CHAPTER 3

APPLICATION OF LANDSCAPE ECOLOGY IN LONG TERM ECOLOGICAL RESEARCH

Case study in China

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Abstract. The consequences of the growing world population imply an increasing demand on housing, industry, roads, airports, recreation, land, water resource, etc. Their impacts on natural landscapes and ecosystems are often significant by changing landscape pattern. The current environmental effects due to human activity, such as global change, ecosystem degradation, biodiversity loss, and others, have already arisen the attention from scientists. The long-term and potential environmental effects, however, were difficult to be identified without enough scientific data across both spatial and temporal scales. A primary goal of landscape ecology is to understand the reciprocal relationship between spatial pattern and ecological flows or processes. Achieving this goal may require the extrapolation of results obtained from small-scale experiments to broad scales. Scientific monitoring data makes a solid and convincing base for studying the dynamics of landscape spatial pattern and ecological processes and the overall environmental effects of human activities. In this paper, the Chinese Ecosystem Research Network (CERN) was introduced. It lays a foundation for landscape ecological research by offering long-term monitoring data. At the same time, how to effectively use the CERN to deepen landscape ecological researches was discussed in detail. Finally, perspectives for the development of landscape ecological researches in China were enumerated with special attention to ecological monitoring and the coupling of landscape pattern and ecological processes.

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1. INTRODUCTION

The consequences of the growing world population imply an increasing demand on housing, industry, roads, airports, recreation, land, water resource, etc. Their impacts on natural landscapes and ecosystems are often significant by changing landscape pattern (Norse, 1992; Verburg et al., 1999; Defries, et al., 2002). The impacts cover direct and indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects (Brismar, 2002). The current environmental effects due to human activity, such as global change, ecosystem degradation, biodiversity loss, and others, have already arose the attention from scientists and governments, and much endeavour were paid (Cooper and Sheate, 2002; Döös, 2002; Meadows and Hoffman, 2003). The long-term and potential environmental effects, however, were difficult to be identified without enough scientific data across both spatial and temporal scales. The impacts on ecosystems and environment would become much stronger with the intensification of human activities.

Scientific monitoring data makes a solid and convincing base for studying the dynamics of landscape spatial pattern and ecological processes and the overall environmental effects of human activities. Historically, these studies were difficult to conduct because of the dominance of short term funding programs. The complexity of the environment and the changing nature require additional research efforts that are not only long term, but also address questions of sale dependency, complex assemblages of species and their interactions, and the role of humans in environmental change. Long-term ecological research offers an important means to the traditional ecological research on data acquisition.

Landscape ecology emphasizes broad spatial scales and the ecological effects of the spatial pattern of ecosystems (Turner, 1989). Specifically, it considers four pats: (a) the development and dynamics of spatial heterogeneity, (b) interactions and exchanges across heterogeneous landscapes, (c) the influences of spatial heterogeneity on biotic and abiotic processes, and (d) the management of spatial heterogeneity. Landscape pattern is spatially correlated and scale-dependent. Thus, understanding landscape structure and functioning requires multi-scale and long-term information. However, the explicit effects of spatial patterns on ecological processes have not been well studied. The spatial patterns observed in landscapes are resulted from complex interactions between physical, biological, and social forces. Spatial heterogeneity is ubiquitous across all scales and forms the fundamental basis of the structure and functioning of landscapes. To understand how landscapes affect, and are affected by, biophysical and socioeconomic activities, we must be able to quantify spatial heterogeneity and its scale dependence. Therefore, the theory on landscape pattern, heterogeneity and scaling, could provide a guideline on establishment of long-term ecological research monitoring stations.

A primary goal of landscape ecology is to understand the reciprocal relationship between spatial pattern and ecological flows or processes (Turner, 1989; Opdam, et al., 2002; Wu and Hobbs, 2002). This goal is difficult to accomplish, however, because the broad spatial-temporal scales involved make experimentation and hypothesis testing more challenging. Thus, achieving this goal may require the extrapolation of results obtained from small-scale experiments to broad scales. Understanding the relationship between landscape pattern and ecological processes is critical for any in-depth research in landscape ecology (Wu and Hobbs, 2002; Haase and Halle, 2004). One of the trademarks of landscape ecology was its extensive use of landscape metrics among numerous methods for spatial pattern analysis (O'Neil et al., 1998; Turner and Gardner, 1990; Gustafson, 1998; He, 2000). Among these landscape metrics, most of them were introduced to describe current landscape pattern, the ecological understanding related to landscape pattern change was less studied than expected (Haines-Young and Chopping, 1996; Li and Wu, 2004). There are two reasons accounting for this. One is that it is easy to describe the landscape pattern than to study the dynamic of landscape change, as well as the ecological processes. The second reason is that to study the ecological processes requires much more monitoring data and takes long time. In most programs, short-term environmental effects were better addressed than the long-term change due to budget limitation. Long-term monitoring data are now recognized as crucial to our understanding of environmental change and management, and to the studies on landscape pattern and ecological processes. Thus, the establishment of the Long-term monitoring stations would lay a good foundation for landscape ecological research.

2. FOUNDATION AND FOCUSES OF LANDSCAPE ECOLOGY

2.1 Landscape heterogeneity, change and driving forces

Landscape heterogeneity is a key concept in landscape ecology, which is defined as the complexity of patch mosaic in space (Farina, 1998); or the uneven and non-random spatial configuration of landscape structures (Forman, 1995). It is even considered that the goal of landscape ecology is to study landscape heterogeneity. Landscape heterogeneity has remarkable impact on ecological functions and processes. For example, it influences the flow and transportation of resources, species, or disturbances in a landscape. Meanwhile, Landscape heterogeneity is also the result of the interactions of some basic ecological and biophysical processes both at spatial and temporal scales. The main sources of landscape heterogeneity are natural disturbances, human activities, and the succession and developing history of vegetation.

Landscape heterogeneity mainly focuses on the three aspects, (1) spatial heterogeneity, i.e., the spatial complexity of landscape structures, including gradient distribution and mosaic structures; (2) temporal heterogeneity, i.e., the differences of landscape pattern at different time; and (3) functional heterogeneity, i.e., the functional differences of landscape structures, for example, the spatial configuration of material, energy and species flow.

