A Comparison of Low Cost Satellite Imagery for Pastoral Planning Projects in Central Asia

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Abstract—*We discuss some of the advantages and disadvantages of satellite data for rangeland planning in Central Asia, with our emphasis being on sources of low cost or free data. The availability and use the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) as a base map and tool for coordinated natural resource planning in Central Asia is discussed in detail. Base maps are important in planning projects to help in identifying vegetation types, water sources, areas of concern (for example degraded sites), structures, for description of past and current uses, and the communication and development of a new plan. The ASTER data are currently free and use a non-continuous acquisition method so not all areas of the globe receive the same repeat coverage. ASTER data were found to have high coverage over Central Asia and "usable images," defined as growing season images and with ≤ 15 percent cloud cover, were found for 93 percent of points sampled in Central Asia. We compare the ASTER reflectance product with two other moderate resolution data sources, Landsat ETM+ and MODIS (250 m). This paper will benefit development agencies and natural resource managers in Central Asia that may not be aware of the advantage and disadvantages of different remote sensed data or sources of data.*

Keywords: *Landsat ETM+, MODIS, ASTER, Xinjiang, Co-management, coordinated planning, resource planning.*

Introduction

The development of natural resource management plans, stressing multiple-uses and values and developed with herders and government officials, have been stressed in several papers in this proceedings (Fernandez-Gimenez; Reading and others; Sheehy and others; Schmidt). We certainly concur in the importance of coordinated resource planning. In China, Mongolia and Uzbekistan we initiated natural resource plans with pastoralists for development organizations as a means for helping conserve biological and cultural resources. In the development of coordinated resource plans, a base map is a necessity for communication and planning. These base maps can be as simple as a drawn map showing key resources to as detailed as Geographic Information Systems showing detailed planning information with aerial photographs as the base map. In general, resource information for natural resource planning in Central Asia is often very limited and/or not easily available, even for the development of base maps. For example, we have found that it is difficult to obtain topographic maps or aerial photographs because of cost and/or security concerns. In one instance we had security personnel confiscate topography maps and in other instances topographic maps were restricted to in country use. When topographic maps have been available, scales were usually greater than 1:100,000, a scale not conducive to effective base maps.

We have used low cost satellite images (such as Landsat ETM+) for the development of base maps for spatially locating resources, for communication of areas of concern to pastoralists and government officials, and for describing historical use. We have found that herders easily "read" moderate resolution images such as Landsat Enhanced Thematic Mapper plus (ETM+) images (fig. 1). Satellite data have been available worldwide

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Figure 1—Mongolian herders identifying various resources using a Landsat ETM+ scene in Gobi Gurvan Saikhan National Park.

for several decades, but often the costs of image data at scales for development of base maps has been too costly and often difficult to obtain. For example, high-resolution satellite data such as the Systeme Pour l'Observation de la Terre (SPOT) or Ikonos may necessitate several scenes for large planning areas required for semi-nomadic groups making price prohibitive in many instances. We have also found that development agencies and natural resource managers in Central Asia are often not aware of the advantage and disadvantages of different remote sensed data or sources of data. There have been many papers reviewing or describing uses of satellite images for natural resource work (Cohen and others 2003; Nicholson and others 1998; Pickup, 1998; Zhou and others 2001) and a comparison of sensors (Chavez and Bowell, 1988; Chavez and others 1991; Cohen and others 2003; Yuhas and Goetz, 1993); however, in this paper we concentrate on the potential use, advantages and disadvantages and availability of free or low cost moderate resolution data products for pastoral planning projects in Central Asia. Our primary data analyses is an examination of the availability of a relatively new sensor, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), that provides data at a higher resolution (15 m in visible and near — IR bands) than LANDSAT and is currently free to the public.

