11 ENGLISH SHORT VERSION

Titel: Forest management in Mongolia

Application of remote sensing and GIS for sustainable forest management and capacity building

Taking as an example the Khan Khentii Special Protected Area (KKSPA)

1. Current status of forest management and remote sensing in Mongolia

Mongolia is situated in northern central Asia, bordering the Peoples Republic of China in the South and the Russian Federation in the North, and has a size of 1.56 million km^2. The present population of Mongolia is approx. 2.5 million (NSO 2005), of which over a million live in the capital city, Ulaanbaatar. In the year 2000 the area of closed forest in Mongolia was estimated at 12.9 million ha (TSOGTBAATAR 2002), which is equivalent to 8% of the country's total territory. The dominant tree species are the Siberian larch (*Larix sibirica*), approx. 60%, pines (*Pinus silvestris* and *Pinus sibirica*), under 10%, and deciduous trees, especially birch (*Betula platyphylla*), approximately 10% (FMPC 1997). Due to its low population density – 1.5 persons per km^2 – Mongolia has the highest amount of forest per capita in Asia. The natural forests are mainly located in the northern *Aimags* (regional administrative unit), and are part of the Siberian taiga forests, which form the largest forest ecosystem in the world. Since the Kyoto agreement of 1997, numerous authors, who recognise the importance of forest resources for the conservation of biodiversity, and for maintaining the global climate (e.g. ROSENQUIST et al. 2003, KRANKINA et al. 2004), have stressed the urgency of quantifying and mapping the temporal changes within this ecosystem.

In spite of an extensive scientific effort to compile information on the natural resources of Mongolia, mainly based on the joint Russian-Mongolian expeditions that took place up to the early 1980s, the application of remote sensing and GIS has been under-utilized. The digital data available is out of date on the whole, and is based on country-wide mapping in the form of small-scale maps (usually on a scale of 1: 1.000.000) unsuitable for detailed regional or locally based research projects. An exception to this are the remote sensing technologies applied since the late 1980s by the *Information and Computer Centre* (ICC) of the *Ministry of Nature and Environment* (MNE) in the fields of environmental monitoring and hazard risk assessment (e.g. forest and steppe fires, dust storms, snow coverage), which are based on medium resolution NOAA-AVHRR satellite data.

The present forest inventory is based on Russian methodologies from the 1950's, modified to suit Mongolian conditions. The last national forest inventory was in 1975, and has not been repeated since. The former *Forest Management Center* in Ulaanbaatar (FMPC) has conducted local forest inventories since 1958, with an annual size of approx. 800.000 ha, establishing forest management maps on *soum*-level (local administrative unit) which should be updated every 10 years. However in reality time intervals can stretch to more than 20 years, resulting in temporally inhomogeneous spatial information between 1988 and 2005. These forest inventories are based on taxation, and objective sampling is seldom performed. As a geometric base, hand-coloured analogue maps are used, developed from panchromatic aerial photographs taken during the Mongolian-Russian cooperation between 1966 and 1982, which contain wide geometric distortions. As a result, the information available on forest resources and levels of exploitation is inconsistent and open to broad interpretation, making it difficult to obtain a reliable picture of the current "state-of-the-forest" in Mongolia.

Since the beginning of the 1990s, the transition to a market economy in Mongolia has resulted in socio-economic dislocation, causing an increase in poverty and putting natural resources under increased pressure. It has been estimated that about 1.6 million ha of forest were lost between the 1950s and the 1980s, and a further 660.000 ha from 1990 to 2000 (ERDENECHULUUN 2006). The main causes of the degradation of the forests in many parts of the country, which is especially severe in proximity to the capital, Ulaanbaatar, and along the trans-Mongolian railway, are illegal deforestation by people collecting wood for fuel, open mining activities, the unsustainable use of non timber products (NTP) and forest fires (*see chapter 3*). The continuous degradation of forest resources and the legal forest industry is exacerbated by inappropriate management structures due to the continuous erosion and decentralization of the central forest administration, and the reduction of forest areas zoned for utilization to 1.2 million hectares (Over 90% of the total forest area is designated as protected, or protected zone forests, according to the forestry law of 1995), which is far too little to support a viable and legal wood-based industry.

