Deforestation and the Transformation of the Landscape of North China: prehistory - present

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ABSTRACT

Environmental evidence shows that 10,000 years ago North China was primarily a lush deciduous forest. Like many other regions of the planet, this landscape has been dramatically transformed by human activity, yet unusually this mostly occurred long ago under pre-industrial conditions.

Fortunately China has a long recorded history of human activity. Complementary environmental evidence helps to extend this record into prehistory, for even prehistoric Chinese substantially altered their environment. The first half of this study examines historical and physical evidence in order to better explain how North China's forests disappeared.

Only recently have there been regional scale activities focused on reversing this tragic trend. Despite many claims of successes in afforestation, there are serious shortcomings in the collection of government statistics and known limitations to area-based forest assessments, so it is difficult to say with much confidence what is happening with North China's forests today.

Phenological measurements from space-based instruments have been effectively used to characterize vegetation trends. In the second half of this study, MODIS sensor observations for 2000-2009 are collected for five study sites and are used to characterize vegetation change over the past decade, independent of government statistics and area-based estimates.

Forests provide tangible benefits to environmental and human well-being. Forest health and growth are critical to addressing global climate change. Much attention has been focused on China's efforts to combat deforestation. A better understanding of North China's forest trends – both past and present – may offer valuable lessons for our environmental future.

华北森林消失及景观转变的研究：从史前到现今

Alan H. Moore

摘 要

有环境证据显示一万年前的华北是一片茂密的落叶林。正如世界上很多其它地区，这一景观因人类的活动产生了巨变，但这种巨变常常发生在很久之前的前工业化时代。

幸运的是，在中国有着悠久的有关人类活动的历史记录。由于史前期的中国就有人类改造环境的大量活动，环境方面的证据就成为有力的辅佐，使历史记录得以延伸到史前。本论文的前半段考察了历史和自然的证据，以图更好地解释华北的森林是如何消失的。

为扭转这一颓势而做出的区域范围的努力只是在近期才发生。尽管有很多造林成功的声称，但政府统计数据存在很多严重的缺点，另外还有很多以面积单位对森林估算的缺陷。因此，很难做出对华北地区森林现状的准确评估。

近来靠空间仪器所取得的物候数据被用来有效地表征植被的发展趋势。本论文的后半段所讨论的是自2000至2009年间以MODIS传感器在五个地点所收集的植被变化特征，其结果独立于政府统计数据和以面积为基础的估算。

森林对环境和人类的裨益是不言自明的。森林的健康成长对调控全球气候变迁至关重要。中国在对抗毁林方面的努力世人瞩目。更好地了解华北的森林发展史 – 其过去与未来 – 将会对我们环境的未来提供有益的帮助。

This work is dedicated to my father, Robert Allen Moore (1940-2009)

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List of Abbreviations

AD - *Anno Domini* (years since 1 BCE)

AVHRR – Advanced Very High Resolution Radiometer

BCE – Before Christian Era

BP – Before Present

CIA – Central Intelligence Agency

EVI – Enhanced Vegetation Index

FPAR - Fraction of Photosynthetically Active Radiation

GTGP – Grain to Green Program

INDVI – Integrated Normalized difference Vegetation Index

LAI - Leaf Area Index

LGM – Last Glacial Maximum (25,000 – 15,000 years BP)

LST – Land Surface Temperature

MODIS - Moderate Resolution Imaging Spectroradiometer

NASA – National Aeronautics and Space Administration

NDVI – Normalized Difference Vegetation Index

NFCP – National Forest Conservation Program

NIR – Near Infrared

ORNL – Oak Ridge National Laboratory

Chapter 1

INTRODUCTION

The landscape of North China has been one of the most intensively and continuously occupied regions on earth. In order to satisfy basic needs for food, shelter and heat, along with growing cultural demands, humans have used whatever tools were available to alter the composition and distribution of what was in the past a dominant deciduous broad-leaved forest. This relentless process has resulted in today's landscape of farms, villages, cities and wasteland.

Western visitors have cited the condition of Chinese forests as an extreme example of the destructive potential of human activity. Nowadays, North China, the cradle of Eastern civilization, is almost totally devoid of any forest cover aside from inaccessible mountain slopes and the mixed results of recent afforestation attempts. The landscape has been so seriously altered that it is difficult to recognize the character of the original land cover.

Extraordinary changes to the environment have resulted from the deforestation of North China. For millennia, exposed soil has eroded and washed down the great river systems causing catastrophic flooding and the buildup of the North China plain. Barren hillsides offer no resistance to violent dust storms blowing in from the west. Desertification continues to progress while diversity continues to diminish. And unquestionably, deforestation and its subsequent consequences have led to untold human suffering.

Purpose

From environmental evidence it has been determined that 10,000 years ago North China was mostly blanketed by a lush primary deciduous forest. Like many other regions of the planet, North China's landscape has been dramatically transformed by human activity, resulting in significant environmental and human impacts. But unlike many other places, much of this transformation occurred long ago under pre-industrial conditions.

Our understanding of the prior transformation of North China's primary forest is clear: it was here but now it is gone. What happened over the course of significant human presence in North China that resulted in a nearly complete deforestation?

This study assumes in North China there existed in the past a pristine 'natural' landscape – an environment unblemished by human activity. The opposite of this would be a hypothetical 'cultural' landscape, completely determined by human design, which is nearly the condition today. As human activity ensued in North China, elements of a cultural landscape were introduced which either subtly or dramatically altered the natural landscape, resulting in a mix of natural and cultural landscape elements, the proportions varying over time.

A continuous progression of dynasties and competing states has resulted in a long recorded history of human activity. Environmental evidence can also extend our understanding of human activity into prehistory, for even prehistoric Chinese substantially altered their environment in many ways. The first half of this study examines this evidence to better explain how North China's forests disappeared.

Only in the recent past - approximately 30 years - have there been regional scale human activities focused on reversing this trend in North China. There have been plenty of claims of successes, but many of these claims remain in question. There are serious shortcomings in the collection and reporting of government statistics, in addition to known limitations of area-based forest assessments. This makes it difficult to say with much confidence what is happening with North China's forests today. These issues with monitoring forest change became even more crucial in 1998 when China's forest protection policies were greatly strengthened, while coincidentally forest monitoring policies were relaxed.

Phenological measurements from space-based instruments have been effectively used to characterize vegetation trends. This capability has been enhanced since early 2000 by the availability of data from the MODIS (Moderate Resolution Imaging Spectrometer, discussed in more detail in Chapter 3) sensor, which was designed to produce improved vegetation indices.

The second half of this study provides a better understanding of recent forest trends in North China. MODIS observations for 2000 through 2009 are collected for five study sites in North China which have participated in recent afforestation projects. Phenological measurements from these observations indicate changes in vegetation character over the past decade, independent of government statistics and area-based estimates.

Forests provide tangible benefits to environmental and human well-being, and their health and growth are critical to addressing the issue of global climate change. Great attention has been focused on China's efforts to address deforestation. A better understanding of North China's forest trends – both in the past and present – may offer valuable lessons for the well-being of our planet.

Looking at North China's distant past, the change in the forest cover is clear, while it is not so clear how it happened. Conversely, in North China's recent past, it is clear how the Chinese are engaged in forest activities, but the changes in the forest cover are less obvious. In summary, the major questions addressed by this study are:

1. **Over the past 10,000 years, what evidence do we have of human activities which influenced the process of deforestation in North China?**
2. **Over the past 10 years, what do new satellite sensors reveal about recent trends in North China's forests?**

Chapter Two will examine the process of deforestation in both a general sense and within the context of Chinese history. A basic understanding of the spatial and temporal patterns of deforestation in North China can be constructed from a review of the causes of deforestation and an examination of physical and historical evidence of human activity in North China. Chapter Two will finish with a brief examination of the primary historical environmental changes resulting from North China's deforestation.

Chapter Three will employ recent satellite observations to analyze current trends in China's effort to battle deforestation. Chapter Four will present the conclusions.

The remainder of this introductory chapter consists of a definition and description of North China as a region, a review of the body of literature on Chinese deforestation, and a summary of the significance of this work.

North China

Defining "North China" is important due to the long history and changing cultural boundaries of the region. To find a robust definition of this North China study area, it seems appropriate to use a Chinese method based on physical geography – Comprehensive Physical Regionalization. Zhao Songquiao (1986, p. 85) has identified comprehensive physical regionalization as "one of the oldest traditions of Chinese geographical study." He defines it as "an effort to identify differentiation among different areas on the earth's surface and document the similarities within the same area." The earliest system of physical regionalization is dated to 2500 years BP (before present); overall, more than 9000 physical regionalization studies are documented in Chinese history (Zhao 1986).

The most extensive physical regionalization to date has been the 1958 study led by Zhu and Huang (Chinese Academy of Sciences 1959). Under this classification scheme, China has been divided into three natural realms (based on geographical location, major climatic characteristics, and major geologic structures), sub-divided into seven natural divisions (based on similarities in temperature and moisture conditions, broad soil types, and vegetation), and further sub-divided into thirty-three natural regions (based on uniform temperature and moisture conditions, and similar zonal soil and vegetation) (Zhao 1986).

Based on this classification scheme, North China is defined as the "Humid and Subhumid Warm-temperate North China" natural division, demarcated by the following natural boundaries: the Bohai and Yellow Seas to the east, the Qinling Mountains-Huaihe River line to the south, the mountains of the Qinghai-Xizhang Plateau to the west, and the northern limit of wheat, cotton, and warm temperate fruit trees to the north (Zhao 1986). This division is sub-divided into four natural regions – Loess Plateau, Shanxi/Hebei Mountains and Basins, North China Plain, and Liaoning/Shandong Hills (Figure 1.1).

Other regionalizations have been undertaken (Domrös and Peng 1988), but these studies agree, in a general way, in their definitions of the North China region. This study will base its definition of North China on the regionalization scheme of Zhu and Huang, a division clearly defined by distinctive natural boundaries, which also closely corresponds to historic climatic and political boundaries (The People's Republic of China defines North China politically as the provinces of Hebei, Henan, Shandong, Shanxi, Shaanxi, along with the municipalities of Beijing and Tianjin.)

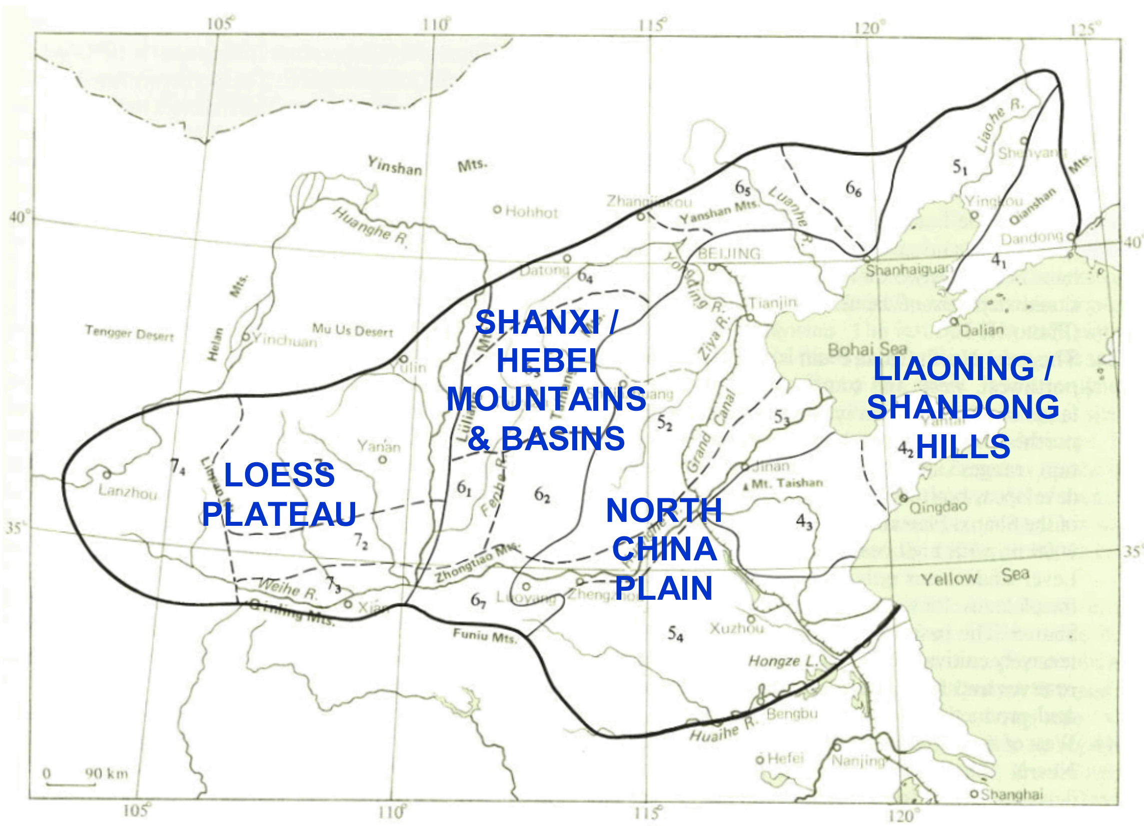

Figure 1.1 – Definition of Study Area (Zhao 1986. *Physical Geography of China)* [fair use]. The four subregions, labeled by the author, compose the "Humid and Subhumid Warm-temperate North China" natural division, which is the focus of this study. Major rivers and cities are also labeled. The background map was scanned from a copy of Zhao's book purchased in Beijing in 1990.

The distinctive surficial feature of North China is the distribution of loess, deposited during the cool dry conditions of the upper Pleistocene major glaciation (from approximately 85,000 to 12,000 years B.P.). This fine silt was brought by prevailing winds from interior Asia and deposited to the West of Luliang Mountains to depths of

100 to 200 meters, forming a broad, fertile plateau (Figure 1.2). Materials of the Loess Plateau are highly subject to erosion and erode to form steepsided gullies and hills, forming a unique region of North China. The surface is generally level with an elevation of over 1000 meters, but it is highly dissected in eroded areas (Zhao 1986). Loess has provided a mineralogically rich and fertile basis for millennia of Chinese agricultural productivity.

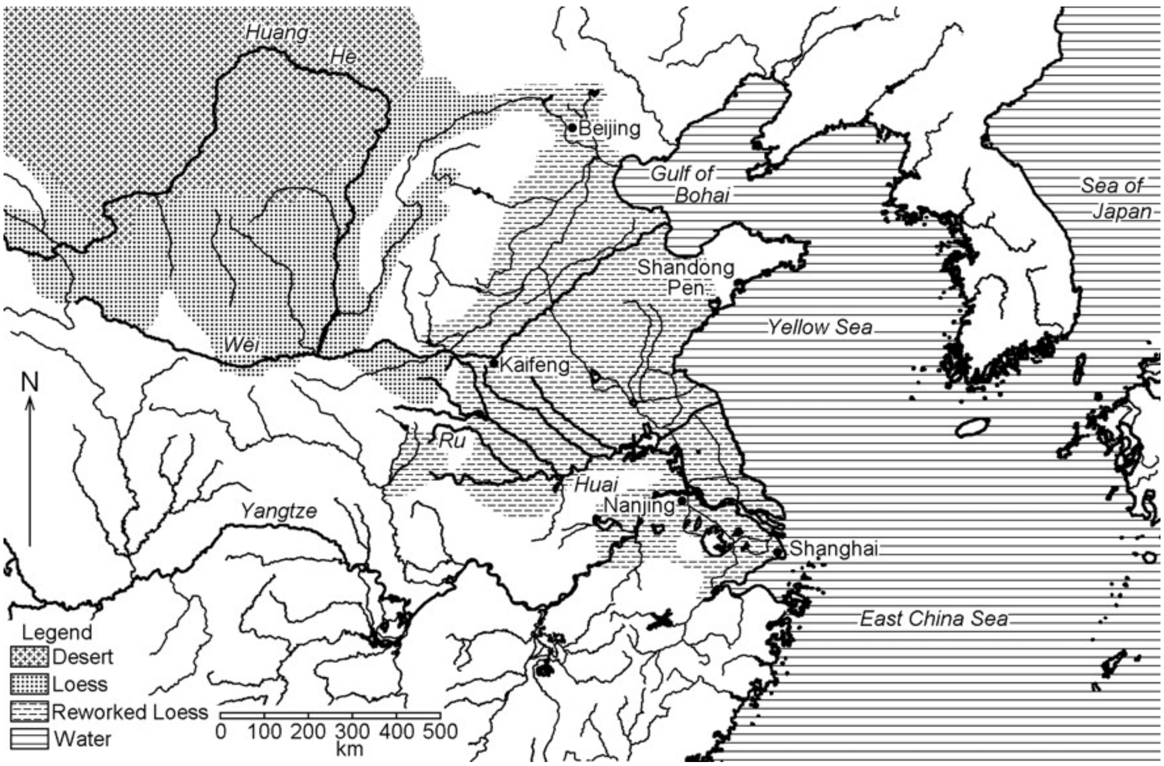

Figure 1.2 - Distribution of Loess in North China (Zhao Songqiao. 1986. *Physical Geography of China*) [fair use]. The Loess Plateau is primarily composed of the lighter windborne particles deposited from the Northwestern desert during the upper Pleistocene. Map areas labeled as "Reworked Loess" are primarily loessic alluvium deposited by the Huanghe (Yellow River) system.

To the east of the Loess Plateau, a region of mountains is found averaging 1000 meters in height and interspersed with relatively level basins. This area is commonly referred to as the Shanxi-Hebei mountains and basins region. The highest peak is Mount Wutai with an elevation of 3058 meters. Loess is also found in this region, but it is limited to the basins and lower slopes.

A third discrete natural region is the North China Plain, whose surface layer consists mainly of loessic alluvium brought down from the Loess Plateau by the Huanghe (Yellow River) and other rivers. Very few localities have an elevation over 50 meters. This very gently sloping region has been subjected to flooding throughout recorded history, maintaining a balance between deposition of alluvium and the slow subsidence of the North China Platform. This deposition process has formed a rapidly expanding delta with alluvial deposits ranging from several hundred to over 5000 meters thick (Zhao 1986).

The hilly areas of the Liaoning and Shandong peninsulas comprise the fourth natural region of North China. This topography is the southern end of a geanticline that continues up through North Korea and the Sikhote Alin mountain ranges of the Soviet Union (Zhao 1986). Average elevation has been reduced to a few hundred meters due to extensive weathering. The Shandong peninsula was once an island until the rapid growth of the Huanghe delta connected it to the mainland.

The climate of North China is dominated by air circulation systems centered outside the defined area. The dominant pressure system in winter is an anticyclone centered over Mongolia and Mid-Siberia known as the Siberian High. The source of dry, cold, stable air, this system maintains an average atmospheric pressure of 1040 mb, among the world's highest, throughout the months of November through February (Domrös and Peng 1988). In contrast, the dominant summertime pressure system is a low-pressure cyclone centered over the northwestern India-Pakistan subcontinent which sustains an average pressure of 995 mb through the months of June, July and August (Domrös and Peng 1988). The remaining months are influenced by the transition from one system to the other.

In North China, the effects of these systems are felt as cold/dry prevailing northerly winds in the winter and warm/moist southerly winds in the summer. This leads to high seasonal variations in precipitation. 60 to 70 percent falls from June to August, while less than 10 percent comes from December to February (Domrös and Peng 1988). North China average precipitation averages from 500 to 700 mm per year, but it is not uncommon to see only 100 mm in a dry year or nearly 1400 mm in a wet year (Zhao

1986). Accumulated growing degree days above 10°C range from 3200 to 4400°C with isotherms running northeast to southwest, indicating climatic variability is primarily a factor of distance to the coast and secondarily a factor of elevation (Zhao 1986). Average temperatures are between 28 and 36°C higher in summer versus winter (Domrös and Peng 1988).

The major drainage system in North China is the Huanghe. It originates high in the Qinghai-Xizang Plateau, flows into the Loess Plateau, through the mountains to the east, and emerges onto the North China Plain to eventually empty into the Yellow Sea. Other major watersheds include the Haihe, which originates in the Shanxi-Hebei mountains and basins region and drains the northern end of the North China Plain; the Huaihe, drawing off the southern end of the North China Plain; the Shandong Peninsula drainage area; the downstream end of the Liaohe, coming from the Da Xing'an mountains of Manchuria; the Liaoning coastal drainage area; the Luanhe; and the Liaodong Peninsula drainage area. North China's rivers can be seen in Figure 1.1

The Huanghe gets its name from the yellow color it picks up as it passes through the Loess Plateau. As noted before, loess is highly erodible. As a result, an average of 37.7 kg per cubic meter are carried away by the Huanghe and its tributaries, giving it the heaviest silt load (1.6 billion tons per year) of any river of its size in the world (Zhao 1986). As the river emerges from the steep gradient of the Shanzi-Hebei Mountains to the slight gradient of the North China Plain, deposition is encouraged. This deposition process, along with the continuing practice of confining the river with dikes has led to the exceptional result that the Huanghe bed is 5 to 13 meters higher than the surrounding plain (Tuan 1970a).

Another interesting feature of rivers in North China is their low annual discharge. When contrasted with a river of comparable size – for example the Changjiang (Yangtze) -the Huanghe has less than half its annual discharge. This can be attributed to the moderate annual precipitation and the high evapotranspiration and percolation rates found in North China (Zhao 1986).

As regards North China's soils, it is important to remember that they have been significantly altered by the prior activities of humans. Generally speaking, soils along the slopes of hills and mountains either have lost significant amounts of topsoil or have been altered through the practice of terracing, while basin, valley and floodplain soils have been affected by the deposition of sediments and the practice of fertilization with 'night soil' (composted human waste), among other wastes.

Because of the extent of human activity on the landscape, it is difficult to directly observe the characteristics of the natural vegetation of North China. However, some scholars have characterized the natural vegetation based upon information in written records and observation of present features of the environment, such as climate, soil, and remnants of natural vegetation (Wang 1961, Zhang 1991). Palynological evidence has also made a significant contribution to reconstructing the character of the past landscape of North China (Shih 1962, Ho 1969, Yu *et al* 2000, Tarasov *et al* 2006).

The natural vegetation of North China emerged only after the Last Glacial Maximum (LGM) (25,000-15,000 BP). During the cool dry conditions of LGM, North China was primarily dry steppe with a steppe-tundra mix in north and west; directly to the west lay the source of all the windborne loess - a vast desert stretching all the way across Central Asia to West Africa (Ray and Adams 2001). Archaeological, historical and physical evidence indicates that since LGM North China has been blanketed by a lush subtropical deciduous forest (Figure 1.3), with wetland plant communities in extensive marshes and salt-impregnated areas of the low coasts and interior basins (Tuan 1970a). The western edge, being adjacent to arid regions, was susceptible to fluctuating environmental conditions. The loess plateau is along the fluctuating "grassland-desert / woodland" (Wang 1961) transition zone, with shrub vegetation bordering on the western grassland-desert side.

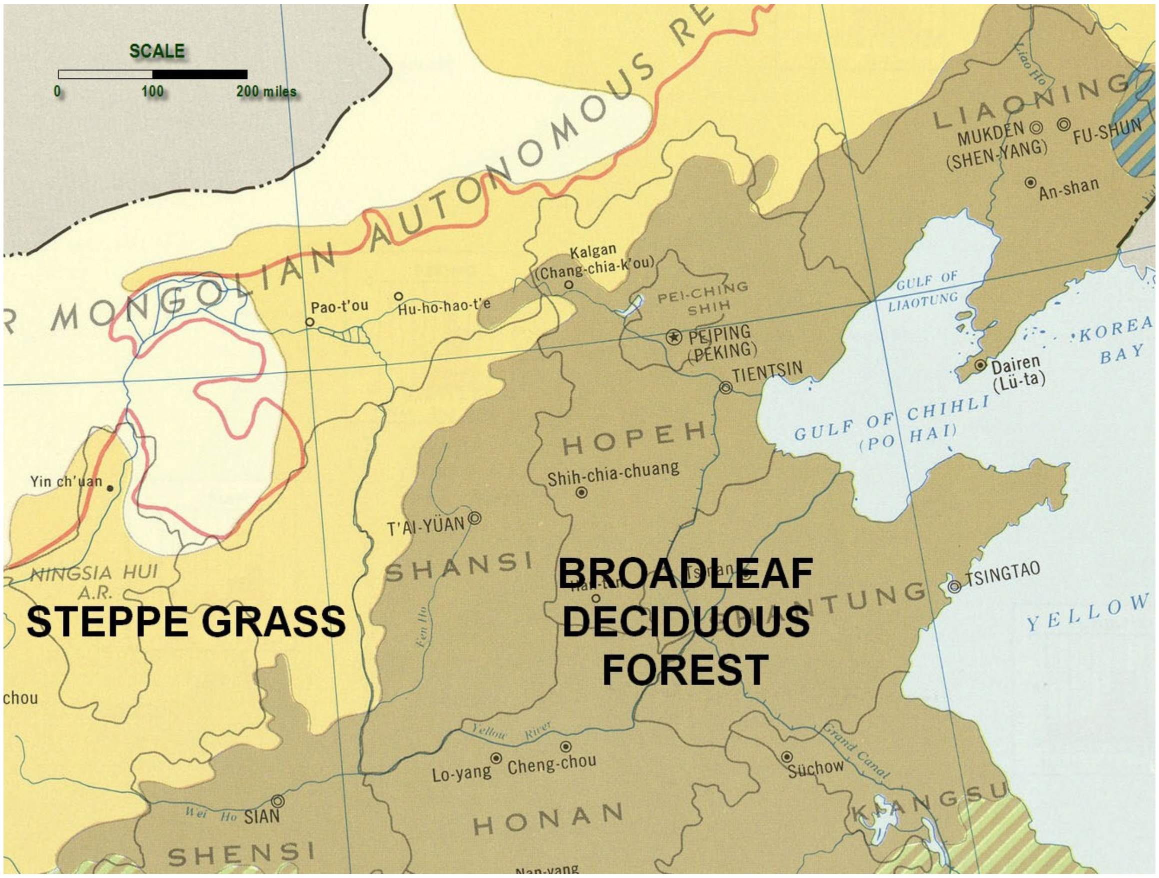

Figure 1.3 - Inset from map *Communist China Natural Vegetation* (CIA 1967). [Public domain] Scanned and published online by Perry-Castañeda Library Map Collection. Legend labels added by author. 10,000 years ago, North China was predominantly broadleaf deciduous forest, bordered by steppe grass in cooler and drier areas in the west.

