Integrated Ecosystem Assessment of Western China

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Funded by

Ministry of Science and Technology of the People’s Republic of China
Millennium Ecosystem Assessment
Chinese Academy of Sciences
National Institute for Environmental Studies of Japan

Participant Institutions

Institute of Geographical Sciences and Natural Resources Research, CAS
Research Institute of Forest Resource Information Techniques, CAF
Information Center, SEPA
Research Center for Eco-Environmental Sciences, CAS
Xishuangbanna Tropical Botanical Garden, CAS
Institute of Mountain Hazards and Environment, CAS
Xinjiang Institute of Ecology and Geography, CAS
Cold and Arid Regions Environmental and Engineering Research, CAS
National Institute for Environmental Studies of Japan

1. Introduction

Western Development is an important strategy of China Government. The ecological environment in the western region of China is very fragile, and any improper human activity or resource utilization will lead to irrecoverable ecological degradation. Therefore, the integrated ecosystem assessment in the western region of China is of great significance to the Western Development Strategy. This project, Integrated Ecosystem Assessment of Western China (MAWEC), will provide very important scientific foundations for both the central and local governments to make decisions on ecological construction, thus assuring the successful implementation of the Western Development Strategy. Meanwhile, MAWEC as one of the MA sub-global assessments is contributing to strengthen capability in boosting the development of the ecological science, interaction between different subjects, and combination between scientific research and practice, and pushing forward international cooperation in the relevant fields.

1.1. Millennium Ecosystem Assessment

Millennium Ecosystem Assessment (MA) is a four-year international cooperation project. The purpose of the project is to meet the demands of the decision makers for scientific information about interrelation between ecosystem services and human well-being (http://www.milleniumassessment.org). UN Secretary-General Kofi Anan announced the commencement of MA in June 2001, and the major assessment reports were and will be published successively in 2003-2005.

MA focuses on the linkages between ecosystems and human well-being and, in particular, on "ecosystem services." In terms of MA, an ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. The MA deals with the full range of ecosystems-from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use, to ecosystems intensively managed and modified by humans, such as agricultural land and urban areas. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (Figure 1.1). The human species, while buffered against environmental changes by culture and technology, is ultimately fully dependent on the flow of ecosystem services.

On the one hand, the impact of ecosystem degradation on human well-being and economic development is increasing sharply with each passing day, and on the other hand, proper ecosystem control for eliminating poverty and achieving sustainable development provides people with hard-won opportunities. Right due to full understanding of this situation, UN Secretary-General Kofi Anan delivered the following speech at the UN general meeting in April 2000 (Millennium Ecosystem Assessment, 2003): Without sufficient scientific information, we can't develop any sound environment policy. Although we've got a great deal of data and information in some fields, our knowledge is till insufficient. Particularly, up to now, we haven't carried out any global ecosystem assessment. MA is right the important international cooperation program that aims to describe the status of the Earth's health through international cooperation.

1.1.1. Connotation of MA

At present, people need ecosystem services a great deal, so it has become an important principle to consider the relations between the ecosystem services. For instance, a state can increase supply of grains by felling forests and expanding farmlands. As a result, other services of ecosystems are weakened. In the forthcoming several decades, the weakened ecosystem services may be of the same importance as or more important than food provision. It is estimated that the world population will increase by over three billion and the world economy will double in 2050, which means the demands for and consumption of biological resources will soar drastically, and increasingly affect ecosystems and their services.