The ASTER sensor was launched in conjunction with the Moderate Resolution Imaging Spectroradiometer (MODIS) as part of NASA's Earth Observing System (EOS) program in December 1999. While ASTER was launched primarily to obtain better understanding of the interactions between the biosphere, hydrosphere, lithosphere and atmosphere, MODIS was designed to improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere (http://modis.gsfc.nasa.gov/about/index.html). The ETM+ sensor, which is the most recent addition to the Landsat project that began in 1972, was also launched in 1999. Enhanced Thematic Mapper plus data were designed to facilitate applications in agriculture, geology, forestry, regional planning, education, mapping, and global change research (http://landsat.usgs.gov/).

We explore the availability of ASTER data for Central Asia as these data sources do not employ a continuous data acquisition strategy. We compare an ASTER NDVI to Landsat ETM+ and MODIS for an area we had developed a resource planning project in Fuyun County, Xinjiang Uygur Autonomous Region, Peoples Republic of China and discuss the uses of these three sources of information.

Methods

ASTER image availability was determined for 165 random geographic points in Central Asia by searching the EOS Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/). ASTER, unlike other satellite data sources, does not employ a continuous data acquisition strategy and thus coverage in Central Asia was unknown. The 165 points included 20 points in each of Mongolia, Kazakhstan, Kyrgz Republic, Uzbekistan, Afghanistan, Turkmenistan, and Tajikistan and 25 points in western China (Xinjiang, Gansu, and Qinghai Provinces) to determine frequency of coverage and mean coverage by country. Points were selected by using a random numbers table to select latitude and longitude. Our search period was from April 1, 2000 to November 1, 2003. We also determined "usable images" as those within the growing season (April 1 to October 31) and with ≤ 15 percent cloud cover.

Spatial and temporal coverage of ASTER images was determined for the growing season (April 1 to October 31, 2000-2003) for a 26,000 km^2 project search site in Fuyun County, Xinjiang Province, China. Fuyun County varies from 600 m to 3600 m in elevation and annual precipitation averages 315 mm in the high mountains to 110 mm in desert areas. Maximum and minimum recorded temperatures are 43.5 °C and –51 °C. The vegetation varies from desert to grassland to forest as elevation increases. The vegetation of the Altai Mountains is predominately forest taiga, mountain grasslands, alpine meadows, and mountain meadows. In 2002, we used Landsat ETM+ for a pastoral planning project in this area and were aware of vegetation and topographic characteristics of this area. Any ASTER image intersecting or included within the study area was included as an available image.

We processed scenes of ASTER, MODIS, and Landsat ETM+ as a Normalized Difference Vegetation Index (NDVI) for the study area to illustrate differences and similarities. The NDVI was computed for ASTER and ETM+ data as (NIR – RED)/(NIR + RED) where RED and NIR are the spectral response in the red and near – infrared wavelengths, respectively. The ASTER Sensor is equipped with 14 spectral channels but for this study, we focused on NDVI computed from the visible and near – IR bands. For visible and NIR channels, ASTER has a spatial resolution of 15 meters while ETM+ has a resolution of 30 meters and both sensors measure radiance in the identical RED wavelength (0.63 – 0.69 µm) and nearly identical NIR bands (0.78 – 0.86 and 0.75 – 0.79 µm for ASTER and ETM+ respectively) (http://landsat.usgs.gov/). In contrast, MODIS offers 36 spectral channels ranging from visible to mid-infrared, with spatial resolutions at 250 meters (bands 1 and 2) 500 meters (bands 3 – 7) and 1000 meters (8 – 36) (Justice and others 1998). The 250 meter RED and NIR bands of MODIS are positioned between 0.62 – 0.67 and 0.84 and 0.87 μm respectively (http://modis.gsfc.nasa.gov/). Another unique feature of MODIS is the production of twelve land products grouped as radiation budget variables, ecosystem variables and land cover variables (Justice and others 1998). Fortunately, NDVI is one of the land products offered by the MODIS product suite. Though we had to compute NDVI for ASTER and ETM+, we used the standard NDVI from MODIS for comparison.

