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Remote sensing in inventory of high altitude pastures of the eastern Tibetan Plateau

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Abstract: The animal husbandry practised on high altitude pastures of the eastern Tibetan Plateau is based on the use of natural pastures. The livestock consists of yaks, sheep and horses. During the recent decades the number of animals has increased in the Dzoge study area, which is located in the north western part of the Sichuan province at an altitude of 2800-4000 meters. Most of Dzoge is treeless grassland with large peat land areas. The remote sensing and Geographical Information System (GIS) methods combined with the conventional pasture mapping provide a methodology to make a cost effective and reliable inventory of large areas. Providing accurate data about the quality and quantity of pastures and also of the amount of natural forage resources promotes sustainable use of the pastures. Two field trips were made to Dzoge. Random test plots (186) covering the main vegetation types in the research area were selected. The Landsat TM image is the remote sensing data in used this study. The image classification was done in the ERMapper program. The final map producing and the accuracy assessment were performed in the ArcGIS program. The Landsat TM image proved to be a useful data source in the mapping of pastures in the Dzoge area. The main vegetation classes were classified accurately. The estimations of the biomass of different vegetation types were made. Elevation differences were relatively small and the shadows on the slopes did not affect the classification significantly.

Key words: high altitude pastures.

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Introduction

The animal husbandry practised on the eastern Tibetan Plateau is based on the use of the natural pastures. The livestock consist of yaks, sheep and horses. Traditional nomadic animal husbandry has adapted to harsh environmental conditions. In traditional herd management the quality of pastures has always been a matter of concern. Basic pasture rotation from summer to winter pastures is essential for the recovery of the pastures (Manderscheid, 2001). During the last few decades the amount of animals has increased in our study area in Dzoge county (Ao & Shiyi, 1988; Local administration, 2000). In Dzoge the local grassland bureau is concerned about the condition of the pastures. There are signs of overgrazing and pasture degradation. The situation in Dzoge is quite similar to the rest of the western Sichuan province where there have been reports of increasing pressure onpastures by a growing livestock number during recent decades. The fencing of pastures has increased during the last five to ten years (Wu, 1997; 1999). Fencing has been used to separate winter and summer pastures as well as to separate pasture land for individual herders. In the Dzoge some erosion areas have been fenced off from grazing by the local administration.

Remote Sensing and Geographical Information System (GIS) methods combined with conventional pasture mapping provide a methodology to make a cost effective and reliable inventory of large areas. Providing accurate data about the quality and quantity of pastures and also about the amount of natural forage resources promotes a sustainable use of pastures (Price *et al.*, 2001). Reliable remote sensing of pastures requires high quality field material (Colpaert, 1998).

Remote sensing has been used in the study of ungulate pastures since the 1970's. In Alaska and northern Canada it was used in studies of caribou, musk ox and bison pastures (George *et al*., 1977; Adams, 1978; Thompson, 1980; Ferguson 1991; Matthews, 1991; Pearce, 1991). The remote sensing aided pasture inventory method for the study of the reindeer herding area of Finland (115 000 km^2) was developed by the Geography Department of the University of Oulu and the Finnish Game and Fisheries Research Institute (FGFRI) (Colpaert *et al.,* 1995). In the studies of the reindeer pastures in northern Scandinavia satellite data (usually Landsat TM) has proven to be a suitable tool for the pasture mapping of large areas. The studies have contributed valuable knowledge to the decision making and managing of the pasture lands. These studies have been based on extensive amount of field material (Tømmervik & Lauknes, 1987; Colpaert *et al.,* 1995; Kumpula *et al.,* 1997).

Only a few remote sensing and GIS studies on pastures have been conducted on the Tibetan plateau, in Northern China and Mongolia (Ryavec & Veregin, 1997; Rasmussen *et al.,* 1999). Rasmussen *et al.* (1999) discovered that a SPOT satellite image combined with a Digital Elevation Model (DEM) is useful in pasture research in Mongolia. In China there is significant concern about soil and vegetation degradation, erosion and desertification. These phenomena are usually related to the conditions of the pastures. Remote sensing and GIS have been used in many studies in those areas where degradation and erosion are a problem. For example Zhang *et al.*'s. (1996) research conducted in central Tibet where they used remote sensing and GIS successfully in mountain soil erosion mapping. In some cases the cause of degradation has been supplemented by increased grazing and human impact (Sujatha *et al*., 2000; Gao & Zha, 2001; Collado *et al*., 2002).