The extensive wooded area was mostly of the deciduous broad-leaved forest type, dominated by oaks (*Quercus*), along with maple (*Acer*), poplar (*Populus*), birch (*Betula*), and elm (*Ulmus*), while willow (*Salix*) were found along the river courses of the North China Plain (Tuan 1970a). Conifers, such as pine (*Pinus*), juniper (*Juniperus*), fir (*Abies*), spruce (*Picea*), and larch (*Larix*) also played a significant role. More species of oak were found in the Liaodong and Shandong peninsulas than in the areas to the west, and species of pine varied from *Pinus densiflora* in the east to *P. Tabuliformis* in the west (Zhao 1986)

Previous studies of deforestation in China

Although 18th and 19th century visitors to China remarked on the poor condition of Chinese forests (Tuan 1970a 142), it was not until rapid industrialization in the west brought about over exploitation of timber resources on a global scale that necessary scientific attention was devoted to the problem of deforestation.

The earliest scientific study of forests and deforestation in China was Shaw's *Chinese Forest Trees and Timber Supply*, published in 1914, soon after the creation of the Chinese Republic in 1911. He undertook a systematic survey of forest lands by province, focusing on vegetative cover (or the lack thereof), forestry practices, and problems resulting from deforestation. Shaw discounted the commonly held idea that Chinese do not appreciate natural beauty, rather insisting that the idea of "do unto the forest before thy neighbor can get to it" had been impressed upon the people by many generations of population pressure.

Shaw's work was closely followed by Lin Taoyang's 1916 study *Chapters on China and Forestry*, which offered a glimpse at a native Chinese view of forest conditions. Lin blamed "the neglect of officials and lack of police protection" as the root causes of deforestation in China, while ignoring the socio-economic forces which had motivated the widespread destruction of forests. He contrasted forestry in China with that of western nations in an attempt to demonstrate the utility of western forest management practices while encouraging education and stricter enforcement of the forest laws of 1914 as a stopgap measure to slow the pace of deforestation.

W.C. Lowdermilk prepared a paper titled "Forestry in Denuded China" for the American Academy of Science in 1925 (published in 1930). He mentioned clearing for cultivation, waste following rebellions, the demand for fuelwood and absence of directive control as causes of forest destruction. He also examined the deforestation problem on a region-by-region basis. He saw soil erosion as the most disquieting consequence of deforestation and urged its control.

The next significant work on Chinese forests did not appear for several decades due to an extensive period of social and political turmoil following the 1927 Japanese invasion of North China, which continued through World War II, the Chinese civil war and the founding of the People's Republic of China. Richardson's *Forestry in Communist China* (1966) concentrated on forest administration and industry while almost totally ignoring the long history of deforestation which had given rise to contemporary forestry practices. His report was based on a short, controlled visit to China and was conspicuously biased by the optimistic forestry reports filtering from the Chinese government.

Richardson's optimism is surpassed by the views expressed by Westoby in "Making Green the Motherland" (1979). His study was narrowly focused on the few successes and showcase projects that were on display for foreign visitors. Soon after the publication of this paper, China's new "open door" policy resulted in revelations that most official forestry statistics were mere fabrications.

Geographer Rhoads Murphey contributed a chapter, "Deforestation in Modern China," to 1983's *Global Deforestation and the Nineteenth-Century World Economy*. Although he admitted that source material was scarce and sketchy, he was able to construct a thorough analysis of many social, political and economic forces influencing the deforestation of late 19th and early 20th century China.

A very comprehensive modern description of deforestation in China to date has been Smil's 1983 paper "Deforestation in China" and the closely related book, *The Bad Earth: Environmental Degradation in China*, published the following year. He cited "illegal cutting for household use, black marketeering, uncontrolled fires, logging and conversion to croplands (1983, p. 226)" as the primary agents in recent deforestation trends. However, as with most other publications on deforestation in China, his is strictly limited to modern times.

Nicholas Menzies has produced some of the best research presenting historical perspectives on the forests of China. He conducted a thorough examination of the recent history of Chinese forests in his 1988 dissertation *Trees, Fields and People: the forests of China from the 17th to the 19th Centuries*; he developed these ideas further in 1994's *Forest and Land Management in Imperial China*. But again we must remember that much of North China's deforestation had already happened by the 17th century.

Most recently, Mark Elvin (2004) has written extensively about Chinese forests in *The Retreat of the Elephants: An Environmental History of China*. He employs contemporary writings to confirm the presence and cultural importance of forests in Chinese history. He also attempts to break the history of deforestation in China into three phases of increasing intensity and impact, but I find these to be not very meaningful for this study, given the broad diversity of ecosystems and ecosystem impacts over Chinese space and time. I believe that by focusing on a single significant region of China, more relevant conclusions can be drawn. Nevertheless, his book is a rich and compelling environmental history.

Significance

The aforementioned studies have primarily focused on deforestation in the recent century, while historical evidence shows that deforestation has been a major problem for millennia. This relatively narrow focus is understandable, given the extreme nature of the problem and the limited amount of information available on the subject in ancient times. My study attempts to narrow this gap in information by examining the causes and effects of deforestation in a general sense and by searching for evidence of these causes and effects in the long history of North China. This analysis becomes more sophisticated as we return full circle to the present, employing satellite and ground observations to independently determine current trends in deforestation.

In broader terms, why study deforestation? Deforestation has been directly linked to many negative consequences not limited to carbon dioxide buildup, desertification, flooding, habitat loss, poverty, and soil erosion. Forests not only provide valuable natural resources and services, but they are also deeply interwoven into our human culture and psyche. This study will contribute to the body of evidence demonstrating human influence on environmental change.

Millennia of deforestation in North China have resulted in the loss of vast expanses of forest. However, removal of forest is only the direct consequence of deforestation. Many subsequent indirect changes are imminent as forest land is altered.

Trees serve to protect the soil from erosion by deceleration of raindrops, cover by forest litter, and mechanical stabilization through root structures (Gouldie 1986, Gregory and Walling 1987). Therefore, an immediate impact of deforestation is soil erosion. This is an especially serious problem on highly erodible surfaces such as the loess plateau.

As soil erosion accelerates, more sediment is available for introduction into streams. Increased sediment load has been correlated with lowered resistance, increased velocity, and increased stream volume (Ritter 2002). This can lead to higher erosion rates and sediment transportation downstream.

There is also a distinct relationship between deforestation and streamflow. Trees intercept rainfall and discourage overland flow. In addition, forest soil tends to have higher infiltration capacities (Goudie 1986). Studies from around the world all have demonstrated that streamflow increases significantly as forests are removed (Gouldie 1986, Gregory and Walling 1987) resulting in higher peak flows and more frequent flooding. Liu has found runoff to be significantly lower in forested loess plateau watersheds. Deforestation can also degrade stream water quality (Gouldie 1986, Gregory and Walling 1987).

Deforestation has also been linked to climatic variations. Increased surface albedo, surface cooling, reduced evapotranspiration, and increased wind speeds have all been associated with loss of forests (Terjung 1974, Smil 1984, Gouldie 1986). Some scholars argue that the global changes wrought by past human activities have been "small and undetectable (Goudie 1986, p. 259)," but most agree that regional climates can be significantly affected (Tuan 1970a, Terjung 1974, Vale 1982, Smil 1984).

Desertification is an associated problem which has been defined as "retrogressive ecological changes in vegetation, soil or water regime that reduce the carrying capacity of the land and makes it more vulnerable to soil erosion (El-Kassas 1977, p. 5)." Deforestation has been definitively linked with the degraded vegetation, soil and water regimes that lead to desertification (Dhir 1982, Dregne 1986).

Skidmore (1986) has concluded that wind erosion becomes serious when certain conditions exist: "(1) loose, dry, finely divided soil; (2) smooth soil surface devoid of vegetation cover; (3) large fields; and (4) strong winds," all of which are present in the deforested loess plateau of North China. As a result, "wind erosion physically removes the most fertile portion of the soil from the field and therefore lowers productivity…

some soil from damaged lands enters suspension and becomes part of the atmospheric dustload (p. 262)."

An often-overlooked consequence of deforestation is depletion of genetic resources. Old growth forests contain extensive storehouses of genetic information that cannot be recovered once lost (Ashby 1987). In addition, other effects of deforestation – changes in streamflow, decrease water quality, climate fluctuations – have a detrimental effect on many plant and animal species

Vaclav Smil (1983) has stated that "deforestation probably causes more economic and everyday human problems than any other form of environmental degradation in China (p. 231)." None of us want to overlook the tremendous human impacts caused by deforestation, but this study chooses to focus on the environmental impacts.

This study also attempts to refute the often cited belief that human-influenced environmental changes are predominantly a result of Western science, technology and doctrine. White (1967) has proposed that it is a uniquely Judeo-Christian notion that "nature has no reason for existence save to serve man (p. 1207)." In contrast, Chinese culture is commonly viewed as harmonious with nature and gracious towards the environment.

It is demonstrated in this study that deforestation had seriously degraded the North Chinese environment prior to any significant influence of Western culture. Tuan (1970b) argues that "esthetic and religious ideals rarely have a major role … in the play of forces that govern the world (p. 244)." It is this discrepancy which allowed deforestation to become so critical a problem while Chinese scholars, artists and poets were busy touting the harmonious relationship between man and nature.

This study also is an effort to add more substance to Tuan's idea that "the balances of nature can be upset by people with the most primitive tools (1970b, p. 244)." Although this study focuses on Chinese history, it also intends to demonstrate that humans were already drastically altering the North Chinese landscape in *pre*historic times.

It is important to note that this study is not an endeavor to fill in the gap of information on deforestation in North China; rather, it is an attempt to *narrow* the gap in understanding. As Bird (1987) points out, "scientific knowledge should not be regarded as a representation of nature, but rather as a socially constructed interpretation with an already socially constructer natural-technical object of inquiry (p. 255)." Therefore, it is unwise to claim to know the 'truth' about an environmental problem. Nevertheless, in this survey of the past of North China, we may find a better understanding of this problem through our interpretation of the historical and environmental evidence. And in examining the recent past of several North China study sites, the application of more sophisticated monitoring tools may get us closer to the truth of this environmental problem.

The deforestation of North China holds valuable lessons for the rest of the world, especially as we move closer toward a troubling climatic future. A better understanding of how this transformation occurred in the past may help us understand similar transformations elsewhere on the earth. And a better understanding of the impacts of recent Chinese efforts to reverse the trend of deforestation may help determine better solutions for addressing global deforestation.

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Chapter 2

DEFORESTATION AND THE TRANSFORMATION OF THE LANDSCAPE OF NORTH CHINA

This chapter begins with a clarification of how we define deforestation and then proceeds to examine chronologically the evidence of human activities in the past of North China that have been shown to contribute to deforestation. At the end of the chapter there is a brief examination of evidence of the environmental effects of deforestation in North China. As noted before, there exist very few direct studies of deforestation in China prior to the 20^{th} century. However, there is significant evidence of human impact on the environment and, more specifically, there are a number of studies concerning the human causes of deforestation (Sauer 1956, Stewart 1956, Boerboom and Wiersum 1983, Allen and Barnes 1985, Goudie 2000, Vale 2002).

Defining Deforestation

In an environment undisturbed by human activity, many factors influence the formation of what we refer to as 'natural' vegetation. Vale (1982, p. 4) has identified five ecological factors that interact to form vegetation characteristics and patterns:

1. Regional climate determines the availability of water and energy, and thus is the dominant influence upon the general structure of vegetation.
2. Topography modifies the availability of moisture by influencing local climate and water movement over the landscape.
3. The soil, or substrate, may also affect moisture supplies, and it likewise is the major factor in the chemical relationships linking plants and the environment.
4. Biotic influences include plant-animal and plant-plant interactions, the common of the second being so-called competition.
5. Finally, disturbance events such as fires alter local climate, substrate characteristics, and biotic interactions.

It is important to note that human activities are rarely absent from this process of interaction. As Vale (1982, p. 4) points out, human activities "contribute to, rather than substitute for, natural factors influencing vegetation."

The UN Food and Agriculture Organization and UN Environment Program in their studies of forest resources in Africa, Asia, and the Americas, have defined deforestation as "the loss of forestland" and "the loss of any kind of closed forest" (Allen and Barnes 1985, p. 167). Yet simply defining deforestation as loss of trees has its limitations. This definition does not accommodate conditions of qualitative change (known as degradation) in forests, in which structure, species composition or dynamics of the natural vegetation are altered (Menzies 1988). Reduction of total area of forest cover and degradation are both possible results of deforestation.

It is a misunderstanding to think of deforestation as a static condition. Deforestation is more appropriately viewed as "conversion," a continuum between two extremes of forest transformation: from a subtle change in species composition to a complete transformation of the forest to some other land use (Menzies 1988). Allen and Barnes (1985) also define deforestation as a continuum, both in terms of land cover type and degree of disturbance of the natural landscape by human activity (Figure 2.1). Since prehistoric times this process has been occurring and intensifying in North China.

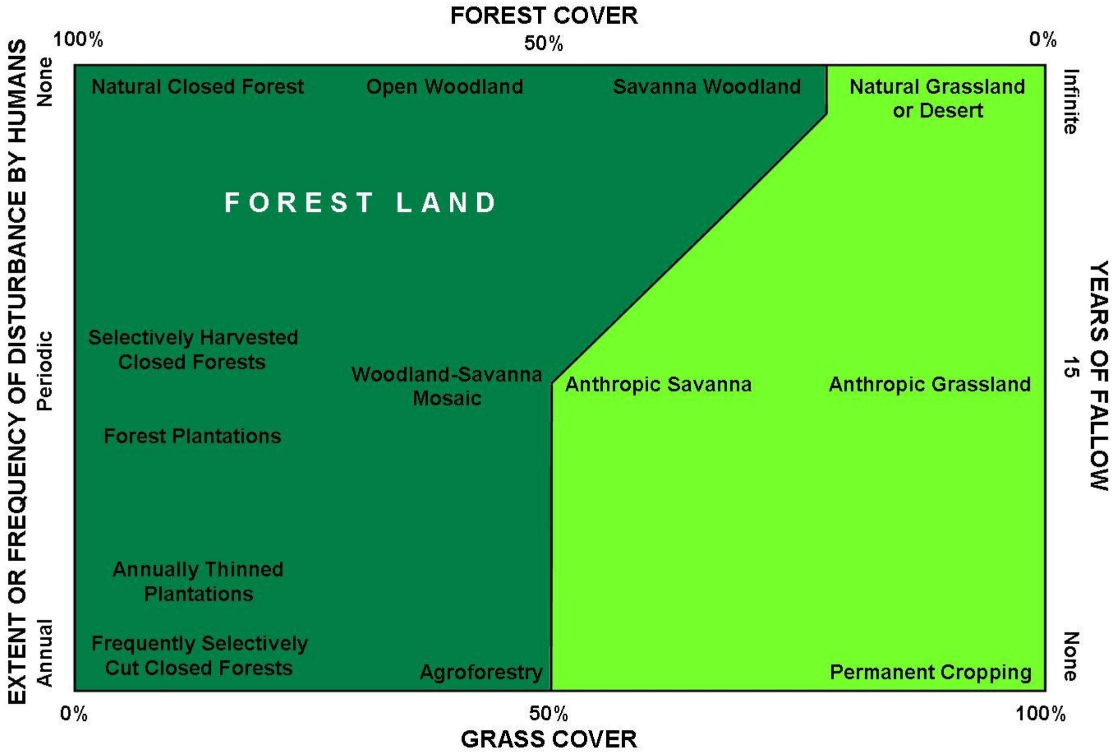

Figure 2.1 - Deforestation as a conversion among a continuum of many potential land covers (after Allen and Barnes 1985) [fair use]. Variability in forest/grass cover and degree of disturbance of the natural landscape from human activity are both important dimensions in defining deforestation. Deforestation in north China has been generally a movement from the upper left (natural closed forest) towards the lower right (permanent cropping).

Deforestation in prehistoric North China

The earliest physical evidence of human presence in North China comes from the caves of Zhoukoudian 23 miles southwest of Beijing. Artifacts and human fossils from over forty individuals, collectively known as Peking Man (*Homo Erectus Pekinensis Sinanthropus*), have been dated to 500,000 BP. Stone tools and implements are evidence that Peking Man made tools. Charcoal, burned body fragments, and hearths are the earliest evidence of human management of fire (Stewart 1956, Chang 1963). The ability to heat and cook increased human survivability, as humans found wider ranges of suitable habitats and edible food (Sauer 1956). Fire also provided security from predators, a focal point of gathering and communication, and an effective means of altering the vegetative cover (Sauer 1969)

At first, fuel needs were supplied by driftwood, drifted or fallen, but early humans also stripped bark from trees to cause them to die and become available for fuel (Sauer 1956). Intentionally set fires were used to drive game during hunting, flush enemies from hiding, kill or drive away predatory animals and other pests, and to protect encampments by controlled burning (Stewart 1956, Goudie 2000). Habitual camp sites and pathways were trampled and disturbed, seeds and roots were dropped, refuse enriched the soil, and digging also led to vegetation changes (Tuan 1970). Tuan has also shown that many sites of early human settlement were continuously occupied, so it may be argued that human impacts on the environment, however slight, were often permanent.

Around 8000 years BP, the Yangshao "Village Farmer" culture brought agriculture to the middle Huanghe valley. Millet was the principal staple crop, supplemented by buckwheat and hemp, domesticated animals (pigs and dogs), hunting, fishing, and wild grains (Chang 1963). Wood was increasingly used for tools, weapons and structures. Chang (1963) found homes were built with large wooden posts. The Yangshao also produced pottery in kilns (Chang 1963). The kilns' high firing temperatures consumed large amounts of wood relative to hearth fires.

Evidence of fire-based shifting cultivation techniques comes from the most excavated Yangshao site at Banpo, Xi'an (Chang 1963). Pollen samples gathered from soil layers corresponding to periods of Yangshao habitation show a cyclical pattern of the presence and absence of tree pollen. Further evidence of forest clearance comes from stone artifacts found at Yangshao sites. Stone chisels, axes and adzes were used for carpentry and felling trees (Chang 1963).

As fields were abandoned for new sites, the forest regrew, but secondary forests are of a different character. "In secondary forests fauna will be radically different from the natural forests and consequently, many of the highly specialized interactions between animals and plants occurring in natural forests can no longer take place… limiting the possibility for reintroduction of certain climax species." (Boerboom and Wiersum 1983, p. 89)

Practices leading to deforestation intensified as the Yangshao were gradually replaced by the Longshan culture between 5000 and 4500 years BP. A fine, thin-walled pottery is characteristic of the Longshan. Potter's wheels appeared for the first time and kiln designs were improved (Chang 1963). Firing temperatures were more easily regulated and controlled, and higher temperatures led to increased demands for fuel.

Agricultural techniques also became more advanced. Most relevant to the focus of this study, it has been demonstrated that the Longshan practiced permanent cultivation (Chang 1963). As Boerboom and Wiersum (1983) have remarked, permanent cultivation typically indicates a complete destruction of the forest. Chang (1963) has also documented more extensive use of axes, carpenters' tools, harvesting tools and wooden cutting implements.

Grazing had a greater impact on forests during Longshan times. As mentioned earlier, the Yangshao primarily domesticated pigs and dogs. The Longshan continued this practice, but also greatly increased the use of cattle and sheep (Chang 1963), which have a much greater impact on the landscape. Heavy grazing has been shown to lead to increased erosion through reduction of the size of soil aggregates, reduction of plant cover and litter, and trampling (Goudie 2000).

Another important facet of Longshan culture is the extensive expansion from the middle Huanghe nuclear area into the eastern plains and coastal areas (Chang 1963). This indicates increasing population pressure, which is certainly a primary factor in deforestation (Allen and Barnes 1985). The result of these migrations was a diffusion of intensifying human activity and disturbance into many forest lands in north China.

From this review of prehistoric human activity in North China, it seems the primary cause of deforestation came with the evolution of agriculture, from simple gardening to shifting "slash and burn" cultivation to total forest clearance for permanent cultivation. Other major contributing factors included burning forests to flush game and enemies, grazing of domesticated animals, the fuelwood demands of hearths and kilns, and the increasing use of wood for tools and structures, all intensified by a growing population as afforded by food surpluses. By the dawn of Chinese history, it can be argued that deforestation was already a well-established practice.

Deforestation in historic North China

The prior description of human activity in North China was based on archaeological evidence, for by definition, there exists no written evidence of prehistoric times. It is the availability of contemporary written information that distinguishes history from prehistory.

The Shang civilization is the earliest in China to be documented with written evidence. The Shang dynasty was established in 1766 BCE and was centered in present-day northwestern Henan province (essentially where the Huanghe emerges onto the North China Plain).

One important feature of Shang culture was the evolution of urban areas. Intervillage networks were organized around central cities which provided a focal point of economy, administration and religion (Chang 1963). Within these cities, palatial buildings were erected on wooden frameworks, placing increasing demands on Chinese forests.

Widespread production of bronze vessels and implements were seen for the first time. For the most part, these were exclusively made for ceremonial, warfare and hunting, while tools made for domestic and agricultural purposes continued to be made of wood, stone, clay or bone (Chang 1963). The processing of ores, alloying and smelting of metal led to ever-widening need for wood and charcoal.

The development of writing during the Shang dynasty also contributed to the deforestation process. The ancestors of modern Chinese characters were brushed onto slips of bamboo or wood (Wang 1993). Ink also demanded wood, as it was primarily made of soot derived from pine ashes.

Other developments to consider include: the chariot, which likely came from the Near East, made of wood with fittings and fixtures of bronze (Blunden and Elvin 1983); extravagant burials of the aristocracy which involved the construction of wooden chambers (Chang 1963); increasing raids and warfare among competing states, which resulted in the destruction and reconstruction of wooden structures; and increased size and extent of grazing herds, which necessitated the creation of pasture lands from forest lands (Tuan 1970), as opposed to earlier practices of grazing animals in the forest.

Population pressure, previously cited as a primary factor contributing to deforestation, became increasingly evident during the Shang dynasty. Eberhard (1977) has estimated the population at the end of the Shang to be between four and five million, resulting in an average density of twenty to thirty persons per square mile, while urban densities were substantially higher (Tuan 1970). Similar densities were found in areas of north China outside the Shang domain, suggesting a figure of ten million in North China by the end of the Shang era (Tuan 1970).

The overthrow of the Shang came at the hands of the Zhou around 1150 BCE. It is from Zhou times that the earliest contemporary account of deforestation in North China is recorded. Mencius (Meng-zi), a well known scholar-philosopher who lived near the end of the Zhou, noted the growing scarcity of timber and condemned the practice of haphazard cutting of forests for conversion to farmland (Tuan 1970). This practice of clearing forests for agriculture became increasingly popular as the feudal system became more firmly entrenched, due to the fact that newly converted lands were not the property of the fief and would not be taxed.

Intensifying population pressure was the major factor in the continuing conversion of forests to agricultural land. Tuan (1970) has estimated the population of Zhou China to have increased fivefold to nearly fifty million at the peak of the dynasty around 500 BCE, but by this time Zhou culture had spread beyond the boundaries of North China, so we must conclude the figure for North China is significantly less than fifty million. The extension of cultivated land and improvements in agricultural techniques, such as irrigation and the use of fertilizers, facilitated this population increase (Blunden and Elvin 1983). Ash from the burning of cleared land was the only fertilizer mentioned in the *Shi Ching* ("The Book of Poetry" – written between the 9th and 7th centuries BCE), yet by the 4th century BCE, manure and night soil were more commonly applied than increasingly scarce ash (Tuan 1970).

Zhou improvements in technology had an intensifying impact on the remaining forests of North China. Most notable are improvements in metallurgy. Bronze became widely used for everyday purposes, and iron making became a major industry by the 6th century BCE. This advance is a significant consideration for the study of deforestation, given that the sophisticated furnaces used for iron manufacture required temperatures between 1400 and 1535 °C (Chang 1963) and must have consumed sizeable amounts of wood.

As with previous eras, developments in architecture also contributed to deforestation. Ceramic tiles were introduced towards the early Zhou era, while bricks were introduced later.

Warfare became more prevalent as the Zhou era progressed. In fact, the final 250 year of the Zhou are known as the "Warring States" period. As mentioned previously, war impacted the forest both directly through the destruction of forests for strategic purposes, and indirectly, through the consumption and destruction of implements and structures. Massive armies were gathered as the Zhou introduced the policy of conscription. "Totals of several hundreds of thousands are routinely mentioned in the sources. Even allowing for literary exaggeration, these were enormous forces for that age in the world's history (Blunden and Elvin 1983)."

Deforestation was also becoming a particularly acute problem in the tenuously established "grassland-desert / woodland" zone on the western end of north China. Settlers penetrated into this area and cleared the land during Zhou times, often with unfavorable results. Evidence of drying of water sources, climatic deterioration and desiccation (Chang 1963,Tuan 1970) demonstrates the extent of deforestation in this region.

