkable progress in resolution. Commercial satellites like IKONOS and QuickBird have super-high spatial resolution such as 3.3m and 2.44m, respectively. Hyper-spectral satellite like EO-1/Hyperion detects reflectance at 220 wavelengths. Interval of observation is also important to detect phenological change of vegetation. NOAA/AVHRR and Terra/MODIS carried out daily observation. Such progresses in sensor may make possible to provide precise, timely and site specific information of grassland. Propagation of Geographic Information System (GIS) and enhancement of accuracy of Global Positioning System (GPS) became powerful tool for clarification of grassland ecosystem.

In this report, we would like to draw the general concept of this system, and estimate steppe biomass using NOAA/AVHRR and Terra/MODIS data, to show real-time monitoring of grass biomass and quality, and animal behavior using satellite data and GPS, and to estimate herbage intake and grazing intensity under free grazing condition in Xilingol steppe.

We started cooperative work with Institute of Botany, Chinese Academy of Sciences since 1997 to construct effective grassland monitoring system.

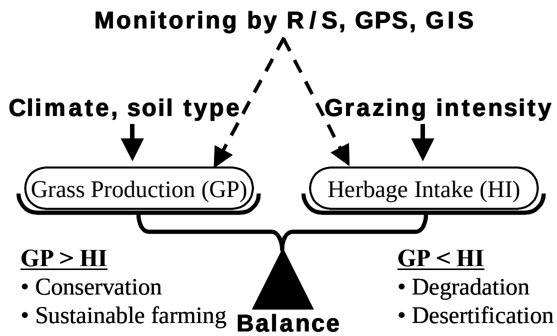

Fig.1 The concept of real-time steppe monitoring system [1] .

2. Experiment sites and methods

2.1 Estimation of steppe biomass and crude protein in Bayinxile Farm (Experiment 1)

2.1.1 Experimental sites

The Bayinxile Livestock Farm (3,730 km^2) in Xilingol steppe is situated in northern Inner Mongolia, which is approximately 400 km north of Beijing. It is located between 43°10'- 44°20'N latitude and between 116°0'- 117°20'E longitude, and covers total area of over 13,000km^2 (Fig.2) . The average altitude is 1,400 m above sea level. The climate is characterized as semi-arid with long, cold, dry winters and short, worm, wet summers. This area belongs to the continental middle temperate semi-arid zone. The mean annual temperature is -0.4ºC; while, the coldest month (January) is -19.5ºC, and the warmest month (July) is 20.8ºC [2]. Annual precipitation is about 300 mm, concentrates in the summer seasons (Fig.3). Total livestock number increased to 252,700 SU (sheep unit) in December 2001. Thus the average grazing intensity for the total

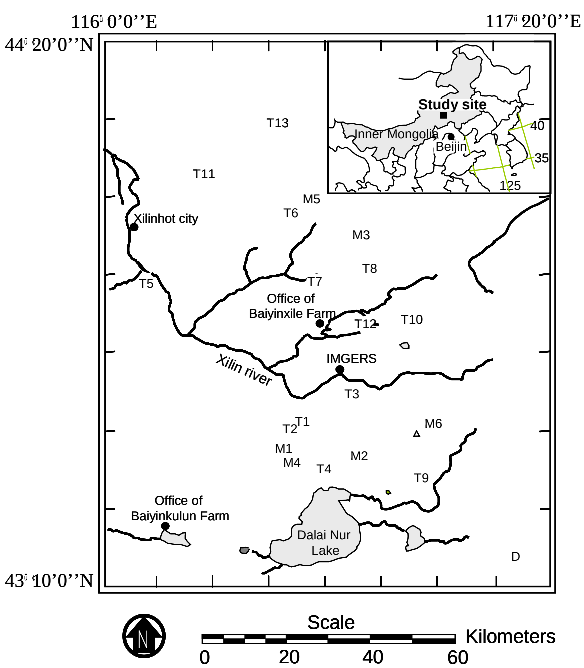

Fig.2 The location of the study area in Xilingol, Inner Mongolia [2].