Results

We located 1419 total ASTER images and 622 "usable" images (during growing season and cloud cover ≤ 15 percent) for the 165 random geographic points (table 1). The mean number of total images/point varied from a high of 11.45 in Mongolia to a low of 7.05 for Kazakhstan (range of 2 to 19). The usable images varied from a high of 4.75/point in Uzbekistan to a low of 2.4/point in western China (range of 0 to 12). The lack of usable images was generally associated with cloud cover greater than 15 percent. Only 6.7 percent of random points had no usable images available.

Table 1—Mean number of available ASTER images and "usable" growing season images for 165 random geographic points in Central Asia.

Country or Area	Mean Available Images/Point	Growing Season Images with ≤15 Percent Cloud Cover
Mongolia[1]	11.45	3.50
Kazakhstan	7.05	3.75
Kyrgz Republic	8.65	2.65
Uzbekistan	8.80	4.75
Tajikistan	7.95	3.00
Turkmenistan	7.30	4.70
Afghanistan	7.85	5.40
Western China	9.52	2.40
Mean	8.57	3.77

[1] A point in Mongolia (106.11E and 46.15N) had 83 images available and 53 usable images (growing season and ≤15 percent cloud cover). We considered this an outlier and not included in our analyses. We believe this is a Japanese study site where researchers had requested additional coverage.

A comparison of spatial and temporal coverage of growing season ASTER images for 26,000 km^2 area in Fuyun County, China showed high temporal and spatial coverage between years (fig. 2). The number of growing season images varied from a high of 72 in 2001 to a low of four images in 2002. The number of available growing season images with low cloud cover (≤15 percent) varied from 23 images in 2001 to four images in 2002. Spatial coverage of growing season and low cloud cover images included 95 percent of the study area in 2001, but only 12 percent of the area in 2002.

An ASTER NDVI of the Fuyun area was processed and compared to Landsat ETM+ and MODIS data for the study area (fig. 3). A quantitative comparison was not appropriate because data sources are from different dates and different resolutions (table 2). However, a visual comparison illustrates similar NDVI patterns across this variable landscape (fig. 3). This is especially true for linear or contrasting features. For example, the relatively long and straight riparian areas of the Ertix River are clearly visible in all three sources of imagery. In addition, heavily vegetated areas near barren regions appear in sharp contrast regardless of the source of imagery.

Discussion

Our primary objective was to determine the potential availability of ASTER images for pastoral planning projects. We found a mean of 8.7 images available and 3.8 usable images (growing season with cloud cover <15 percent). Obviously, the number of low cloud cover images will be associated with climate and dates of ASTER data acquisition are not continuous. As ASTER data are free, and relatively easy to process, it is a ready source of information for developing base maps and for communication of information in developing natural resource plans in Central Asia.

Our secondary objective was to compare low cost moderate resolution satellite images for pastoral planning projects