The culmination of the Warring States period was the triumph of the Qin state and the creation of the first unified Chinese empire. But soon after the first emperor died, Qin was quickly overthrown by 206 BCE and succeeded by the unifying Han dynasty, which endured for four centuries.

The Han dynasty is widely known for large-scale grand projects (Great Wall, Grand Canal) which consumed vast human and physical resources. Contemporary sources indicate peasants increasing relied on shrubs for fuel as forests were confined to progressively distant and inaccessible areas (Ban and Qian 1974).

Archaeological evidence gives many examples of widespread use of iron for every aspect of daily life (Wang 1982). Extensive artifacts in frontier areas indicates the Han produced an iron surplus for export. Iron became so commonplace and important that the government monopolized the iron industry. A contemporary record from the Han mentions the mobilization of over 100,000 miners annually to mine iron and copper ores (Wang 1982). The main factor in the establishment of an iron-smelting center was the availability of timber for fuel (Hartwell 1967). Important centers of the iron industry in early Han times are shown in Figure 2.2. It can be surmised that deforestation intensified in these areas as a result of increasing demands for iron products.

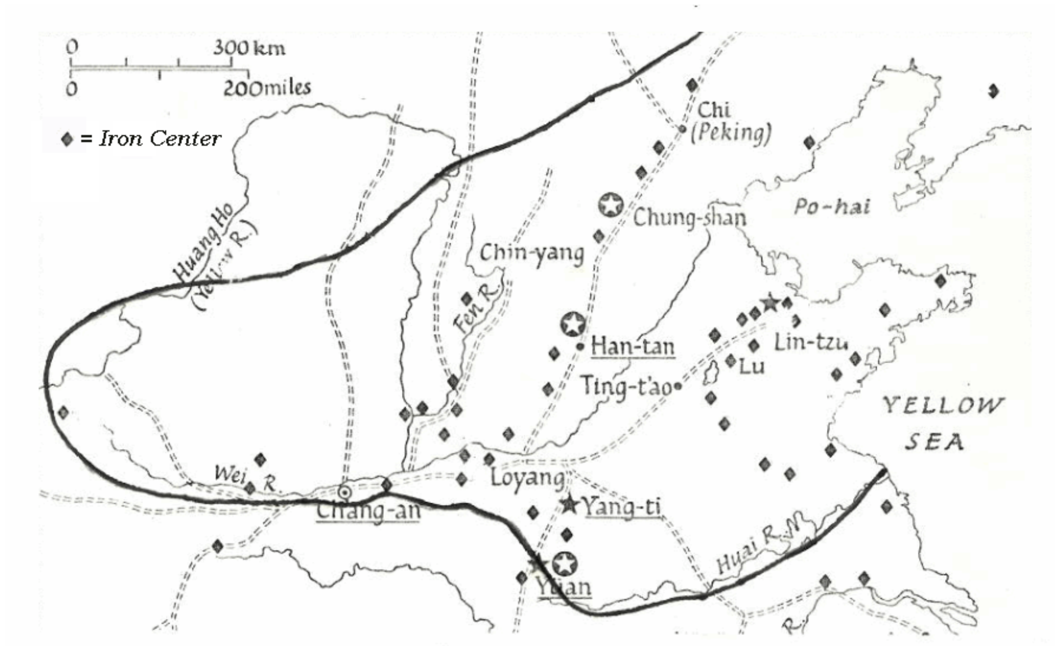

Figure 2.2 – Location of Iron Industries in the Early Han Period, circa 200 BCE (Gernet 139) [fair use]. The main factor in the establishment of an iron-smelting center was the availability of timber for fuel, so it is likely that deforestation intensified in these areas during the Han

By 100 AD a useful type of paper was developed. Its use became widespread and the number of books published increased exponentially. Manufacture of paper added a new component to the deforestation of North China, while ink continued to be derived from pine ashes.

As noted previously, population pressure is a primary factor in deforestation. The first official census was compiled in 2 AD. Early censuses give an opportunity to explore population dynamics as related to deforestation. In 1957 Hans Bielenstein conducted a detailed analysis of the first four official censuses of China and produced very useful population distribution maps (reproduced in Figure 2.3), accounting for political subdivisions, topography, and historical evidence of the situation in different regions. The first census in 2 AD recorded about 60 million individuals (Bielenstein 1957), but since the Han empire extended beyond North China, the total North China population has been estimated to be 43 million (Tuan 1970). Bielenstein's map of the 2 AD census shows the highest concentration of people was found around the capital, Chang'an, although a majority of the population lived on the North China plain. This shift of population from west to east progressed further soon after the first census, as the capital moved from Chang'an in the west to Loyang in the east. Increased population pressure was placed on the North China plain, while in the highlands of the west the pressure slowly decreased. This may have led to a temporary recovery of forests and grassland in the west.

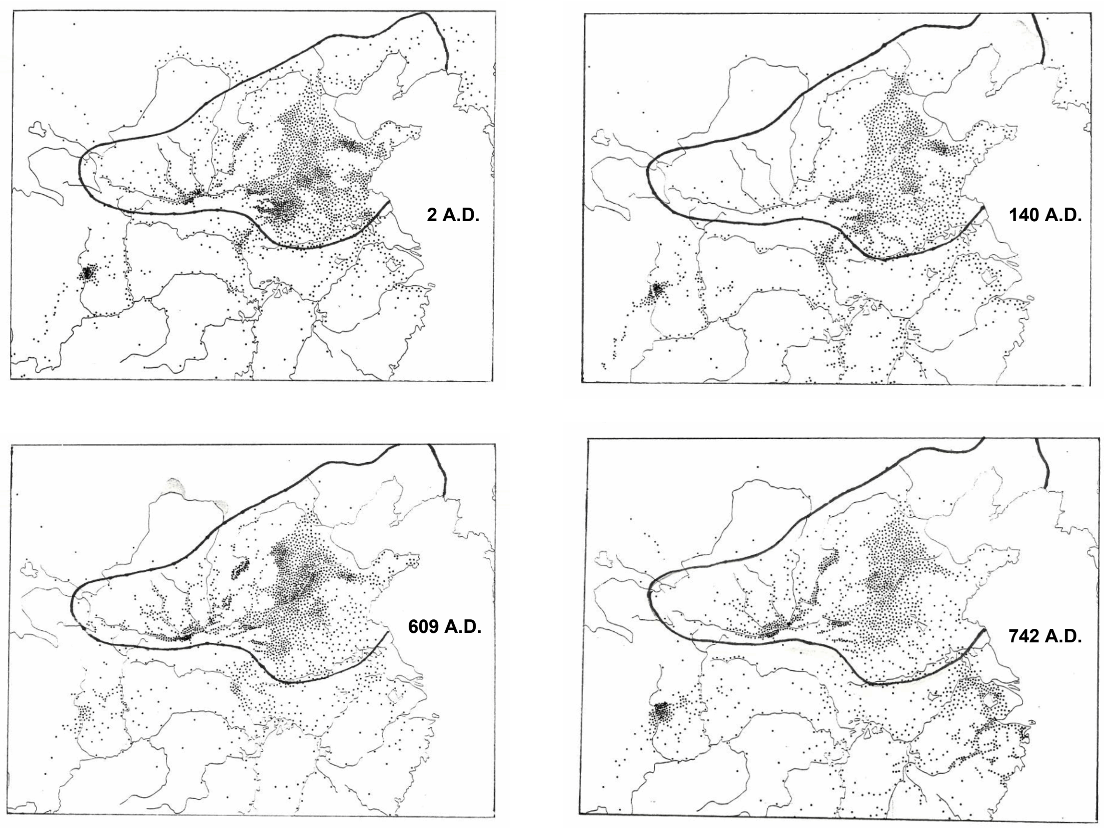

Figure 2.3 - Population distribution in North China, 2-742 AD (Bielenstein 1957) [fair use]. 1 dot = 25,000 persons. Labels and approximate North China boundary added by the author.

By 57 AD, Han China population had declined to around 40 or 45 million due to civil wars, rebellion, frontier wars, floods, famines and plagues. As a result, there were also extensive shifts of population, to the uplands of the Shandong peninsula in the east, and generally towards the south (Tuan 1970). The next census in 140 AD recorded a figure of around 49 million (Bielenstein 1957) for the Han empire, but a shift from North to South continued. Tuan (1970) estimates the loessic valleys lost 6.5 million, while the North China plain lost 11 million.

This trend continued well beyond the fall of the Han dynasty in 220 AD, into the time known as the Period of Disunion. "Barbarians" invaded from the North, and plagues and famines further contributed to population decline in North China. A census in 280 AD recorded about 16 million. Although it is understood that population had declined significantly, Bielenstein (1957) and Tuan (1970) agree that the census number was a gross undercount due to the chaos of the time. Refugees continued to flow towards the South and Southwest, and by 464, the population of South China had increased fivefold (Tuan 1970), facilitating a substantial degree of recovery in North China's forests. The noted Huanghe historian Tan Qixiang established a clear relationship between human activity and the behavior of the Huanghe (personal communication, and in Vörösmarty *et al* 1998). He has shown that during the Period of Disunion the Huanghe was relatively stable and there were no course shifts of major floods. This is attributed to the Period of Disunion population shift and recovery of vegetation upstream.

Before proceeding to examine later dynasties, it is important to note the arrival of Buddhism in China and its impact. Buddhism was first introduced from India in the first century and had become well integrated into Chinese society by the end of the Period of Disunion. The two major impacts of Buddhism on the environment of north China came in the form of, one, the stimulation of grandiose architectural projects, and, two, the practice of cremation. Clearly cremation demanded substantial wood, while the boon in architecture consumed large amounts of building materials, such as wood, bricks, tiles, iron and other metals, all of which have been previously related to forest removal. In Loyang, the capital of the Northern Wei state in the Period of Disunion, construction of temples grew to occupy two-thirds of available land (Tuan 1970).

In 589 China was again unified, but under a short-lived, two-emperor dynasty – the Sui. Emperors Wen and Yang undertook many large-scale projects, and two in particular contributed to a renewed deforestation of North China. First was the reconstruction of ancient capitals at both Chang'an and Loyang. The scale of the construction, as evidenced by the millions of laborers involved, demanded enormous amounts of building materials. The second project of importance to this study was the launching of an imperial navy which was involved in expeditions to Formosa, the Ryuku islands, Sumatra, southern Vietnam, and Korea (Gernet 1972).

The Sui restoration of northern capitals led to a steady increase in the population of North China. The next official census was taken in 609 and counted about 46 million persons in all of China, yet Bielenstein (1957) believes the population of south China had been undercounted. The population distribution map for 609 (Figure 2.3) shows that North China had regained much of its population by this time.

The Sui dynasty overexerted itself through its many massive projects and extensive military campaigns. Rebellions followed and the Sui was succeeded by the Tang dynasty in 618.

One of the most notable elements of the Tang was the development of a "conservation ethic" among the ruling class (Schaefer 1962). The motives for this new outlook were complex. Schaefer (1962) believes a proper combination of religious attitudes, the desire to preserve historical remains, a perceived need for aristocratic privileges such as private hunting grounds and gardens, the evolution of esthetic ideals, and even scientific aims, made a conservation ethic possible.

These principles were not sufficient to save the forests of North China, but they may have slowed the rate of destruction. One manifestation of the conservation ethic was a set of laws designed for fire prevention. Arson, burning of fields, and fires along public roads were all prohibited, although difficult to enforce. There was also state encouragement of the planting of economically valuable trees and forest plantations (Schaefer 1962). Unfortunately, these principles were somewhat unique to the Tang period and were not embraced by future dynasties. Evidence of the conservation ethic disappeared as central government control began collapsing in the eighth century.

By the middle of the Tang era, evidence of the effects of the iron industry on the forests of North China began to emerge. Severe deforestation in Shandong drove the iron industry away from many areas where it had previously prospered (see Figure 2.2) (Hartwell 1967). Yet the iron industry continued to prosper in other areas.

Other important aspects of the Tang were developments in the military. The Tang greatly expanded the military campaigns of the Sui to battle the Tibetan, Turkic and Muslim frontier areas. At its greatest extent, the Tang Empire reached to Kashmir. An important factor in this expansion was the extensive use of horses. According to contemporary texts, the Tang had only five thousand horses at the beginning of the dynasty, but by the middle of the seventh century, over 700,000 horses were grazing in present-day Gansu and Shaanxi (Gernet 1972), creating additional pressure on the remaining land.

Once again it is important to note changes in population. A comparison of population distribution maps from 609 and 742 (figure 2.3) reveal a drop in North China population, which can be attributed to wars, famines, and floods, the same factors seen in other periods of dynastic decline. Tuan (1970) notes that an additional factor may have been the stimulation of commerce in the South, as Arab traders developed extensive trade routes in the eighth century, as well as Persian and Japanese merchants who became frequent visitors to the southeast coast. The Tang census of 742 recorded about 49 million individuals, 32 million of which were believed to have been in North China (Bielenstein 1957). Overall, it is believed that the uplands of western North China lost approximately two million people from 609 to 742, while the North China plain lost about 7.5 million (Bielenstein 1957). During the same time period, the population of South China increased by over 8 million (Bielenstein 1957).

A half-century of fragmentation and disorder known as the Five Dynasty period followed the Tang dynasty collapse in 907. As many as fifteen states struggled for power in this time, and "barbarians" – the Xia to the west and the Liao to the northeast - grew considerably more powerful and troublesome. Conflicts with these frontier peoples continued well into the next dynasty, resulting in a steady pressure on North Chinese forests from the ongoing military consumption of resources.

China was reunited again in 960 under the Song dynasty. Hsu (1970) believes Song China may have been on the verge of an industrial revolution. From the 9th to the 11th century, annual iron production increased twentyfold (Hartwell 1967). This growth was prompted by the demand for iron and steel weapons, agricultural implements, salt pans, nails, anchors, armor, and iron currency (Hartwell 1967) . Gernet (1972) estimates that 200 billion coins were minted during the Northern Song period (960-1279). The metal industries as well as the manufacture of salt, alum, bricks, tile and liquor led to a period of rapid deforestation (Tuan 1970). Large scale forest cutting by great monasteries and soldier-farmers also contributed to the problem (Tuan 1970). North China was hit the hardest; by the 11th century, an acute fuel shortage led to the first widespread substitution of coal for charcoal (Tuan 1970). With a new solution to the fuel crisis, industrial growth may have continued. But invasions of nomadic tribes into North China eventually severed the Song from sources of iron ore and coal necessary for further development (Hsu 1970).

Without a comprehensive census during the Song Period, population in north China is difficult to estimate. Tuan (1970) believes the population of all of Song china ranged from 60 or 70 million in 980 to over 100 million in 1100. Estimates of what percentage inhabited North China range from 20 to 50 percent (Kracke 1953). If one considers that the 1195 census conducted by the Jin recorded 48.5 million in North China and sparsely populated parts of Mongolia and Manchuria, then the higher estimates are likely more accurate.

The Jin state was created by the Jurchen people (descendents of the troublesome Liao), who in 1126 seized the northern capital at Kaifeng and separated most of North China from the southern Song. Conflict continued between the Jin and Song, but with a relatively stationary front, resources were not consumed as voraciously as in previous times of conquest. And despite Jin efforts to revive the Song iron industry, poor management, loss of markets, and natural disasters combined to a rapid decline (Hartwell 1967). These iron-producing areas would not reach Song production levels again until the 20th century. A minor recovery of North China's forests did not last long.

War again became the source of forest destruction in North China. Genghis Khan began his attacks against the Jin in 1210, completing a conquest of North China by 1234. Consumption of forest resources continued as the Mongols carried the conquest to Song China, Korea, Central Asia, Persia, Russia and Hungary. Also significant was the launching of massive naval expeditions against Japan (1274 and 1281) and Java (1292-3).

By the 14th century the Mongol Yuan dynasty had stabilized its borders, but internal destructive forces grew to become widespread: rapacity of the ruling class, corruption, oppression, and poverty (Gernet 1972), compounded by natural disasters. Rebellions gained momentum and by 1368 the Mongols had retreated.

China was reunified under the Ming dynasty in 1387. The Ming period began with a large-scale reconstruction of the agrarian economy. Transfers of population and government incentives led to the restoration and reclamation of large areas of farmland, reaching a peak of 5 million acres in 1374 alone (Gernet 1972). Farmland policies, and the later introduction of New World crops, led to increased food production and by 1600 the population of Ming China had surpassed 150 million (Tuan 1970).

As was true early in previous dynasties, the Ming also began in an expansionist fashion as land campaigns were launched against the Mongols, Manchus and Vietnamese, while maritime expeditions were launched as far as East Africa. This gave way to a defensive posture by the mid 15th century due to increased attacks from nomads in the North. By 1580, the Ming had reinstated a Northern Song policy of promoting regrowth of border forests to deter nomad attacks (Tuan 1970). Ming officials also promoted the restoration of economically valuable trees through a law requiring each family to plant 200 mulberry and 200 jujube trees (Gernet 1972).

Despite a few positive policies, tremendous population growth resulted in deforestation on a massive scale. Many areas were completely denuded of trees. Tuan (1970) translated a Ming account of deforestation in practice, from a 1596 gazetteer of Shanxi province: "When the timber by the streams was gone the wood cutters went into the midst of the valleys in crowds of a thousand or a hundred, covering the mountains and wilderness; axes fell like rain and shouts shook the mountain… the beautiful scenery of Ch'ing-liang became like a cow and horse pasture (p. 141)."

In the northeast, the Manchus (descendents of the Jurchens) grew in power while Ming power waned early in the 17th century. They slowly eroded away Ming territory until they captured Beijing in 1644, which became the capital of the Manchu's Qing dynasty. A 15-year war of resistance by the southern Ming was very destructive and by its peak the population had fallen to 120 million (Gernet 1972). After finally conquering the Ming, the Manchus took the war to frontier areas to add new territories and make the Qing Empire the largest and richest country in the world.

Population exploded in Qing times. A 1787 census recorded about 292 million people, with about 110 million of these in North China; by 1850 the total had risen to 430 million (Ho 1969). With so many appetites to satisfy, the demand for farmland tends to overshadow other causes of deforestation. Mountain slopes were stripped and terraced to provide more food. Elaborate measures were devised to log old-growth forests in previously inaccessible areas (Menzies 1988). The forests of North China came close to extinction. Western visitors to China in the Late Qing remarked at the absence of trees. Rockhill visited in 1892 and remarked there was "not a forest tree to be seen, only a few poplars recently planted along the irrigation ditches (Tuan 1970, p. 142)". The only clues that North China had once been forested were restricted to imperial parks, monasteries and clan lands that could be protected (Menzies 1988). It is interesting to note that non-Manchu Chinese were prohibited from Manchuria, so most of the forest in the northeast remained untouched until late in the Qing dynasty.

As mentioned in Chapter 1, many scholars have written about the problem of deforestation in modern China (Shaw 1914, Lin 1916, Lowdermilk 1930, Richardson 1966, Westoby 1979, Murphey 1983, Smil 1984). Wood was so scarce by 1930 that remaining clusters of trees had to be heavily guarded (Lowdermilk 1930). By 1949, less than four percent of China's forests remained. This small percentage survived primarily due to remoteness and inaccessibility.

As we approach the present, modern technology and science affords an opportunity to examine North China's forest trends with a more analytical approach. Chapter 3 will give an overview of forest changes in the era of the People's Republic (1949 – present) and analyze detailed forest changes at several study sites in North China.

Transformation of the Landscape of North China

In North China over the past 10,000 years, major changes in the environment of North China have occurred as a result of deforestation. Archaeological and historical evidence suggest that North China was significantly warmer and moister than the present. Written records are lacking prior to 1100 AD, but excavations in Henan province have yielded fossils of subtropical plants and animals (bamboo, elephant, water deer, bamboo rat), which indicate a warm and more humid climate. Inscriptions on oracle bones indicate winters around 3500 BP were about five degrees Celsius warmer than today

(Domrös and Peng 1988). Written records concerning events such as freezing of lakes and streams, snowfall, and dates of blooming of certain flowers indicate that the temperature was fluctuating but steadily decreasing from 1100 BCE to 1400 AD (Ge *et al* 2008) .

Comprehensive meteorological records began to appear in the 15th century. These indicate continuing fluctuations with a cooler mean than present. Temperatures have steadily climbed since the late 19th century. Figure 2.4 shows the estimated temperature changes during the last 5000 years in China. Some scholars (Chang 1963, Tuan 1970, Smil 1984) argue that the cooler and drier climate of modern China is a result of deforestation.

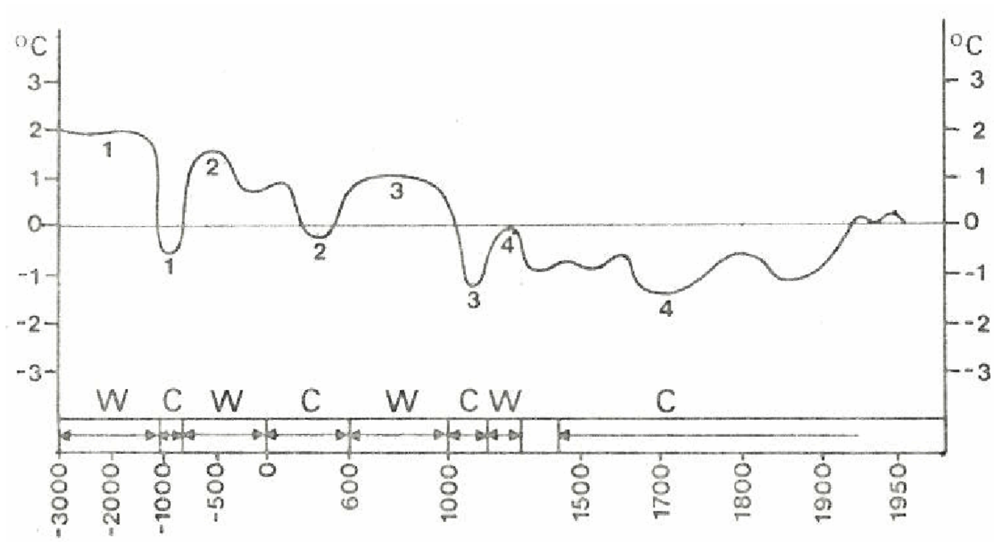

Figure 2.4 – Temperature Change in China during the last 5000 years, expressed as deviation from 1950 mean (Zhang, P.K. and C. Gong. "Three Cold Episodes in the Climatic History of China" 1987) [fair use]. Data used in this study was primarily from north and Central China. The cool dry trend is believed to be a result of deforestation.

The earliest permanent settlements were along the river courses in the fertile loess plateau. As humans cleared the forests for any of a number of reasons, the highly erodible loess was washed into the streams and was transported downstream through the mountains and basins region. Once the Huanghe emerged from the hills and valleys onto the nearly flat North China Plain, deposition of the sediment occurred. As the Huanghe emptied into the sea, the deposition process continued and deltas extended into the sea.

Around 4000 BCE, the North China Plain was extensively settled and peasants began to confine the banks of the river to prevent flooding. This process often met with disastrous consequences as the channel bed rose above the surface of the plain. The resulting inevitable floods were catastrophic. At the same time, farmers reclaiming the newly formed land at the mouth of the river assured its permanence as they planted crops and stabilized the soil.

One piece of evidence is the often-changing course of the Huanghe, as shown in Figure 2.5. According to Blunden and Elvin (1983), "the primary cause of these rapid shifts of course has been the uniquely heavy load of silt carried by the Huanghe. As the current slackens near the sea, much of this is redeposited, building up the riverbed and sooner or later forcing the water to run elsewhere (p. 16)." Figure 2.5 also shows the amount of land surface built up by sediment deposition over the past 2000 years

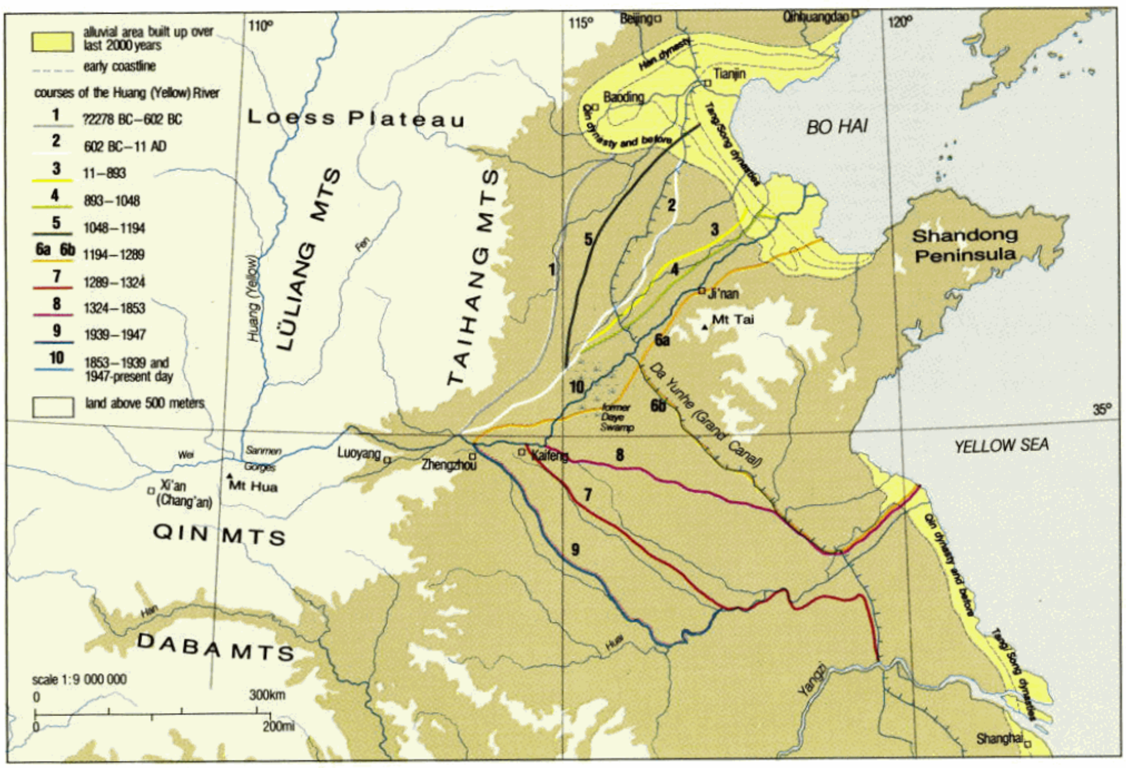

Figure 2.5 – Major Course Changes of the Huanghe (Blunden and Elvin. *Cultural Atlas of China* 1983) [fair use]. The course of the Huanghe has changed dramatically in the past 4000+ years. While the course changed only twice in the first three millennia, it has changed eight times in the last millennium. Also notable is the alluvial area built up over the past 2000 years (yellow shading).