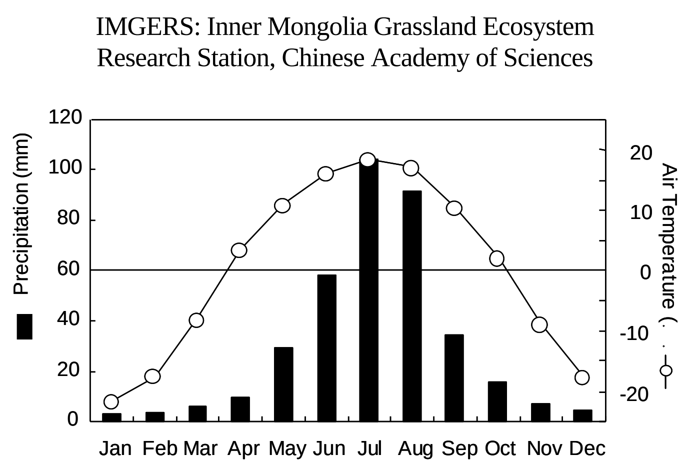

Fig.3 Seasonal mean air temperature , (□, □) and precipitation (mm,■) at IMGERS from 1982-1998) [2].

grassland area is 0.67 SU ha^{-1} including mowed land for winter [3]. Fig.4 shows changes in livestock numbers during the years of 1950-2001 at the Baiyinxile Farm. Total numbers are equivalent to sheep units (SU) where one horse is 6 SU, one cattle is 5 SU, and one goat is 0.8 SU, according to Zhang and Liu [4]. Horses were the most dominant animals in the farm just after its foundation in 1950. Stock numbers increased steeply from 1959 to 1967, and then experienced two sharp declines in 1968 and 1977. After 1983, ownership of the land changed from governmental to private and since then, stock numbers have been increasing. Total livestock increased to 252,700 SU in December 2001. Thus, the average grazing intensity of the total grassland area, which is calculated by simply dividing total livestock number by grassland area, was 0.67 SU/ha, including mowed land.

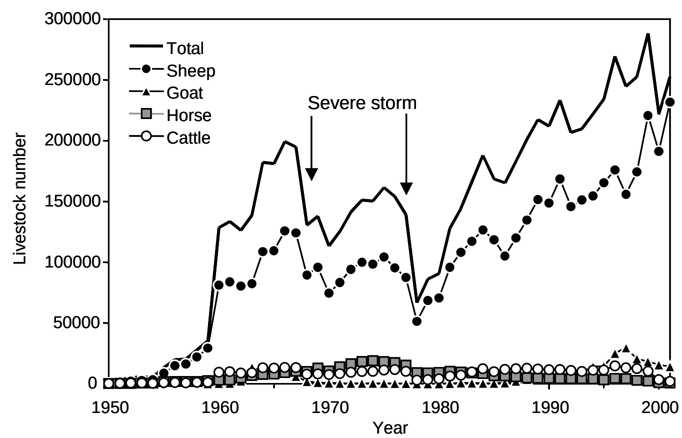

Fig.4 Changes in livestock numbers during the years of 1950-2001 at Baiyinxile livestock farm. Total numbers are equivalent to sheep units (SU) where one horse is 6 SU, one cattle is 5 SU, and one goat is 0.8SU, according to Zhang and Liu [4].

2.1.2 Satellite data and field sampling

NOAA/AVHRR Local Area Coverage (LAC) data, which was collected by the Satellite Image Database System (SIDaB) were used in this research. They are obtained by the Computer Center for Agriculture, Forestry & Fisheries Research, MAFF in Tsukuba. LAC has a nominal resolution of 1.1 km for nadir views. The 10-day Maximum Value Composite (MVC) method [5] was used to create a single cloud-free NDVI image with a minimal atmospheric effect and a sun-surface sensor angular effect.

The location of sampling sites were determined in advance using land cover maps derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images acquired on 10 July 2000. For the areas of sampling, relatively homogeneous vegetation sites spreading over at least 3km by 3km were identified in steppe grassland. Of the 20 ground sites; 6 meadow steppes M, 13 typical steppes T and 1 desert steppe D were selected in the Xilingol steppe area (107km x 130km, Fig.2). Field measurements of total aboveground biomass (AB) were carried out from 26 July to 20 August 2001, during the peak season of biomass. Sampling data from 178 points were collected using 9 (1m x 1m) quadrats for each of the 20 sites (8 points in 2 sites because of the limitation of stand shape). As shown in Fig.5, the quadrats were set up at 700m intervals using GPS, and all plant material was removed at ground level and weighed after oven dry.