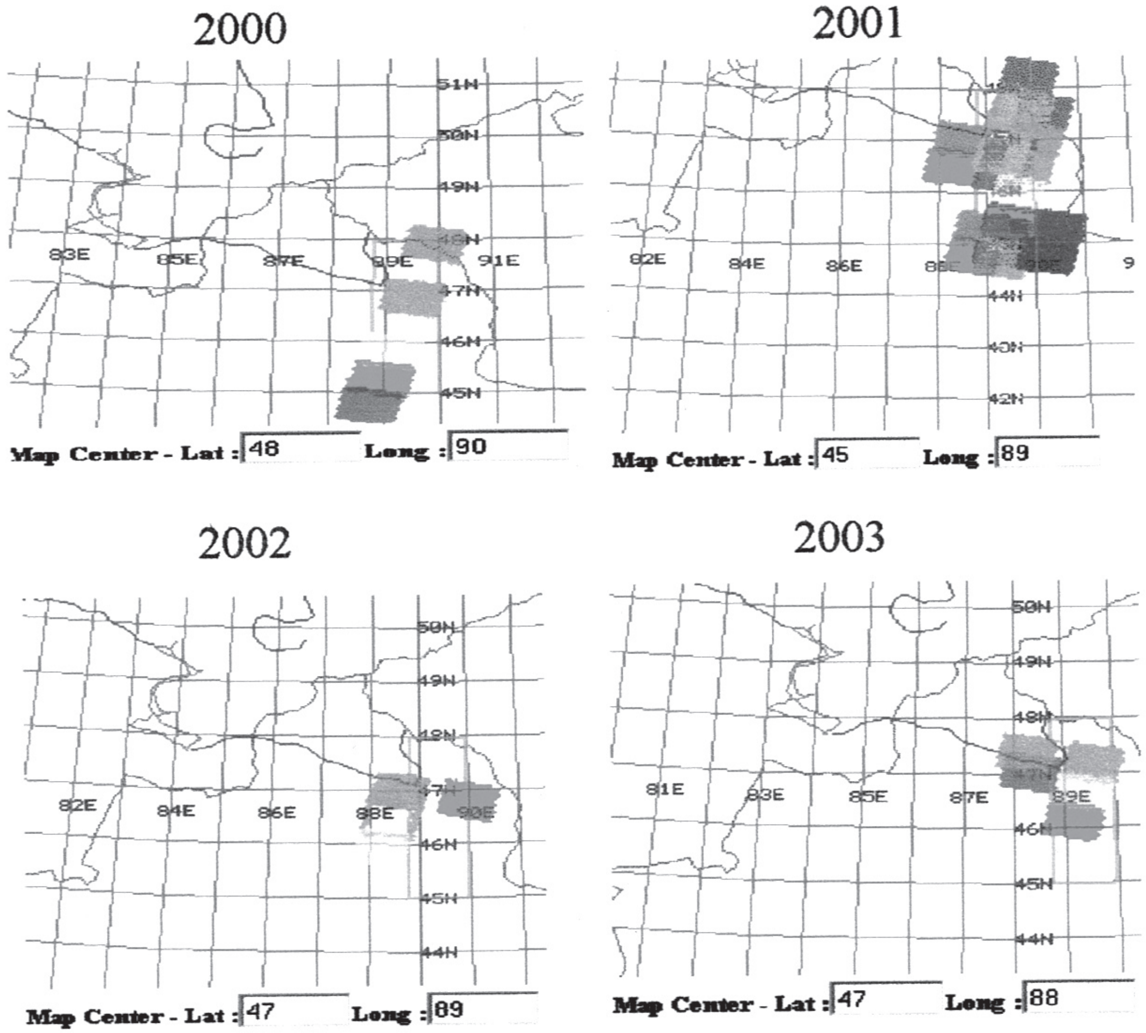

Figure 2—Temporal and spatial coverage of ASTER data (April 1 to October 31) for Fuyun project area, Xinjiang Uygur Autonomous Region, Peoples Republic of China.