There are numerous indications that the forestry sector in Mongolia is rapidly approaching a crisis for which the country seems largely unprepared (CRISP et al. 2004, ERDENECHULUUN 2006). Instead of dealing constructively with the primary problem of unsustainable resource exploitation, the government has been focusing on peripheral issues such as the outdated forest inventory system described, fire and pest control and reforestation attempts that have no ecological or economic base. A good example of this is the so-called *Green Belt Eco-Strip National Program* started in 2005 with the aim of replanting *Saxaul* vegetation (bush-like type of vegetation) over an area of 150.000 ha in the Gobi region over the next 30 years.

The forestry law of 1995, together with the „national forest policy program“(NFP) of 1998 designed to run until 2010, provide a framework for sustainable forest management. The NFP suggests institutional reforms in the forestry sector such as the improvement of educational facilities (“capacity building”) and strategic measures to implement GIS and remote sensing techniques for the quantification and evaluation of current forest resources, as well as the modification of forest inventory methods in selected model areas. However, a lack of financial and personnel resources, and unclear institutional responsibilities, are hindering the long-term regeneration of forest resources. These problems are enhanced by the already mentioned unavailability of reliable, geometrically accurate and updated forest management maps. Also, up to now, no maps of appropriate scales showing the delineation of forest utilization zones have existed. Both levels of information are urgently needed for decision-making in natural resource management on regional and local levels. They are also needed for assigning concessions for forest utilization, either to private enterprises or to the participatory community based forestry projects that have been implemented with the support of international donors since the late 1990s.

2. Capacity building in cooperation with GTZ, Ulaanbaatar

This thesis emphasises the scope for applying remote sensing and GIS-techniques within capacity building programmes, with the aim of initiating and supporting ecologically sustainable forest operations in selected pilot areas in the western and eastern buffer zone o*f the Khan Khentii Special Protected Area* (KKSPA). The practically oriented project work processes were developed between 2001 and 2004 as part of the former GTZ projects, “*Nature Conservation and Buffer Zone Development Project*” (NCBDP), and the current *“Protection and sustainable utilization of natural resources”* (SBNR) project, in cooperation with forestry specialists from the former *Forest Management Project Center* (FMPC) of the *Ministry of Nature and Environment* (MNE) in Ulaanbaatar, as well as private companies and students from the National University of Mongolia (NUM). The main objective has been to increase general interest in the new remote sensing and GIS methodologies and their practical application in order to modernize forest inventory mapping projects, and develop a methodological concept suitable for the institutional and organisational framework in Mongolia. The training was carried out using a multidisciplinary and participative approach, following the principle of “*learning by doing*”, to ensure positive medium and long-term results. The collecting and processing of data within the GIS was implemented primarily by the participating institutions and persons, which allowed local professionalism to be strengthened and integrated.

3. Methodology

A wide variety of sensors are currently available marked by different spectral characteristics, geometric resolutions and periodicity. Methods of measurement, interpretation, classification and mapping of remotely sensed data have undergone fundamental changes over the past 20 years, due to accelerating developments in computer technology. Today, remote sensing combined with terrestrial inventories and GIS-technologies provide the tools for a “rapid appraisal” of natural resources. The knowledge of the type, location, extent, quality and accessibility of forest types, and of current land use patterns, is urgently needed to establish a consistent and realistic data base for the rational planning of economic development and sustainable rural development in Mongolia. In the initial phase of the project, priority was given to providing a suitable geometrically correct “base map” for mapping purposes and the transfer of spatial information. Emphasis was placed on the utilization of freely available satellite imagery, such as Landsat ETM+ or SRTM (*Shuttle Radar Topography Mission*), to ensure the long-term sustainability of the project because of its low cost.

