MONITORING LANDSCAPE DYNAMICS AND CONDITIONS OF NATURAL RESOURCES WITHIN AND ADJACENT TO PROTECTED AREAS

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ABSTRACT:

The challenges of managing natural resources of protected areas not only come from the inside of the protected boundaries, but also from the surrounding territories because most of protected lands are open systems that face threats from adjacent areas. The lands of such open systems alter water quality and flow regimes, increase the likelihood of invasive plant and animal range expansions, reduce contiguous forest, and affect the integrity of the protected ecosystems. This paper addresses general issues of the role of remote sensing data in monitoring and reporting ecological integrity of protected lands. We examined two case studies in the Northeast Temperate Network of the National Park Service's Inventory and Monitoring Program of the United States and the Changbai Mountain Natural Reserve of the Northeast China. Knowledge of historical trends, not only how much has changed but also where and when changes have occurred, can help land managers identify key resources and ecosystem stressors, as well as prioritize resource management efforts in monitoring vital signs as the indicators of ecosystem conditions. The appropriate scale for understanding and effective managing protected lands could range significantly in spatial and temporal contents. Remote sensing data with varied spatial resolutions and spectral coverage can play a significant role in monitoring sensitive indicators, such as land cover change and dynamics of landscape patterns, trends in geographic extent and distribution of invasive exotic species, insects and pathogens through vegetation indices, as well as human population and socioeconomic indicators that are critical for regional ecological securities.

1. INTRODUCTION

1.1 Monitoring of the Protected Areas

Promoting and facilitating the use of remotely sensed data for monitoring and managing national parks and other protected areas have been the focus of many research and governmental agencies. For example the North American Network for Remote Sensing Park Ecological Condition (NARSEC) was established in 2005 as a collaborative initiative of the national park agencies of Canada, Mexico and the United States. The US National Park Service (NPS) implemented an inventory and monitoring (I&M) program for monitoring of the vital signs, which is a key component in the NPS's strategy to provide scientific data and information needed for management and education (Gross, 2007). A primary role of NPS I&M networks is to collect, organize, and make available natural resource data and to contribute to institutional knowledge by facilitating transformation of the data into information through analysis, synthesis, and modeling (Fancy et al., 2008). Parks Canada Agency initiated collaborations with research and education institutions to use satellite-based Earth observation as a basis for a park ecological integrity observation system. The operations of the system include coarse filter ecological integrity measures corresponding to landscape patterns, succession and retrogression, net primary productivity, and focal species distributions (Fraser, et al., 2007).

Urban development, timber harvests and increasingly fragmented natural habitats due to a variety of human land use practices are just a few of the factors outside of park boundaries that impact the ecosystems within the protected lands. Knowledge of historical trends of land-cover change, not only *how much* has changed but also *where* and *when* changes have occurred, can help land managers identify key resources and ecosystem stressors, as well as prioritize management efforts. The NPS Vital Signs Monitoring Program, which is primarily implemented by the NPS I&M networks, aims to monitor a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Mitchell *et al.*, 2006). The vital sign monitoring will help determine the status and trends in selected indicators of the condition of park ecosystems; provide early warning of abnormal conditions of selected resources; provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with altered environment (Gross, 2007). Vital signs that could be monitored by remote sensing include land cover types and change, landscape pattern, vegetation conditions and disturbance patterns, plant phenology that can be used as an indicator for climate variation and change. Landscape dynamics was a commonly selected priority vital sign, which can reflect the change in area and distribution of ecological systems within and adjacent to protected areas, extent of major disturbances, and integrity of the ecological systems. Urban development, for example, is one of the most important stressors that the parks and other protected areas are facing. The aspects of urbanization that can be remotely sensed

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include road network extent, proportion of nearby lands in various categories of human uses, and percentage of impervious surface in watershed and landscape buffers. Monitoring landscape dynamics can answer questions of what is the spatial extent of land-cover types within and adjacent to the parks and the protected areas, and how have they changed over time.