Another clue to this dramatic change in the landscape comes from the name of the Huanghe. Over 2500 years ago, it was known only as the *Da he* – "great river." It gradually came to be known as the *Huang he* – "yellow river." From this it is understood that the Huanghe did not always carry enormous amounts of the yellow-colored loess, but only after human activity led to removal of forest land that erosion and sedimentation occurred at a large scale.

As mentioned previously, also important is the work of Tan Qixiang in measuring relationship between human activity and the behavior of the Huanghe (personal communication, and in Vörösmarty *et al* 1998). Figure 2.6 shows the 30-year flood frequency of the Huanghe, which shows an increased frequency over time. This problem was well understood, as is reflected by a Ming official's statement on deforestation in Shanxi province: "If heaven sends down a torrent, there is nothing to obstruct the flow of water. In the morning it falls on the southern mountains; in the evening, when it reaches the plains, its angry waves swell in volume and break embankments causing frequent changes in the course of the river (Tuan 1970, p. 141)."

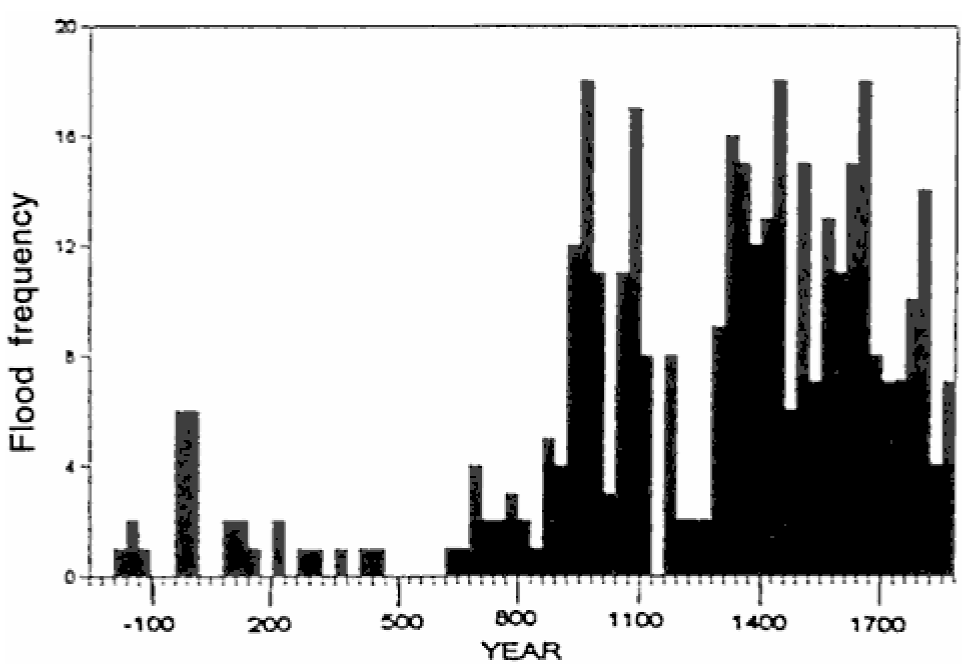

Figure 2.6 - 30-year flood frequency of the Huanghe, 250 BCE – 1880 AD (Vörösmarty *et al* 1998 222) [fair use]

As mentioned earlier, in the first millennium BCE, farmers penetrated into the semi-arid grassland-desert / woodland zone on the western end of North China. Attempts were made to farm this fragile environment, and the eventual result was desiccation and desertification which has slowly migrated eastward (Chang 1963, Tuan 1970). With little vegetation to hold the soil and few trees to the east to serve as wind breaks, severe dust storms have become a serious problem in recent centuries.

Analysis by Zhang has shown that dust fall coincides with cooler, drier periods (Domrös and Peng 1988). This assertion seems logical. More remarkable is the temporal distribution of dust storms as shown in Figure 2.7. Using historical literary sources and weather gazetteers, Zhang's curve shows the frequency of occurrence of dust storms from 300 AD to present. It is interesting to note the peaks that coincide with periods of known rapid deforestation. The same relationship was manifested in 1988 as massive dust storms resulted from the deforestation of Heilongjiang after the Great Black Dragon Fire (Salisbury 1989).

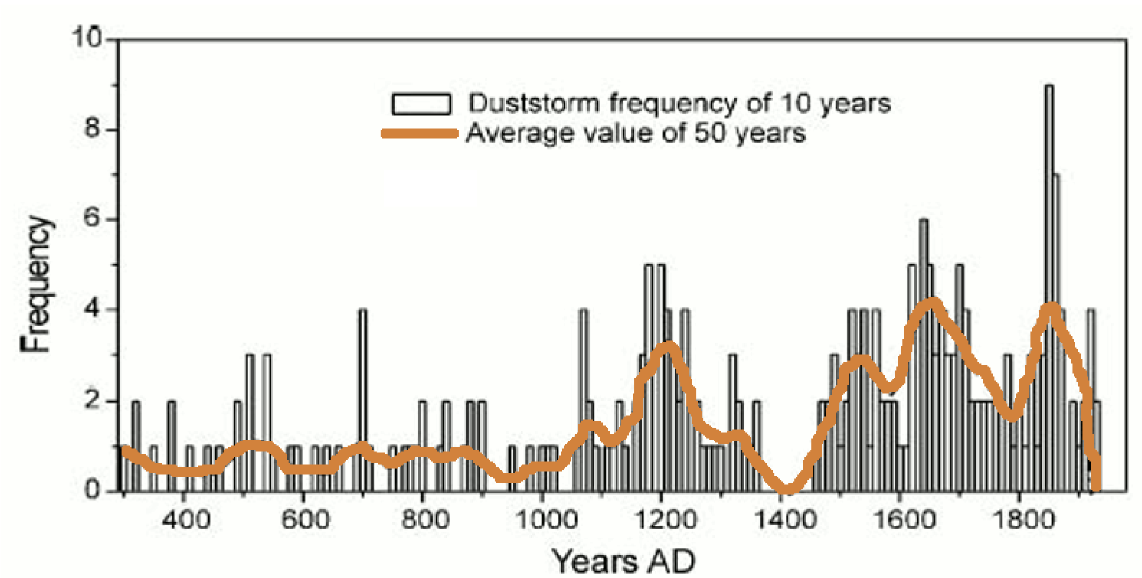

Figure 2.7 – 10-year North China Dust Storm Frequency since 300 AD (Domrös and Peng. *The Climate of China* 1988) [fair use].

The consequences of genetic losses from deforestation cannot be measured easily. The biological resources of China are considered to be rich and varied, but they are only a poor reflection of what once existed (Zhao 1986).

Summary

At the beginning of the chapter, deforestation was defined as a continuum between two extremes of forest modification – from a subtle change in species composition of a natural forest to a complete transformation of forest to some other land use. In North China, this process has been occurring and intensifying since prehistoric times.

It has been demonstrated that it was not only industrialized and modernized Chinese who deforested North China, but primarily with the aid of fire, primitive humans were also able to significantly impact their environment. Fire was used for warmth and cooking, and soon spread to the landscape in the form of game drives, pest removal, and eventually land clearance for agriculture. Early deforestation was most significant along river courses where most evidence of early human settlements have been found.

Fire also played a major role in the deforestation of North China as a fuel for manufacturing and industry, from the hardening of spears in Neolithic times, to the firing of pottery, tiles and bricks, to the smelting of bronze, iron and steel. Wood was also consumed as a raw material for the manufacture of everything from toothpicks to temples.

Warfare also severely impacted the forests. From prehistoric times, burning forests to expose or flush an enemy was a common strategy. Times of conflict increased demands for weapons, armor and wooden ships. Forest was converted to pasture to sustain armies of horses. Destruction and reconstruction of cities and forts denuded entire mountains.

Yet the primary factor influencing deforestation has been shown to be population pressure. The immediate response to population pressure has repeatedly been to convert forest land to agricultural land. All previously mentioned factors only intensify as population pressure increases.

What was once an expansive subtropical forest has been transformed into a semiarid, virtually treeless landscape. Increased windspeeds and exposed soil have resulted in tumultuous storms of yellow dust, and desertification continues its march eastward. China's deforestation has resulted in loss of valuable soil. The Huanghe and other rivers have become heavily laden with silt and excess overland flow resulting in frequent and violent flooding and loss of untold millions of lives. The quality of river water has been seriously degraded, and countless species of flora and fauna have vanished.

Today's residents of North China know the consequences of deforestation as well as anyone. It is they whose quality of life has been compromised by millennia of neglect and abuse of the forests. It seems only fitting that it is in modern China that we see the some of the greatest efforts to restore forested landscapes.

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Chapter 3

ASSESSING RECENT TRENDS IN NORTH CHINA'S FORESTS

1) Introduction

China, with its unmatched population and scope of environmental degradation is in a unique position to play a critical global role as evidence mounts of dramatic climate change on our planet. Great attention has been focused on China's efforts to address the effects of long-degraded landscapes. These efforts have primarily focused on China's forests, which provide tangible benefits to environmental and human well-being. The mistakes and grave consequences of China's deforestation provide valuable lessons for the places on earth where natural forest remains (Sayer and Sun 2003).

Despite many physical, cultural and political obstacles, the young People's Republic of China engaged in an array of public forest planting projects of varying scale. Even before agricultural land had been redistributed, the new government claimed ownership of all natural forests in 1950 (Ross 1988). By 1955, problems of desertification prompted the Chinese Government to plant its first shelter forests in the semiarid Northwest (Runnström 2000). These and other local- and regional-scale multipurpose afforestation programs continued through the early 1960's (Hyde *et al* 2003). Nevertheless, deforestation continued to outpace afforestation, primarily due to massive nationwide campaigns to expand agricultural lands, as during the Great Leap Forward (1958) and Cultural Revolution (1966-76) (Hyde *et al* 2003)

Development of commercial resources was the initial focus of forestry policy, but the impact of environmental issues quickly became too severe to ignore. The first major effort in response to an environmental crisis was the Project on the Development of *Sanbei* ("Three Norths") Shelter Forest, also known as "Great Green Wall". This project was initiated in 1978 to protect against increasing desertification and severe dust storms. This project aims to establish by 2050 35.6 million hectares of protective forests over a swath of Northeast, North, and Northwest China (Ministry of Environmental Protection 2008). State Forestry Bureau reports claim over 23 million ha had been reforested

(Peoples Daily 2001), but Smil (1993) estimates a survival rate below 30%. Government funding of the Sanbei project has decreased since 1986, and fraud, waste, pests and drought are among many widespread problems (Smil 1993)

Afforested areas are often not viable due to poor planning or execution, inappropriate species-climate compatibility, drought, pests, fire, poor maintenance, monoculture vulnerabilities, and, of course, illegal harvesting. There is a history of ground observations contradicting government claims of large-scale afforestation successes; areas of ‘success’ often are found to have experienced marginal changes or even complete failure (Trac et al 2007). Systematic measurement of the success of afforestation programs has proven tricky, primarily due to the uncertainty of government-supplied statistics and data. Smil (1993) compared actual survival rates with official claims of afforestation through 1990 and found very large discrepancies (Figure 3.1). Comparing forest growth rates became even more challenging in 1998, when official forest survey methods were changed. Areas with forest cover as low as 20% are now defined as forested (the prior threshold was 30%). Bamboo is also now defined as forest, and shelter forest in any condition is included as well (Hyde et al 208).

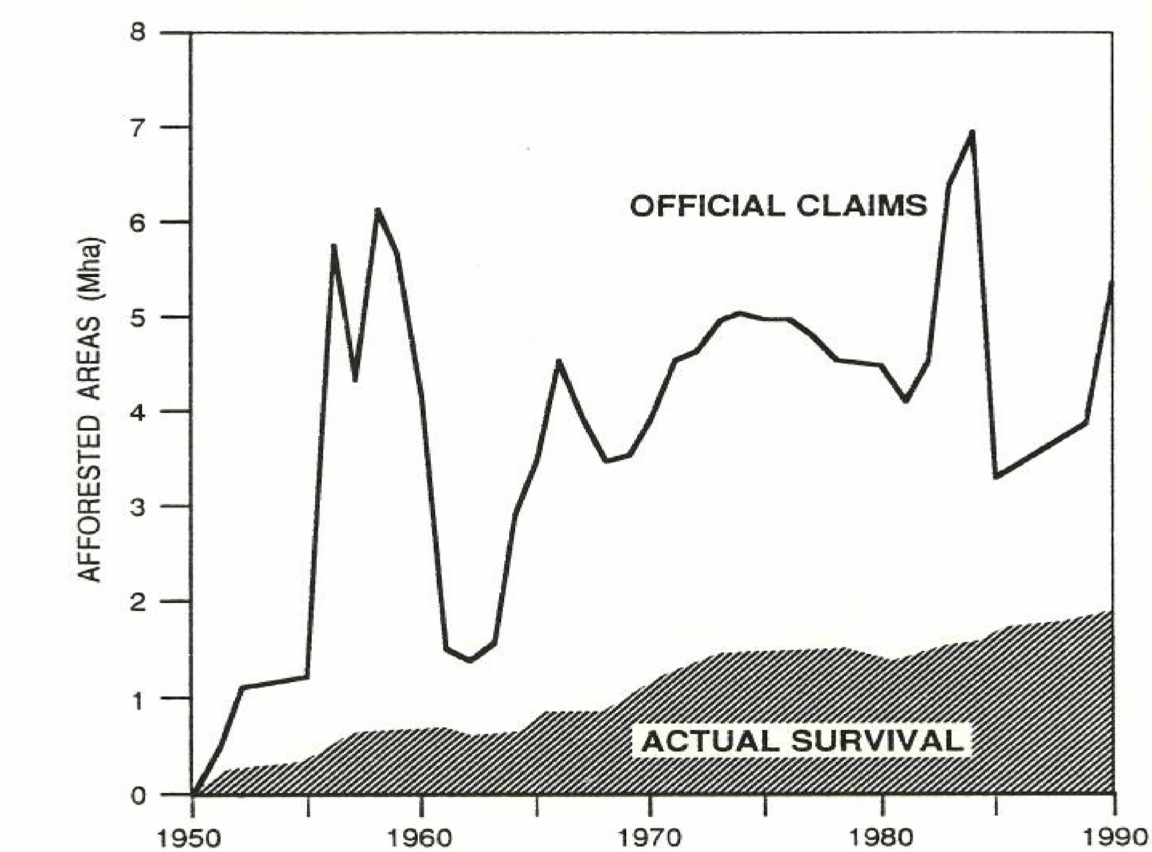


Figure 3.1 – Discrepancies in Afforestation Claims (Smil 1993) [fair use]. Official claims of afforested areas vary dramatically, especially among periods of political reform. The actual survival reflects a more natural pattern of afforestation.

According to the 6th National Investigation on Forest Resources (1999-2003), forest area across the country totaled 175 million ha, an increase of 16 million ha, as compared with the findings of the 5th National Investigation on Forests Resources (1994-1998) (Ministry of Environmental Protection 2008). Total forest coverage was reported as 18.2%; this figure is often repeated but has yet to be independently validated.

A significant change in government priorities seems to have taken place after the Great China Flood of 1998. Although this flood paled by comparison to historic Chinese floods – two floods of the Yellow River in the 19th and 20th centuries had killed up to a million people– in an era of modern flood control systems and easier access to information, the statistics were shocking to many in China: approximately 3000 dead, 150 million displaced, 14 million homeless, and about a $26 billion loss, the most costly flood since the 1950s (Lang 2002). This disaster prompted the central government to acknowledge the primary culprit as illegal logging in upper watersheds, and by the end of the year, a new policy banning logging in seventeen provinces was strictly implemented. Within a year a number of major afforestation projects had been undertaken (Ministry of Environmental Protection 2008):

- Natural Forest Conservation Program (NFCP, also referred to as NFPP – National Forest Protection Program)
- Grain to Green Program (GTGP)- Farmers abandoning farmland and former forestry sector employees are given compensation in grain and cash
- Project on the Development of *Sanbei* Shelter Forest (The 1978 *Sanbei* shelter forest program reinvigorated and expanded to the Chang Jiang basin after 1998)
- Control Project on Wind Dust Sources to Beijing and Tianjin
- Project for the Conservation of Wildlife and Development of Nature Reserves
- Project on the Development of the Fast-growing Commercial Forest Bases in Key Regions

Before we examine forest trends in China in more detail, it is important to note that environmental policies in China have a significant impact on the rest of the world. Chinese importers have increasingly been buying up lumber from the Russian Far East, Malaysia, Indonesia, and other countries (Renner 2005). Between 1998 and 2008, China's imports of wood products increased by 450 percent (see Figure 3.2); of every ten tropical trees traded in the world in 2004, five were destined for China (Ma 2008).

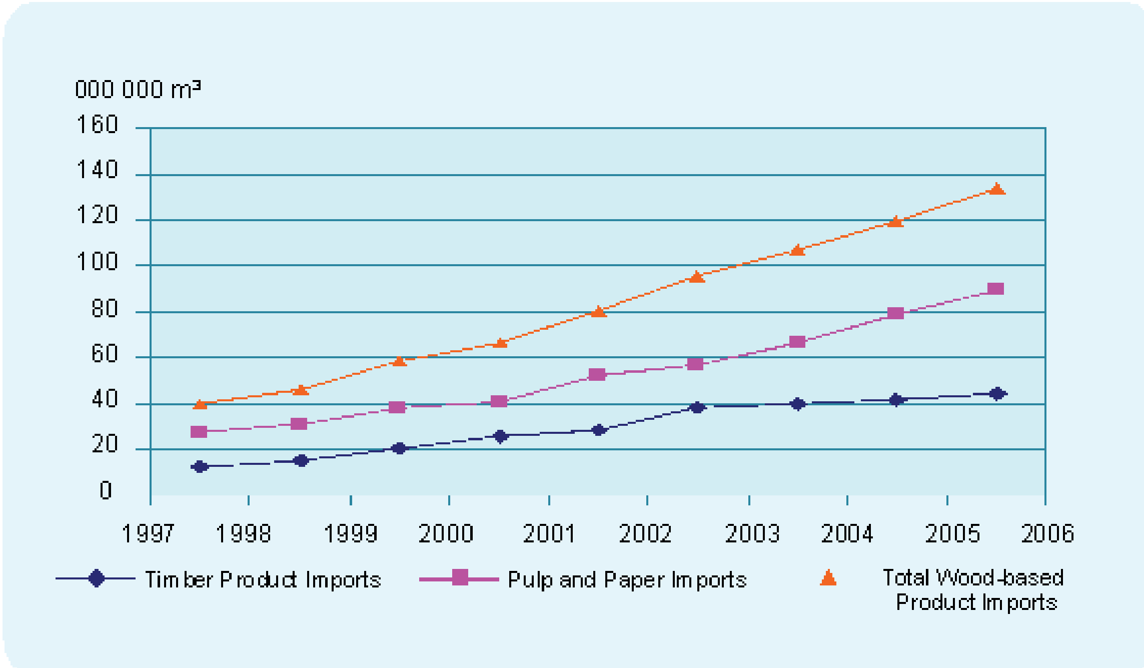


Figure 3.2 - China Forest Imports 1997-2006 (Bull 2006) [fair use]. Pressure on Chinese forests is relieved through dramatic increases in imports of wood products, facilitating the success of afforestation projects.

It appears that 1998 was a watershed year for North China's forests. On the one hand, very clear action was taken by the government to improve stewardship of Chinese forests. With such large scale and well-funded programs ($12 Billion for NFCP – Hyde *et al* 2003; over $13 Billion for GTGP by 2005 – Liu *et al* 2008), we should expect to see genuine positive growth in North China's forested lands. Monitoring the success of this endeavor is meaningful for the study of global climate change. The Chinese environmental programs are among the largest ever undertaken in the world (Liu *et al* 2008), and early reports indicate there are important signs that the millennia-old trends of deforestation may be reversing. Zhang *et al* (2000) reviewed the first two years of the implementation of NFCP and found encouraging results. The United States National Academy of Sciences commissioned a report on the two major policy changes – NFCP and GTGP. Published in 2008, the report showed sustained growth both in government investment and areas impacted for both programs through 2005 (Liu *et al* 2008).

On the other hand, since 1998 the utility of many such reports has been compromised by the acknowledged shortcomings of government statistics. It has been shown that government statistics regarding forest cover are often exaggerated, not only by revisions of the measurement criteria, but also by the long tradition of local bureaus over-reporting the successes of central government policies. Local bureaus are reimbursed for areas converted to forest or grassland through NFCP and GTGP, a system which encourages exaggeration (Liu *et al* 2008).

Meaningful forest monitoring at the national scale is not uniquely a Chinese problem. Throughout the world, aggregate national statistics tell us little of the environmental health and value of forests; even the best assessments of forest area and volume fall short in measuring trends in quality of non-timber forest benefits (Sayer and Sun 2003). In order to better understand forest trends, it may be more practical to compare observations over time.

Improvements in satellite sensors give opportunities for more sophisticated analysis of vegetation than in the past. de Beurs *et al.* (2009) collected and analyzed satellite time series for Northern Eurasia, then used a seasonal Kendall trend test corrected for autocorrelation to determine areas of significant positive and negative vegetation trends for 2000-2008. Their results show China had much larger areas of positive trends than negative trends, especially in North China. Significant positive trends throughout China were predominantly in grasslands (30.4%) and croplands (26.1%). They did not specifically address forest trends in general or North China in particular, but this type of analysis is useful in identifying areas to be examined in more detail.

This paper examines more closely several small areas of positive vegetation trends in North China. Satellite observations are collected for study sites which have been reported to have participated in afforestation project activities in the recent past. These observations at fixed sites are used to determine changes in vegetation character over the past decade, independent of government statistics and area-based estimates.

2) Data

Sensors aboard satellites give us opportunities to observe changes on the surface of the earth. Every day the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor passes over any given location aboard the Terra satellite and measures surface reflection in 36 spectral bands (http://modis.gsfc.nasa.gov). Because vegetation reflects infrared energy well and red energy poorly, MODIS observations in the red (Band 1: 620 – 670 nm) and near-infrared (NIR) (Band 2: 841 – 876 nm) are essential for calculating the Normalized Difference Vegetation Index (NDVI), a useful indicator of vegetation or vegetative "greennesss."

$$NDVI = \frac{NIR - red}{NIR + red}$$

NDVI has been widely used since 1978 (Tucker 1979), primarily with Advanced High Resolution Radiometer (AVHRR) sensor data, to analyze characteristics of vegetation.

The high spectral resolution of the MODIS sensor has enabled to the use of an alternative vegetation index, the Enhanced Vegetation Index (EVI):

$$EVI = 2.5 * \frac{(NIR - red)}{(NIR + C_1 * red - C_2 * blue + L)}$$

C_1, C_2, and L are coefficients used to apply observed atmospheric effects in the blue band (MODIS Band 3: reflectances between 459–479 nm) to correct for atmospheric influences to the red band. The MODIS EVI product uses coefficients of C_1=6, C_2=7.5 and L=1 (Huete *et al* 2002). EVI has been shown to be a more effective indicator of changes in vegetative structure (Pettorelli *et al* 2005), and is less susceptible to variations in non-vegetative background reflections such as from snow, soil moisture, litter (Huete *et al* 2002).

I searched Chinese news sources for references to sites participating in China's recent major afforestation projects in the past decade in North China. Five such sites with a documented record of forest project participation were selected for further analysis using MODIS data products in order to gain a better understanding of forest land cover changes as related to environmental policies of the past decade (see Figure 3.3). Characteristics of the five study sites are outlined in Table 3.1.