The application of GIS and RS-based methodologies for the quantitative and qualitative mapping of forest resources in the pilot areas have covered various methods of visual and digital interpretation of multispectral and multi-temporal Landsat satellite images, GPS based documentation, navigation and orientation in the field, as well as GPS-based terrestrial forest inventories. In 2001 and 2002 the main focus was on the visual interpretation of multi-temporal Landsat ETM+ satellite images, using winter as well as late summer acquisition dates. The main objective during this first phase of orientation was to provide an overview of existing forest resources in the western buffer zone of the KKSPA, and to use the knowledge of forest experts to establish a visual interpretation key. For this purpose pan-sharpened and geometrically corrected Landsat image maps (SIM) were produced, that included reduced topographical information taken from topographical maps with a scale of 1: 50.000. The map series contained detailed maps with a scale of 1: 50.000, and overview maps with a scale of 1: 100.000 and 1: 200.000.

For both winter and summer SIM the false natural colour band combination 5 (MIR), 4 (NIR), 3 (Red) was chosen, as this combination showed the highest spectral information for forest type delineation and the identification of damaged areas caused by forest fires or pests. The multi-temporal approach was chosen to distinguish between pine (*Pinus sibirica*, *Pinus sylvestris*) and larch vegetation (*Larix sibirica*), based on the high near infrared reflection (NIR) of the pine trees during the winter months. Landsat images taken in late summer (end of August to mid September) allowed an additional classification of deciduous tree types, such as birch (*Betula platyphylla*), due to the discolouring of foliage resulting in a bluish reflection. The identification of Siberian pine (*Pinus sibirica*), which grows in altitudes higher than 1700m above sea level, was only possible using additional height information taken from available topographic maps with a scale of 1: 50.000, or using the knowledge of the interpreters. The overall accuracy of image interpretation was limited due to the inhomogeneous composition of forest types, and the relatively low pixel resolution of 30 m (MS), which resulted in mixed pixels. In addition the interpretability was reduced on north-facing slopes, particularly in winter, because of the distinct shadow effects caused by low sun altitudes. A modification of these effects is possible by applying image processing methods such as topographic normalization using high resolution DEM data. The available SRTM imagery with a spatial resolution of 90 m showed no significant improvement. As a result the visual interpretation key contained 14 classes (dominant tree species, mixed tree stands and other land cover categories such as open mining areas, steppe vegetation and agricultural areas). The visual interpretation was flanked by field investigations (“ground truthing”) using hand-held GPS receivers to establish detailed photo-documentations within the research areas, and GIS training sessions at the FMPC. The results of the visual interpretation were digitalized on a scale of 1: 50.000 covering a total of 48 map sheets for the western buffer zone of the KKSPA, and merged using GIS-based boundary operations such as “*edge matching*” and the aggregation of forest polygons to obtain a map sheet free database.

In the years 2003 and 2004 the methodologies were modified for project areas in the eastern buffer zone of the KKSPA through the integration of traditional forest inventory maps with a scale of 1: 50 000. Although largely outdated and geometrically distorted, these analogue maps offer important additional thematic and statistical reference data on tree type, tree height, circumference and age class which can be used to discriminate additional coniferous and deciduous tree types such as spruce (*Abies sibirica)*, fir (*Picea obovata)* or poplar (*Populus tremula*), and to enhance the results of visual image interpretation. For the integrated use within a GIS, the existing boundaries of the forest inventory maps, which are organized into main and sub-compartments, were geometrically corrected and digitally reinterpreted using Landsat satellite imagery. Additional “ground truthing” was performed on the base of extensive terrestrial forest inventories in the pilot areas.

The objectives of the training measures were to develop technical capacity for the standardisation and quality control of forest inventory methods, and to support the privatisation of the forestry sector. The reinterpreted forest inventory maps provided the spatial information necessary to perform a systematic and pre-stratified forest inventory based on polygons, which were stratified according to their dominant tree type and age class. Training involved the accurate GPS-based location of sample points and navigation and orientation in the field, as well as mapping methods for the collection of site-related attributes, such as slope and aspect as well as tree-related data for the calculation of forest stand volumes e.g. tree height, circumference and distance. The sample points were converted to GIS layers with attribute information contained in a relational database system. Both spatial levels of information can be used as reference information to support and verify a more detailed digital image interpretation and, when used in conjunction, can provide a suitable basis for tree volume estimation, leading to the provision of sustainable forest management and utilization concepts.