1.2 Challenges in Remote Sensing Applications

Remote sensing data have been broadly applied in mapping of natural resources (*e.g*., Skole and Tucker, 1993; Wang and Moskovits, 2001; Welch et al., 2002; Turner et al., 2003). Methodologies and techniques for monitoring land surface changes have been developed and advanced significantly. Methods in change detections appear to perform successfully for case studies (Woodcock and Ozdogan, 2004; Rogan et al., 2002; Hayes and Sader, 2001; Mas, 1999). However considerable challenges in monitoring land surface change still exist. Those include more systematic error analysis, additional testing in a wider range of environments, and peer review of the methods intended for ongoing monitoring. Significant barriers also exist between remote sensing and user group communities for application of existing methods and data products. Although promising remote sensing technologies exist that offer the potential to provide new or improved information on land surface characteristics and changes, further research and application development need to be vigorously pursued.

Quantification of landscape patterns is among the interests of both scientific research and management practice. Establishing connections between landscape patterns and ecosystem functions will help answer specific questions in landscape configuration and composition for protected areas in landscape context with adjacent lands. However landscape patterns are easy to measure but difficult to make a meaningful and logical interpretation. The positive aspect is that methods and tools in landscape quantification have been developed and tested under limited sets of conditions, such as ecologically scaled landscape indices and metrics, simulation models and theory. Justification and testing on the usage of the approaches and models are necessary in order to achieve the goals of management and research goals. In particular existing remote sensing data and products may contribute to the measurement and interpretation of landscape patterns in a variety of scales. New developments in remote sensing have the potential to significantly improve quantification and analysis of spatial, temporal and thematic information for characterization of landscape patterns.

Protected areas are often associated with conservation of biodiversity. Integration of remote sensing observation with in situ measurements is necessary to address issues of distributions of individual species or species assemblages. Remote sensing data and products may support assessment of habitat. Barriers still exist in terms of spatial scales provided by remote sensing systems and those addressed by ecologists which need to be addressed for monitoring habitat conditions and species distribution.

In the 2007 NARSEC conference, the concepts of targets, thresholds and desired conditions were among the topics of discussions (NARSEC, 2007). Although the ‘threshold’ concept has been extensively studied in ecology, ‘assessment points’ that specify levels of ecological variables at which detailed analysis of a need for action is warranted are preferred in the context of park management. Various conceptual problems remain that require further work in defining theoretically sound and practically useful assessment points for specific ecoregions, parks, focal species, and other aspects of parks and protected areas that are important from management perspective. It may not always be feasible to define ‘desired condition’, particularly where historical data are not available or the environmental circumstances are changing (e.g., climate change impacts, land use pressure). The importance and value of remote sensing technology depends on the questions addressed and the ecological setting. It will thus also depend on the evolution of ecological and management concepts that underpin the targets, thresholds/assessment points and desired condition.

2. EXAMPLES OF CASE STUDIES

2.1 Examples of Protected Areas

In this paper we present two examples of remote sensing applications in observing land cover change in the landscape context and vegetation indices for protected areas. The Appalachian National Scenic Trail (A.T.) traverses the high elevation ridges of the eastern United States. The trail is 2,175 miles long and crosses 14 states while intersecting 8 national forests, 6 units of the National Park System (NPS), more than 70 State Park, Forest, and Game Management units, and 287 local jurisdictions. The A.T.’s and its surrounding 100,000 hectares of protected lands with gradients in elevation, latitude, and moisture have allowed species to survive dramatic changes in climate and landscapes. As a result, the Appalachian Mountains support one of the richest assemblages of temperate zone species in the world. As scientists often use a transect to systematically collect data on species or environmental conditions across a landscape, the A.T. offers a mega-transect to monitor the environment of the Appalachian Trail from urban development, acid rain, invasive species, polluted water, and climate change (Dufour and Crisfield, 2008). Although the roughly 300 m-wide AT central corridor is protected, the adjacent landscape has been changing in the past decades. A recent study analyzed the extent and spatial distribution of forest clearing along a 16 km-wide corridor centred on the A.T. and concluded that managed forest harvests in northern New England accounted for 76.8% of forest clearing within the corridor (Potere et al., 2007). This result highlights the importance of documenting baseline conditions and monitoring change of land cover types along the A.T. corridor. The challenge of protecting and managing such a linear open system is that there is no single spatial or temporal scale that is appropriate for all A.T. system components and processes. The appropriate scale for understanding and effectively managing a resource might range spatially from site-specific to regional, and might vary temporally from sub-annual to decadal or more. Understanding the magnitude and pattern of land cover change helps establish a landscape context for the parks and protected areas, and offers resource managers a better understanding of how park ecosystems fit into the broader landscape. A study conducted by the Northeast Temperate Network of the NPS I&M program selected ten (10) representative segments along the A.T. with accumulated length of about 362 km from Maine to Pennsylvania (Figure 1). The selection of segments was based on observed changes and on the potential for future change as perceived by resource managers. The study documented general land-cover types within a 5-km buffer zone adjacent selected A.T. segments for 3 time periods of the mid-1970's, late-1980's, and 2002; quantified land-cover change in land-cover types and revealed patterns of land-cover change on the neighbouring protected lands. This is a representative example of linear protected land with latitudinal variations in landscape features and ecosystem types.