In 2002, ten study sites including four in meadow steppe and six in typical steppe were established on grasslands in the Xilingol steppe. Field measurements were carried out 3 times from end of June to early August on each of the 10 sites to determine the mean standing crop of live and dead vegetation and the mean total crude protein (CP) concentration. The CP of the plant was determined by the Kjeldahl method (method 7.015) [7]. The standing CP was computed as the dry weight of the live biomass by multiplied by the % CP of live biomass. MODIS EVI was used for the analysis.

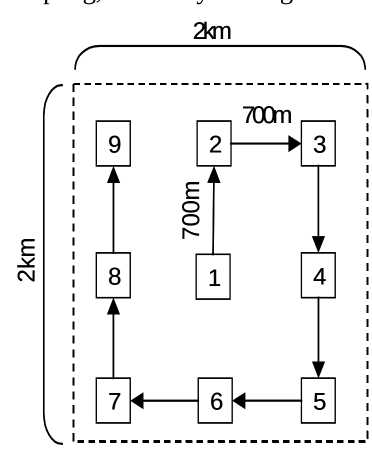

Fig.5 Sampling points for estimating aboveground biomass (AB) from NOAA data using GPS [4].

2.2 Measurement of grazing behavior at private farm (Experiment 2)

2.2.1 Grazing field

The private farm experimental area was established in 2002, on the Xilingol steppe of the Xilin River basin. The experimental area lies in the southern part of the Baiyinxile Livestock Farm, between 43°36'- 43°39'N latitude and between 116°36'- 116°41'E longitude. It covers a total area of approximately 20 km^2. Five families live in the experiment area and of these, three families stock sheep and goats. There was a total of 1,721 SU. During grazing between sunrise and sunset, the three herds of sheep grazed freely in areas restricted by fencing and farmer control. Livestock were kept overnight in fences near the farmhouses.

2.2.2 Measurement of animal behavior

The experiment of grazing behavior was carried out over five days from August 4 to 8, 2002. Four sheep from each of the three farms were fitted with handy-type GPS (PCQ-HGR3S, Sony) using hand-made belts, as shown in Fig.6. Information regarding sheep positioning from the GPS was collected every 1 min during grazing. The data-logger, which can store up to 12,600 points, was attached to the GPS. Recorded data included date, time, traveling distance, land speed, and traveling direction. Using geographic information system (GIS) software (ArcGIS 8.1, ESRI), the coordinate were converted from a latitude/longitude form to a universal transverse Mercator (UTM) form to facilitate algebraic derivation of distances and areas. In 2004, recorder for jaw movement was fitted to one of GPS sheep to count bite number.

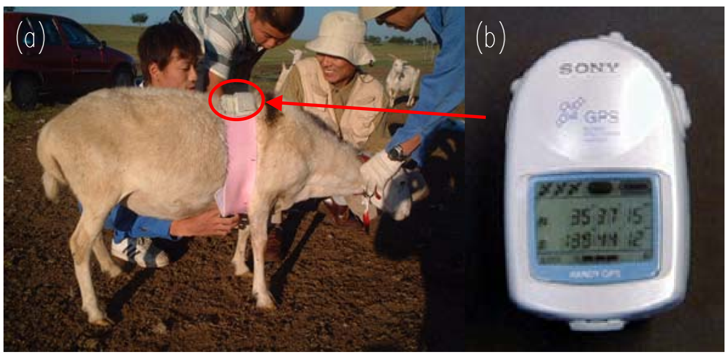

Fig.6 Fitting the GPS receiver (b) onto the sheep (a) using a hand-made belt [3].

3. Results and discussion

3.1 Biomass and standing CP in Baiyinxile Farm

3.1.1 Estimation of aboveground biomass

There are some distinctive differences in the floristic composition between meadow and typical steppes. As shown in Fig.7, a strong positive correlation was found between NOAA/NDVI and aboveground biomass (AB). (r=0.62, P<0.01) for all 20 sampling sites and can be obtained by the equation (1).

AB= 450.91NDVI – 58.99 (1)

When data is separated into two different vegetation types, meadow and typical steppes, a simple correlation between NDVI and AB can be obtained as shown in equations (2) for meadow (ABm), and (3) for typical (ABt) steppes.