Post processing included a pixel based digital classification of the pilot areas based on maximum likelihood algorithms using a hierarchical approach. The knowledge- based classification combined multiple information layers such as spectral indices (NDVI and other ratios to produce forest masks), reference data taken from the visual interpretation results and inventory samples, as well as the additional integration of topographic parameters derived from SRTM data. A very high correlation between the spatial distribution of tree species and primary topographic parameters such as elevation, aspect and topographic wetness (TWI) could be determined. The hierarchical approach produced a good classification accuracy of over 70% within the pilot areas.

4. Fire Management in Mongolia

In addition to the described methodologies to support forest resource management based on GIS and remote sensing, this thesis gives an overview of current fire management in Mongolia, and discusses the potential of satellite imagery to support strategic fire management based on MODIS (*Moderate Imaging Spectroradiometer*) global daily active fire products with a spatial resolution of 1 km^2. The results show the temporal and spatial distribution of active forest fires for the years 2000 to 2005 in the northern Aimags: *Selenge*, *Töv* and *Hentiy* surrounding the KKSPA, and were compared with NOAA-AVHRR data which the ICC has been receiving since 1987.

4.1 Natural and anthropogenic causes

Every landscape has a specific fire regime, and the adaptation methods of vegetation types are diverse. In the Taiga- und Sub-taiga forests, fire is a natural ecological factor which, in conjunction with climatic and edaphic factors, influences species composition and the spatial distribution of forest ecosystems. (Goldammer 2002, Mühlenberg et al. 2003). The main natural cause of forest fires in the Taiga ecosystems during the summer months is lightning (Chuluunbaatar 1998). Aggressive fire prevention methods in these ecosystems can cause an ecological unbalance, not only influencing species composition but also causing an increase in pest damage, and leading to higher levels of fire susceptibility. Since the transition to a market economy at the beginning of the 1990's, the duration, frequency and intensity of forest fires has grown signi-ficantly. 90% of the forest fires are man-made, and are linked to new livelihood strategies for income generation such as illegal deforestation, and the intensive and unsustainable utilization of non-timber products (NTP), such as collecting deer antlers, pine nuts, herbs and berries in the spring and autumn months. The main causes of forest fires are uncontrolled campfires, smoking, bullets (hunting activities) and sparks from tractor exhausts. Fire hazards are additionally triggered by droughts as experienced in 1996 and 1997, as well as in 2002. The seasonal outbreak of fires correlates with socio-economic activities resulting in a main fire season from March to June (80% of forest fires), and a smaller fire season during the autumn months from September to October (5 to 8% of forest fires) (*Goldammer* 2002). Forest fires are one of the main causes of the drastic degradation of Mongolian forest resources over the past 15 years. From 1990 to 1999 forest fires occurred over an area of 7.3 mio. ha (56%). The highest ever-recorded volume of forest fires was 2.3 mio. ha in 1996 and 2.6 mio. ha in 1997.

Fires have been monitored since 1987 in Mongolia at the ICC (National Remote Sensing Centre) in Ulaanbaatar using NOAA-AVHRR data. The mapping of forest fires has shown a continuous increase since 1990 resulting in extreme fire hazards in 1996 (10.7 Mio. ha) and 1997 (12.4 Mio. ha). Between 1990 and 1999, a total area of 47 mio. ha was recorded, of which 7.3 mio. ha were forest fires (15% of the total forest area). In addition to the socio-economic activities described, the fire activity was also certainly increased to an extreme by the airborne fire suppression activities of the Aerial Patrol Service (APS) during socialist times, which resulted in the accumulation of highly inflammable fuels. An effective management of forest fires in Mongolia through ecologically based fire prevention methods, and the establishment of an early warning system, is being restricted by the lack of decentralized communication facilities, education, qualified manpower and fire fighting equipment, as well as the inaccessibility to many areas. These factors show the importance of satellite-based fire detection visualizing spatial patterns of fire occurrence, which could be used as a basis for implementing ecologically sustainable fire prevention methods, and accurately mapping scorched areas to quantify the actual loss of forest resources.