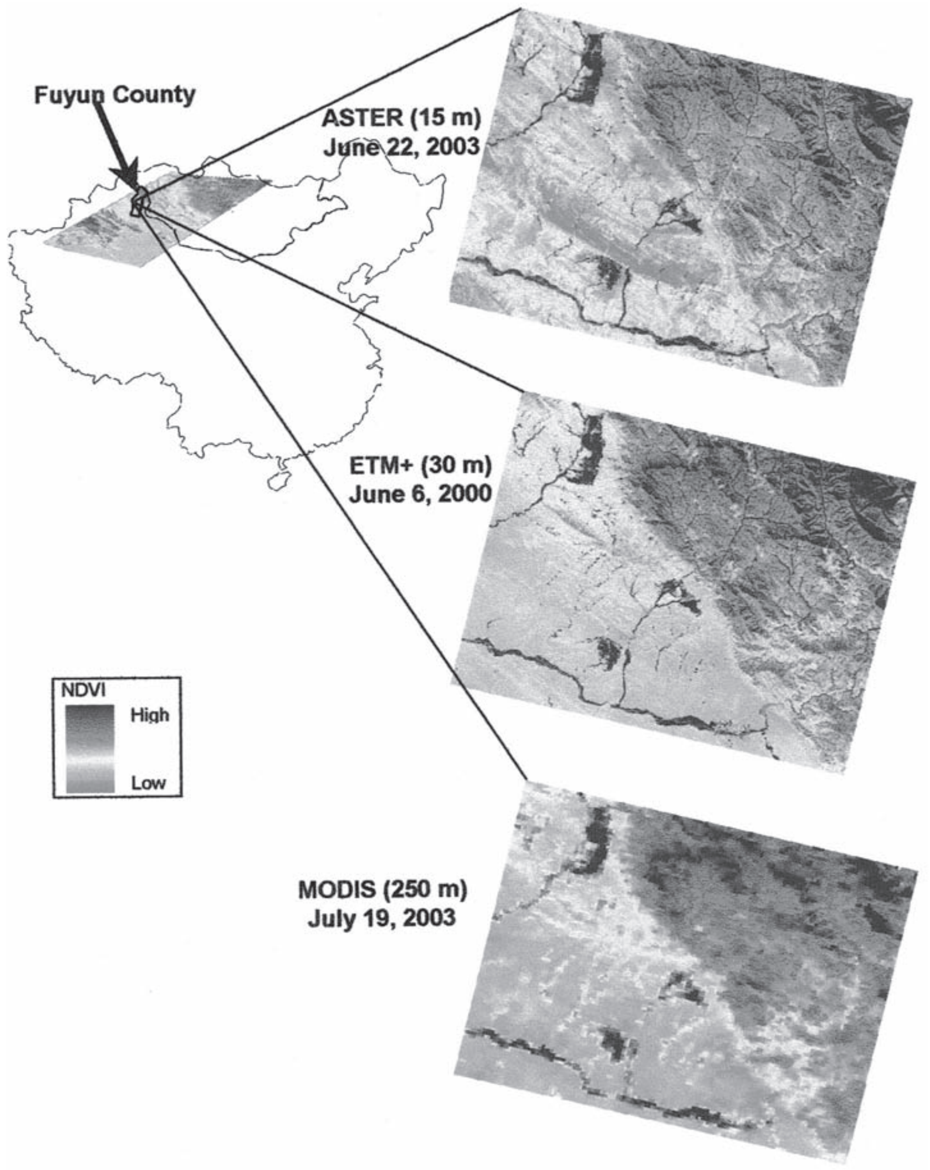

Figure 3—Study area, Fuyun County, showing MODIS scene coverage over portions of China and Mongolia. MODIS, ASTER and ETM+ NDVI's are illustrated for a subset of Fuyun County, Xinjiang Uygur Autonomous Region, Peoples Republic of China. The Normalized Difference Vegetation Index (NDVI) was computed as (NIR – RED)/(NIR + RED) where RED and NIR are the spectral response in the red and near – infrared wavelengths respectively.

Table 2—Spatial coverage of Fuyun County, Xinjiang Uighur Autonomous Region study area (88.73, 89.94E, 48.02, 45.01N) during April 1 and October 31 in 2000-2003.

Year	Total ASTER Images Available	Low Cloud Cover ASTER Images (≤15 percent cloud cover)
2000	16	5
2001	72	23
2002	4	4
2003	5	5

in Central Asia. Remote sensing instruments are necessarily designed with specific trade-offs in mind. For example, there is an inverse relationship between pixel resolution, repeat frequency and scene size. Accordingly, Landsat ETM+, ASTER and MODIS have different sensor characteristics encompassing a suite of spatial and spectral resolution, repeat frequency and cost of data (table 3). Despite these differences, the NDVI from these sensors produced remarkably similar vegetation patterns for our study area in China. This begs the question of what are appropriate uses for each different dataset? The answer depends on the intent of the analysis, the amount of data needed, the size of the study area and the operating budget. For example, we recommend use of MODIS 250-m NDVI for evaluating regional spatio/temporal patterns of vegetation. However, if the intent of the analysis is developing basemaps for identifying key landscape features and planning with herders and government workers, we recommend ASTER.