ABm= 342.34NDVI +32.59 (2)

ABt= 135.49NDVI + 21.76 (3)

In this study, desert steppe was omitted, because it was a special case sampled at only one site. In this case, for meadow steppe, r=0.47 and for typical steppe, r=0.60 (<0.05) are showing a lower positive correlation compared

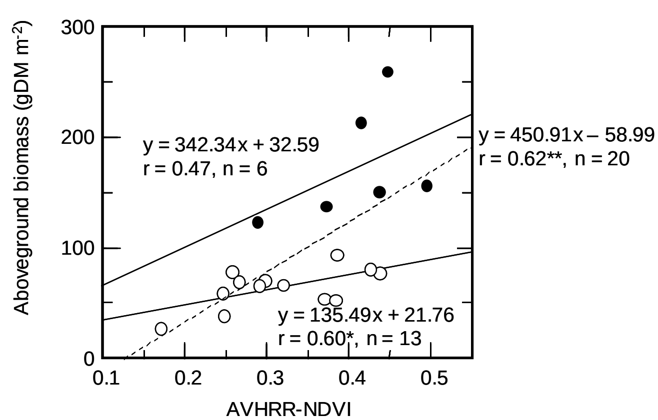

Fig.7 Simple correlation between NOAA/NDVI and AB of meadow steppe (□) , typical steppe(●), and the mixed (dotted line) [2].

to equation (1). However, the mean error rates are about 20% lower than the case using equation (1). If so, vegetation classification by satellite data becomes necessary in order to realize these processes. Although, Xiao et al. [8] classified steppe grassland using Landsat TM image, there have not been established from the NOAA data due to its low ground resolution. However, it might be possible by using NOAA data characterized by frequent observation and low spatial resolution, that a novel vegetation classification can be achieved.

Using equation (1), spatial dispersion in AB was calculated and shown in Fig.8. In this area, AB generally increased from 210 kg ha^{-1} in the west to 2,470 kg ha^{-1} in the east. The average AB for whole study area of Xilingol steppe (13,910 km^2) was estimated as 1,189 kg ha^{-1}. This result was about 40 % lower than Xiao et al. [9] obtained by analyzing Landsat TM in the Xilingol steppe (29,440 km^2) in 1987. The amount they estimated was 1,780 kg/ha. Even though there are spatial differences between NOAA (1.1 km) and Landsat TM (30m), the discrepancies in the target area, the clear tendency of average AB to decrease suggested that the degradation and desertification trend is expanding.

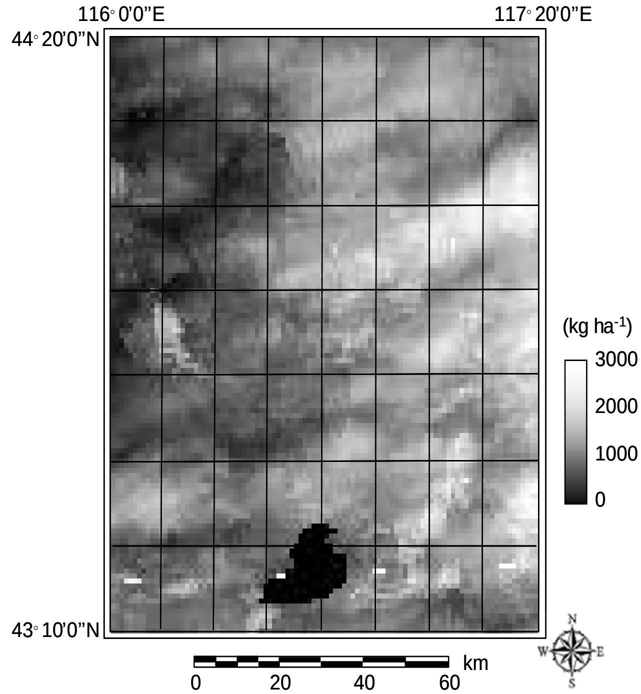

Fig.8 Distribution map of estimated AB by NDVI at mid summer 2001 over the Xilingol steppe [2].