4.2 MODIS based fire monitoring

The first satellite sensor specifically developed to assess fires is MODIS (*Moderate Resolution Imaging Spectroradiometer*) on board the TERRA-EOS Satellite (NASA), which was launched in 1999 (Kaufmann et al.1998). The advantages of MODIS are the free availability, the high temporal resolution (1 – 2 days), the large coverage (swath of 2330 km) which enables environmental analysis on a supra-regional level, and the number of spectral bands (a total of 36 bands covering VNIR, MIR and TIR). These aspects compensate for the low spatial resolution of 1 km^2. In addition, a large variety of derived products such as Active Fires (1 km resolution), NDVI and LST (Land Surface Temperature) with a resolution of 250 – 500 m, or Land Cover products with a resolution of 1 km, are freely available. For effective fire management a higher temporal resolution than 1 day is necessary. Therefore the MODIS team initialized a MODIS "*Rapid Response System*" in the year 2001 which provides information on active fires in "*Real Near Time*" (interval of 2 – 4 hours after image recording (Justice et al. 2002). These products are available online for selected areas (*http://rapidfire.sci.gsfc.nasa.gov*). Another alternative for interactively accessing fire information is to use the „*Web Fire Mapper"(http://maps.geog.umd.edu/*) developed by the University of Maryland (USA).

To monitor the temporal and spatial characteristics of fire occurrence in the project areas, freely available MODIS active fire products, accessible through the DAAC (*Distributed Active Archive Center*) of NASA in a hierarchical data format (HDF-EOS), were processed. The high temporal resolution of the fire products (daily or as 8-day composites) allows the generation of fire statistics on a daily, monthly or annual basis. The statistics show a significant main fire period starting in March (day 089 of the year) which declines in the summer months due to more intensive rainfall, and a second fire season in autumn starting at the end of August and lasting until the middle of October (day 181 of the year). The highest fire activity was recorded in the years 2000 and 2002 with a total of 2979 pixel in 2000 and 2353 pixel in 2002. This accounts for approx. 200.000 ha of scorched land in these two years. The years 2001, 2003, 2004 and 2005 show a decrease of fire activity with a mean scorched area of approx. 70.000 ha. The spatial overlay of all fire occurrences shows a distinct concentration of fire activity within areas of high socio-economic activity, especially along the main development axis in the proximity of the transmongolian railway, starting in Ulaanbaatar and continuing northwards towards the town of *Darchan,* and up to the Russian border towards *Sukhbaatar* (main town of *Selenge* Aimag). A second concentration of fires can be found in the northwest of the *Hentiy* aimag as a result of its higher continental climate and its lower annual rainfall than in eastern areas. In total 780.000 ha of forest and steppe fires were recorded, of which 50% were forest fires.

The MODIS active fire product was validated on the basis of the available high resolution Landsat ETM+ imagery, which clearly depicted the burnt scars in the chosen band combination 5,4,3 (RGB). Despite the low accuracy of 1 km (MODIS) the relative geometric accuracy of the active fire pixels is high. A comparison between MODIS active fire products and the results of fire mapping performed by the ICC in Ulaanbaatar using NOAA-AVHRR data shows significant differences. In the five-year period 2000-2005, a total of 620.000 ha of forest fires were interpreted using AVHRR data, nearly twice the amount of recorded forest fires using MODIS. The AVHRR-interpretations show similar spatial patterns but seem on the whole over-interpreted. According to Stocks et al (2001) the MODIS sensor is considerably better at detecting smaller and more detailed fires. The exact quantification of scorched areas can best be achieved using the methods of multi-temporal change detection, which were carried out within selected areas of the KKSPA buffer zone using the 1989 additional Landsat TM data, and based on the evaluation of MODIS NDVI or EVI-products. The additional integration of SRTM data and the derived topographical parameters, such as slope, elevation and aspect, allows the modeling of fire risk and fire propagation.