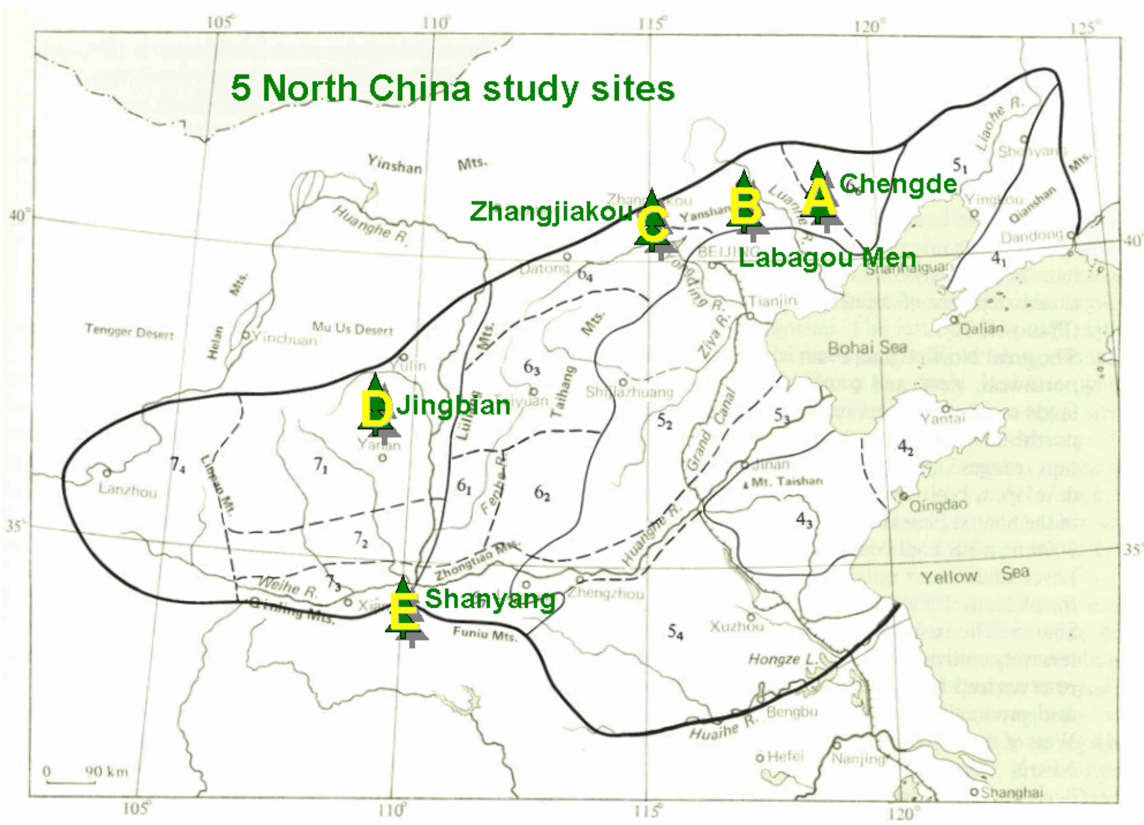


Figure 3.3 – Locations of MODIS Study Sites, plotted on a figure of Zhao 1986 [fair use].

	Chengde	Labagou Men	Zhangjiakou	Shanyang	Jingbian
Province	Hebei	Hebei	Hebei	Sha'anxi	Sha'anxi
Lat / Lon	41.0 N, 117.9 E	40.8 N, 116.6 E	40.9 N, 114.9 E	33.6 N, 109.9 E	37.7 N, 108.8 E
Observation Period	**February 18, 2000 to May 25, 2010**	**February 18, 2000 to May 25, 2010**	**February 18, 2000 to May 25, 2010**	**February 18, 2000 to May 25, 2010**	**February 18, 2000 to May 9, 2010**
Mean Elevation (m)	396	535	726	326	959
Primary Land Cover Class	Mixed forest	Mixed forest	Cropland – Forest transition	Mixed forest	Grassland
Estimated Mean Annual Precipitation (mm) *	600	475	375	800	375
Estimated Mean Annual Temperature (°C) *	9	8	8	10	9
Climate Zone (Köppen-Geiger)	Dwa – Humid continental, hot summer	Dwb – Humid continental, warm summer	BSk – Semi-arid	Dwb – Humid continental, warm summer	BSk – Semi-arid

Table 3.1 – Characteristics of MODIS study sites. Historical precipitation and temperature data were not available at these sites; * estimated values were interpolated from climate maps

In Chapter 2, deforestation in North China was defined as a conversion from natural, undisturbed primary forest cover towards permanent cropping and other anthropic land uses. In attempt to better characterize the five selected study sites, their locations on the forest conversion chart from Chapter 2 (Figure 2.1) have been estimated below (Figure 3.4).

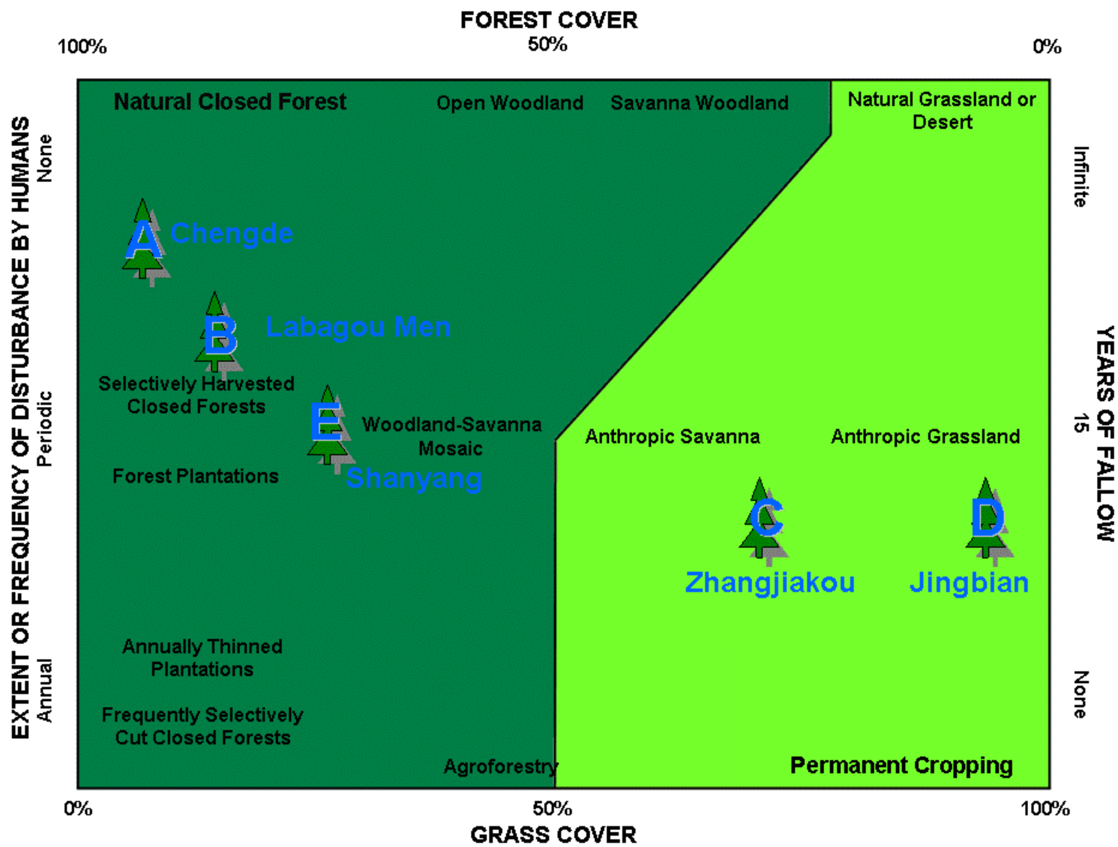


Figure 3.4 - Estimated Deforestation "Conversion" position of the five study sites, based on a figure of Allen and Barnes 1985 [fair use].

I downloaded 20x20 km subsets of MODIS/Terra MOD13Q1 NDVI and EVI vegetation indices, 16-Day composites, level 3 processed 250m pixel grids from 2000 to 2009 for each of the five sites. NDVI and EVI are two of several MODIS data products that are freely available from the Oak Ridge National Laboratory web site (http://daac.ornl.gov/MODIS/modis.html).

I closely examined the most recently acquired imagery from Google Earth to accurately locate the MODIS subsets, and more importantly, to ensure that the locations to be studied were sufficiently homogenous at the 250m scale of a MODIS pixel.

I also collected monthly temperature data from NASA Goddard Institute for Space Studies Surface Temperature Analysis (http://data.giss.nasa.gov/gistemp/station_data/) for eight weather stations in North China in order to see if there were any significant climatic fluctuations from 2000-2009 which may have influenced peak vegetation and phenological timing.

3) Methods

3.1 Land Surface Phenology

Sensor-derived vegetation indices are the most widely-used measurement in the study of land surface phenology. Phenology is derived from the Greek φαινό [phaino] – to show or to appear; this root is most commonly seen in English in the word 'phenomenon.' It is defined as the study of the timing of biological cycles as related to environmental factors. Land Surface Phenology refers specifically to the study of spatial and temporal variation in vegetative cover through the use of optical sensors (de Beurs and Henebry 2004).

NDVI thresholds are widely used in land surface phenology to determine annual timing of seasons. Start of season is defined as the first day of the year when the threshold value is reached; end of season is defined as the day of the year when NDVI drops below the threshold (Figure 3.5). Different thresholds may be selected for different land cover classes. In this study, a simple threshold of NDVI= 0.5 is used for forest; NDVI= 0.2 is used for grassland and cropland. Although simple thresholds are less consistent for intercomparison of sites across a larger study area, they are well suited for independent evaluation of smaller sites over time. Because this study examines only a few small study sites with a focus on time as a variable, it is important to use a constant definition of seasonality as is provided by the simple threshold. Other common methods of measuring seasonality from NDVI – including percent threshold, derivative, smoothing algorithms and model fitting - are less suitable since they annually vary, depending on the changing shape of the NDVI curve.

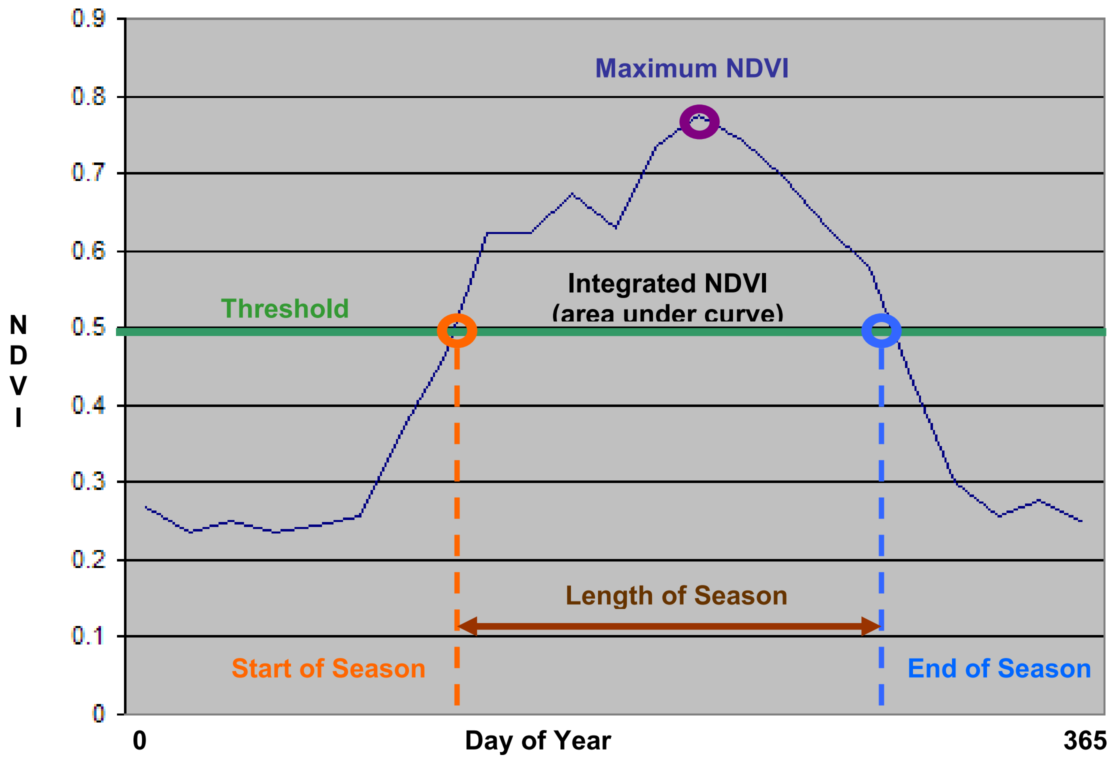


Figure 3.5 - Sample 1-year Northern Hemisphere Vegetation Curve. Many useful phenological measures can be derived from an annual vegetation curve.

We can make further inferences about recent trends in the landscape of North China through additional processing of the MODIS NDVI time series. Petorelli et al (2005) have conducted a survey of the literature and have outlined the utility of various NDVI-derived measurements for ecological studies.

Length of season, or length of 'green' season, is a common phenological index defined as the number of days between start of season and end of season (Figure 3.5), both of which can be calculated by a variety of measures. As noted previously, a threshold has been used here to calculate start and end of season. In seasonal environments such as North China, length of season is an effective measure of number of days of vegetative productivity (Pettorelli *et al* 2005). Koltunov *et al* (2009) have shown that even partial forest clearing can shorten the growing season and decrease overall greenness, therefore one would expect that areas of healthy afforestation would experience a lengthened growing season and higher NDVI maxima.

Annual Maximum NDVI is a measure of overall site productivity and biomass. It is defined as maximum value of the NDVI over a year (Figure 3.5) and is often correlated with annual production of vegetation (Pettorelli *et al* 2005). Paruelo and Lauenroth (1998) have shown annual maximum NDVI to be a better measure of primary productivity than other seasonal variables.

Integrated NDVI (INDVI) is another measure of overall productivity and biomass that is strongly correlated with total annual photosynthetic activity (Pettorelli *et al* 2005). It is determined by summing positive NDVI values over a given period; this study sums over one year to find INDVI (Figure 3.5). Tucker *et al* (1985) accurately estimated primary production in Africa using integrated NDVI observations.

Relative annual range of the NDVI is used as a measure of interannual variability in productivity, determined by comparing the annual range of NDVI values relative to the annual INDVI (Maximum NDVI value-Minimum NDVI value)/INDVI (Pettorelli *et al* 2005). Relative annual range of the NDVI can provide useful interannual comparisons of vegetation biomass. Guerschman *et al* (2003) found the Relative annual range of the NDVI to be effective for identifying areas of land use change in Argentina.

EVI datasets are unique to the MODIS sensor and have not been studied nearly as extensively as NDVI. The aforementioned NDVI methods are also used to analyze the EVI datasets for the five North China study sites.

3.2 Characteristics of Study Sites

Hebei province is located in Northeastern China. It surrounds the administrative regions of Beijing and Tianjin and it contains afforestation sites which are likely to receive increased government and public scrutiny compared to more remote and less visible areas of the country. A mature forest site and two afforestation sites were selected in Hebei province.

Sha'anxi Province is located in the western end of the North China study area and is considered the critical battleground in the fight against deforestation and desertification. Northern Sha'anxi is primarily loess plateau; Southern Sha'anxi is more mountainous and is better able to support forest ecosystems. Two notable sites were selected in Sha'anxi province: a "Grain for Green" site in the North, and a healthy afforestation site in the South.

A. **Chengde** – Hebei Province

Chengde is the site of the mountainous summer getaway of the Qing Emperors. This site provided an escape from the sweltering summer heat of Beijing. The site is encompassed by a miniature "Great Wall" which has long afforded a significant level of protection to the forest contained within. This protection was compromised by the chaos of the first half of the 20th century; the current vegetation – a mixed forest dominated by *Pinus Tabuliformis* - is a reflection of afforestation efforts from the 1950's (Jiang *et al* 1992). It will be useful to compare this "stable" forest site with other sites anticipating forest growth.

The NDVI time series for Chengde (Figure 3.6) shows a very regular annual pattern, indicating a healthy mature forest. It is also interesting to note that in the colder months the selected center pixel of the Chengde subset (blue squares) has a significantly higher NDVI than the average of mixed forest pixels in the subset (red squares). This discrepancy is most likely a result of a higher ratio of coniferous to deciduous trees at the center than in other areas. Annual NDVI profiles of coniferous forest show less difference between winter minima and summer maxima (Knight *et al* 2006). In the annual comparison of NDVI values (Figure 3.7), a delay in the start of season can be seen for 2001 and 2006. In these two years, the sharp rise in slope which is associated with spring "green up" appears approximately 2 weeks later than other years in the decade. This is also apparent in the measurements of seasonality in Figure 3.8. Both figures 3.6 and 3.7 show comparably lower vegetation reflectance through the summer of 2000.

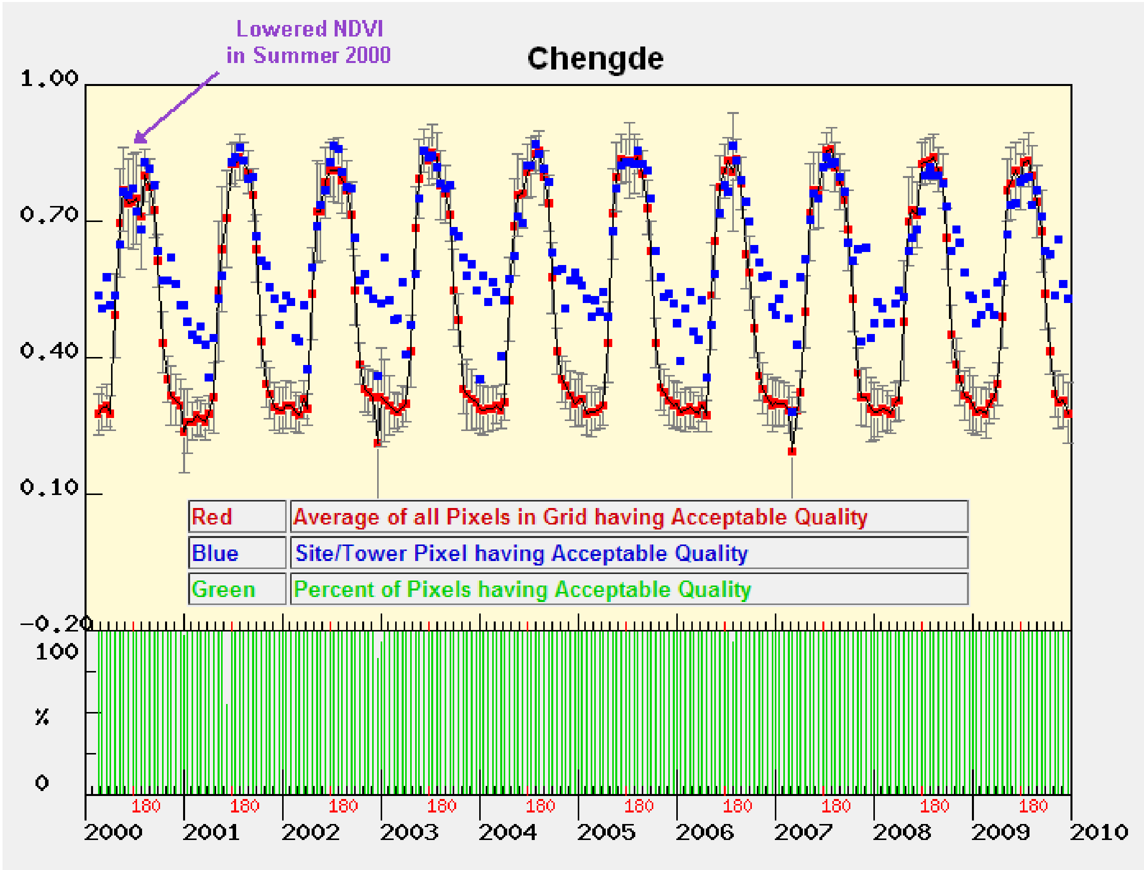


Figure 3.6 – MODIS NDVI 2000-2009 Time Series of all Mixed Forest Pixels in Chengde Subset (ORNL 2010)

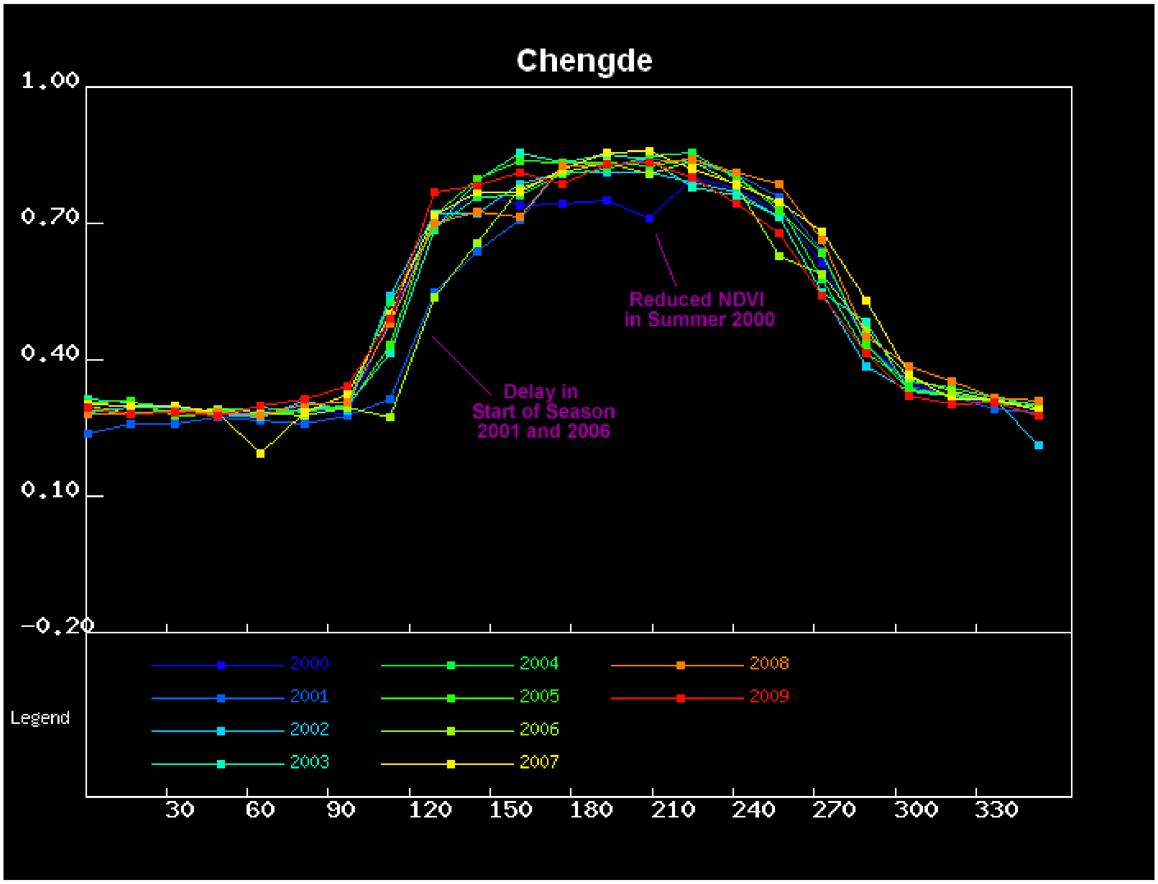
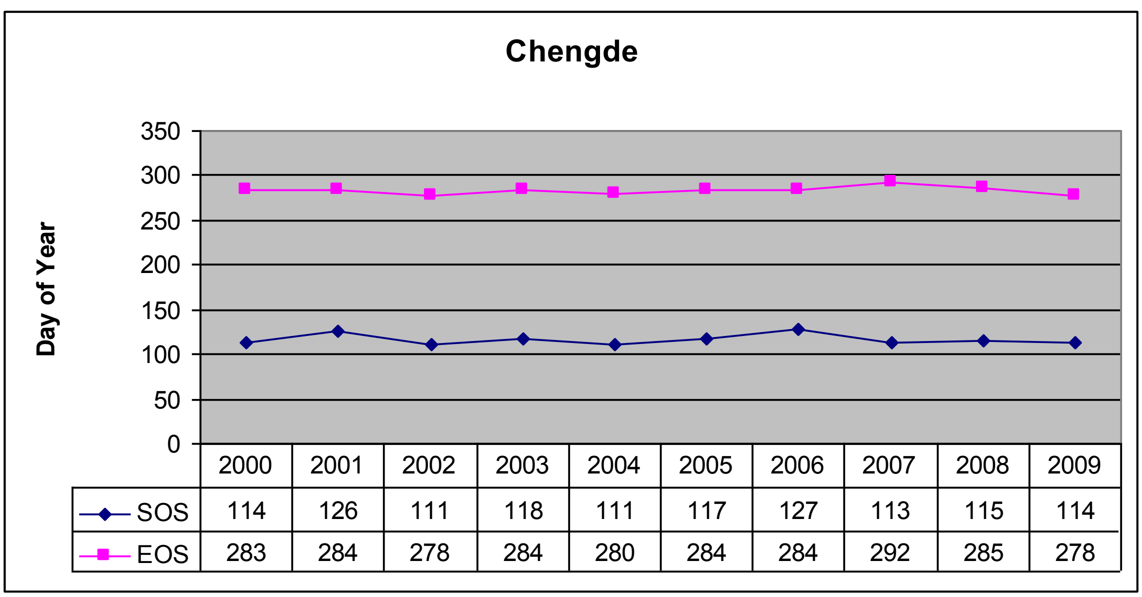


Figure 3.7 – MODIS NDVI 2000-2009 Annual Comparison of all Mixed Forest pixels in Chengde Subset (ORNL 2010)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SOS	114	126	111	118	111	117	127	113	115	114
EOS	283	284	278	284	280	284	284	292	285	278

Figure 3.8 – Chengde Phenology 2000-2009: Start and End of Season, t=0.5

Chengde MODIS Data Visualization and Download:

http://daac.ornl.gov/glb_viz_2/15Jun2010_13:25:57_514382170L41.000833L117.927222S161L161_MOD13Q1/index.html

B. **Labagou Men** – Hebei Province

Labagou Men is a forest park about 160 km north of Beijing. It is situated in mountainous Huairou county which has a history of protecting forests and native trees (Dai *et al* 1990). This area has been part of a local afforestation program to protect watersheds since 1997 (Yuan *et al* 2002), and in 2008 the park received official protection at the national level as part of a program to increase forestation and improve air quality in Beijing (Xinhua 2008). The vegetation is a diverse mixed forest dominated by deciduous trees and contains a rich reservoir of Chinese medicinal plants (Yuan *et al* 2002).