3.1.2 Regression model for estimating forage quantity and quality

The relationships between MODIS/NDVI and live, and total biomass, crude protein (CP) concentration, and the standing CP are shown in Fig.9. Both the CP concentration and the standing CP have two deficit (n=28). In the regression analysis, the EVI explained 80 % (p<0.001) of the statistical variation in the live biomass, 77 % (p<0.001) of the variance in the total biomass, 11 % (p<0.05) of the variance in the CP concentration, and 74 % (p<0.001) of the variance in the standing CP. Kawamura et al. [2] reported that the

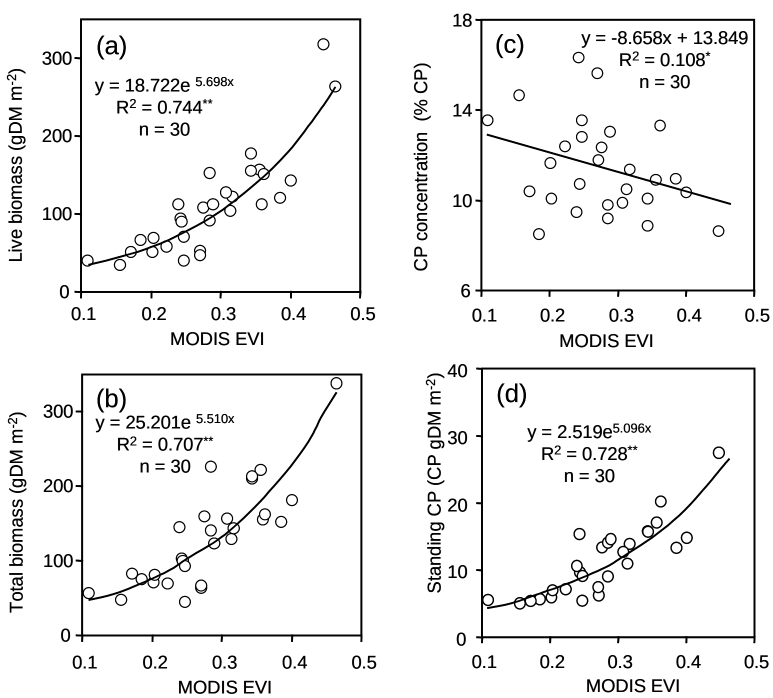

Fig.9 Scatter plots of (a) live biomass, (b) total biomass, (c) crude protein (CP) concentration, and (d) standing CP versus EVI from MODIS imagery. *p<0.05, **p<0.01, ***p<0.001 [6].

AVHRR/NDVI accounted 36 % of the variation in the total biomass in 2001 in the same study area of Inner Mongolia. From additional comparison, we tested the AVHRR/NDVI in 2002 using this study data and same method. As the result, the AVHRR/NDVI explained 62 % (p<0.001) of the variation in the live biomass, 65 % (p< 0.001) in the total biomass, 19 % (p<0.05) in the CP concentration, and 62 % (p<0.001) in the standing CP. From these results, MODIS/EVI appear to be superior to AVHRR/NDVI for estimating forage quantity, presumably because the MODIS red channel is much narrower (620-670 nm) and therefore more highly chlorophyll-sensitive than that of the AVHRR (580-680 nm).

Fig.10 shows seasonal changes of grassland resources estimated from MODIS in different grazing pressures. Both live biomass and standing CP showed increases during spring and summer, and decrease from late August. Contrarily, CP concentration decreased during the first half of the season, and increased from late August, ranging between 9 and 14 %.

Using regression equation, the distribution map of standing CP was created from MODID/EVI (Fig.11). The average standing CD (±S.D.) was 14.1±6.4 gCP m^{-2}. In general, the CP concentration decreases throughout the growing season with increasing fiber concentration. Furthermore, it is well known that increasing grazing intensity tends to increase CP concentration in grasslands, decreasing fiber concentration in available and residual forages [11].