5. Outlook

The forests of Mongolia have great importance for the sustainable development of the country. Because of the high amount of forest per capita, and the failure of industry and trade to boost the Mongolian economy, international development cooperation must enhance the multifunctional use of the forest areas, and emphasise the importance of their role in Mongolia's socio-economic development. To this end new ecologically and economically sustainable forest management concepts must be developed. Since the early 1980s the need of developing countries for the assistance of environmental organisations in managing their environmental resources has been emphasised in German and international development programmes. But since the 1990s this need is qualitatively different and presents a new challenge, due to the propagation of modern information management systems in the form of GIS. Many of the solutions have been exceedingly cost intensive and specialized, resulting in a dependence on highly technological knowledge and specialised manpower for system maintenance, and have therefore often been referred to as "inappropriate technologies". Sustainable development projects with an emphasis on satellite-mapping require a functioning institutional infrastructure for utilising the satellite remote sensing data, and considerable expertise in thematic mapping, remote sensing, cartography and GIS. The exact qualitative and quantitative mapping of existing forest resources is a necessary first step in establishing a functioning planning culture, and providing a basis for rural development concepts. For this purpose a continuous update of spatial information as well as the continuous and sustainable development of qualified manpower are necessary. Compared to many developing countries, Mongolia brings a large amount of accumulated local knowledge to dealing with the newer information technologies. Nevertheless the effective management of existing environmental information is hindered by a lack of transparency and cooperation between national institutions in respect to data exchange and information on data availability and quality. Some positive developments in the area of resource management, however, should be mentioned. They are the planned configuration of an extensive Environmental Information System (EIS) at the MNE with the organisational support of the Dutch government, and the NUM-ITC-UNESCO programme, in existence since 2005, for developing scientific expertise in the fields of GIS and remote sensing at the NUM in Ulaanbaatar.

The described methods and work process within GTZ-activities have demonstrated the potential of GIS and remote sensing for developing new spatial information levels for sustainable forest management. So far capacity building is at a first orientation or preparatory stage, which to permit a realistic assessment of the practicality of operational follow-ups, and the provision of a sustainable basis for detailed planning, should be continued by new projects under individual responsibility. Future activities should not only modernise mapping techniques, but also lead to the formation of an efficient forest management and information system (FIS). Due to the lack of communication and infrastructure, as well as to the vast distances and low population density, a centralized data management system will be necessary, which in the long term must be accessible to all administrative levels. Until then alternatives, especially in the form of user-specific products such as suitable thematic maps, need to be provided on regional and local levels to support communication, decentralization and rational and comprehensive decision-making in the implementation of environmental laws, as well as the allocation of forestry concessions and support for reforestation projects. Despite continuous institutional reorganisation, the former FMPC is now re-established as the *Forest and Water Research Center* (FWRC), and motivation is high to continue applying GIS and remote sensing to improve the institutional technical frame conditions. Future capacity building programmes should concentrate on the construction of the GIS database, and the form and content of a FIS, preferably in cooperation with the ICC to utilize their knowledge in the field of remote sensing for environmental risk assessment. A basic condition for the success of future capacity building programmes should be to mediate not only specialized technical skills but also a general understanding of geographic phenomena und spatial coherences.

Considering the current socio-economic situation in Mongolia, a constant increase of anthropogenically caused environmental problems can be expected in the future. Unsustainable pasture management and overgrazing, uncontrolled deforestation as well as forest and steppe fires, in conjunction with climatic extremes such as severe droughts, will lead to a further degradation of Mongolia’s natural resources. Therefore effective environmental observation, the monitoring of temporal changes and the development of mitigation strategies will become more and more important. In the years to come a new MODIS receiving station is planned at the MNE. The research undertaken on fire monitoring has shown the feasibility and quality of near-real-time fire mapping. This methodology should be continued in future especially during the main fire seasons, and could contribute to the development of ecologically sustainable fire management concepts.

The sustainable use and protection of natural resources should concentrate not only on their scientific documentation, but require holistic and anticipatory data management to support the privatisation and pluralisation of institutional structures within the rather conservative forestry sector and the other environmental agencies.