ASTER data provide sufficient resolution for identification of specific landscape features that aid in identifying vegetation types, geographic features and navigating diverse terrain. Features such as small pockets of riparian vegetation and individual agricultural fields are readily apparent in ASTER imagery (fig. 4). Other features such as roads, man-made structures and water-ways are also visible in ASTER imagery (fig. 4), which aids local navigation and communication between development specialists and pastorolists, particularly when other sources of information are lacking. Indeed, both the Ertix River and surrounding irrigated hayland are easily identified in ASTER imagery (fig. 4). The fine resolution of ASTER data also provides an ideal basemap for overlaying point data. For example, if vegetation attributes are measured in a 1-m^2 quadrat they should theoretically be more representative of a 15 meter image pixel (as in the case of ASTER) than a 30 or 250-m pixel (as in the case of ETM+ or MODIS). Thus, for spatially and temporally limited studies of vegetation patterns and for creating basemaps, ASTER data are quite useful.

The main disadvantage of ASTER data is the lack of continuous coverage for a particular area. While the results indicate that 93 percent of the study area had at least one image during the period from April 1, 2000 to October 31, 2003, the same coverage cannot be expected everywhere on earth. This is because ASTER does not employ a continuous data acquisition strategy and each acquisition must be scheduled and prioritized. Three categories of data acquisition exist: local observations, regional monitoring, and global map (Abrams and others 2004). For localized acquisition, the ASTER team designed an acquisition system that facilitates requests from authorized users. For example, a registered user can request ASTER imagery for any region in Central Asia. Currently, three groups of scientists can be registered users. These include ASTER Science Team members, Earth Observation System (EOS) principal investigators, and other approved investigators. In contrast to "local observation," "regional monitoring" occurs on a regular basis on a pre-determined set of locations around the globe including the worlds mountain glaciers, active and dormant volcanoes, and the Long-Term Ecological Research (LTER) field sites (Abrams and others 2004). Finally, "global map" acquisition is set to facilitate investigation by researchers in nearly every field. As such, each region of the earth has been prioritized by the ASTER Science Team (Abrams and others 2004). Currently, local observation, regional monitoring, and global acquisitions are allocated approximately 25, 50 and 25 percent of ASTER acquisitions, respectively.

In contrast to the ASTER system, the ETM+ sensor acquires data continuously along a set path. This means that for each area on the globe there will be coverage at an interval of approximately 16 days for every point on the globe. The ETM+ (and its predecessor Landsat 5) have been used more extensively for evaluating natural resources than either MODIS or ASTER. Thus, a wealth of information exists for processing and evaluating Landsat imagery. The 30-m resolution of ETM+ permits better visual identification of landscape features than MODIS, but not ASTER. Carefully designed plot-level analyses can also be coordinated with ETM+ in a similar fashion to ASTER. The primary disadvantages to ETM+ data are the cost ($605/scene), the lack of atmospheric correction, and since May 31, 2003 a sensor problem. The lack of atmospheric correction may not impose a problem for projects where the aim is developing base maps to aid in development of natural resource plans. Perhaps of greater concern is that the sensor anomaly, known as the scan line corrector (SLC) anomaly, produces large areas of missing data for every image. The United States Geological Survey (USGS) is currently implementing a series of improvements to remedy the problems being encountered within the ETM+ data stream, but there is no doubt that the problem greatly decreases the value of this data source and there are no known plans to replace the ETM+ sensor. Some facilities, such as the Global Land Cover Facility (http://glcf.umiacs.umd.edu/index.shtml)

Table 3—Selected sensor characteristics of the ASTER, ETM+, and MODIS Sensors.

Sensor Characteristics	ASTER	ETM+	MODIS
Cost (US$)	Free	$605 [2]	Free
Repeat frequency (Days)	Variable[1]	16	1 – 2 [3]
Atmospheric correction	Yes	No	Yes
Spatial resolution of VNIR (m)	15	30	250 – 1000
Spatial Coverage (ha/scene)	470,610	4,854,299	144,000,000

[1] Can be pointed off-nadir to increase repeat frequency but is typically about 16 days.
[2] Some websites now offer a limited source of free ETM+ data.
[3] Close to the equator the repeat time is approximately 1.2 days.