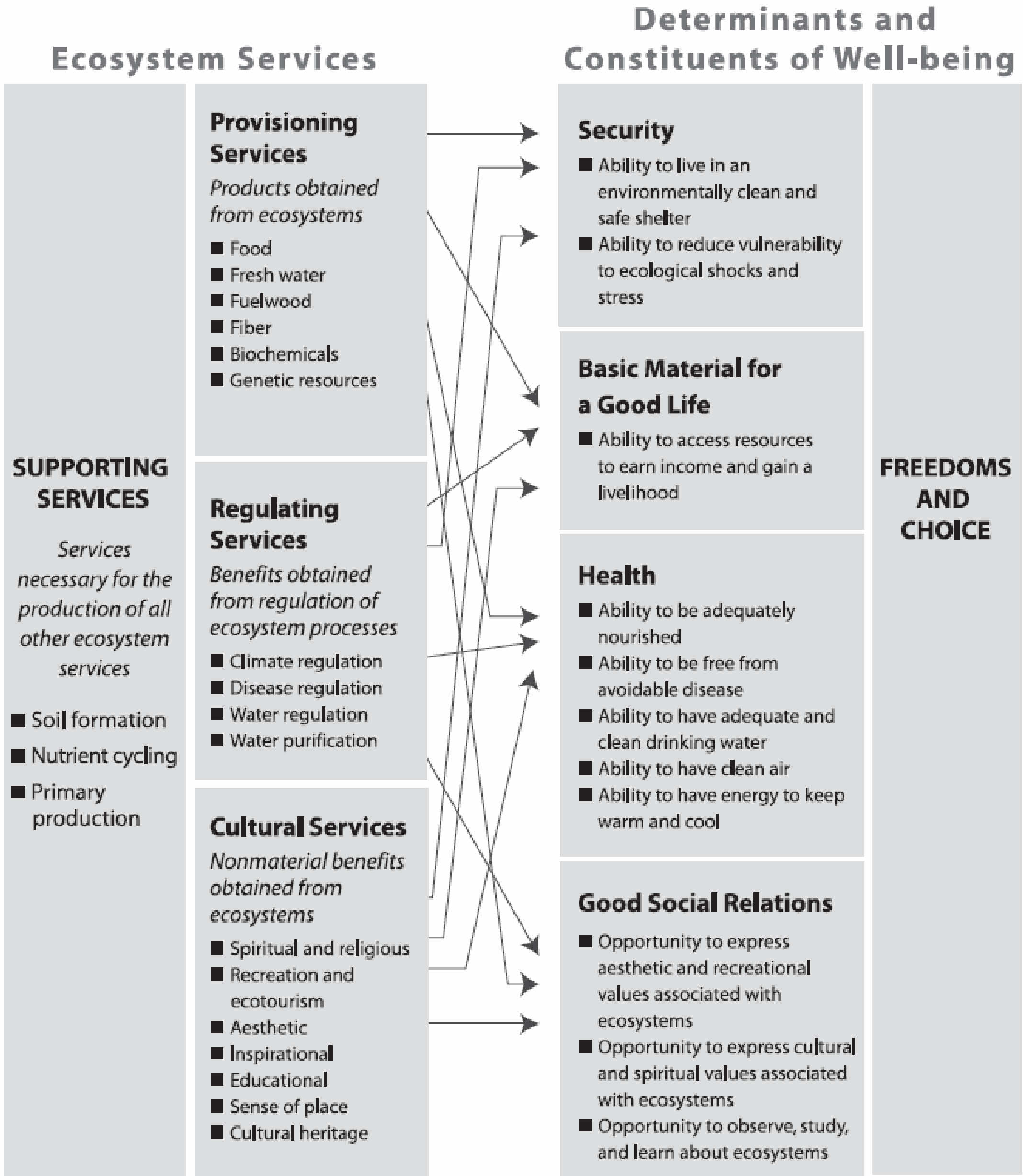

Figure 1.1. Ecosystem services and their links to human well-being

Ecosystems degrade with each passing day, while people's demands for their services constantly increase. This seriously impacts on the sustainable development people expect. Human well-being is affected by not only the gap between demand for and supply of ecosystem services, but also the rising fragility of individuals, communities and states. Highly productive ecosystems and their services can assure the security of people. Well managed ecosystems can reduce risks and fragility, while poorly managed ecosystem may lead to flood, aridity, poor grain yield, or diseases, thus further increasing risks and fragility.

In recent decades, the world's ecosystems have changed a great deal, and complicated changes have taken place in the social system as well. Meanwhile, the changes of the social system have result in both pressure on ecosystems and opportunities of relieving the pressure. As the force of a more complicated system combination (containing regional administrations, transnational companies, UN and non-governmental organizations) increases constantly, the force of individual states decreases accordingly. The colonies of various interests have participated in the decision-making processes more actively. Ecosystems can be affected by the decisions of a range of departments, so it becomes an increasingly severe challenge to provide the decision-makers with information about ecosystems. Meanwhile, new systems provide unprecedented opportunities for information about ecosystems to expand quickly. In order to improve control of ecosystems and achieve the purpose of boosting human well-being, it is necessary to develop new system and policy combination, and change the ownership of resources and the right to use them. On the background of fast social development today, it hasn't been more possible to obtain the above-mentioned conditions than any time before.

1.1.2. Conceptual framework of MA

The conceptual framework for the MA assumes that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being (Figure 1.2). At the same time, social, economic, and cultural factors unrelated to ecosystems alter the human condition, and many natural forces influence ecosystems. Although the MA emphasizes the linkages between ecosystems and human well-being, it recognizes that the actions people take that influence ecosystems result not just from concern about human well-being but also from considerations of the intrinsic value of species and ecosystems. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else (http://www.milleniumassessment.org).