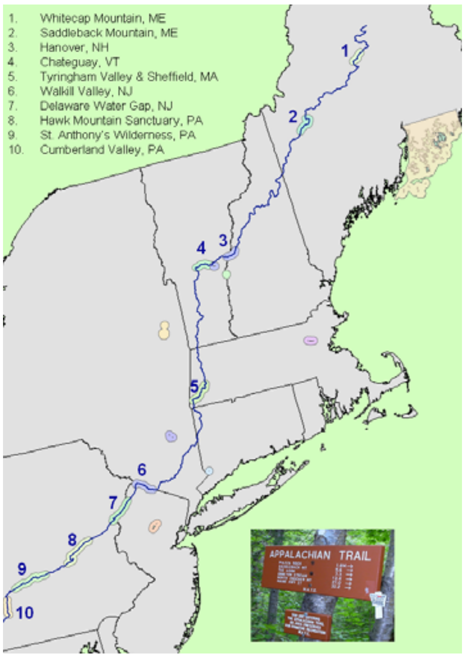

Figure 1. Ten selected segments along the A.T. between Maine and Pennsylvania.

The Changbai Mountain Nature Reserve is about 190,000 hectares of protected land in the Chinese side on the border between China and North Korea. The reserve was established in 1961 and admitted into the UNESCO's Man and Biosphere Program in 1979. This natural reserve was also among the 54 stations under the Chinese Ecological Research Network, which is a parallel program to the Long-Term Ecological Research (LTER) program in the United States.

The Changbai Mountains are a mountain range situated between 41°41' and 42°51'N; 127°43' and 128°16'E. The range extends from the Northeast provinces of Heilongjiang, Jilin and Liaoning in China to the North Korean provinces of Ryanggang and Chagang. Geologically the region is situated at the edge of the Eastasia Continent on the border of the Pacific competent zone. The Himalayan tectonic movement since the Miocene Epoch had resulted in volcanic eruptions and hence the formation of a typical volcanic geomorphological region composed of volcanic cones, inclined plateau and lava table lands (Zhou et al., 1990; Wang, et al, 2003). Volcano in the Changbai has been quiet since minor eruptions in 1597, 1688, and 1702. The highest peck in the Chinese side is 2,691 meters above sea level. The volcanic lake, so named the Heaven Lake and which is a centerpiece of the reserve, is the origin of the Yalu, Tumen and Songhua rivers. Among them the Yalu and Tumen rivers serve as the border between the China and North Korea two countries (Figure 2).