Landscape is changing, and this change will lead to profound influences on the ecology and the environment of a landscape. The result of landscape change not only altered the spatial configuration of the landscape, hence influenced the energy distribution and material cycling, some irrational landscape change also will cause some serious environmental problems, such as land degradation and non-point source pollution, thus has profound influence on the society and economy.

Landscape change is the joint result of natural processes and human activities, where natural driving forces often determine the landscape at large spatial scales, causing the large-scope change. These factors include the formation of geomorphology, the influence of climate, the influence of organisms, the development of soil, and natural disturbances. Meanwhile, anthropogenic driving forces are population, technology, politics, economy, and culture etc., which are considered the more and more important factors among the abundant driving forces to landscape change in nowadays.

We can see that more positioning data on the ecological function and process is required for the study of landscape heterogeneity; only using the remotely sensed data is obviously not enough. At the same time, it is the same for landscape change study, long-term time series data could provide more reliable evidence.

2.2 Landscape pattern and processes

Landscape pattern refers to the configuration of patches at different size and shape in space. Landscape pattern represents landscape heterogeneity in space, and determines the rate and intensity of ecological processes in a landscape. Meanwhile, landscape pattern is also the result of the interactions among these ecological processes at different scales, including disturbances (Turner and Gardner, 1991).

It is obvious that remotely sensed data can only provide information on landscape pattern, but could not supply detail information on the ecological processes in landscape. Therefore, we must have the support of on site monitoring data and combine the RS data with the monitoring data to give a clearer explanation on the interactions between landscape pattern and ecological processes.

2.3 Landscape analysis and scale change

Scale is the focal issue in landscape ecology from the very beginning. Landscape heterogeneity is always existed, although it will change in intensity along with observing scales. In contrast, homogeneity is relative, which only emerged at some special scales. We need to clarify spatial scale when studying spatial heterogeneity.

Landscape pattern also has strong scaling characteristics. It is even considered that there is no pattern if you do not mention scale. Meanwhile, various ecological processes happen at different scales, how they correlate with landscape pattern at different scales is another important issue in landscape ecology.

Moreover, the interactions of pattern and process at different scales determined that scale is also needed to be considered in landscape change study. With different observing scales, the processes and results of landscape change will differ.

As modern landscape ecology is moving from spatial to temporal, from phenomena to driving forces, and from single scale to multiple scales, long-term monitoring networks becomes more and more important to landscape ecologists.

Each research station could provide positioning data for landscape change and pattern and process studies at landscape and smaller scales; while the networks of many research stations would support the scaling studies from landscape to regional scales. Such a novel study manner would explore a completely new era of landscape ecology.

3. INTRODUCTION TO CHINESE ECOSYSTEM RESEARCH NETWORK (CERN)

The Chinese Ecosystem Research Network (CERN), one of the founding members of the International Long Term Ecosystem Research Network (ILTER), and Global Terrestrial Observation System (GTOS), consists of 36 field research stations, including 14 stations for agriculture, 9 for forest, 2 for grassland, 5 for desert, 1 for marsh, 2 for lake and 3 for marine ecosystems (Figure 1), in addition to five disciplinary centers and a synthesis center. All the CERN stations engage in monitoring work, research, experiment and demonstration, while the disciplinary centers are responsible for the calibration of monitoring instruments and data quality control. The synthesis center is responsible for data exchange and inter-disciplinary research. For years, through its long-term monitoring, research and experiment, demonstration and extension, it has served as an important facility to control desertification, soil erosion, salinization, and eutrophication.

Figure 1. Location of Chinese Ecosystem Research Network (CERN).

The Mission of CERN is to promote ecosystem conservation and improvement, environmental quality enhancement and agricultural development, and to advance the studies in ecology and related inter-disciplines. Its mandate includes monitoring, research and demonstration on typical ecosystems in China

4. CERN-BASED RESEARCH ON PATTERN AND PROCESS FROM LARGE SCALE

4.1 Landscape pattern and ecological process study across water gradient in China

4.1.1 Spatial Distribution, Representation, Scientific Themes and Research Missions

The rainfall in China is unevenly distributed and declines gradually from the southeast to the northwest, with an annual average rainfall over 2000mm in southeastern China and less than 50 mm in northern Xinjiang (Figure 2). Consequently, the production of cropland ecosystems and its interaction with climate/water varies greatly in different parts of China.

Based on rainfall distribution, major crops and soil types, twelve field research stations on cropland ecosystems are established from the northwest to the southeast (Figure 3), which roughly correspond to the water gradient from north to south. The annual average rainfall for these stations is shown in Figure 3.

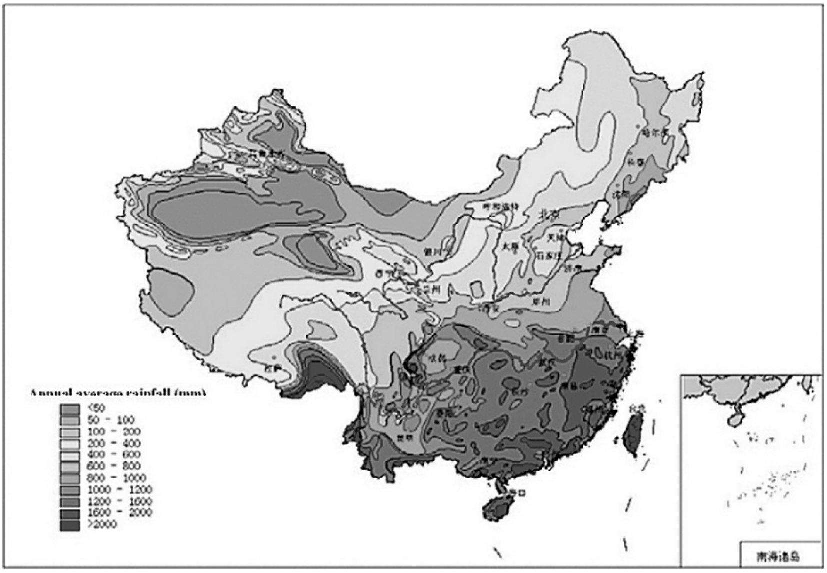

Figure 2. Distribution map of annual average rainfall in China [data source from China Institute of Water Resources and Hydropower Research (IWHR)].