A major objective of our efforts was to estimate the usability of the Landsat TM 5 images for natural pasture classification on the eastern Tibetan Plateau. Our aim was to distinguish the main pasture types, summer and winter pastures and the intensity of grazing. A further objective was to estimate the biomass on the basis of image classification and field measurements. The research methods used in the Finnish reindeer pasture inventory were adjusted to the local environmental conditions (Kumpula *et al.,* 1997:4-12).

The research area

The study area is located in the county of Dzoge, in the north western part of the Sichuan province (Fig. 1). The area is located on the eastern edge of the Tibetan Plateau at an altitude of 2800 - 4000 meters a.s.l. In the eastern part of Dzoge there are deep valleys with large vertical differences and the treeline is at about 2900 a.s.l. Smooth slopes, wide valleys, treeless grassland with vast peat land areas on the flat plateau are characteristic of most of Dzoge. Altitudinal differences are less than 400 meters. The annual mean temperature is 0.6 °C and in July the average is 10.4 °C. The annual rainfall in the area is about 645 mm per year and most of it occurs between April and October. The winter is long and the grazing animals have to survive with low temperatures, snowstorms and the frost of the pasture grounds. The time for recovery and to fatten the livestock for the winter is about 6 months (Lehmkuhl, 1993; Wu, 1997).

The Dzoge grasslands are divided into high frigid meadows, swamp meadows and alpine shrub meadows. The soil is fertile and produces high-yield herbage with strong renewability and high nutritive value (Wu, 1997). Dzoge is an important part of the north western Sichuan grazing ground and it is one of the five wide pastoral areas in China. Nomadic animal husbandry is the main source of livelihood. The livestock on the grasslands consists of 430 000 yaks, 540 000 sheep and 30 000 horses (Local administration, 2000).

The case study area of the research is located in the western part of Dzoge where the Yellow River makes a 180 degree turn back to the northwest (Fig. 1). It was chosen because there the image was almost cloud free and the main vegetation types of Dzoge county were represented. The area is relatively flat with diverse meadows (Wang *et al*., 2001). There are large areas of fluvial deposits in the Yellow River valley. Sandy deposits like dunes are vulnerable to erosion. Active erosion areas are found in the region (Lehmkuhl, 1993). In this area animal husbandry is the main form of land use, besides which there are some small scale oat (*Avena*) and turnip rape (*Brassica rapa*) fields. There is a sparse road network and a few small villages. Pastures are fenced mainly between the families and partly between villages and some family groups. In many cases the summer and winter pastures are separated by iron fence (Fig. 2).

Fig. 1. The location of the Dzoge county.

Fig. 2. A fence dividing winter and summer pastures near the Yellow River. A tall grass meadow is on the left and short grass meadow on the right. These borders are also visible in the Landsat TM 5 image (see Fig. 3).

Methods and material

Field work and data

Two one month field excursions were made in the Dzoge area (in August 2000 and September 2001). The field sampling method used was basically the same as the one used in Finland (Colpaert *et al.*, 1995), although vegetation classes and the pasture type classes were different. Preliminary vegetation classes based on the literature (Wu, 1997) and on the first field trip in the year 2000 were developed further to be used in the second field trip and in the image classification.

Each test site selected and inventoried for the classification represented a homogenous vegetation or land use type. A test site size of at least two hectares (200 m x 200 m) proven to be satisfactory (Kumpula *et al.*, 1997). Smaller areas were not accepted as a class in classification because they are not usually visible in the Landsat TM 5 image. The test sites were selected randomly. The aim was to collect test sites from the main vegetation types and land use patterns in the research area. A total of 185 field sites were inventoried. The vegetation and landuse type and intensity of grazing were estimated from each test site. Intensity was evaluated on the scale little-moderate-heavy according to signs of grazing. Then from each site 5-10 vegetation quadrates (50 cm x 50 cm) were inventoried. Plant species percentage to the lowest possible taxon and bare soil coverage, and the average height of the plants were measured. The locations of test sites were measured with GPS. The average height of plants was also measured in order to differenciate between moderately grazed, heavily grazed and low grazed sites. Digital camera images were taken from each test site and quadrate.

The biomass of the vegetation was measured from 122 test sites. All the plants from one quadrate in each test site were cut and weighed. The biomass values represent the total fresh, above ground grass yield. The area of the quadrate is 0.25 m^2 (0.000 025 ha). For each class, a fresh biomass average was calculated. The biomass estimations were used to indicate the productivity of each pasture type. Altogether, 22 ground control points (GCP) for the image rectification were collected using GPS.