The NDVI time series for Labagou Men (Figure 3.9) also shows a regular annual pattern – as we would expect from a healthy mature forest – but not quite as regular as Chengde. A significant drop in NDVI can be seen in 2001, apparently due to the influence of some low outliers. In the annual comparison of NDVI values (Figure 3.10), we can narrow down this anomaly to June 2001. If this were due to a climatic event, we would expect to see a similar dip in the other Hebei study sites. It also unlikely to be due to fire, cutting or some other forest destruction; with any destructive event in the forest, we would not see the NDVI value return to normal at the next observation. Figure 3.9 shows that about half of the pixels were rejected for quality control reasons at this time, making a strong case for data error. As with the Chengde subset, we see a delay in the 2006 start of season, in this case about 18 days later than the mean, in Figure 3.10. We can also see this reflected in the measurements of seasonality in Figure 3.11.

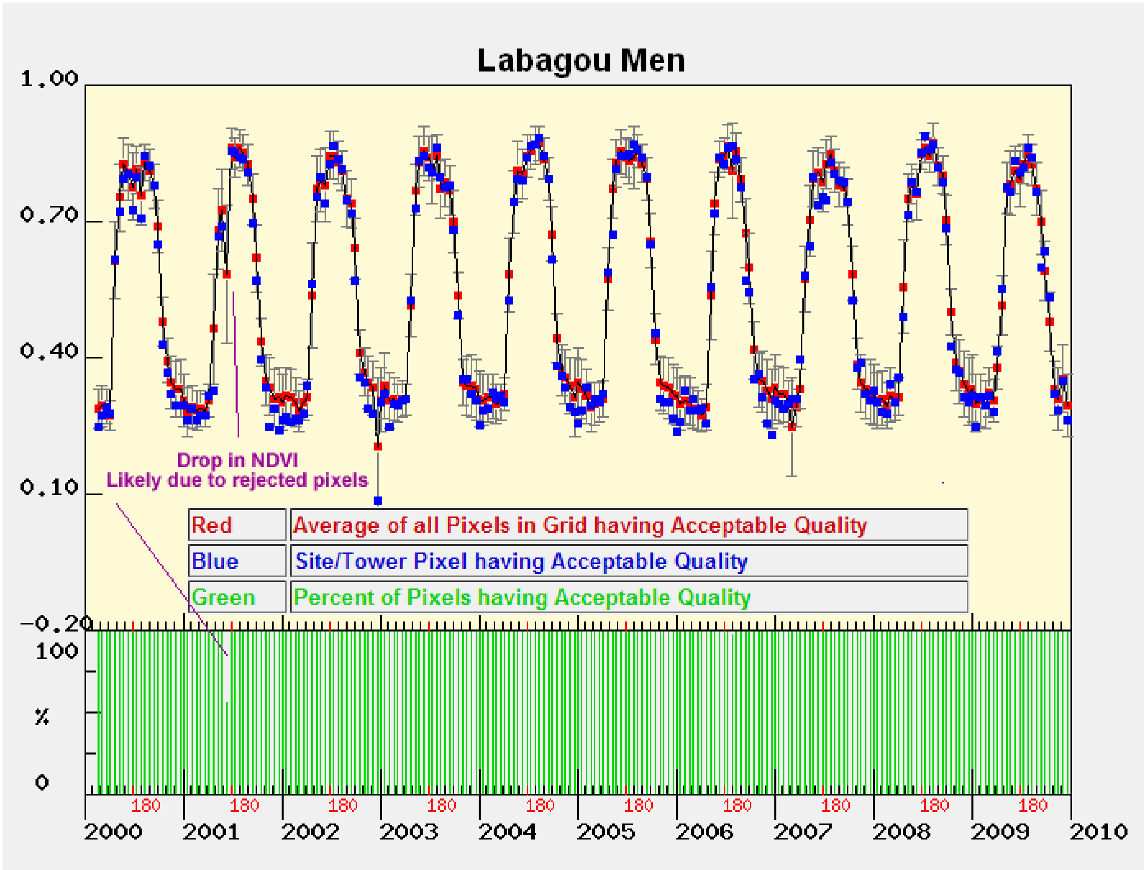


Figure 3.9 –MODIS NDVI 2000-2009 Time Series of all Mixed Forest Pixels in Labagou Men Subset (ORNL 2010)

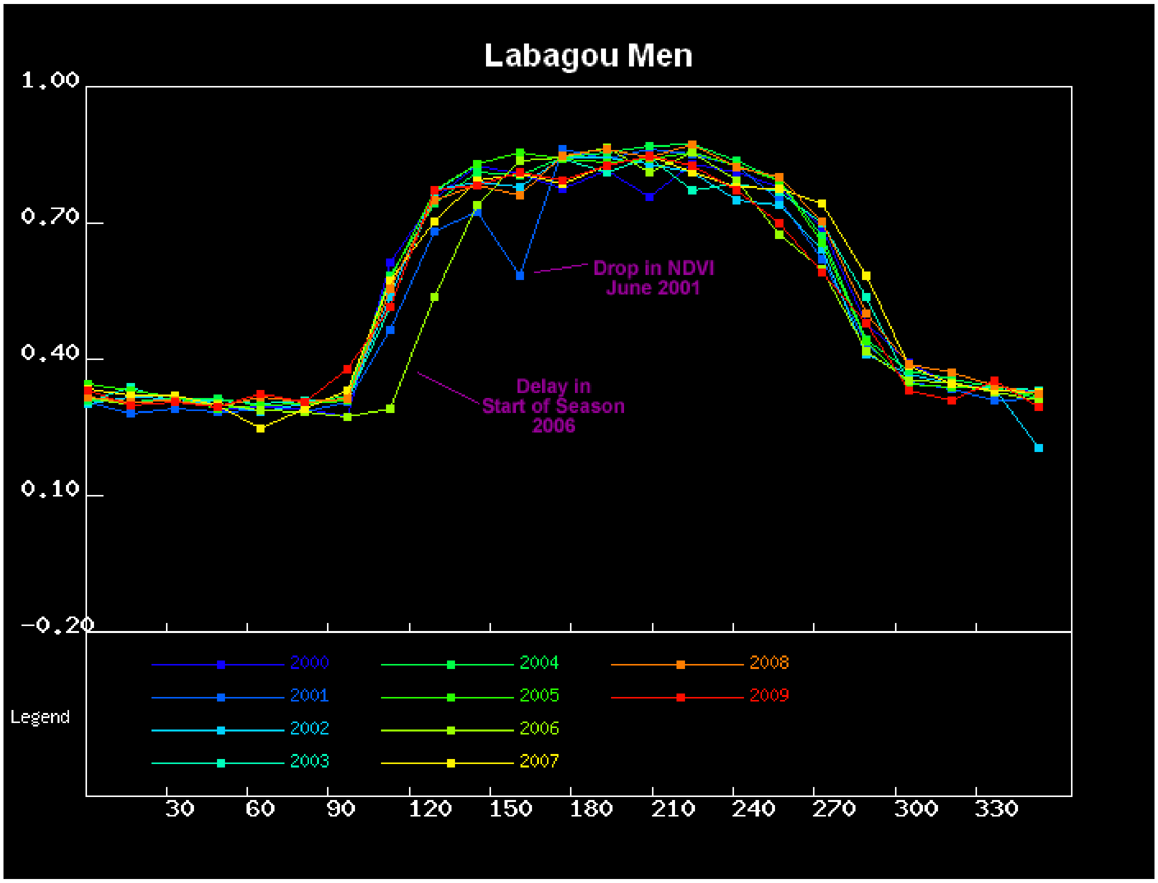
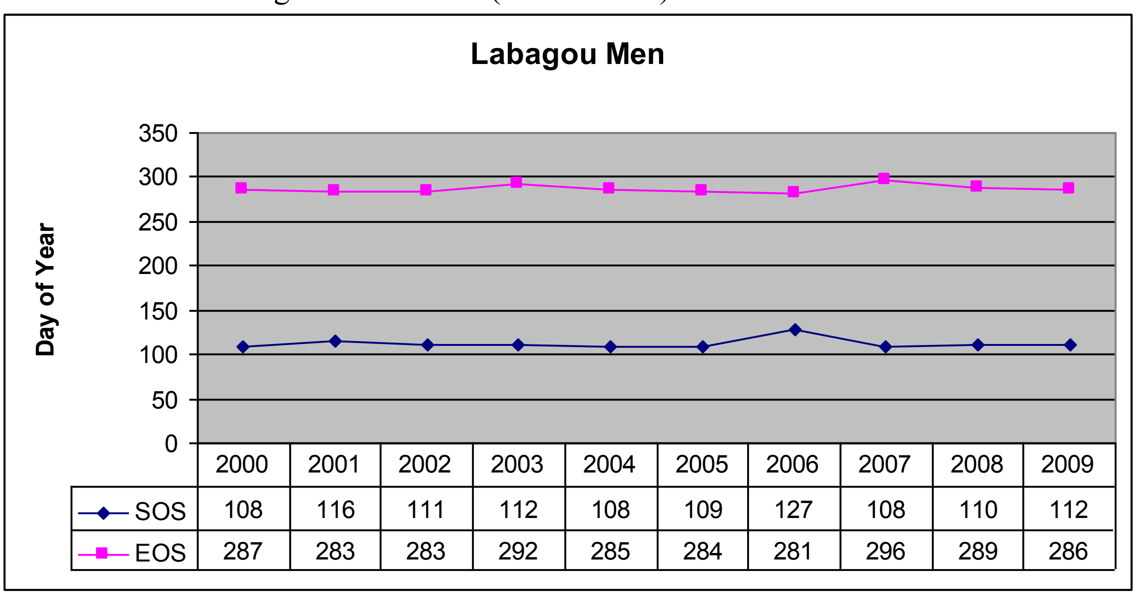


Figure 3.10 –MODIS NDVI 2000-2009 Annual Comparison of all Mixed Forest Pixels in Labagou Men Subset (ORNL 2010)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SOS	108	116	111	112	108	109	127	108	110	112
EOS	287	283	283	292	285	284	281	296	289	286

Figure 3.11 – Labagou Men Phenology 2000-2009: Start and End of Season, t=0.5

Labagou Men MODIS Data Visualization and Download:
http://daac.ornl.gov/glb_viz_2/15Jun2010_13:28:47_779655106L40.787778L116.571944S161L161_MOD13Q1/index.html

C. **Zhangjiakou** – Hebei Province

Zhangjiakou is situated within the major path of windborne dust storms blowing from the northwest into Beijing. It is a focal point of the "Beijing-Tianjin windblown sand sources control project." (China Daily 2007). Zhangjiakou also provides the primary source for Beijing's water supply and contains watershed protection afforestation sites (Feng 2009). The vegetation was primarily cropland in 2000 but has been transitioning to deciduous scrub forest (Yuan *et al* 2006).

The NDVI time series for Zhangjiakou (Figure 3.12) shows a steady growth pattern, especially in the first half of the decade. Frequent periods of lower data quality can be seen exclusively in the winter months, which imply a seasonal event such as snow or sandstorms affecting the surface reflectance. Snow and sand have high reflectances in visible wavelengths and can cause large drops in NDVI values. The annual comparison of NDVI values (Figure 3.13) also shows a steady growth of the annual curve from 2000 through 2004, which could reflect some successes in afforestation. But little change is apparent in the second half of the decade, and peak values do not yet approach those of the two previous forest sites. The measurements of seasonality (Figure 3.14) show more variations in start of season, but end of season timing seems to closely mirror that of start of season each year, so length of season seems fairly consistent.

The automated land classification system for MODIS data has classified the pixels of interest as cropland, while examination of recent imagery and anecdotal statements from Chinese colleagues indicate the area of interest is more characteristic of a shrub forest. This discrepancy could be due to limitations of the classification models, which in fact are derived primarily from African AVHRR time series (Strahler *et al* 1999). Misclassification of pixels could result in data contamination by pixels of differing land cover classes. A proposed site visit could clarify this discrepancy.

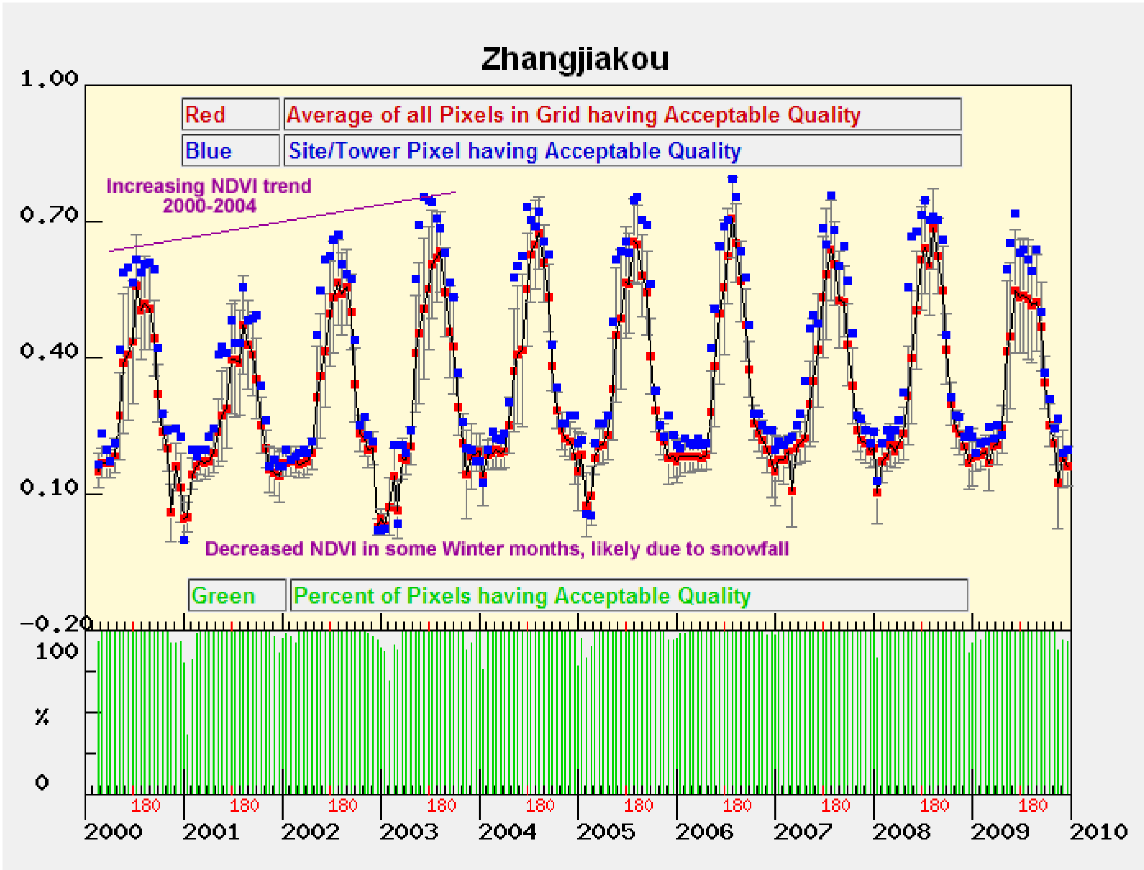


Figure 3.12 - MODIS NDVI 2000-2009 Time Series of all Cropland Pixels in Zhangjiakou Subset (ORNL 2010)

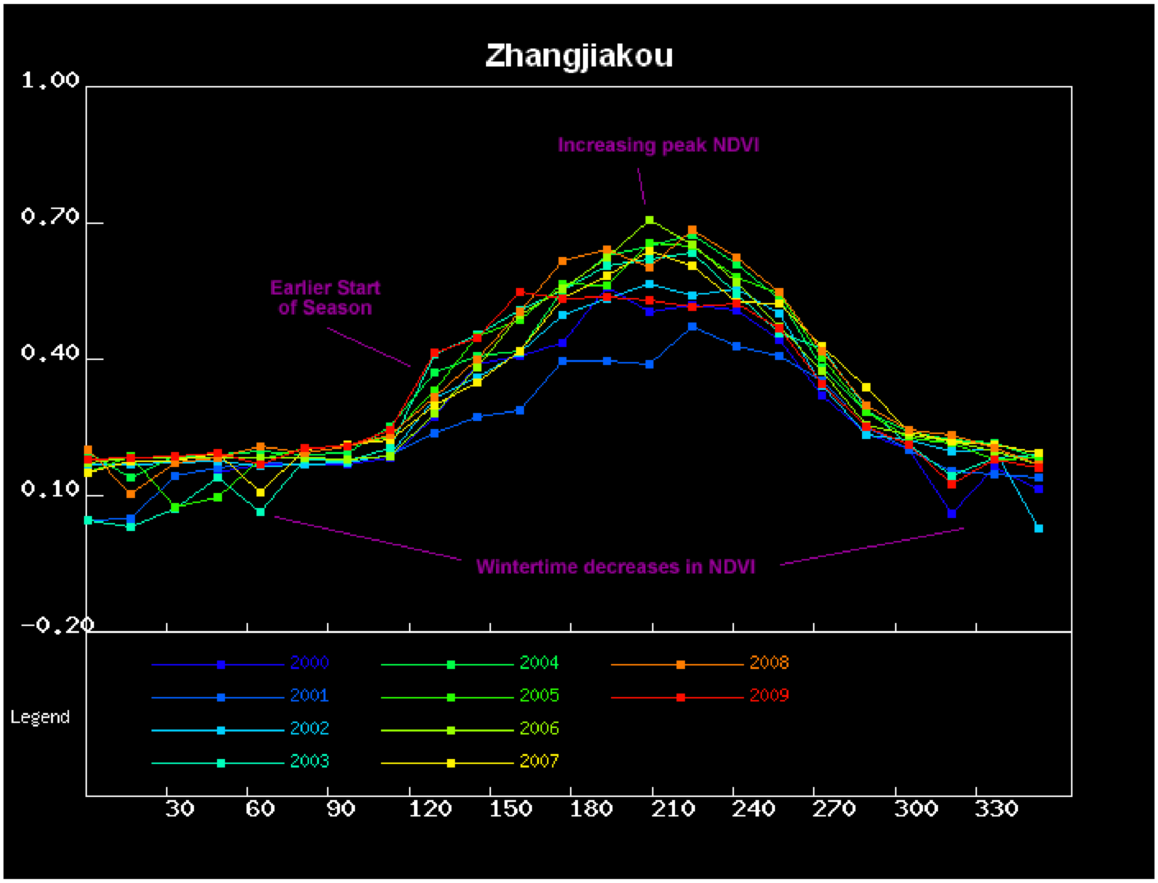
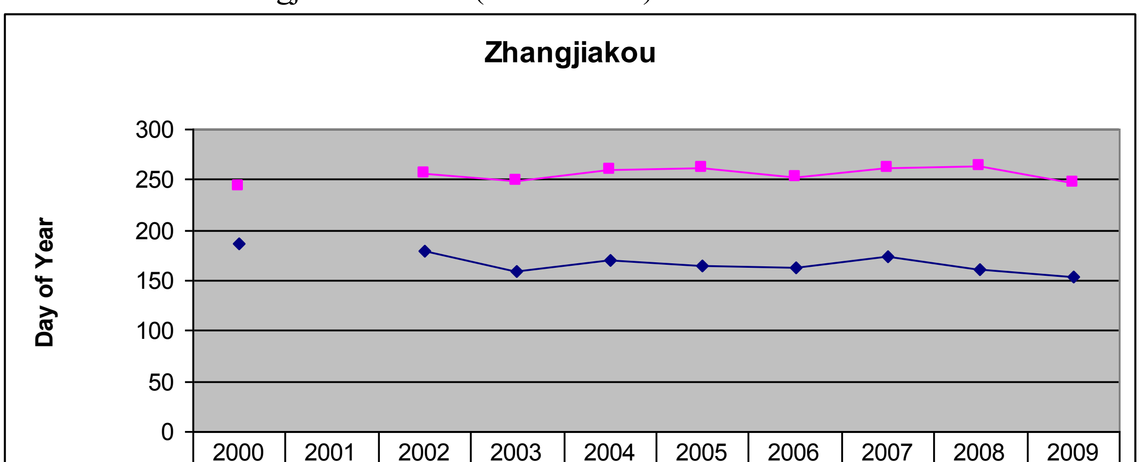


Figure 3.13 - MODIS NDVI 2000-2009 Annual Comparison of all Cropland Pixels in Zhangjiakou Subset (ORNL 2010)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SOS	186		179	159	171	164	162	173	161	154
EOS	243		257	249	260	262	253	261	263	247

Figure 3.14 - Zhangjiakou Phenology 2000-2009: Start and End of Season, t=0.5

Zhangjiakou MODIS Data Visualization and Download:

http://daac.ornl.gov/glb_viz_2/15Jun2010_13:31:15_494777983L40.914167L114.8575S161L161_MOD13Q1/index.html

D. **Jingbian** – Sha'anxi Province

According to the Yulin-Jiaxian Local Culture Board (2008), Jingbian county is among the best examples of the success of the NFCP and ranks highest in natural vegetative cover in northern Sha'anxi. This site is mostly grassland. This transitional zone provides a useful contrast to other primarily-forested sites.

The NDVI time series for Jingbian (Figure 3.15) shows clear, steady growth in NDVI values throughout the decade, and this can also be seen in the annual comparison of NDVI values (Figure 3.16). We can see a seasonal pattern of wintertime rejection of pixels for quality control, similar to the other dust-threatened site (Zhangjiakou). The relatively low overall NDVI values are characteristic of this grassland landscape, but annually higher NDVI peaks and earlier start of seasons (Figure 3.17) are indicators of growing vegetative biomass and productivity. As mentioned previously, Jingbian start and end of season was calculated based on a threshold of NDVI=0.2, which is more appropriate for grassland ecosystems.