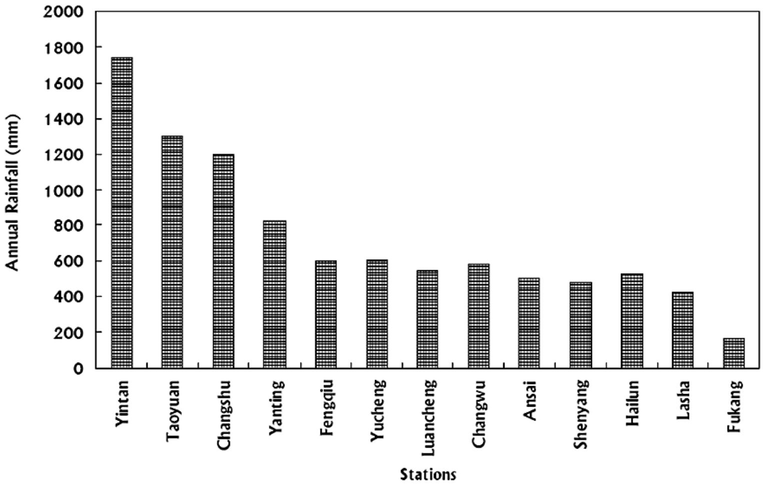

Figure 3. Annual average rainfall for CERN-based stations of cropland ecosystems.

Among them, there are four experimental stations located in Southern China along Yangtze River. Yingtan Ecological Experimental Station of Red Soil (N 28° 15'20", E 116°55'30") is located at Yujiang County, Jiangxi Province, representing the hilly area of red soil in southeastern China (coverage of 113.3 km^2, about 11.8% of China). It lies in the tropical/sub-tropical monsoon climate zones, with an annual rainfall of 1785 mm and annual mean temperature of 17.8 ℃. The annual accumulated temperature above 10℃ reaches 5528℃ and 262 days are recorded frost-free. As a region rich in water and thermo resources, it plays a significant role in agricultural production and economic development. As the main soil developed from Quaternary red clay, it is an ideal place to conduct research on red soil ecosystems. Taoyuan field research station of Agro-ecosystem Research, representative of red soil in the hilly areas around Dongting Lake, focuses its research on the structure, succession of red soil agro-ecological areas and their interactions with the productivity, the principles and relevant technologies for agricultural resources management, optimum allocation and sustainable development of regional agriculture. Changshu field research station (N31°33', E120°38') is situated in the Yangtze River Delta, representing the cropland ecosystems in the fast-growing economic area in the Yangtze River delta. Yanting field research station, representative of purple soil (N31°16’, E 105°27’), is located in the hilly area of Sichuan Basin, with an elevation of 420m. It has a mid-sub-tropical monsoon climate, with an annual mean temperature and precipitation of 17.3°C and 826 mm respectively. The purple soil was developed from Cretaceous and Jurassic purplish shale, and the vegetation was dominated by mixed forest of *Alnus cremastogyne* and *Cypressus funebris* with few arbors and grass.

There are three field research stations in Northern China. As an important field station located in Huang-Huai-Hai plain, Fengqiu field research station (N35°00’, E114°24’) focuses on long-term monitoring, data accumulation and regional ecosystem dynamics research. Another one in Huang-Huai-Hai alluvial plain, Yucheng field research station is situated in Yucheng, Shandong Province in the alluvial plain of the Yellow River, with a semi-humid, warm temperate monsoon climate. Luancheng field research station (N 37°50', E 114°40'), with an elevation of 50.1m, lies in the semi-humid and warm temperate monsoon climate zone in eastern China. It represents the high-yield agro-ecosystem in cinnamon (gray-yellow) soil at the foot of the Taihang Mountain.

There are two field research stations in the Loess Plateau region. The first one is located in Changwu County, Shaanxi Province. Changwu field research station (N35°12′, E107°40′) lies in the central southern part of the Loess Plateau. The elevation ranges from 940m to 1220m. It has a semi-humid, warm-temperate and continental monsoon climate, with an annual average precipitation and temperature of 584mm and 9.1°C, respectively, and 171 frost-free days. It is also known as a typical dryland agricultural area, with the ground water depth reaching 50~80m. Geomorphologically, it represents the hilly and gully region in the Loess Plateau, in which 65% is covered with gully slopes and 35% with highlands. Soil is characterized by dark loessial soil (or Heilu soil), a porous soil. The second one, Ansai field research station (N36°51'30″, E 109°19’23″) is situated in Ansai county, Shaanxi province in the central Loess Plateau, with an elevation ranging from 1068m to 1309m. As a representative of loess hilly areas in the Loess Plateau, it lies in the transitional zone from semi-humid and warm temperate zone to semi-arid climate zone and a transitional area between steppe and deciduous broad-leaved forests in warm-temperate area, with an annual mean temperature and rainfall of 8.8°C and 500mm, respectively. However, this area suffers from serious water and soil erosion mainly due to human activities.

In northeastern China, there are two field research stations. Shenyang agro-ecological experimental station lies in Shenyang, Liaoning province, a representative of agro-ecosystem in the lower reaches of Liaohe plain, which is known as one of the major food production bases in China. Hailun agro-ecological experimental station (N47°26’, E126°38’) is located in the western suburb of Hailun, northeastern Songnen plain, with an elevation of 240m. It has a temperate and continental monsoon climate with dry and cold winter but warm and rainy summer. The rainfall and heat occur in the same season. As one of the three largest areas of black soil in the world, the Songnen plain ranks among the most important food production bases in China because of its high soil organic matter.