Satellite remote sensing data and image processing

The remote sensing data used in this study was the Landsat TM 5 image acquired on 31st August 1999. The spatial resolution of image is 30 meters. The cloud percentage is 10-15, and totally cloudless images were not available for the growing season (May - August). Cloud conditions on the Tibetan plateau are naturally such that a cloud free Landsat TM 5 image (185 km x 185 km) is almost impossible to obtain. Haas (1992) pointed out that the degree of pasture utilization differences shows best when the acquisition date of the Landsat TM 5 image follows the active growing season.

The ERMapper 6.3 image processing software was used for the image processing. For visual interpretation, different RGB (Red, Green and Blue) combination algorithms were created from different Landsat TM bands. The band combination 2, 3 and 4 which is a green, red and near infrared combination was the most suitable for visualization of the vegetation (Fig. 3). Then the image was rectified into the UTM- coordinate system by using the rectification test sites collected from the field. Rectification was successful with an RMS error of less than 1 (the unit is pixel size, in the case of Landsat TM 5 it is 30 meters).

According to the field data and the visual interpretation of the image, the suitable number of vegetation and landuse classes to be used in the classification was between 12-15. The unsupervised classification with 12 and 15 classes confirmed our suggestion. A higher number of classes leads to the mixing of classes and a lower number of classes was too generalized for our research purposes. The supervised classification of the image used both maximum likelihood and minimum distance methods. The accuracy assessment, the GIS–processing and the final map producing were done in the ArcGIS program (Fig. 4).

Fig. 3. The RGB combination of the Landsat TM 5 image bands 2, 3 and 4 presenting part of the study area. The Yellow River with white sand banks is on the left side of the picture. At the point of arrow is a fence between the winter and summer pasture (see Fig. 2 which is taken from this point). The road from the south to the north is on the right.

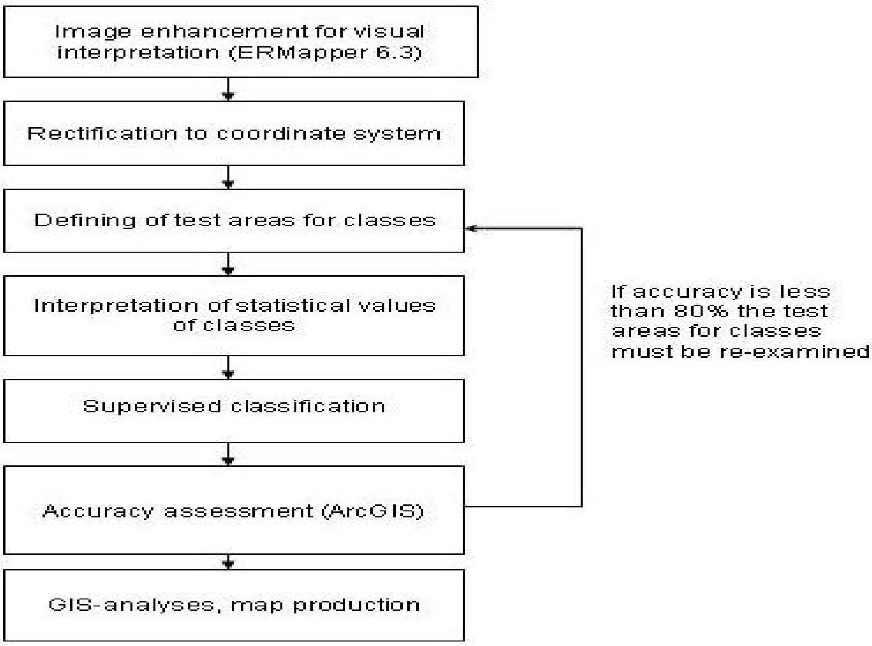

Fig. 4. The image processing procedure.

Results

Pasture type classification

The grasslands of Dzoge were divided into 12 classes in the satellite image classification. Eight classes represented different vegetation types, one class represents sand (erosion areas), two classes water and one clouds (Table 1).