Changbai Mountain Nature Reserve has the largest protected temperate forest in the world. It is home to endangered Siberian tigers and the last stands of virgin Korean pine-mixed hardwood on the planet. It's one of the most spectacular and relatively undisturbed ranges in China (Stone, 2006). The climate and terrain conditions support four vertically distributed vegetation zones including, from bottom to top, needle- and broad-leaved mixed forests (below 1000m); old-growth mixed broad-leaved Korean pine (*Pinus koraiensis*) forests (1100-1800m); dwarf-birch (*Betula ermanii*) forests (1800-2100m); and Alpine tundra (above 2100m). This natural reserve and the surrounding areas have been a research focus in ecosystem and biodiversities (e.g., Zhau and Zhau, 1991; Chen and Bradshaw, 1999; He et al., 2002; Chen and Li, 2003; Yang and Xu, 2003), and with remote sensing applications (Sun et al, 2001; Liu, et al., 2005; Shao, et al., 1996).

Increasing human population and socioeconomic and urban development are among key factors that affect the function of the preserve. Aggressive logging along the reserve's edge in Chinese side and conversion to croplands on the Korean side threaten to turn Changbai into an oasis in a sea of clear cutting (Stone, 2006).

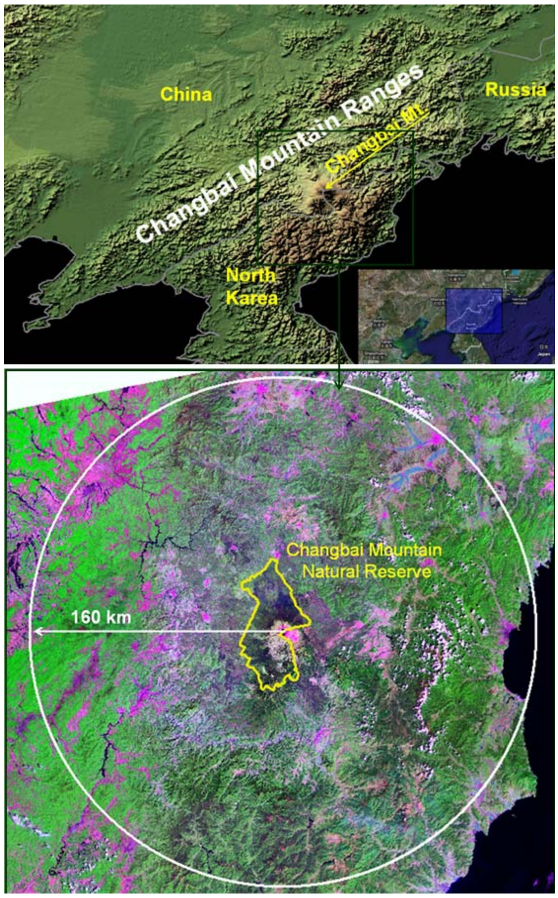

Figure 2. Geographic location of the Changbai Mountain range, the Changbai Mountain Nature Reserve and the adjacent areas.

2.2 Quantification of Land Cover Changes

Understanding the magnitude and pattern of land cover change within and adjacent to protected areas helps establish a landscape context and offers a better understanding of how ecosystems of the protected areas fit into the broader landscape. In general, land-cover changes are divided into conversions from one land cover type into another, *i.e.* between-class changes, and transformations within a land cover type, *i.e.* within-class change.

Among many different types of remote sensing data, Landsat and MODIS data products have been among the most popularly used. The case study of the A.T. segments used Landsat remote sensing data as the primary data source for the derivation of generalized land cover information with several considerations. Firstly, Landsat multispectral data provided coverage from the early 1970s to the early 2000s with nearly continuous coverage, which makes the study of land cover change for the selected time periods possible. Secondly, as the purpose of this study was to provide a general landscape characterization and change analysis instead of detailed vegetation and resource mapping, the spatial resolution of Landsat data was appropriate. Thirdly, data availability and cost were also an important factor. A significant amount of Landsat data is available at no cost from on-line open resources or at low cost from other data archives that could meet the budget of many applications.

This study extracted land cover information using supervised, unsupervised, and stratified classifications, as well as post-classification cross-checking with the National Land Cover Dataset (NLCD), National Wetland Inventory (NWI) and NPS vegetation mapping project data sets. Upon completion of the land cover classifications spatial buffers of 500-meter, 1-km and 5-km were applied to the A.T. central line to reveal the spatial pattern and magnitude of land cover changes. Upon finishing the classification and accuracy assessment, the post-classification comparison approach was employed to obtain the information on change of major land cover categories.