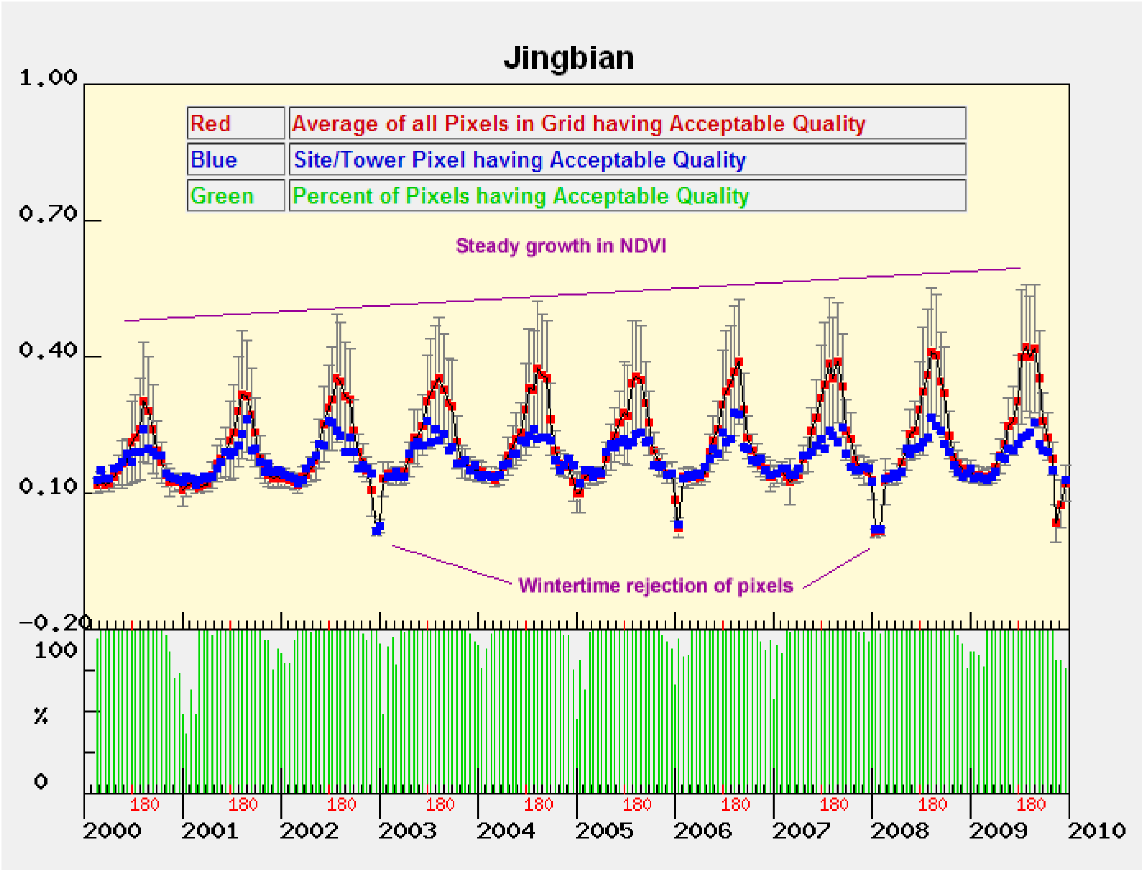


Figure 3.15 – MODIS NDVI 2000-2009 Time Series of all Grassland Pixels in Jingbian Subset (ORNL 2010)

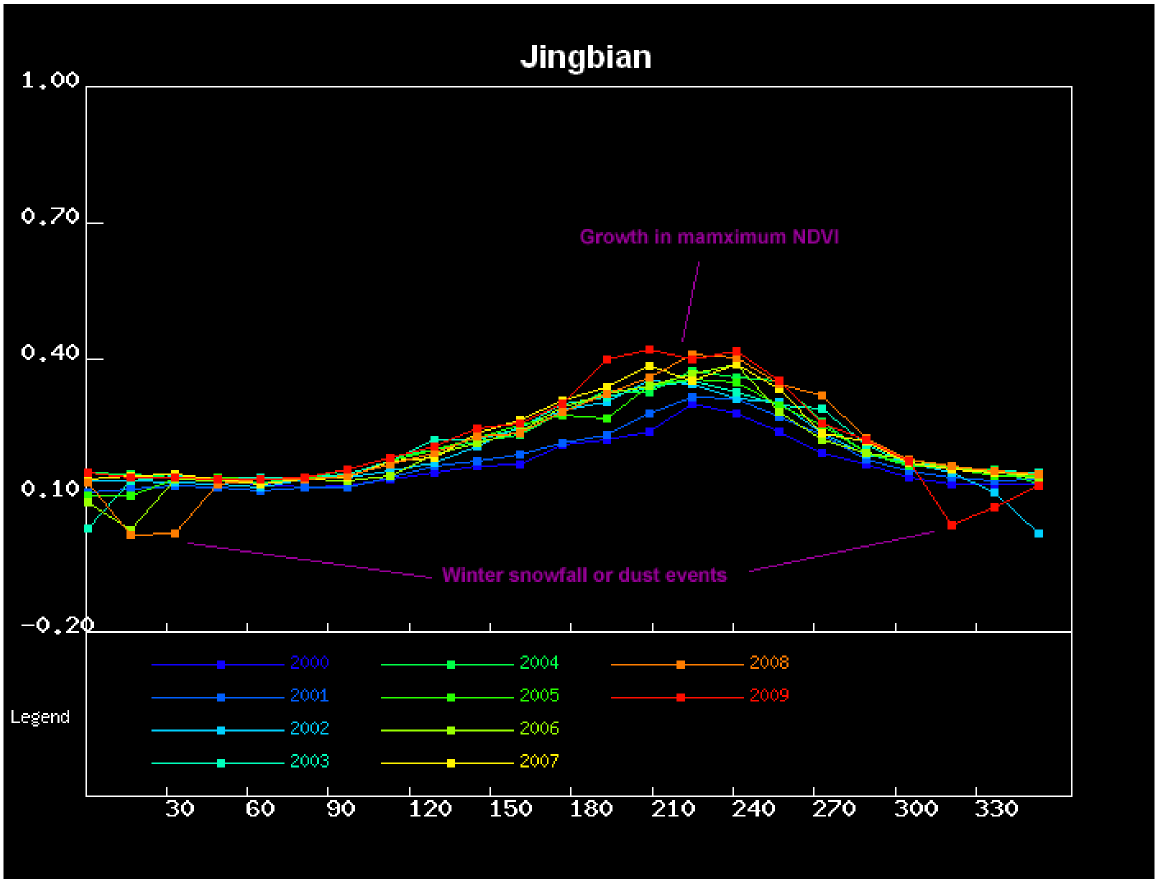


Figure 3.16 – MODIS NDVI 2000-2009 Annual Comparison of all Grassland Pixels in Jingbian Subset (ORNL 2010)

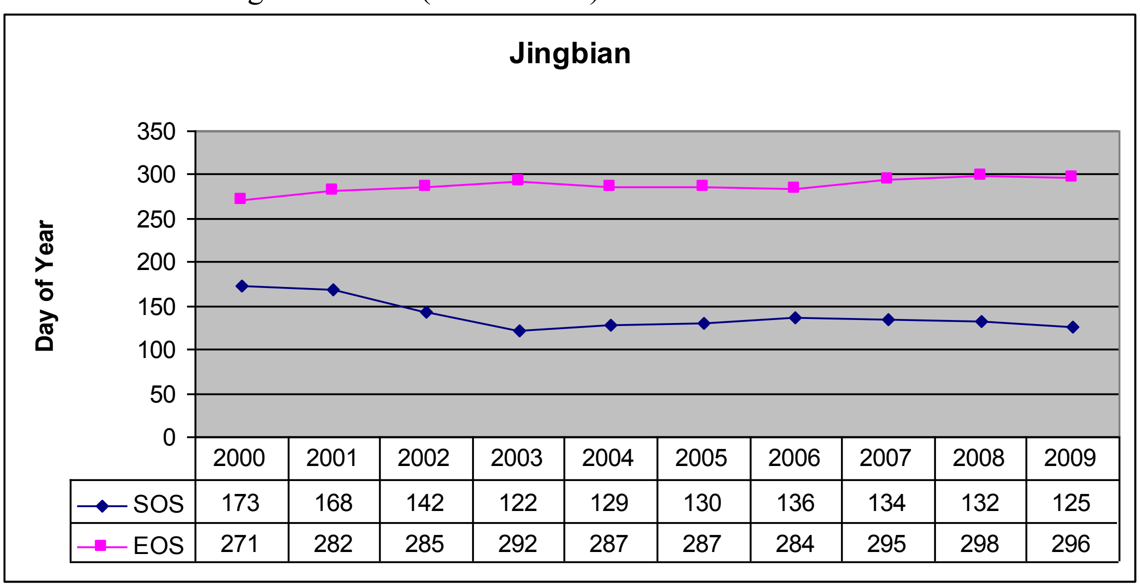


Figure 3.17 – Jingbian Phenology 2000-2009: Start and End of Season, t=0.2

Jingbian MODIS Data Visualization and Download:

http://daac.ornl.gov/glb_viz_2/15Jun2010_18:54:08_029608497L37.67L108.8S161L161_MOD13Q1/index.html

E. **Shanyang** – Sha'anxi Province

The Government Website of Sha'anxi Province (http://english.shaanxi.gov.cn) indicates that Shanyang county has been a leading participant in many of the more recent central government afforestation programs. Afforested areas are mixed with primarily pine on hilltops and primarily deciduous species on slopes (Government Website of Sha'anxi Province). Lavizzari (2009) reported that forest cover in Shanyang County increased from 52 per cent in 2000 to 58.9 per cent in 2007.

The NDVI time series for Shanyang (Figure 3.18) shows the regular annual pattern indicating a healthy mature forest. There are also frequent periods of lower data quality but no discernable seasonal pattern. The two sharpest drops in NDVI can be seen in the annual comparison of NDVI values (Figure 3.19). These two drops also recover quickly by the time of the following observation, so they are unlikely due to some sort of forest destruction. Given that the two drops occur in October and January, it is possible they are due to significant snowfall events. The Shenyang measurements of seasonality (Figure 3.20) do show a general increase in season length over the decade, as start of season comes earlier and end of season arrives later. Annual profiles with long summer periods of high NDVI values and a gradual decline to low NDVI values in the fall are characteristic of healthy forests (Knight *et al* 2006).

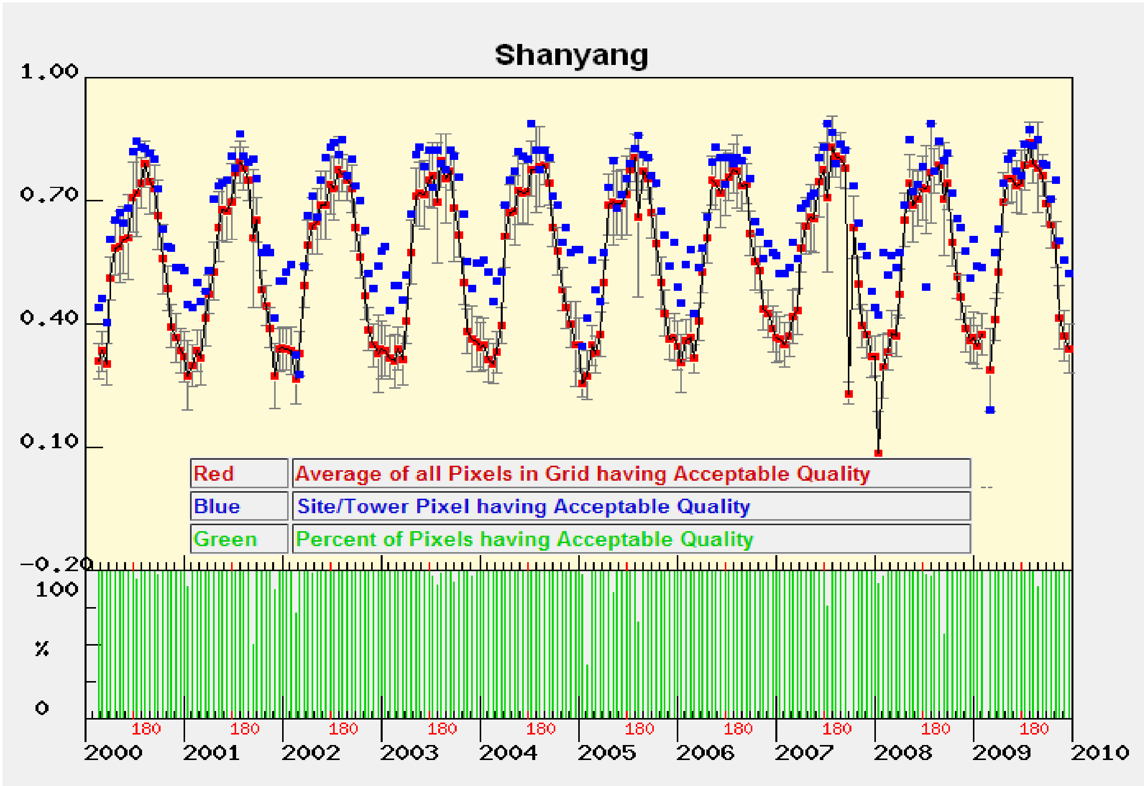


Figure 3.18 - MODIS NDVI 2000-2009 Time Series of all Mixed Forest Pixels in Shanyang Subset (ORNL 2010)

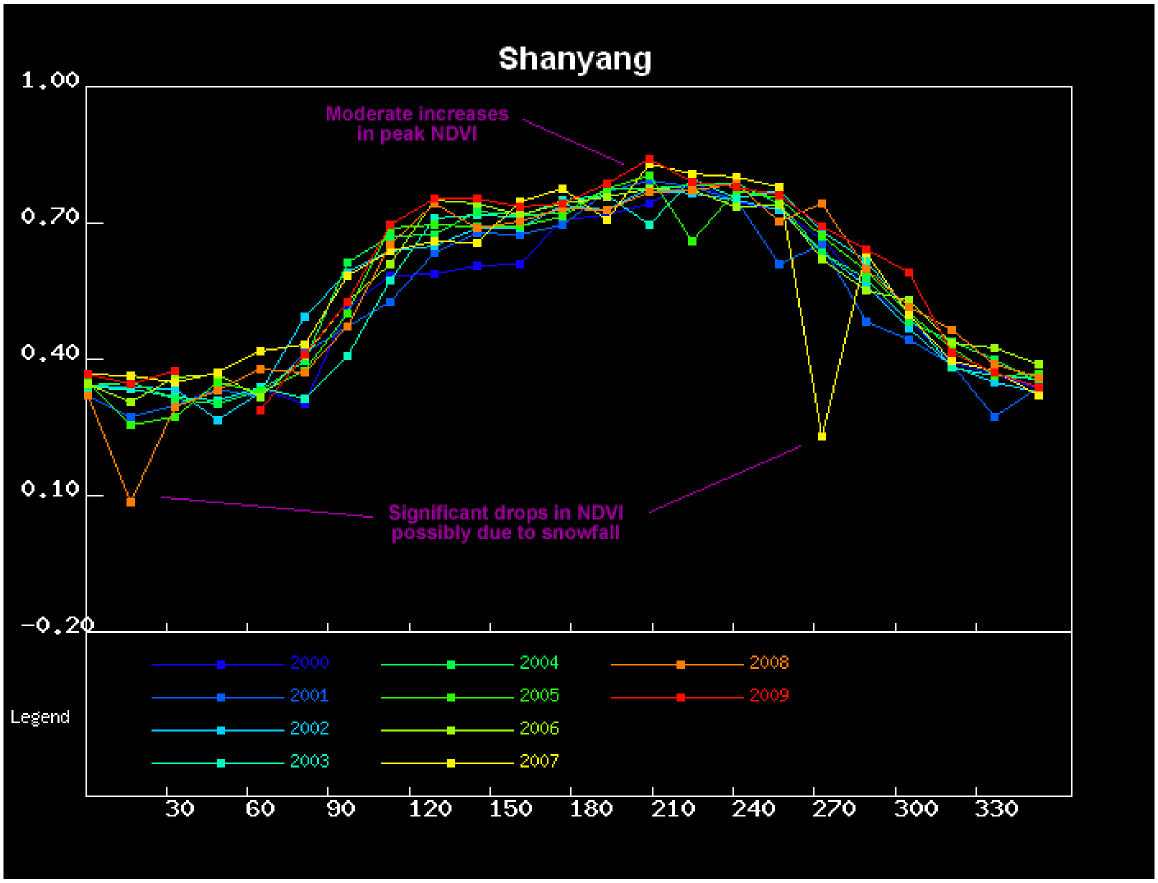
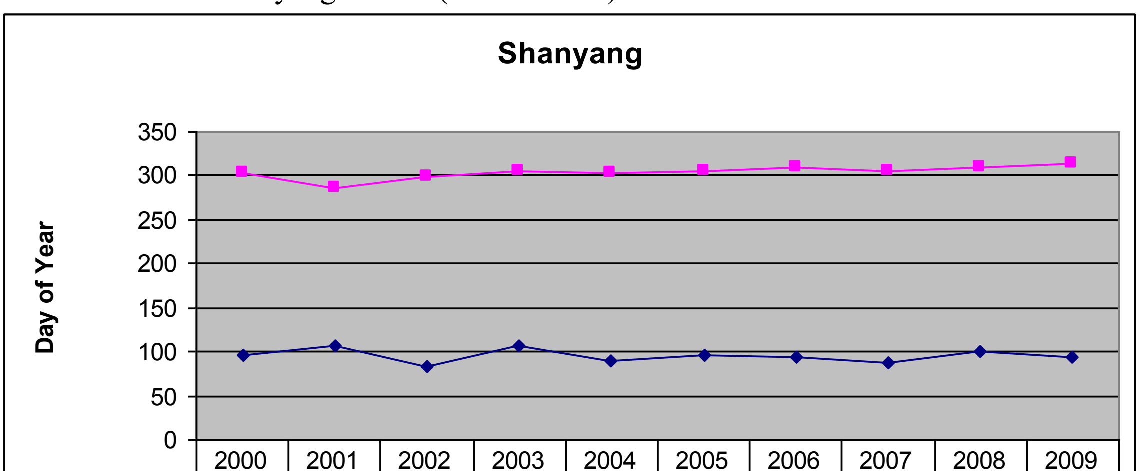


Figure 3.19 - MODIS NDVI 2000-2009 Annual Comparison of all Mixed Forest Pixels in Shanyang Subset (ORNL 2010)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SOS	96	106	83	106	89	97	94	88	100	93
EOS	302	287	299	305	302	305	310	305	310	313

Figure 3.20 - Shanyang Phenology 2000-2009: Start and End of Season, t=0.5

Shanyang MODIS Data Visualization and Download:

http://daac.ornl.gov/glb_viz_2/15Jun2010_13:48:06_242444712L33.5598496L109.889116S161L161_MOD13Q1/index.html

4) Results

Length of season is a measure of number of days of vegetative productivity. For the five study sites, from 2000 to 2009 the NDVI series show relatively consistent length of season at the mature forest sites Chengde (standard deviation σ = 6 days; change from 2000 to 2009 Δ= -5 days) and Labagou Men (σ = 9 days, Δ= -5 days), a gradual increase at Shanyang (σ = 11 days, Δ= 14 days), and larger increases at Zhangjiakou (σ = 12 days, Δ= 36 days) and Jingbian (σ = 23 days, Δ= 73 days). These trends are visible in Figure 3.21, but they are better described by finding the slope of a simple regression line calculated from a least squares fit to the data points. The results show small positive slopes at Labagou Men and Chengde (slopes m = 0.2 and m = 0.4 respectively), becoming larger at Shanyang (m=2.3), Zhangjiakou (m=3.6) and Jingbian (m=6.3). Table 3.2 contains a summary of results for all NDVI-derived phenology measurements.

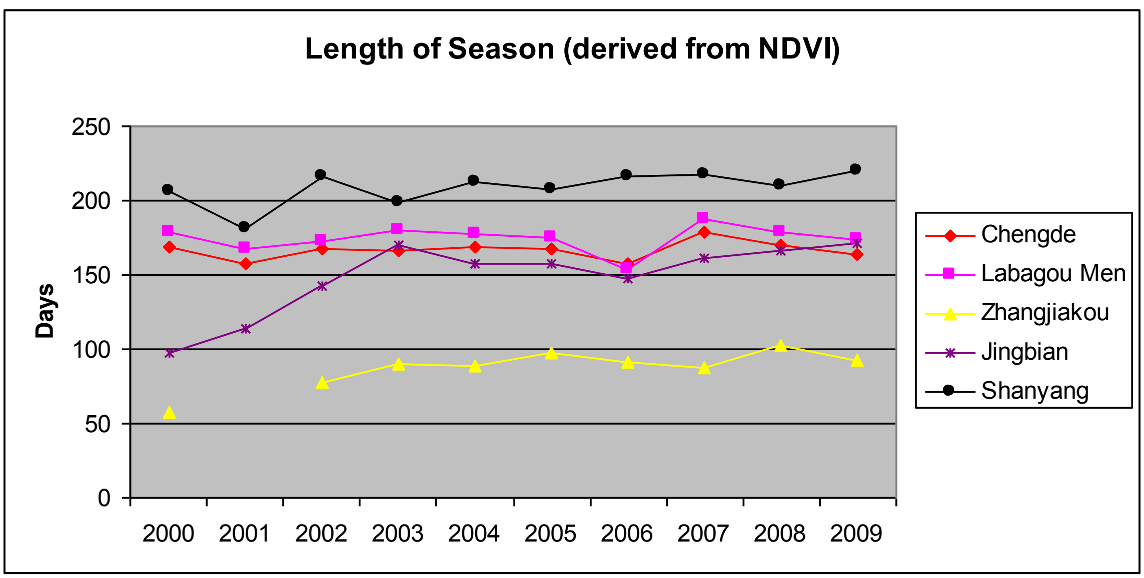


Figure 3.21 – Study Sites Length of Season 2000-2009, derived from NDVI

	Chengde	Labagou Men	Zhangjiakou	Jingbian	Shanyang
Change in Length of Season (slope of regression line)	0.4	0.2	3.6	6.3	2.3
Change in Annual Maximum NDVI (slope of regression line)	0.003	0.002	0.012	0.012	0.004
Change in Integrated NDVI (slope of regression line)	0.003	0.002	0.008	0.004	0.004
Percent Variability in Relative Annual Range of NDVI (coefficient of variation)	6%	6%	11%	21%	14%

Table 3.2 - Comparison of 2000 to 2009 phenological measures determined from MODIS NDVI

The EVI series (Figure 3.22) also show relatively consistent length of season at Chengde (slope m=-0.1) and Labagou Men (m=-0.4), a more gradual increase at Shanyang (m=1.3), a larger increase at Zhangjiakou (m=2.0) and the largest increase at Jingbian (m=4.9) (Figure 3.20). Table 3.3 contains a summary of results for all EVI-derived phenology measurements.

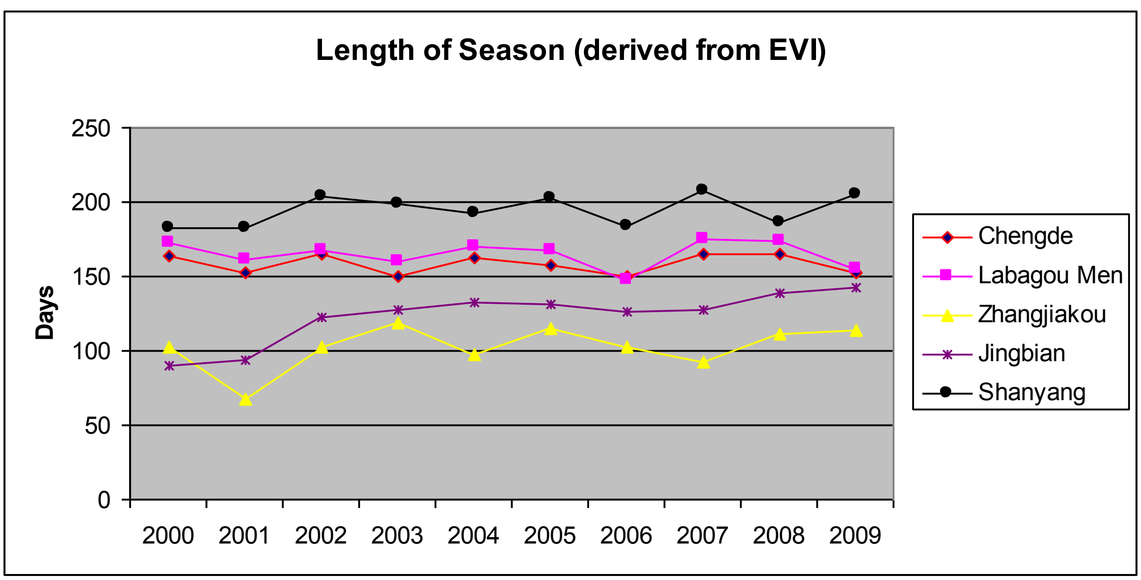


Figure 3.22 – Study Sites Length of Season 2000-2009, derived from EVI

	Chengde	Labagou Men	Zhangjiakou	Jingbian	Shanyang
Change in Length of Season (slope of regression line)	-0.1	-0.4	2.0	4.9	1.3
Change in Annual Maximum EVI (slope of regression line)	0.006	0.001	0.005	0.005	0.002
Change in Integrated EVI (slope of regression line)	0.0012	0.0003	0.0022	0.0016	0.0022
Percent Variability in Relative Annual Range of EVI (coefficient of variation)	5%	6%	8%	14%	5%

Table 3.3 - Comparison of 2000 to 2009 phenological measures determined from MODIS EVI

Annual Maximum NDVI is a measure of overall site productivity and biomass. From 2000 to 2009 there is lower change in peak NDVI at Labagou Men (slope m=0.002), Chengde (m=0.003), and Shanyang (m=0.004). Change in peak NDVI is largest at Zhangjiakou and Jingbian (m=0.012) (Figure 3.23).

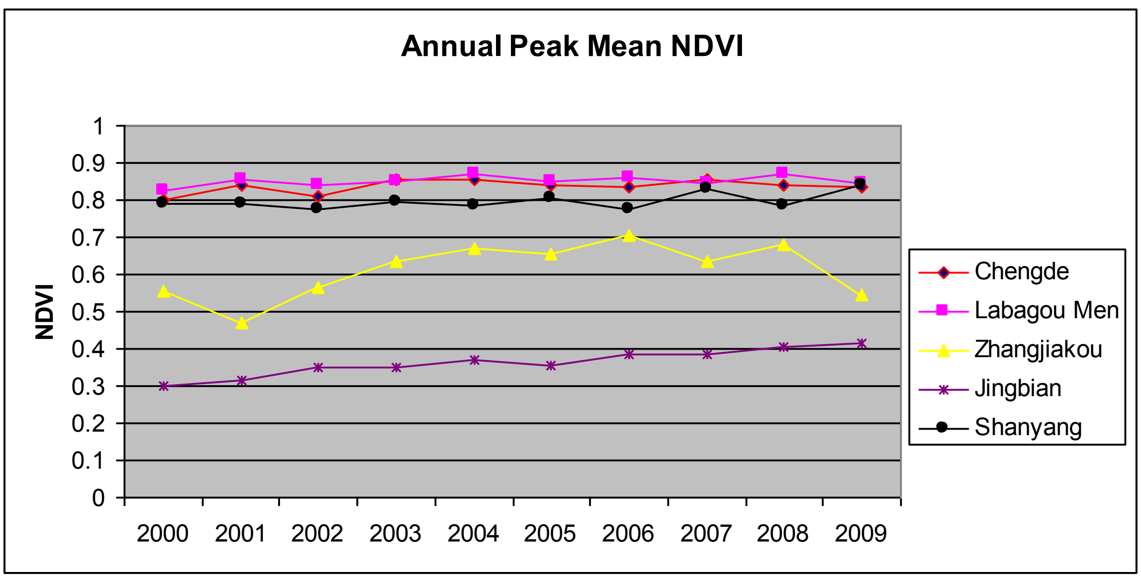


Figure 3.23 - Study Sites Annual Peak Mean NDVI 2000-2009

From 2000 to 2009 there is lower change in peak EVI at Labagou Men (slope m=0.001) and Shanyang (m=0.002). Change in peak EVI is larger at Zhangjiakou and Jingbian (m=0.005). Chengde's EVI peak increased the most (m=0.06) (Figure 3.24).