Tall grass meadows are mainly used as winter pastures. Along the Yellow River, the distribution of tall grass meadows is very high. This is the most productive pasture type according to the biomass estimation (Table 1). The most common plant genera are *Polygonum, Potentilla, Kobresia, Carex, Festuca, Gentiana, Ranunculus, Aconitum, Anemone* and *Thalictrum.*

Short grass meadows are summer pasture. The short grass meadows by the Yellow river have been used as summer pastures. This type, in most cases, is the result of grazing; originally this type of meadow has been either tall grass meadow or grass meadow (moist). Bare soil coverage is usually about 20%, but in some cases it can be as high as 30%. This indicates the heavy grazing pressure. There are also other visible signs of grazing and trampling *e.g.* a high amount of yak and sheep trails, and droppings. The biomass on this type is relatively low, but that is the result of grazing that has continued throughout the whole summer (Table 1).

Grass meadow (moist) is usually used during the summer period. The fresh biomass productivity of this type is 3200 kg per hectare. The main plant genera are *Poa, Deschampsia, Stipa, Polygonum, Potentilla, Kobresia, Carex, Festuca, Gentiana, Ranunculus, Anemone* and *Thalictrum.*

Alpine short grass meadow is a typical pasture type on the hills. The biomass productivity is noticeably lower than in the tall grassland (Table 1). The slopes are dry habitats, and the productivity is naturally lower. This type is sensitive to degradation because of the topography and grazing all the year. The main plant genera are *Potentilla, Berberis, Taraxacum* and *Elymus.*

Shrub and grass meadows are usually distributed on slopes and especially on those slopes facing north. This type is used both as summer and winter pasture. The main plant genera are *Potentilla fruticosa, Spirea alpina* and *Spenceria.*

Sedge peatland is a spring and early summer pasture. The main plant genera are *Carex, Kobresia, Potentilla* and *Pedicularis*. Wet peatland is important spring and early summer pasture. The constant depth of water is 5 cm to 30 cm. The main plant genera are *Carex, Kobresia, Pedicularis* and *Juncus.* The biomass of fresh grass is quite high in both peatland type (Table 1).

Dry peatland areas have been dried or there have been some attempts to do so to increase the productivity. Drainage has not given the desired result, rather it has led to the degradation of these areas. This type as pasture land is not valuable. If the biomass of this type is compared to sedge peatland or wet peatland which might have been the earlier type before the drying, the productivity is drastically lower.

The sand class consists of active sand dune areas, erosion areas and sand bars in the Yellow River. In some places, re-activated sand dunes have been fenced off to prevent the grazing, and in some locations there are some willows (*Salix* sp.) planted to help the re-vegetation process. The biomass productivity of this type is extremely low (Table 1).

The biomass of the fresh above ground vegetation varied between 200 and 6000 kg per hectare in the different pasture types (Table 1). The tall grass meadow is the most productive pasture type. In the five pasture types productivity was over 2000 kg per hectare. The short grass meadow low values are due to the grazing which had been practised throughout the whole summer when the August and October field measurements were made.

The accuracy of the classification

The first stage in accuracy interpretation was to calculate in ERMapper 6.3 the statistics for each class. By examining the distance between the means of the classe values it is possible to make preliminary estimations of the accuracy of the following classification. From earlier studies we have found that when the distance between classes values is lower than three, in classification it will cause considerable mixing between these two classes (Table 2).

In the final accuracy assessment, we used 134 test sites collected from the field as reference data. Also 5 sites from the RGB- combination image were chosen to present clouds, and 5 sites water (total number 144). The classification of the Landsat TM image was compared to the classification done at each test site in the field. Each site was checked with a 3 * 3 pixel grid which means 90 m x 90 m in the nature. In this way we avoided the possible position errors that are due to the GPS- accuracy and the rectification of the satellite image. Classification was estimated as accurate when a minimum of 5 out of 9 pixel matched the classification done in the field. Only by checking each site individually could a reliable estimation of accuracy be conducted. This procedure allows the use of other supporting checking methods, like the comparison of the achieved classification to the RGB- composition, field data, the digital photographs taken in the field etc.

The final accuracy of the classification was 84% (Table 3). The lowest accuracy value of 73% is in the alpine short grass meadow class. According to distance between mean values (Table 2), this was to be expected.

Table 1. Characteristics of the pasture classification classes.