2.3 NDVI and Indications

For the Changbai Mountain Nature Reserve area, we analyzed MODIS data products land cover type I (MOD12Q1) IGBP classification system data and MODIS NDVI (MOD13A2) in combination with 3 arc-degree digital elevation model data from Shuttle Radar Topography Mission (SRTM). We projected the MOD12Q1 and MOD13A2 NDVI data to the Albers Conical Equal Area with 1-km spatial resolution using MODIS Reprojection Tool V4.0 (USGS EROS Data Center, 2008). The MOD13A2 data provide NDVI every 16 days at 1-km spatial resolution. The MOD13A2 should complement with NOAA's AVHRR NDVI products and can provide continuity for time series historical applications (USGS - NASA Distributed Active Archive Center, 2008). We projected SRTM to Albers Conical Equal Area with 1-km spatial resolution as well. We then derived aspect information for southern and northern slopes from the SRTM data.

For demonstration purposes we focused on deciduous broadleaf forest, mixed forests, and croplands in this paper. We analyzed the MOD13A2 NDVI data for 8 continuous years from 2000 to 2007. For making the comparisons, we created analyzed three sets of subset data, i.e. the greater Changbai Mountain ranges which is about 500,000 Km^2 between 40^0N and 47^0N and 120^0E and 132^0E; the buffer area covers the reserve and adjacent area defined by the circle of 160-km radial from the centre of the volcanic lake at 128^0N and 42^0E; and the protected reserve only (Figure 2).

We built masks based on the selected land cover types of deciduous broadleaf forest, mixed forests, and croplands from MOD12Q1. We extracted the mean NDVI in each land cover type for each subset of data. We excluded the pixels that contained no values in the original MODIS data products. In order to analyze the difference in vegetation distributions from different elevation and southern- and northern-facing slopes, we applied additional thresholds of 450-m elevation and azimuth angle from 45^0 to 225^0 to calculate the mean NDVI.

3. WHAT THE DATA INDICATE?

3.1 Magnitude of Land Cover Change

The results demonstrate how the land immediately adjacent to this huge protected linear park has changed in the past three decades. Data analysis for individual segments reveals where the change had occurred and trends of change. Monitoring land cover changes will guide decision-making for resource management of these protected lands. The buffer and change analyses indicated that for the selected segments except one in Maine (Whitecap Mountain segment) urban land increased 169% and 189%, respectively, within the 500-m and 1-km buffer areas in the past 30 years. Significant increase of urban land next to the A.T. shows that the areas face critical management challenges. Management of protected lands have to consider the context of the landscape as well as past and future changes in order to achieve the goal of science based analysis, synthesis, and modeling. Many linear protected areas such as river-based parks, roadways, habitat corridors, or other trails could face the same challenges and remote sensing data and approaches will be among the key steps to develop the baseline data for effective management.

3.2 NDVI Trends and Indications

As the Changbai Mountain Nature Reserve is a relatively isolated protected land in a maintain range that has significant variations in natural conditions because of the complexity and landscape contexts that are beyond its boundaries, comparative analysis for selected subset areas could help understand the response of different land cover types or ecosystems on the landscape. For example, the NDVI of the greater Changbai Mountain range shows the variation between years of 2000 and 2007. The years of 2005 and 2006, in particular, experienced significant decrease in NDVI at around the 209 day of the year. This pattern is about the same for the land cover types of deciduous broadleaf forest and mixed forest. Although the similar patter exists for the cropland category, the data indicate that cropland category was more significantly affected than the other two types of land cover categories (Figure 3).