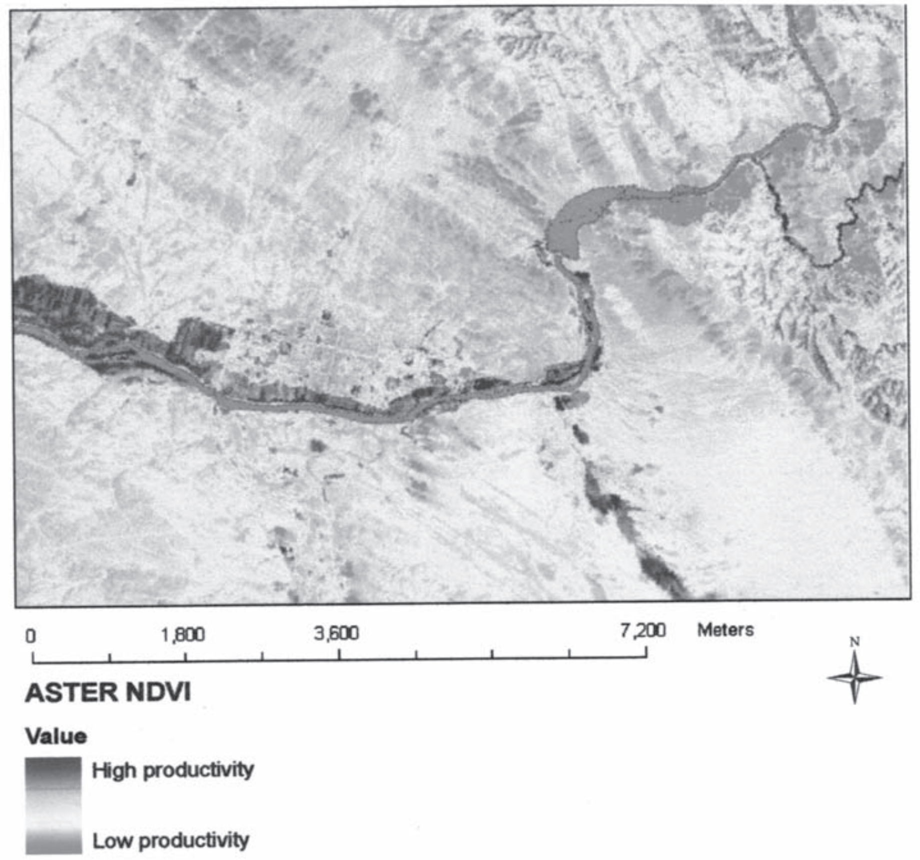

Figure 4—ASTER NDVI (1:40,000 scale) of Fuyun region, Xinjiang Uygur Autonomous Region, Peoples Republic of China.

are now offering free ETM+ data for many areas around the globe. At this time, spatial coverage, and especially temporal coverage, of free ETM+ scenes are limited.

MODIS data lack the resolution of ASTER and ETM+, but provide a logical choice for evaluating vegetation trends over a large region. For example, figure 3 indicates that it would require few MODIS images to completely cover China. In addition, MODIS data are cloud - screened which is a clear advantage compared with standard ETM+ or ASTER imagery. Since MODIS data are cloud screened and collected for the globe every 1 – 2 days, temporal composites are typically produced such that even if a pixel is cloud-covered for a given day, it can be replaced with the next un-clouded value in the temporal sequence. Such is the case with the standard MODIS NDVI product, which is a 16 – day composite.

In contrast, ASTER and ETM+ data are acquired using longer repeat cycles (table 3), hence only a few images may be acquired during the growing season, which often yields only a few useable images because of cloud cover. Another benefit of MODIS data is that it is atmospherically corrected prior to dissemination and contain a variety of quality control (QC) information permitting the user to interactively determine which pixels are suitable for analysis. In the case of the standard 250 – m NDVI MODIS product there are 13 data fields that can be accessed for each pixel that describe different aspects of the data quality (Huete, 2002; Huete and others 1999).