Class	Herb. %	Grass %	Sedge %	Shrubs %	Plant height cm	Bare ground %	Biomass kg/hec.	Biomass plots (nr)	Grazing time
Tall grass meadow	40	30 - 40	> 10	> 10	> 30	< 5	6000	30	Winter
Shortgrass meadow	35	40	10	> 10	10 - 20	20 - 40	800	19	Summer
Grassmeadow (moist)	20 - 30	> 40	20	< 15	25	< 20	3200	19	Summer
Alpine short grass mead.	< 30	30 - 40	30 - 40	< 20	10 - 20	20 - 30	1400	8	Winter
Shrub- and grass mead.	30	30	< 5	> 30	20 - 35	20 - 35	2400	11	Winter/ summer
Sedge peatland	< 20	< 5	35 - 85	0	15 - 30	< 10	2800	17	Spring
Wet peatland	5 - 15	< 5	40 - 85	0	30 - 40	0	2800	4	Spring
Dried peatland	10	1	30	0	2 - 10	40 - 50	400	5	Spring
Sand	5	5	0	1	2 - 15	> 75	200	9	-
Cloud	-	-	-	-	-	-	-	-	-
Water	-	-	-	-	-	-	-	-	-

Table 2. The distance between the means of the classes. When the value is higher than 3, the mixture of classes diminishes.

Class	Cloud	Dried peatl.	River	Sedge peatl.	Grassmead (moist)	Lake	Sand	Alp. short grass m.	Shortgrass m.	Shrub and grass m.	Tall grass mead.	Wet peatl.
Cloud	0,0	14,0	33,1	28,6	28,1	31,7	6,7	21,4	11,5	28,2	28,9	24,0
Dried peatland	14,0	0,0	15,5	5,9	5,3	11,0	10,2	5,6	6,4	4,4	7,6	13,2
River	33,1	15,5	0,0	12,1	20,1	6,3	30,4	27,7	26,8	20,9	26,5	9,8
Sedge peat.	28,6	5,9	12,1	0,0	5,1	12,1	21,2	9,9	11,3	5,5	8,3	14,2
Grassmeadow (moist)	28,1	5,3	20,1	5,1	0,0	16,5	19,4	5,6	8,2	3,3	3,2	18,6
Lake	31,7	11,0	6,3	12,1	16,5	0,0	24,9	20,3	19,6	16,5	21,7	15,6
Sand	6,7	10,2	30,4	21,2	19,4	24,9	0,0	13,9	6,3	18,9	20,2	23,8
Alp. short grass	21,4	5,6	27,7	9,9	5,6	20,3	13,9	0,0	4,1	5,0	6,3	22,2
Shortgrass meadow	11,5	6,4	26,8	11,3	8,2	19,6	6,3	4,1	0,0	7,8	8,6	19,7
Shrub and grass m.	28,2	4,4	20,9	5,5	3,3	16,5	18,9	5,0	7,8	0,0	7,3	19,7
Tall grass meadow	28,9	7,6	26,5	8,3	3,2	21,7	20,2	6,3	8,6	7,3	0,0	21,7
Wet peatl.	24,0	13,2	9,8	14,2	18,6	15,6	23,8	22,2	19,7	19,7	21,7	0,0

Discussion

The Landsat TM 5 images proved to be a useful data source in the mapping of pastures of the Dzoge area. The spatial coverage of the Landsat TM images (185 km x 185 km) is suitable for eastern Tibet conditions The resolution of the Landsat TM 5 (30 m) allows the use of a certain number of classes so that the main vegetation types can be classified accurately. If more detailed pasture classification is desired the use of higher resolution satellite images is required. These would be for example, the IKONOS-2 (4 m resolution) and the Quickbird-2 (2.6 meter resolution) satellites, the spatial coverage of which is about 10 km x 10 km. In the study of large areas the use of these small scale images would be very expensive and the size of data would increase considerably. The limiting factor in the use of the Landsat TM is the availability of cloud free images from the region and from the growing season period.

Misclassifications were caused for several reasons. Cumuli clouds were classified correctly, but on the edge of the clouds there were some pixels classified as sand, which was not correct. This was because the pixels on the edge of a cloud had a quite similar spectral reflection as the actual sand areas. On the other hand, in sand areas there were no pixels classified as clouds. The second problem connected to the clouds was their shadows. The shadows affect the reflection of the vegetation in the image. The vegetation *e.g.* the pasture type that was in the shadow was always misclassified. In the darkest shadows, dry grasslands were classified as water. In some cases the shadows caused by the topography resulted in misclassification. There were for example, some steep North West oriented slopes that were in the shade. The misclassifications caused by the topography were, however, a minor problem in this area because of the low relief.