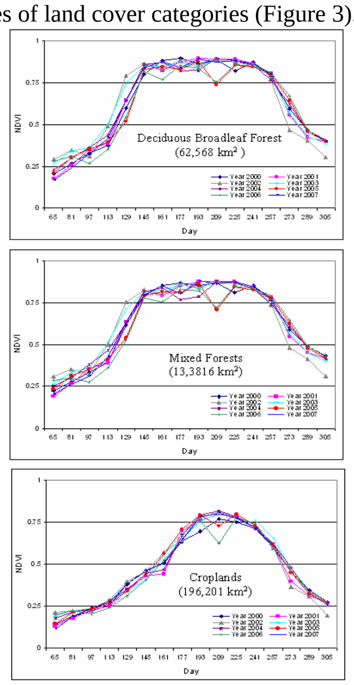

Figure 3. NDVI of greater Changbai Mountain ranges.

For the area that include the reserve and adjacent land that centered at the reserve as illustrated by Figure 2, the NDVI shows the same pattern as the broader Changbai Mountain range but the effects on deciduous broadleaf forests and mixed forests are more significant than the impacts on cropland of this circular area (Figure 4).

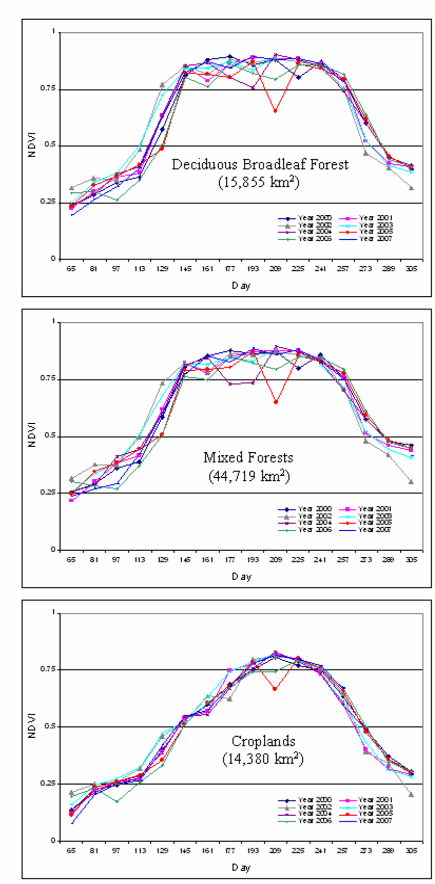

Figure 4. NDVI of the reserve and adjacent areas.

The NDVI of the mixed forest within the protected reserve shows the pattern of variation that confirmed the change in the same time period as the other land cover types in the region (Figure 5). At the time of writing, field data analysis are underway to examine the correlation between field observation and the data pattern from remote sensing data.

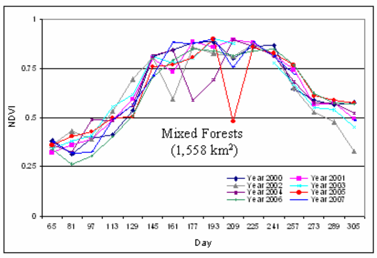

Figure 5. NDVI of mixed forest within the reserve.

4. DISCUSSIONS

Remote sensing data provide not only the snap shots (e.g., Landsat and the similar type of sensors) of the landscape at the time of image acquisitions, but also continued data collection for large areas (e.g., MODIS type of sensors) that have increased the application capacity of monitoring the national conditions and landscape dynamics of both protected areas and the immediately adjacent areas for a more comprehensive and comparative studies. Continued efforts in data processing techniques and modelling approaches that can bridge integration of remote sensing and in situ observations have the great potentials. The complexity of the landscape of the study sites and image processing methodologies in information extraction impose challenges to obtain the necessary information for science-based decision making in management of protected lands. Land cover change analysis and monitor the dynamics of indicator data such as the NDVI can be a powerful tool for assessing natural and anthropogenic impacts at landscape-scale to protected lands, provided that we identify independent variables or processes that can be related to the changes observed with the remote sensing data. For example, assessing the impact of urbanization on invasive species in a given protected area would ideally be conducted by observing the spatial patterns of invasive species colonization over the years, and using spatial statistics to correlate severity of invasive species with the urbanization or fragmentation processes that can be estimated from the maps. Identifying these independent variables requires multidisciplinary expertise, with ecologists, botanists, biologists, hydrologists, and others working together and with land cover data to answer questions about landscape-level threats and processes.

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