There is only one field research station in northwestern China. It is named as Fukang Desert Ecological Research Station (N43°45’, E87°45’), which is situated at the southern edge of Junggar Basin, Sangonghe River-basin of Fukang city, Xinjiang Uygur Autonomous Region. It ranges from the highest peak of eastern Tianshan Mountain---Bogda Peak, at an elevation of 5445m to the southern fringe of Gurbantunggut Desert at an elevation of 460m. A natural landscape belt of 80 km is formed in the site, from alpine glacier, high mountain and sub-alpine meadow to mid-montane forest, lower mountain steppe and desert. It is broadly a representative of inland desert of temperate zone in the center of Eurasia. As an area dominated by saline alkali arid soils, it has a continental arid climate, with a mean temperature of 6.6°C. Its annual mean precipitation is 164 mm but the annual potential evaporation reaches 2000mm.

The primary goals of these field research stations are to fully understand the structure and function of agro-ecosystems based on long-term observation, experimentation and research on various ecological factors. It is also aimed to reveal the matter cycling and energy transfer patterns between environmental resources and human activities, to establish practical models for wise use of agricultural resources and effective management of agro-ecosystems, and to provide a scientific basis for ecological protection in the representative regions.

4.1.2 Experimental Facilities, Measurement Items and Research Approaches

The field research stations of agro-ecosystems under CERN are generally equipped with the following facilities including the soil physio-chemical laboratory, physio-ecological laboratory, laboratory for matter cycling simulation, computer center, library, meteorological observation site, observation site on microclimate gradient, experimental site on nutrient balance in cropland, runoff field and lysimeter. Some of these stations are also provided with plastic tunnel, glass greenhouse and other instruments, including the graphite furnace, atomic absorption spectroscopy, IR gas analyzer, UV-visible spectrometer, oxygen-bomb calorimeter, leaf area meter, photosynthesis evapotranspirometer and TDR soil water measurer, etc. The major items to measure include the routine meteorological observation items and the ecological indicators for crops, such as group dynamics, LAI, dry matter accumulation process, soil water and temperature profile, soil nitrogen, ground water changes, irrigation and runoff. A commonly agreed observation standard and indicators system is adopted by these stations for them to conduct comparative research across the network at regional scale. In addition, demonstration sites are available in these field stations to present and disseminate the best practices in agro-ecosystems.

In general, the field research stations under CERN focused on data accumulation based on long-term monitoring of major ecosystems and their dynamics, and the research on the structure, function of these ecosystems and their responses to global change; quality assessment and health diagnosis of cropland ecosystems; wise use of agricultural resources and sustainable development in these regions; mechanism and regulation of productivity in ecosystems.

In these stations, a variety of tools are used at different scales. For example, at the site level, emphasis is paid on the test and observation data to explore the process of crop/water and crop/nutrient interactions in cropland ecosystems. Mathematical models are developed to improve the ability to predict the dynamics of cropland ecosystems. Other models related to SPAC, crops, nutrient and water dynamics, are also applied in this process. At the regional scale, mathematical models, combined with GIS and remote sensing technologies, are used to study the spatial variability of the components and processes in cropland ecosystems, their long-term changes under the climatic factors and the trends under global change, based on the data collected from the sites. Therefore, the layout, monitoring and research foci of the agricultural stations under CERN have been shifted from static to dynamic, and from micro to macro-scales. An observatory of agro-ecosystem is established to conduct comparative synthesis research, which is made possible by the sufficient and highly representative sites with standardized measurement and testing methods, instruments and facilities. Research programs of common interests have been implemented to conduct long-term observation, to promote data sharing and synthesis on research findings, to provide information related to environmental change and ecosystem succession, and to develop holistic assessment and prediction models.

Significant achievements have been made on the researches at the site-landscape-regional scales based on CERN so far. For instance, the Program of Water Circulation and Regional Variation for Cropland Ecosystems in Northern China, funded by the Natural Science Foundation of China (NSFC), is based on the agricultural sites under CERN in northern China and aimed to address the issues concerning water consumption process, production process and water use efficiency for the cropland ecosystems, and to fully understand the crop production/water interactions in northern China.

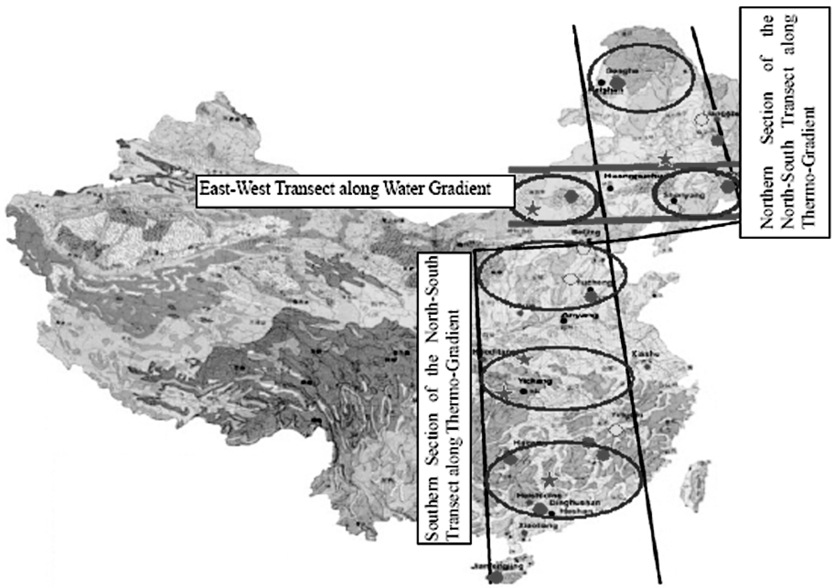

Figure 4. NECT and NSTEC under IGBP Terrestrial Transect (adapted from the synthesis of 'Peng and Ren, 2000' and 'Wang and Gao, 2003').

4.2 Landscape pattern and ecological process study across thermo-gradient in China

Two major transects are established with the field research stations of CERN, one along thermo-gradient extending from north to south and the other along water gradient from east to west. Some backbone sites along the North East China Transect (NECT) and North-South Transect of Eastern China (NSTEC) under the IGBP Terrestrial Transect, representing the major areas and ecosystems in eastern China, serve as a fundamental platform for long-term synthesis research on ecosystem pattern and process across the site-landscape-region scales (Figure 4).