Altogether the pasture classes used differentiated from each other relatively clearly. The spectral similarity between the alpine short grass meadow type and the short grass meadow type caused misclassification between these two classes. If the data had been divided into even more exact vegetation types there would have been more misclassifications between the classes. A more detailed vegetation type division is not possible with the Landsat TM 5 image.

The fresh biomass values of the pasture types can be used as an indicator of grazing pressure. On the other hand, all vegetation types are different and some produce less than others, even without grazing. In those test sites where the biomass was very low, there were also signs of heavy grazing pressure. For example, a lot of yak and sheep trails, a high amount of bare soil coverage and visibly grazed vegetation. On the other hand when the biomass was very high there were few signs of grazing, and usually those test sites were fenced off to be used in winter. On some of the test sites where the biomass values were very low, the amount of unpalatable plant species (*e.g. Ligularia virgaurea*) was higher than on the low grazed test sites.

The fresh biomass values were connected to the yearly use of pasture. The field work was carried out at the end of the summer when the animals had been grazing on the pastures for three to four months. This, of course, affected the biomass values of certain pasture types. On the other hand, the winter pastures had been recovering for the whole summer, and at the time of the field work they were in their best shape.

Winter and summer pastures were well distinguishable on the satellite image in some cases. Especially in those cases where these two pasture types were separated by a fence into summer and winter pastures *e.g.* grazing intensity were detectable. In these cases the differences were clearly visible also in the field. The differentiation of summer and winter pastures *e.g.* intensity of grazing from the Landsat TM 5 image would be much more difficult without fences. The boundary between these pasture units is less drastic in nature than it is with clear boundaries like fences. To detect winter and summer pastures from the Landsat TM 5 image requires basic information about the pasture using system from the study area. Also this emphasizes the importance of field work.

In China, land degradation is a serious problem. The amount of degraded areas has been increasing. At the same time, the degradation degree has been increasing (Li *et al*., 2001). In this study, we noticed that the condition of the pastures in the Dzoge county was not alarming although there were some sites which were noticeably overgrazed or degraded. The proportion of sand or seriously eroded areas was not significant.

The local nomadic herders who are managing the pastures are concerned about the condition of their pastures. The most important management method is pasture rotation, which gives time for the pastures to recover from grazing. The increasing use of the fencing is changing the traditional system. The local administrators in the grassland bureau also have their concerns for the pastures. The erosion areas are fenced off from grazing, the suitable number of animals is estimated in each region etc., although there is pressure to increase the number of animals due to free trade and the opening of the markets.

Table 3. Classification accuracy. User's accuracy describes the percentage of the pixels that are classified into a certain class representing the same class also in the field data. Producer's accuracy describes the amount of the field points that were also classified also into a certain class (Longley *et al.*, 2001: 326-327).

Class	Tallgrass meadow	Shortgrass meadow	Grass meadow (moist)	Alpine shortgrass meadoe	Shrub and grass meadow	Sedge peatland	Wet peatland	Dried peatland	Sand	Cloud	Water	Total	User's accuracy %
Tall grass meadow	**23**	1	2									26	88
Shortgrass meadow	1	**16**		3								20	80
Grassmeadow (moist)	1	1	**15**		1							18	83
Alpine short grass mead.		3	1	**11**								15	73
Shrub- and grass mead.		1		1	**10**							12	83
Sedge peatland					1	**16**	3					20	80
Wet peatl.							**6**					6	100
Dried peatl.							1	**4**				5	80
Sand									**13**			13	100
Cloud										**5**		5	100
Water											**5**	5	100
Total	25	22	17	15	12	16	10	4	13	5	5	**144**	
Producer's accuracy %	92	72	88	73	83	100	60	100	100	100	100		**84**

Conclusions

Remote sensing is a suitable tool for pasture inventory in the eastern Tibetan Plateau. It can be used when collecting background information about the pastures and can be further processed by the GIS. The information and results produced are usable for planning and management purposes of the grasslands on the eastern Tibetan plateau.

The Landsat TM 5 images proved to be a useful data source in the mapping of pastures of the Dzoge area. The Landsat TM image used in this study was taken in late August, at a time when the summer pastures were already heavily grazed. This was visible both in the field and in the satellite image. Winter and summer pastures were distinguishable from the image. Further information on different pasture type characteristics was established by estimating the biomass of fresh green grass.

The accuracy of the classification was 84%. Clouds and their shadows affected negatively the classification results. Because the topography of the area is quite smooth the shadows on the hill slopes did not affect the classification significantly.

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