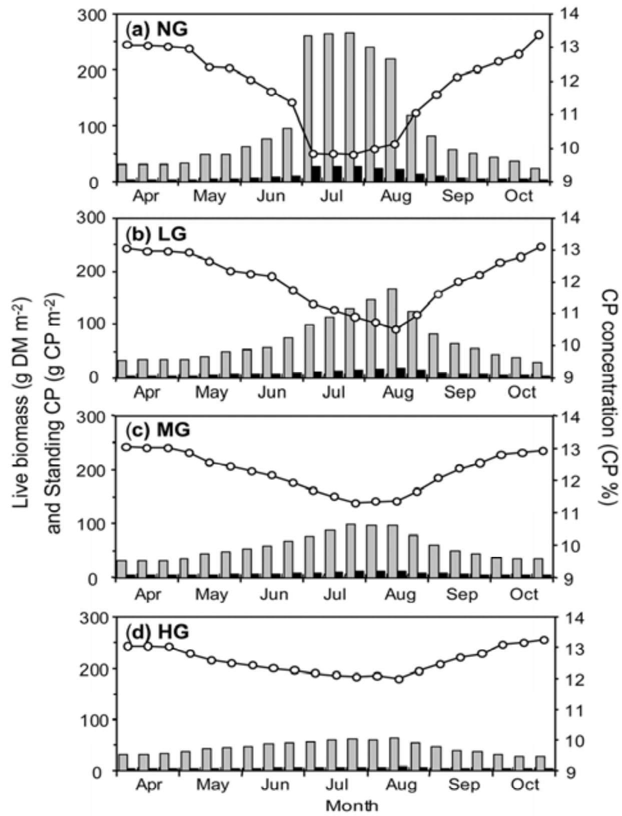

Fig.10 Seasonal changes for estimated live biomass (■, gDM m^{-2}), standing CP (■, gDM m^{-2}), CP concentration (○, %) , in (a) NG:non-grazed grassland, (b) LG:lightly grazing grassland, (c) MG:intermediately grazed grassland, (d) HG:heavily grazed grassland [12].

3.2 Quantifying grazing intensities using GIS, GPS and remote sensing data

3.2.1 Daily tracking of sheep grazing

Over 5-day study period, each GPS obtained 12,464 integrated positions. In total, 52 of the 60 GPS (4 sheep x 3 groups x 5 days) functioned well, delivering on average 86.7 % of the possible data. The locations of each sheep group between August 4 and 8 in 2002 are shown in Fig.12. Utilization distribution in the experiment in the experimental area was split into two areas, northern areas used by group 3 and southern areas mainly used by groups 1 and 2. All sheep arrived at the Xilin River to drink water once a day. During the 5-day study period, mean daily traveling distances (±S.D.) were 11.2±1.1, 11.2±1.3, and 12.6±2.4 km for groups 1, 2 and 3, respectively. It is possible to suggest that group 3 traveled longer distance than other 2 groups because the grazing area of group 3 is located furthest away from the Xilin River.

3.2.2 Quantification of grazing intensity

To quantify grazing pressure, a grazing distribution map of the sheep flocks was created above mentioned method. The experimental area (4km x 5km) was divided into 250m x 250m cells (6.25ha each) to adjust MODIS pixel size using GIS software (ArcGIS 8.3, ESRI). Grazing intensity in each cell was calculated by the numbers of sheep that visited during the test period. Finally, the relationship between estimated grazing intensity and MODIS/NDVI that presents steppe biomass was

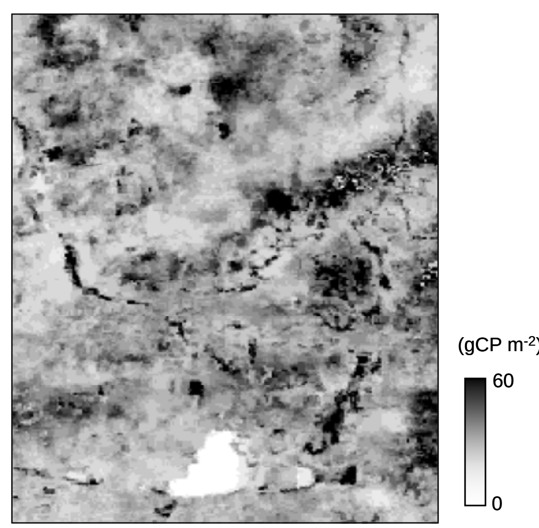

Fig.11 Calculated distribution map of standing CP obtained from enhanced vegetation index in early August 2002 [10].

demonstrated (Fig.13). The NDVI showed a negative correlation to the grazing intensity.

From these results, MODIS data combined with GIS and GPS was able to estimate plant biomass and grazing intensity. This system should provide useful information to assist range managers assess sustainable uses of grasslands.