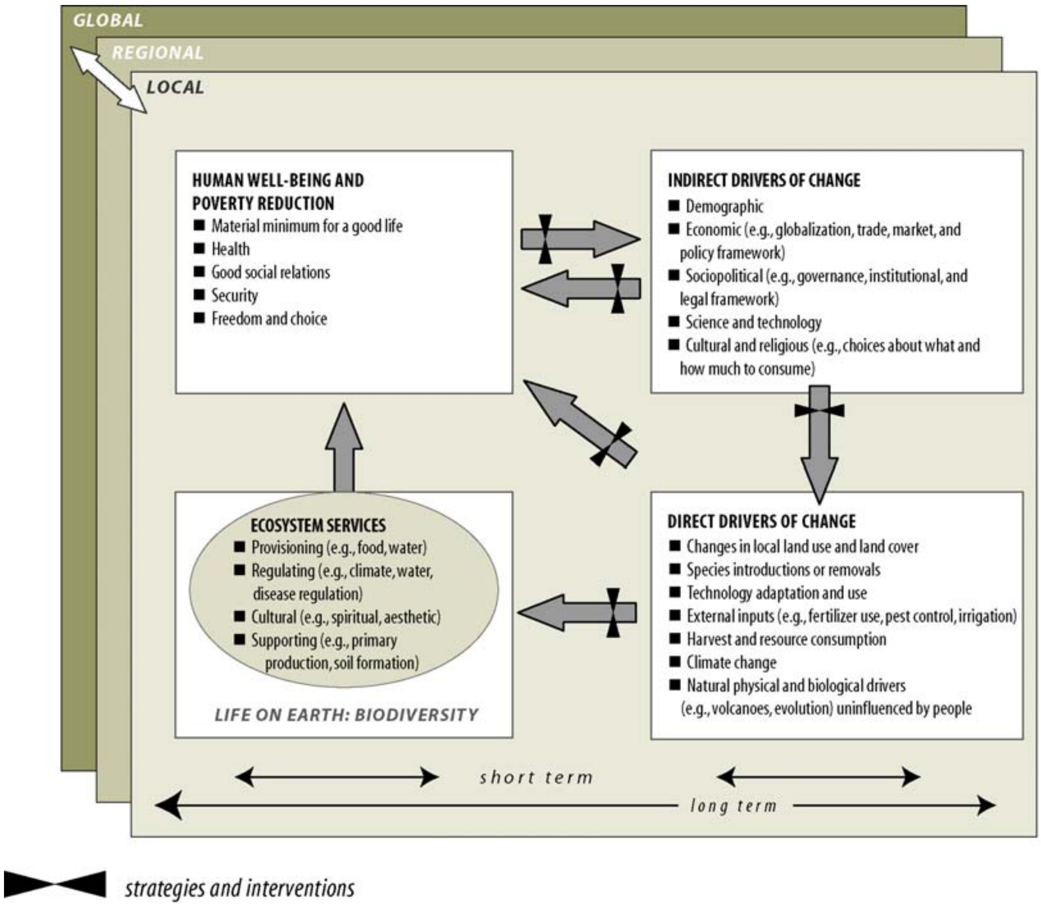

Figure 1.2. MA conceptual framework

1.1.3. Spatial distribution of MA sub-global assessments

Changes in drivers that indirectly affect biodiversity, such as population, technology, and lifestyle, can lead to changes in drivers directly affecting biodiversity, such as the catch of fish or the application of fertilizers. These results in changes to ecosystems and the services they provide, thereby affecting human well-being. These interactions can take place at more than one scale and can cross scales. For example, an international demand for timber may lead to a regional loss of forest cover, which increases flood magnitude along a local stretch of a river. Similarly, the interactions can take place across different time scales. Different strategies and interventions can be applied at many points in this framework to enhance human well-being and conserve ecosystems.

In addition to its distinct focus on ecosystems and human well-being, the MA includes another pioneering aspect that distinguishes it from past 'global' assessments. It is being conducted as a 'multi-scale' assessment with integral assessment components being undertaken at local community, watershed, national and regional scales, as well at the global scale. Each of the assessments at sub-global scales contributes to decision-making in the regions and communities where they are being undertaken, and each will be strengthened by the information and perspectives gained from each other and from the global assessment. Assessments at sub-global scales are needed because ecosystems are highly differentiated in space and time, and because sound management requires careful local planning and action. The sub-global assessments will directly meet the needs of decision-makers at the scale at which they are undertaken, strengthen the global findings with on-the-ground reality, and strengthen the local findings with global perspectives, data, and models.