NECT is mainly a rainfall-driven transect extending from east to west, while NSTEC is a thermo-gradient transect from north to south, as well as the significant change of water gradient (Figure 5). They provide unique conditions for scientists to carry out research on ecosystem pattern and process in eastern China, and cross-scale studies on ecosystem change at the site-landscape-region scales.

Transect Approach is a unique and valuable tool for global change and landscape ecological study, which aims to link the sites and regions (site-transect-region), to couple and transfer in various spatio-temporal scales, and to conduct integrated analysis on the interactions between ecosystem structure, function, process, and their driving forces. It can be also used to maximize the efficient integration and use of data resources from different sites, and enhance the scientific understanding by analyzing the temporal succession with spatial pattern and experiments.

The transect-based research along environmental gradient is currently focused on the ecosystem pattern and process changes driven by environmental and human factors, and is designed to address some new scientific issues including water, carbon and nitrogen cycling process and their coupling; biodiversity/ecosystem functions interaction; and ecosystem response and adaptation. More emphasis is placed on the comprehensive monitoring of matter, energy and stable isotope fluxes of ecosystems based on observation, test and transect survey. It is also a multi-process and cross-scale approach that integrates the comprehensive monitoring with field experiments, ground monitoring and research with remote sensing measurement, and monitoring data with ecological modelling.

So far, studies have been conducted along NECT and some results were achieved, including the development of databases covering vegetation, soil, topography, climate, remote sensing, plant physiology, paleoclimate and paleophyte, the implementation of dynamic monitoring and experiments in representative ecosystems along the transect (Zhou, 2002; Tang, 2003), the development of ecological models at various scales such as the stomatal conductance, climate-vegetation, natural vegetation NPP, biogeochemistry and remote-sensed monitoring (Zhang et al., 1997; Zhou et al., 2003; Gao et al., 1997), preliminary study on the potential response of NECT to global change, as well as the feedback of natural vegetation NPP and typical steppe and broad-leaved Korean pine ecosystems to climate change.

Similarly, comprehensive measurements have been made along NSTEC, covering water, soil, atmosphere and biomass among different cropland ecosystems.

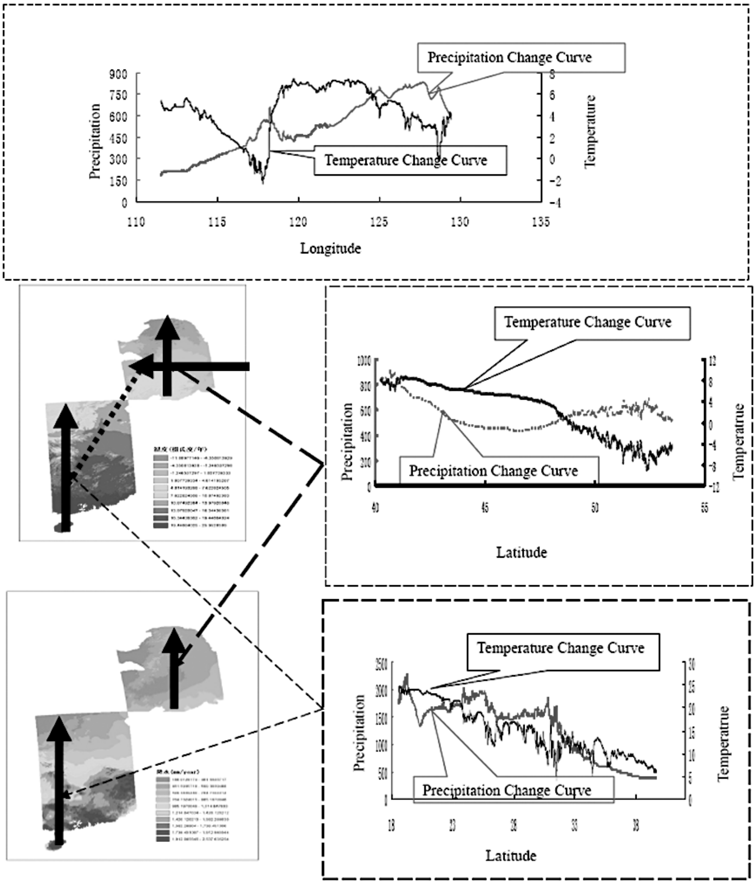

Figure 5. Temperature and Precipitation Changes of NECT and NSTEC under IGBP Terrestrial Transect.

Other achievements include the development of a distribution pattern map on biomass and productivity of agricultural ecosystems in the transect to simulate their potential responses to global change (Peng, 2002; Sun et al., 2003), the application of transect approach to study the structure, function and process of agricultural ecosystems in eastern China, the revealing of land use/cover change along NSTEC and its natural and socio-economic implications. In addition, the bio-geographical, biogeochemical and function-process coupling models are developed for the major agricultural ecosystems at various scales (patch, landscape and regional scales). Some policy options are proposed to address the potential impact of global change and greenhouse gases on agricultural production.

However, due to financial limitation in transect research, the long-term monitoring, comparative experiment and data accumulation along the two transects, as well as the transect-based integrated research, are not fully implemented. Therefore, more efforts are required to establish a platform which integrates monitoring, experiment and research, based on site-transect-network, to address the scientific issues such as the response and adaptability of ecosystems to global change; carbon-nitrogen-water cycling process and their coupling relationships, biodiversity/ecosystem function interactions, the effect of human activities and natural process on ecosystem patterns, modelling and forecasting of ecosystem pattern, structure and function at regional scale. An integrated system for data-model integration will also be made available to simulate the pattern, process, structure and function of interactions across community, landscape and regional scales, which can be applied to quantifying the vegetation pattern, carbon, nitrogen and water flux and balance; change of biodiversity and ecosystem productivity, the impact of global change on regional ecological function, and food security.