The primary limitation of MODIS NDVI is the relatively coarse spatial resolution (250 – m). While the MODIS 250 – m spatial resolution is superior for global and regional analyses, it is insufficient for developing the cartographic output necessary for developing base maps for pastoral planning projects showing micro-resource areas or for navigating in complex terrain.

Summary and Management Implications

Coordinated natural resource planning stressing multiple-uses is critical for conserving natural resources and pastoral livelihoods in Central Asia. We have been involved in a number of development projects where base map information for developing resource management plans have been lacking. The use of satellite imagery such as Landsat ETM+ and ASTER provide planners inexpensive sources of information for development of base maps. MODIS offers the ability to illustrate temporal changes and regional differences. We have found that pastoralists often easily "read" ASTER and Landsat ETM+ images. For example, we have had pastoralists draw in grazing areas, past land-use and past-movement of herds, current and past wildlife areas, important resources or areas of resource concerns on printed images. We have also used images for identification of monitoring sites and communication of plans with pastoralists and government officials or other pastoral groups. It is very likely that there will be greater free or inexpensive web resources of satellite images in the future, but at this time we believe that ASTER with its high degree of coverage in Central Asia, its relatively high resolution (15 m), offers a valuable resource tool for natural resource planners.

References

Abrams, M., Hook, S. and Ramachandran, B. 2004. ASTER User Handbook, Version 2: 135.

Chavez, P.S. and Bowell, J. 1988. Comparison of the spectral information content of Landsat Thematic Mapper and SPOT for three different sites in the Phoenix, Arizona region. Photogrammetric Engineering and Remote Sensing, 54(12): 1699-1708.

Chavez, P.S., Sides, S.C. and Anderson. J.A. 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. Photogrammetric Engineering and Remote Sensing, 57(3): 295-303.

Cohen, W.B., Maierpserger, T.K., Gower, S.T., Turner, D.P. 2003. Comparison of land cover and LAI estimates derived from ETM+ and MODIS for four sites in North America: a quality assessment of 2000/2001 provisional MODIS products. Remote Sensing of Environment, 88: 233-255.

Huete, A., 2002. MOD13 User's Guide. http://tbrs.arizona.edu/projects/modis/UserGuide_doc.htm.

Huete, A., Justice, C. and Leeuwen, W.V. 1999. MODIS vegetation index (MOD13) algorithm theoretical basis document: version 3. 129.

Justice, C., Vermote, E., Townshend, J. R. G., Defries, R., Roy, D. P., Hall, D. K., Salomonson, V.V., Privette, J., Riggs, G., Strahler, A., Lucht, W., Myneni, R., Knjazihhin, Y., Running, S., Nemani, R., Wan, Z., Huete, A., van Leeuwen, W., Wolfe, R., Giglio, L., Muller, J-P., Lewis, P., and Barnsley, M. (1998). The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research. *IEEE Transactions on Geoscience and Remote Sensing:* 36(4), 1228-1249.

Nicholson, S.E., Tucker, C.J. and Ba, M.B. 1998. Desertification, drought, and surface vegetation: An example from the west African Sahel. Bulletin of the American Meteorological Society: 79(5): 815-829.

Pickup, G., 1998. Desertification and climate change-the Australian perspective. Climate Research, 11: 51-63.

Yuhas, R.H. and Goetz, A. 1993. Comparison of airborne (AVIRIS) and spaceborne (TM) imagery data for discrimination among semi-arid landscape endmembers, Ninth Thematic Conference on Geologic Remote Sensing, Pasadena, California, pp. 503-511.

Zhou, L., Tucker, C.J., Kaufmann, R. K., Slayback, D., Shabanov, N.V., and Myneni, R. B. 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981-1999. Journal of Geophysical Research, 106(D17): 20,069-20,083.