Figure 1.3. Spatial distribution of the MA sub-global assessments

（◉ represents the approved sub-global assessment, ◉ represents the associated assessments）

Sub-global assessments that have been approved by the MA include Small Islands in Papua New Guinea, the Philippines Millennium Ecosystem Assessment，Downstream Mekong River Wetlands Ecosystem Assessment of Vietnam, **Integrated Ecosystem Assessment of Western China**，Altai-Sayan Ecoregion, Local Villages in India，Southern African Sub-Global Assessment, Norwegian Millennium Ecosystem Assessment, Ecosystem Management and Social-Ecological Resilience in Kristianstades Vattenrike and River Helgeå Catchment, Stockholm Urban Assessment, Portugal Millennium Assessment, Assessment of the Northern Range of Trinidad, Vilcanota Sub-Region of Peru, Salar de Atacama of Chile, Assessment of the Caribbean Sea, Coastal British Columbia in Canada, and the Pan-Tropic Research Sites of the CGIAR "Alternatives to Slash and Burn"(Figure 1.3).

The associated assessments include Arab Region Millennium Ecosystem Assessment, Sinai Sub-Global Assessment, Arafura and Timor Seas Sub-Global Assessment, Indonesia Sub-Global Assessment, São Paulo City Green Belt Biosphere Reserve Assessment, Chirripo Basin of Costa Rica, Ecological Function Assessment of Biodiversity in the Colombian Andean Coffee-Growing Region, Assessment of the Central Asian Mountain Ecosystems, The Great Asian Mountains Assessment, The Upstream Region MA of the Great Rivers, Northwest Yunnan, China, Fiji Sub-Global Assessment, Environmental Service Assessment in Hindu-Kush Himalayas Region, Indian Urban Assessment with Focus on Western Ghats.

1.2. Western region of China and western development strategy

1.2.1. The western region of China

The western region of China are administratively composed of twelve provinces that are Sichuan province, Chongqing city, Guizhou province, Yunnan province, Tibet Autonomous region, Shaanxi province, Gansu province, Qinghai province, Ningxia Hui Autonomous region, Xinjiang Uygur Autonomous region, Inner Mongolia Autonomous region and Guangxi Zhuang Autonomous region. The western areas cover approximate 6.7546 million square kilometers, which account for 71% of the total. By the end of 1999, the population of the western areas was approximately 365 million, accounting for 29% of the total.

Figure 1.4. The western region of China

(The red points represent typical areas at local scale, as see in section 4)

The western region of China has a vast territory, complicated natural conditions, diverse geomorphic landforms, and largely distributed land areas that are hardly to be utilized. Mountainous areas account for the highest proportion, about 49.7%. Hilly areas, tablelands, plains and plateaus account for 14.9%, 1.7%, 17.1% and 16.6% respectively (Figure 1.4). In addition, such lands that are hardly to be used as deserts, Gobi, and stony and rocky lands are widely distributed. There are abundant natural resources and biological diversities in the western region, which are the cradles and catchments of a range of big rivers such as

Yangtze River, Yellow River, Heihe River, Lancang River and Pearl River. In the western China, the climatic conditions vary a lot. It is arid and short of precipitation in Northwest China, temperate, wet and rainy in southwest China, and cold and short of oxygen in Qinghai-Tibet Plateau. The western region of China is featured by vast land and rich natural resources. On the one hand, the standard of living of the people in the western region is much lower than the average level of the whole China; the economy the western China is relatively backward; and the economic volume is small. On the other hand, resource and economic development is extensive and backward; the industrial output value is low; and the economic structure and exploitation of natural resources at the core sharply increases the pressure on the ecological environment.

1.2.2. The Western Development Strategy

The purpose of the Western Development Strategy is to, through generations of strenuous work, fundamentally change the relatively backward status of the western region, apparently shorten the development gap between different areas, and spare no effort to establish new western region featured by prosperous economy, advanced society, stable life, unity of various nationalities, beautiful mountains and rivers, as well as rich people in the middle of the 21st century when modernization is basically accomplished. Over the past five years, our central government has emphatically offered great support to the Western Development Strategy in respect of programming, construction of major projects, fund and investment, policies, etc. Accumulatively, our central government has invested approximate 4.60×10^{11} RMB in the western region for construction, and more than 5.0×10^{11} RMB as fiscal transfer payment and special subsidies, considerably boosting the economic construction and social development in the western region. People in different areas and different departments, particularly, the cadres and broad masses of people in the western region, earnestly carry through the Western Development policies and arrangements developed by CPC Central Committee and the State Council. They have made great efforts and dedicated a lot. As a result, important progress has been made in Western Development, and the urban and rural areas in the western region have all taken on a new look.