4.3 Biodiversity monitoring and management in China

Over the past few decades, the growing human activities have intensified the global climate change, landscape fragmentation and environmental pollution, and the rate of species extinction has accelerated globally (Brook et al., 2003). As the most populous country in the world, China is challenged with biodiversity loss. Biodiversity is the earth's life-support system as a result of about 4 billion years of evolution (Chen, 1993), including the plants, animals, microorganisms, the ecosystems and ecological processes. The loss of biodiversity not only results in the damage of food chain and the disconnection of ecological relationships among various species, but also alters the ecosystem functions.

Since it takes a rather long time for the succession of biodiversity and ecosystems, transects along various environmental gradients need to be applied as the natural laboratories to explore the driving mechanisms of biodiversity, vegetation and ecosystem distribution, to predict their dynamics, intensity and scope within limited periods, to analyze the temporal succession with spatial pattern, and to define the roles of various driving forces in biodiversity and ecosystem change. NSTEC and NECT, the two major transects in eastern China, are ideal for scientists to conduct research on biodiversity and ecosystem change and bio-resources management, since the vegetation cover types distributed along the NSTEC from the north to south are the coniferous forests in cold temperate zones to tropical rainforests, while along NECT the deciduous broad-leaved and coniferous mixed forests, grasslands and deserts can be found from east to west (See Figure 6).

A number of important results were achieved in the following fields along NECT and NSTEC, including the eco-geographical characters and its relationships with vegetation gradient (Zhang et al., 1997; Ni et al., 1999; Teng et al., 2000; Ni and Zhang, 2000), climate variability and vegetation, vegetation and landscape change, land use/cover change, and agricultural regional change under the impact of global change (Peng and Ren, 2000; Peng, 2001, 2002; Zhou, 2002, 2003; Tang, 2003; Ni and Wang, 2004); the spatial distribution characteristics (Chen et al., 2002) and temporal dynamic changes (Chen et al., 2000, 2001, 2002, 2003) for major tree species in eastern forest areas, C4 plant distribution/climatic factors interaction (Tang, 1999); spore and pollen/vegetation interaction, major plant functional types, spatial distribution and their interactions with climate (Ni, 2003; Wang and Ni, 2005); NDVI seasonal changes/precipitation interaction (Tang and Chen, 2003); thermo driving effect and the water-thermo effect of forests (Zhou, 1997); the productivity pattern of agricultural ecosystems (Qian et al., 2001); and NDVI change of typical vegetation in central southern section of the transects (Sun et al., 2003).

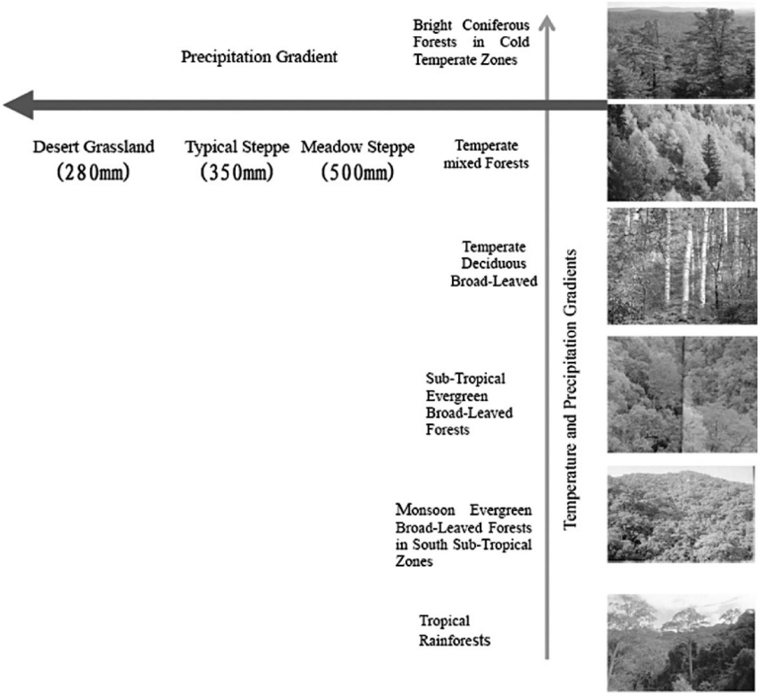

Figure 6. Major Natural Vegetation Types along NECT and NSTEC.

As for the predictive trend in vegetation, such issues were addressed, including the spatial distribution of biomes and its response to global change along NECT (Li, 1995; Tang et al., 1998; Ni, 2000); the remote sensing information-driven model of regional vegetation and its response to global change along NECT (Gao and Zhang, 1997; Gao and Yu, 1998); the potential changes of vegetation and agricultural ecosystem patterns along NSTEC (Peng et al., 2002); the vegetation status under land use constraint and the response of its productivity to global change (Zhang, 1997; Gao and Yu, 1998).

In spite of this, we are still uncertain about some issues, such as how does the biodiversity of major grassland and forest ecosystems in China changes with the temperature and precipitation gradients; how will the abrupt changes of water-thermo factors and the increasing efficiency of nutrients along temperature and water gradients influence the biodiversity and ecosystem function of grassland and forests; how the climate change and human activities will contribute to the change of ecosystems/vegetation patterns and how these patterns will adapt to the climate change. In such cases, the field stations along NECT and NSTEC need to be organized to conduct biodiversity inventory, ecosystem observation and research, with an objective to study the response and adaptation mechanisms of biodiversity and ecosystem function to global change (water, temperature, nitrogen and their composites), and to understand the pattern of biodiversity with the water-thermo gradients; the response and adaptation of grassland biodiversity and ecosystem function to the abrupt changes of water, heat and nutrients, as well as the impact of their abrupt changes on forest biodiversity and ecosystem functions. Comparative synthesis research on the environmental driving mechanism for the changes of ecosystem/vegetation pattern along the two transects is also necessary to predict the adaptability of natural and human-induced changes of ecosystem/vegetation pattern to climate change, and to identify the thresholds of change for ecosystem/vegetation pattern, the intensity and contribution of human activities.