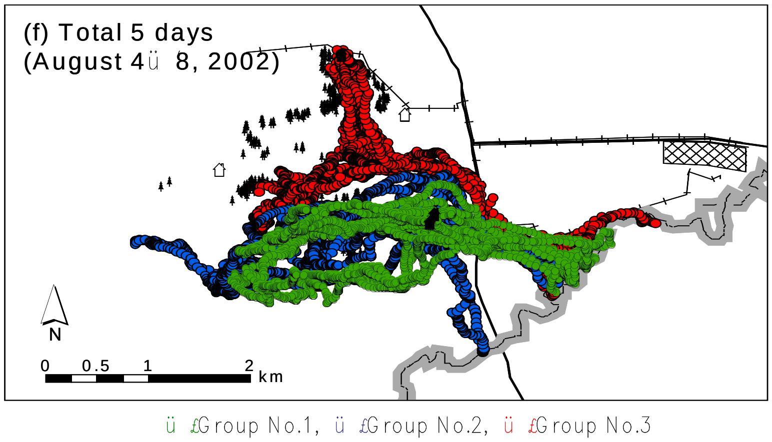

Fig.12 Location of sheep in the experiment area sampled at 1-mn intervals with GPS over 5 days (August 4-8, 2002) [3].

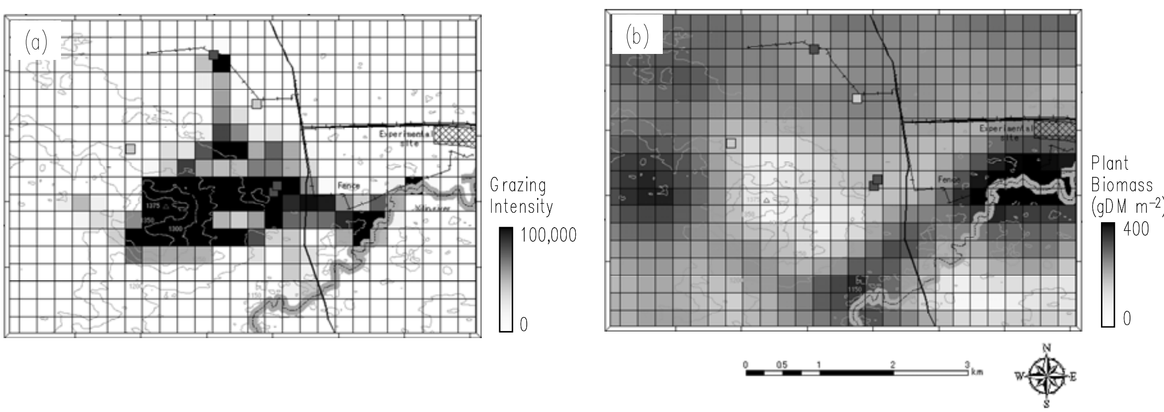

Fig.13 Distribution maps of grazing intensity GI (a), and estimated plant biomass AB (b) during 5 days (August 4-8, 2002). Distribution map of (a), which was calculated using GI=(FxN)/6.25, was showed ranging 0-72.048 and (b) estimated plant biomass AB=20.428exp(4.446NDVI), was showed ranging 95.64-378.70 (g DM m^{-2}) in the experimental area [3].

4. Conclusions

(1) Plant aboveground biomass was estimated using by NOAA/AVHRR and MODIS/EVI data in Xilingol steppe. It revealed that biomass in this region was 1,189 kg ha^{-1}in 2001, which decreased about 40 % compared with that of 14 years ago.

(2) Standing crude protein (CP) and CP concentration had related with MODIS/EVI values. It might be useful information for animal management in grazing grassland. Thus, seasonal changes of grass quantity and quality could be estimated in semi-real time.

(3) Fitting GPS on the back of sheep, traveling trail and distance were measured. On early August, sheep traveled about 11 to 12 km in a day. Combining staying time and visiting frequency, grazing intensity to the area was calculated.

(4) There was negative correlation between plant biomass and grazing intensity.

Such system with the new information technology like remote sensing, GIS, GPS might be powerful tools for the grassland management for determination of carrying capacity of the site for sustainable use and prevention of desertification of steppe.

Acknowledgement

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