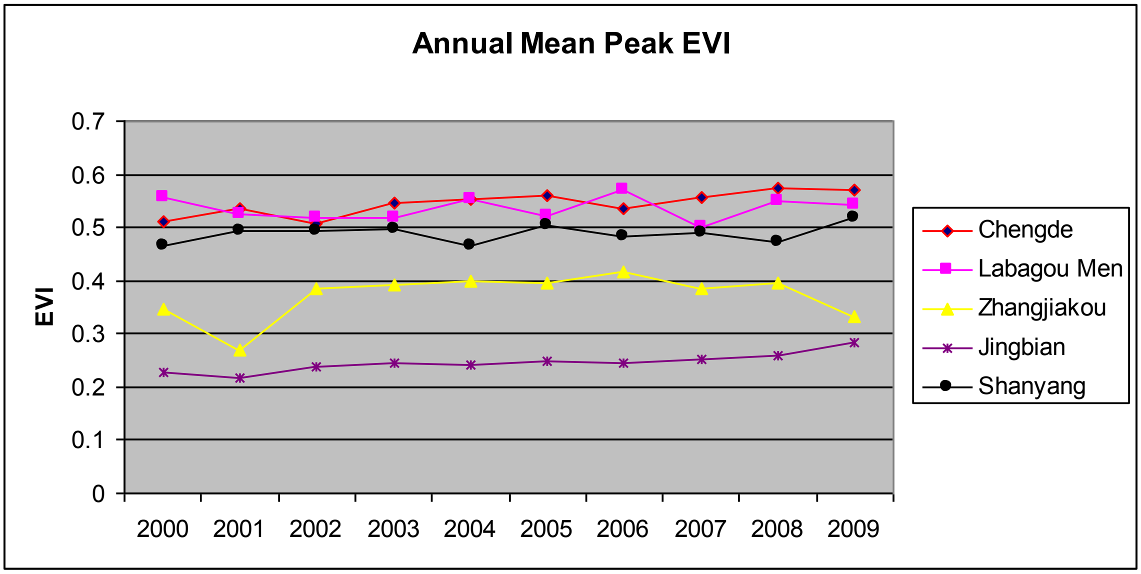


Figure 3.24 - Study Sites Annual Peak Mean EVI 2000-2009

Integrated NDVI (INDVI) is another measure of overall productivity and biomass. INDVI could not be calculated for the year 2000 because MODIS data was not available before February 2000. From 2001 to 2009 there is least change in Integrated NDVI at Labagou Men (slope m=0.002) and Chengde (m=0.003). Change in Integrated NDVI becomes gradually larger at Shanyang and Jingbian (m=0.004), and is largest at Zhangjiakou (m=0.008) (Figure 3.25).

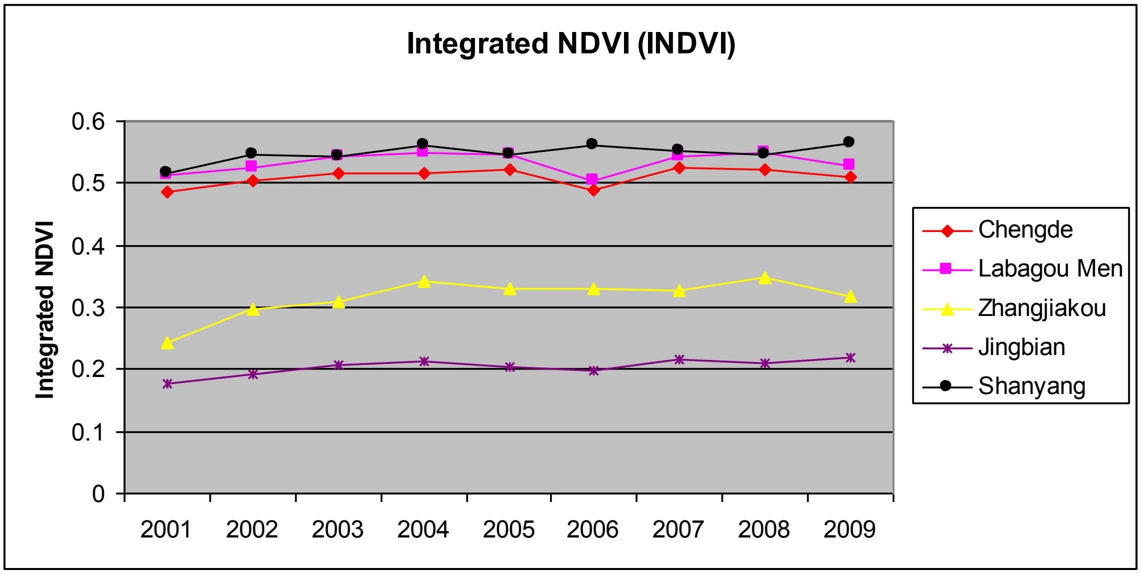


Figure 3.25 - Study Sites Annual Integrated NDVI 2001-2009

Integrated EVI also could not be calculated for the year 2000. From 2001 to 2009 there is least change in Integrated EVI at Labagou Men (slope m=0.0003). Change in Integrated EVI becomes gradually larger at Chengde (m=0.0012) and Jingbian (m=0.0016), and is largest at Zhangjiakou and Shanyang (m=0.0022) (Figure 3.26).

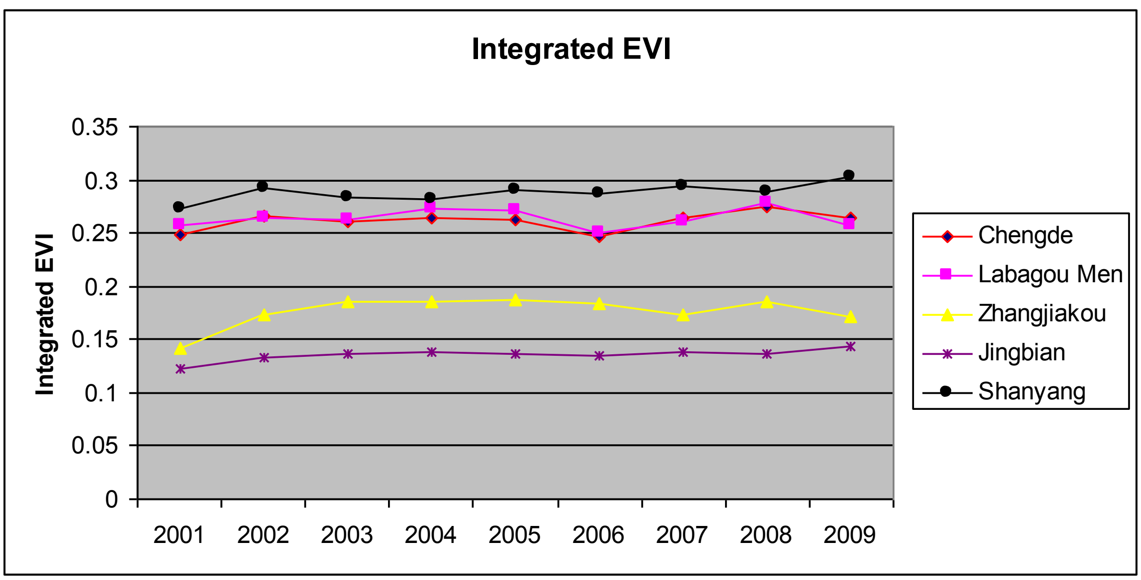


Figure 3.26 - Study Sites Annual Integrated EVI 2001-2009

Relative Annual Range of NDVI is a measure of interannual variability on vegetative productivity. Relative Annual Range of NDVI could not be calculated for the year 2000 because there was no INDVI measure available. From 2001 to 2009, Chengde and Labagou Men both show low variability (coefficient of variation $C_v = 0.06$); Zhangjiakou and Shanyang show more variability ($C_v = 0.11$ and $C_v = 0.14$ respectively), while Jingbian shows the highest variability ($C_v = 0.21$) (Figure 3.27).

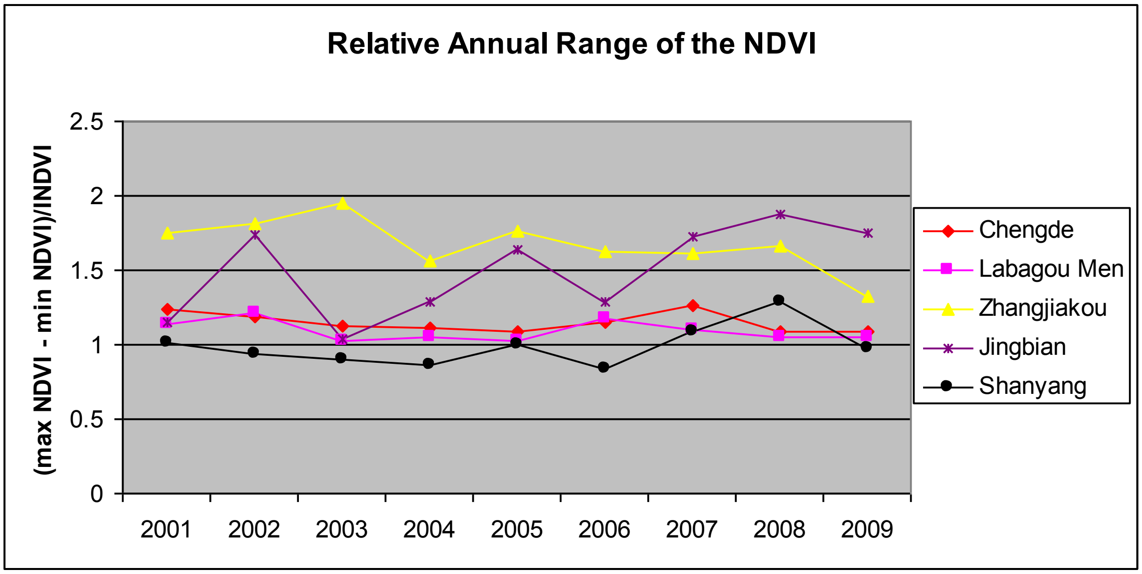


Figure 3.27 - Study Sites Relative Annual Range of NDVI 2001-2009

Relative Annual Range of EVI could not be calculated for the year 2000 because there was no Integrated EVI measure available. From 2001 to 2009, Chengde and Shanyang (coefficient of variation $C_v = 5\%$) and Labagou Men ($C_v = 6\%$) all show lower variability Zhangjiakou show more variability ($C_v = 8\%$), while Jingbian shows the highest variability ($C_v = 14\%$) (Figure 3.28).

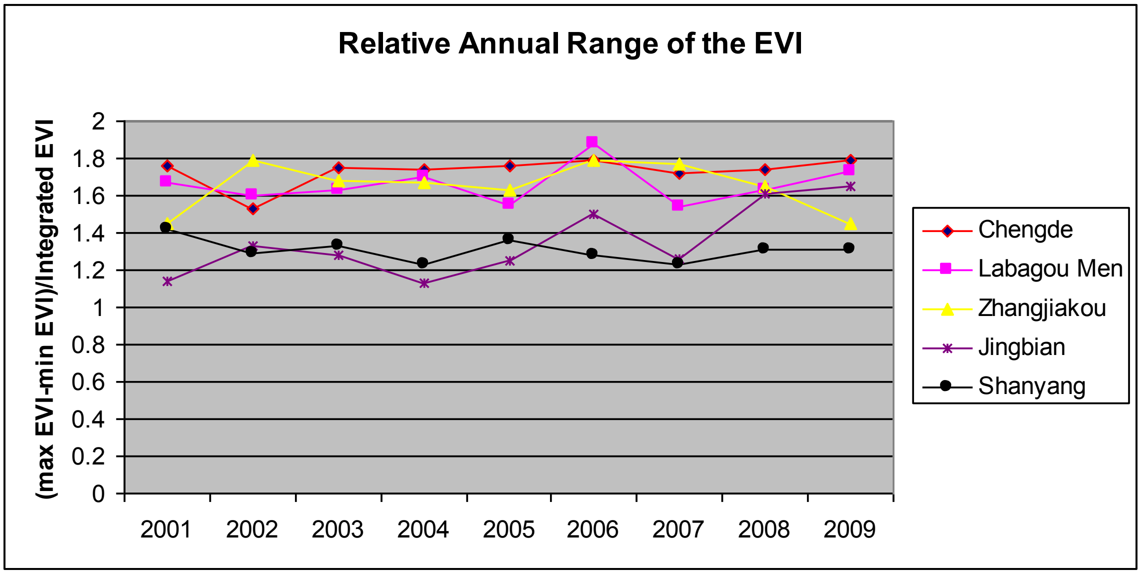


Figure 3.28 - Study Sites Relative Annual Range of EVI 2001-2009

Because climate data was not available at the study sites for the observation period, temperature data from eight North China weather stations were averaged over the growing season (defined as March-November) between 2000 and 2009, in order to determine if there variations in North China regional temperatures which may be relevant to observed changes in vegetation index values for the five study sites (Figure 3.29). Unfortunately, there are no weather data at the sites selected for analysis, so inferences must be made from other weather stations in the region. MODIS Land Surface Temperature (LST) data were also collected and examined, yet no relationship has been established between the MODIS vegetation indices and the available temperature data. Further interpretation of MODIS NDVI and EVI time-series would likely benefit from a comparison with precipitation data.

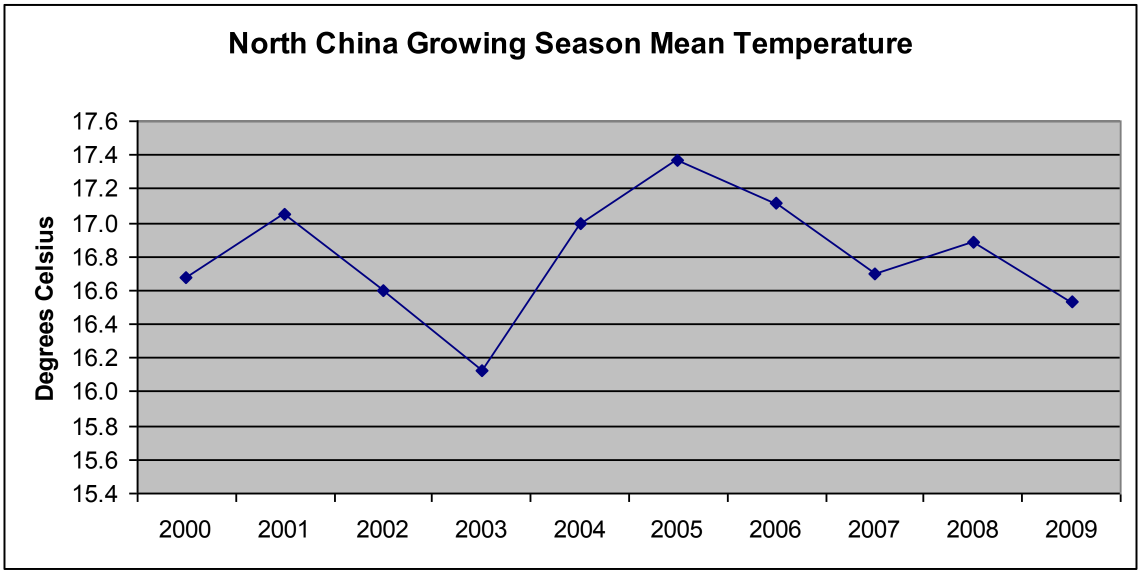


Figure 3.29 - North China Growing Season (Mar-Nov) Mean Temperature 2000-2009

Even inside China it is difficult to get recent weather/climate data. There is no mechanism of sharing this type of data on a national level. If an organization needed this type of data, they would typically send someone to a city government's meteorological agency to buy them (personal correspondence, J. Fan, July 25, 2010). The China National Agrometeorological Network collects data on climate and phenology for over 500 stations throughout China. The availability of this data is being investigated

5) Discussion

The measurements made herein based on MODIS Vegetation Indices do allow distinctions to be made regarding trends in the vegetative character of the selected study sites over the period 2000 to 2009 (Tables 3.2 and 3.3).

The changes observed in NDVI and EVI time series were for the most part comparable, but they did not always concur, most likely due to the fact that NDVI is influenced more by non-vegetative background reflections. Comparison of NDVI and EVI is also complicated by the tendency for normalized EVI values to be substantially lower than normalized NDVI for any given pixel. Concurrence of NDVI- and EVI-derived measures were strongest with calculations of Length of Season and Relative Annual Range of Vegetation Indices. Relative Annual Range holds promise as an effective means to compare NDVI and EVI; because it is measured on a ratio scale, it allows changes to be expressed as a percentage of the mean (coefficient of variation - C_v), thereby minimizing the differences between NDVI and EVI normalizations.

Chengde is a historically protected mature forest site which should see little impact from recent forest policy changes. This stable forest state appears to be reflected by the remotely sensed indicators of changes in vegetative character which were generally the smallest at the Chengde study site. One noticeable exception is that Chengde had the highest change in peak EVI. The fact that the Chengde dataset does include forest pixels outside the Chengde protective wall could lead to some unclear results.

Labagou Men has a shorter history of forest stewardship, but it does predate the 1998-99 forest projects. Small changes in vegetative character were also observed at this site.

Shanyang was predominantly a degraded forest landscape which has seen increased protection under NFCP and other programs. Indicators of changes in vegetative character were often larger at Shanyang than at the other primarily forested sites

Zhangjiakou began the decade with reflectances similar to cropland, but it has reportedly seen increasing forest cover through dust control and watershed protection projects. NDVI signatures of mixed pixels are more characteristic of cropland early in the decade, but increasing peak NDVI and longer growing seasons become more like forest in the later years.

Jingbian is cited as one of the more successful NFCP sites in the semi-arid transitional area in the west of North China (Yulin-Jiaxian Local Culture Board website. 2008). Most indicators of change in vegetative character were greatest at Jingbian, a good sign that the recent afforestation projects are proving effective in helping to combat desertification in northern Sha’anxi and are observable with coarse scale satellite imagery.

These variations in remotely sensed measurements of biomass and productivity collected over a decade do appear to confirm favorable assessments of afforestation activity at these sites as reported in Chinese academia and media.

6) Suggestions for further research

Vegetative structure is the primary mechanism through which benefits are provided by forests to combat runoff, soil and wind erosion, and to support increased air quality and greenhouse gas sequestration. Data from satellite based sensors such as MODIS are critical to systematic, thorough monitoring of the dynamics of vegetative cover. Insights from observed variability in vegetation indices show promise as a useful complement to traditional area- and volume-based analyses of forest cover. The ability to measure variability in vegetation with satellite imagery can improve assessment of the impacts of environmental policies (and their absence), and perhaps help facilitate the navigation of an uncertain climatic future.

A better familiarity with the study areas, and collection of temperature and precipitation data, would enable a much richer characterization of vegetative trends.

Recommendations for further research:

- Locate better North China climate datasets to facilitate a thorough statistical analysis of vegetation trends in relation to climate.
- Verify satellite-derived results through collection of ground observations at sites
- Conduct a county- or province-level MODIS VI analysis, find areas of change and then relate to policy / climate / environmental context
- Integrate the use of other sensors (i.e. AVHRR) for study of long-term afforestation sites (i.e. Three Norths shelter forest)
- Cartographically, this research could benefit from improvements to spatial visualization of temporal trends in MODIS subsets
- Further evaluate characteristics of NDVI- and EVI-based measures to identify differences and their causes

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Chapter 4

CONCLUSIONS

North China offers unique opportunities for observing both the past and future of environmental change. Loess is the primary surficial feature of the North Chinese environment, and the transportation of loess across the landscape by wind, water and humankind reveals important clues as to the nature of the landscape's transformation. This and other environmental evidence is critical for characterizing past environments.

And being the heart of Chinese civilization, North China has one of the longest continuous recorded histories on earth. Historical and archaeological records are crucial to understanding the impacts of human activity as related to the environment. North China's historical and environmental record shows a persistent, intensifying trend of human impact on the environment.

Environmental evidence shows that after the retreat of the last glacial maximum over 10,000 years ago, the natural landscape of North China was predominantly warm humid deciduous forest, transitioning to grassland in the drier western zone. From the macro to the micro scale, several ecological factors determine the character of natural vegetation, but humans have a demonstrated ability to influence all of them.

It is simplistic to view deforestation as the removal of trees; more commonly it occurs as degradation. So we should not view deforestation as a state – the trees were there one day and now they are gone - rather it is a dynamic continuum, manifested in North China primarily as a degradation from natural closed forest to permanent cropping.

It does not take a bulldozer to destroy a forest. Even the simplest tools are sufficient to alter the character of vegetation, although technological advances do facilitate accelerated deforestation. There is evidence of human-induced changes to North China's natural forest cover going back well into prehistory.

Human impacts to the landscape intensify as population pressure increases. Temporary reduction of human impacts has been shown to catalyze recovery towards a more natural landscape character. So the primary factor influencing deforestation has repeatedly been shown to be population pressure.

North China's greatest present-day environmental challenges are a direct result of deforestation. Flooding, desertification and dust storms have all increased as the deforestation of North China has progressed. Release of carbon into the atmosphere, loss of habitat, and loss of species diversity are among the significant secondary impacts..

Given that forests are essential to human well-being, it comes as no surprise that over the millennia deforestation has increasingly reduced the quality of life of the average Chinese, especially in regards to poverty. A scarcity of wood and other forest products and benefits has also transformed the character of Chinese culture. Many cultural innovations – from the wok to the concrete utility pole – are persistent reminders of the preciousness of trees.

Modern China has undertaken increasingly ambitious regional scale afforestation projects, but overwhelmingly these have a poor record of success. Afforested areas are often not viable due to a combination of environmental and social factors.

A dramatic strengthening of policy occurred in response to devastating 1998 floods, and initial results are encouraging. At the same time, dramatic increases in imports of wood products, in part fueled by a growing and increasingly affluent middle class, have relieved some of the pressure on domestic forests, thereby improving the chances of success of governmental afforestation policies, but with subsequent negative impacts to the exporting countries.

Assessing the impact of government policy on the North Chinese environment is difficult. Government statistics, especially those related to the environment, are notoriously exaggerated, and changing standards of classification only make matters worse. Fortunately satellite observations are useful for determining evidence of vegetative change, although traditional area-based satellite analyses often tell us little about the nature of this change. A focus on *trends* in satellite observations can reveal more about the character of vegetative change.

Direct phenological observations have been recorded for centuries, and they give us important information about past events environmental trends. The science of land surface phenology builds on the tradition of direct phenological observations, although techniques have been modified to suit the nature of spaceborne sensor-based data collection. Continental-scale phenological observations show extensive significant positive trends in north China in the past decade.

Land surface phenology characterizes vegetative change through the use of various phenological measurements from sensor-derived vegetation indices. In recent years, improved sensors and increasingly sophisticated processing and analysis techniques have helped to clarify the nature of environmental change in many areas. Herein our observations were based on data from the MODIS sensor, which since 2000 has provided enhancements in technology, data products and validation. MODIS' unique data product – the Enhanced Vegetation Index - offers better characterization of vegetation under certain conditions, nevertheless EVI and NDVI methods and results have been found to comparable.

In this study, greater positive trends were observed at recent afforestation sites than at more mature forest sites. Many of the larger positive trends were observed at the predominantly grassland site, which has received protection under recent afforestation policies.. At the predominantly cropland site, annual vegetation curves became more characteristic of scrub forest through the past decade. These positive changes observed at study sites in 2000-2009 support claims of success of Chinese government policies. Nevertheless, identification and analysis of local climate data could facilitate a better understanding of results.

Satellite observations of annual vegetative trends offer a useful complement to area- and survey-based measures, furthermore they are independent of political and economic pressures to produce favorable results. A better understanding of forest trends, past and present, holds promise for identifying responses to regional and global environmental challenges.

Appendix A

FAIR USE CHECKLISTS

(attached)

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Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: ***in favor of fair use***

Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Alan Moore

Description of item under review for fair use: Figure 2.6. 30-year flood frequency of the Huanghe, 250 BCE – 1880 AD. Source: Vörösmarty, C.J., C. Li, J. Sun, and Z. Dai. "Emerging impacts of anthropogenic change on global river systems: The Chinese example." In: J. Galloway and J. Melillo, eds, Asian Change in the Context of Global Change: Impacts of Natural and Anthropogenic Changes in Asia on Global Biogeochemical Cycles, pp. 210-44. Cambridge: Cambridge University Press. 1998

Report generated on: 10-07-2010 at : 16:59:27

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in*

Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Alan Moore

Description of item under review for fair use: Figure 2.7. 10-year North China Dust Storm Frequency since 300. Source: Domrös, M., and Peng, K.P. The Climate of China. Berlin: Springer-Verlag, 1988

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Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: ***in favor of fair use***

Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Alan Moore

Description of item under review for fair use: Figure 3.1. Discrepancies in Afforestation Claims. Source: Smil, V. China's Environmental Crisis: An Inquiry into the Limits of National Development. Armonk, N.Y.: M.E. Sharpe, 1993

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Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Alan Moore

Description of item under review for fair use: Figure 3.2. China Forest Imports 1997-2006. Source: Bull, G. "The role of emerging countries in the paper and forest products world markets: China." ACPWP 47th Session FAO Advisory Committee on Paper and Wood Products. 2006. [http://www.fao.org/docrep/009/j8386e/j8386e07.htm] Accessed April 8, 2010

Report generated on: 10-07-2010 at : 16:57:13

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: ***in favor of fair use***

Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Alan Moore

Description of item under review for fair use: Figure 3.3. Locations of MODIS Study Sites. Source: Zhao, S.Q. Physical Geography of China. Beijing, China: Science Press, 1986

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Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: ***in favor of fair use***

Draft 09/01/2009

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Name: Alan Moore

Description of item under review for fair use: Figure 3.4. Estimated Deforestation "Conversion" state of the five study sites. Source: Allen, J.C. and D.F. Barnes. "The Causes of Deforestation in Developing Countries," Annals of the Association of American Geographers, 75(2): 163-184. Philadelphia, Pa: Taylor & Francis Group, 1985

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Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***in favor of fair use***

Based on the information you provided, your use of the copyrighted work weighs: ***in favor of fair use***