4.4 Landscape pattern analysis and ecological process at multiple scales

4.4.1 Agricultural landscape and ecological processes study in China

Agricultural landscapes are mosaics of natural and human-managed patches that vary in size, shape and arrangement. The spatial pattern exerts important influence on many ecological processes. Based on field research stations and the principle of landscape ecology, the research of agricultural landscape and ecological processes can be carried out in China.

Agricultural landscape and ecological processes study in the Loess Plateau There are two agricultural stations (Ansai and Changwu) in the Loess Plateau, which are used for long term monitoring and research. These two stations focus more on soil erosion, rational land use, soil water balance, nutrients cycling and deteriorated ecosystem restoration. Based on the two stations, the scale-pattern-process theory in landscape ecology can be applied in the study of agricultural landscape and its effects on soil and water loss, soil nutrient and soil moisture at multiple scales.

At slope scale, there are lots of research plots with different slope lengths, gradients and shapes as well as different crops and management practices in Ansai and Changwu stations. Many researches were carried out to detect the effects of land use or topographical characters on soil erosion, runoff, nutrient loss, and soil moistures by using the monitoring data (Fu et al., 2003; Tian et al., 2005). For example, some research found that farmland was the most susceptible land use type on runoff, soil loss and nitrogen loss, and landscape structure at slope scale may alter soil moistures reference catchments, landscape pattern change and its driving forces can be derived by landscape indices and GIS techniques (Chen et al., 2001;

Zhang et al., 2004). For example, some research found that farmland was the most susceptible land use type on runoff, soil loss and nitrogen loss, and landscape structure at slope scale may alter soil moistures and nutrient obviously (Fu et al., 1999; Wang et al., 2001).

At small watershed scale, by using the long term monitoring catchments of CERN and loss often consider landscape structure and soil erosion model (Yu, 1996; Liu et al., 2001). As for soil nutrient and moistures, it was found that land use, landscape position and management are main driving factors at small watershed scale (Wang et al., 2001; Wen et al., 2005; Qiu et al., 2003).

At regional scale, there are some methods on the researches of landscape pattern and ecological process for Loess Plateau. One is to combine the monitoring data and scientific results of the two stations, and draw some conclusions for the loess area. Another way is using up-scaling methods to study the ecological mechanism of large area (Chang et al., 2005). Furthermore, some models at watershed scale may be used at regional scale and integrated study of multiple scales may be realized for some ecological process, such as land use and soil loss.

Agricultural landscape and ecological processes study in Northern China Northern China is the main region of wheat production in China, and three field research stations are established in this region (Yucheng, Fengqiu and Luancheng). Committing to the long term on-site experiments and observations, these stations dealt with the research on ecological and environmental factors and ecological processes, dynamics of structure and function of agro-ecosystems, rational utilization of agricultural resources. The study of agricultural landscape and ecological processes in this area focused on the following aspects: movement and utilization of water, nutrient distribution and leaching, and development of agricultural productivity.

At plot scale, the data of field experiments of CERN stations can be used to address the issue of the effects of crop growth on water movement and nutrient leaching. For example, movement and utilization of water may involve soil water, crop water evapotranspiration and demand, crop water consumption and water use efficiency (Zhao et al., 2002; Wang et al., 2003). And the possible reasons for nutrient leaching may be the factors such as spatial distribution of soil type, topographical feature, fertilize and irrigation regimes. As for the crop yield at plot scale, not only the function of water and fertilizer, but also plant structure needs to be explored. Some research has verified that plant structure will change crop yield obviously (Wu and Yang, 1998).

At regional scale, spatial distribution of nutrient can be studied by considering soil types (Zhu et al., 2004) and other environmental factors. As for water movement, nutrient leaching and agricultural production, some regional models, such as hydrological model and crop growth model, may offer support to landscape pattern analysis and ecological process research at regional scale. Furthermore, comparative studies resulted from different stations can conduct the research of landscape pattern and ecological process, which may offer valuable base for regional agricultural development.

Agricultural landscape and ecological processes study in Southern China

There are four field research stations under the CERN in south China rice cultivating region, including Changshu, Taoyuan, Yingtan, and Yanting. The geomorphological features of these stations are alluvial plain (Changshu) of the Yangze river delta, red soil hilly areas (Taoyuan and Yingtan), and purple soil area (Yanting).

Changshu agricultural experimental station is mainly focused on the theories and practices of intensive agriculture and the pertinent environmental impacts in rapid urbanizing area. The other three stations pay more attention to red soil agro-ecosystem utilization and sustainable management in the hilly areas. Whereas, the common missions of the stations are oriented to conduct research at the field scales and performing demonstrations of 1) optimization of nutrient cycling (Ding et al., 2004; Wang et al., 2004) and management for farmland ecosystems, 2) construction of models of efficient eco-agriculture, 3) the comprehensive control of land or environmental degradation (Li, 1993), and 4) long-term monitoring of agro-ecological processes and the environmental variables of the surface and underground water, soil, atmosphere, climate, and biological communities (Zong, 1998a, b; Shi et al., 2002). All these researches, although conducted at small scales, are helpful to improve the understanding of the patterns and processes of the agro-ecosystems and to develop techniques for the wise use of resources and effective control of environmental pollution.

At small watershed or regional scales, the researches are extended to landscape dynamics and the driving forces (Yue et al., 1997; Zhang et al., 2003), ecological-environmental-economic quality assessment (Wang et al., 2002; Zhang and Li, 2002), and the management and effects of ecological rehabilitation or reclamation (Lou, 1997). These researches integrated both natural environment and human dimensions in identifying and solving practical problems and thus more relevant for multi-level land use decision making from farmer households and other stakeholders to governments.

4.4.2 Forest landscape dynamics and management in China

There are nine field research stations in CERN involved in forest observation. Together with the forest experiment stations from China Forest Research Network (CFERN), 23 stations are involved in forest ecosystems monitoring and ecological research. The forest experiment stations in CERN represent the typical forest ecosystems of the humid needle-broadleaved mixed forest ecoregion of the temperate zone, humid and semi-humid deciduous broadleaved mixed forest ecoregion of warm temperate zone, humid evergreen broadleaved forest ecoregion of the sub-tropical zone, Tibet plateau forest and extremely cold meadow ecoregion, and humid and semi-humid evergreen broadleaved forest ecoregion of south Asia monsoon zone (Fu et al., 2004). The zonal and azonal geographical differentiation of the main forest ecosystem types in China is captured by the CERN and CFERN forest experiment stations. The forest ecosystem types under observation vary widely from pure natural to artificial and from climax to the degraded. The monitoring items of these stations include the dynamics of the climatic and atmospheric conditions, the pattern and processes of biological entities from species to communities, hydrological cycle and water quality, and the dynamics of soil conditions. Apart from these long-term monitoring, the experiment stations usually have their special scientific interests. For example, Huitong forest ecological experiment station (Hunan province, south China) is characterized for the ecological researches on forest plantations (Yu, 2000).

These experiment stations form a concrete basis for conducting ecological studies at various spatiotemporal scales. At specific geographical locations, many ecological issues such as C and N cycling (Shen et al., 2003; Tian et al., 2004), the dynamics of biotic and abiotic factors in the processes of forest ecosystem succession or restoration (Tong et al., 2004; Xu et al., 2005), forest ecosystem functions and biodiversity (Xu and Liu, 2005), and forest landscape ecological analyses (Ma and Fu, 2000a, b; Liu et al., 2003; Chang et al., 2004) have become hot research topics recently.

The researches based on these experiment stations in the past decade were also summarized into ten branches including carbon cycling, biodiversity, biomass, photosynthesis and hydrology, ecosystem functioning, restoration ecology, ecological modelling, urban forestry, global climate change, and other basic comprehensive forest ecological studies (Feng, 2004). At regional or national scales, these experiment stations facilitate comparative studies (Liu et al., 2003), ecosystem assessments, and long-term environmental change analyses.

5. CONCLUDING REMARK

5.1 Roles of CERN in landscape ecological study

Landscape ecology deals with the structure, dynamics, functioning, and scaling of landscapes (Wiens, 1999). It should be regarded as a multidisciplinary, better a trans-disciplinary science where different views and approaches from both natural and social sciences should be involved in a holistic manner (Bastian, 2001). Ten important research topics were proposed for future development of landscape ecology in theory and methodologies (Wu and Hobbs, 2002). CERN, as an important research infrastructure on long term monitoring, serves for at least eight of these research topics concerning data acquisition and the core issues of landscape pattern and ecological process relationships and their scaling.

These experiment stations cover agro-ecosystems, forest ecosystems, grassland ecosystems, desert ecosystems, everglade ecosystems, wetland ecosystems, and ocean ecosystems. The functioning of these stations have contributed greatly to landscape ecological studies in China from the aspects of land use structure and ecological processes, human disturbance and landscape health, landscape management and sustainable resource utilization, integration of physical and human factors, and landscape modeling in various regional contexts (Fu and Lu, 2006). All these contributions are indispensable for the achievements ever made in landscape ecological studies of China. Furthermore, these experiment stations are also important bases for international research collaborations such as Millennium Ecosystem Assessment.

5.2 Further the study of the interactions between landscape pattern and ecological processes in landscape ecological research

Much progress has been made on theory and practice since the birth of landscape ecology as a scientific discipline. However, many problems are still waiting to be addressed in further study. Within which the interactions between landscape pattern and ecological processes remain to be poorly addressed core issue in landscape ecological research both in the international context and in China. However, only after the interactions between landscape pattern and ecological processes are well understood, the landscape ecological theories and applications can be successfully bridged to the societal needs such as resource use and conservation, ecological rehabilitation, land use planning and design, and ecosystem management.

China is a developing country with large population and diverse landscape types. It is currently in a stage of rapid socioeconomic development. The drive for socioeconomic development is strong, and environmental quality, resource availability and ecological security are also important concerns for regional sustainable development. Many new problems concerning natural resources utilization, ecological conservation and rehabilitation, and the balancing of inter-regional development are waiting for solutions and call for the active participation from landscape ecologists. Despite all the past encouraging progresses, landscape ecology in China still lags behind the change of actual societal needs. Facing the theoretical and practical challenges, the core issue of landscape pattern and ecological processes need to be lucubrated in China.

Any kinds of landscape ecological research, including theoretical development, modelling, planning and design, need to be based on or verified by certain scientific data from long term monitoring, survey and experiments (Fu and Lu, 2006). Therefore, Long-term monitoring, experiments, surveys, and simulation need to be strengthened. Field experiment stations have been set up since the 1950s to conduct research on such landscape ecological issues as water and thermal balance, agro-ecology, desertification and soil erosion control (Huang et al., 1990). Many scientific data have been produced from these stations. So far, the environmental and ecological monitoring, experimenting, and data sharing mechanisms have been established and put into operation, such as CERN, CFERN, China Meteorological Data Sharing Services Network (http://data.cma.gov.cn), Data sharing Network of China Earth System Science (http://eng.wdc.cn:8080/Metadata/index.jsp). Therefore, the researches on the interactions between landscape patterns and ecological processes have been receiving more and more data support from both the various kinds of field stations for monitoring and research and the web-based data sharing mechanisms. Further efforts need to be directed to the improvement of spatial distribution and data quality of the field monitoring and research stations.

Consequently, the core issues of the relationships between landscape pattern and ecological process and scaling will be more informative during landscape ecological research and applications.

At larger spatial scales, systematic ecological modelling is necessary in understanding and regulating the relationships between landscape pattern and ecological processes. The hierarchical patch dynamics (HPD) paradigm and the scaling ladder strategy (Wu and David, 2002) are insightful as theoretical framework for this kind of modelling initiatives. Meanwhile, the land unit approach (Zonneveld, 1989) and land evaluation are believed to be helpful in the integration of landscape pattern with ecological processes. Therefore, multidisciplinary and transdisciplinary approaches need to be encouraged in disentangling the overwhelming complexity of real world landscapes through long term and widely distributed monitoring and experimentation based ecological modelling.

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