Economy in the western region of China steps on the juice. From 2000 to 2004, the GDP of the western region grew annually at a rate of 8.5%, 8.8%, 10.0%, 11.3% and 12% respectively, higher than the growth rate of the previous years. In the western region, economic re-structuring has been accelerated; industries with distinguishing features start to move; fiscal revenue has been growing year after year; economic returns have been increasing step by step; and the standard of living has been improved.

Considerable progress has been made in construction of infrastructure facilities. Over the past five years, investments in fixed assets have been growing by over 20% per year on average in the western region, much higher than the mean level of the whole country. Sixty important construction projects have been started successively, and the total investment of these projects amounts to approximate 8.50×10^{11} RMB. The construction of such major infrastructure facilities as some communication trunk lines, some key water control projects, the west-east power transmission project, the west-east gas transmission project, and the communication network project has been carried out successfully. Progress has also made in he construction of some rural infrastructure facilities, like asphalt roads to counties, power supplies to towns, radio and television to villages, drinking water supplies to people and domestic animals, utilization of marsh gas, and water-saving irrigation.

Eco-environmental protection and construction have been apparently reinforced. In the western region, more than 7.35×10^9mu lands have been returned from farmland to forest; more than 9.57×10^9mu wastelands have been forested; 1.90×10^8mu lands have been returned from grazing lands to grassland. Exciting achievements have been made in protection of natural forests, control of the sources of

Beijing-Tianjin sandstorms, control of land resources and prevention of water pollution in the Three Gorges Reservoir area, ecological protection in the sources of rivers, and other major projects.

Social undertakings such as sciences, technologies and educations have been quickened. The innovation of the scientific and technological system has been constantly moving forward, and the capability of transferring scientific and technological achievements has been reinforced. Preliminary achievements have been made in construction scientific research bases and experimental hi-tech industry projects. Infrastructure facility construction and subject construction of the key colleges and universities have been accelerated. Compulsory education in the rural areas has been reinforced, and over 7000 primary and middle schools have had their ramshackle buildings re-constructed. The medical and health care conditions have been improved in the rural areas, and our central government has offered financial support to build up 260 hospitals in the poverty-stricken counties. Progress has also made in construction of diseases prevention and control centers. Cadre exchange and human resource training have been carried out step by step.

The Western Development Strategy boosts the development of other areas as well. Many of the equipment and technologies the western region need in construction of the key projects are from the eastern and central areas. Therefore, the Western Development Strategy effectively expands the market space of the eastern and central areas, spurs the adjustment of their industrial structure, and creates more job opportunities. Meanwhile, the western region provides a large quantity of resources like energy and raw materials, meeting the demands of other areas in their economic development. All these supports have boosted economic development in the eastern and central areas, and play a very important role in maintain quick but stable development of our national economy.

The achievements made in the Western Development over the past five years make people all over the country, in particular, people in the western region, find out hopes of Western Development, and further strengthen their confidence and resolution in building a welfare society in an all-round way. Practice has fully proved that the Western Development Strategy developed by CPC Central Committee and the State Council is absolutely correct, and that the key tasks that have been specified and the policies and measures that have been taken are practical.

Further pushing forward Western Development is an important task in building a welfare society in an all-round way, an important measure for establishing new development pattern of our national economy, an important condition for achieving sustainable development all over the country, and an important guarantee for maintaining long period of peace and stability. Adhering to Western Development Strategy is of extremely great economic and political significance.

1.3. MAWEC Assessment Process

After a Chinese delegation organized by Ministry of Science and Technology of the People's Republic of China (MOST) visited United Nations Environment Program (UNEP) in Nairobi in early December of 2000, Integrated Ecosystem Assessment of Western China (MAWEC) was proposed, which has been funded by MOST. In early May of 2001, MOST, State Environmental Protection Administration (SEPA), Chinese Academy of Sciences (CAS), Chinese Academy of Forestry (CAF), Ministry of Agriculture of the People's Republic of China, and Ministry of Water Resources of the People's Republic of China, Ministry of Land and Resources of the People's Republic of China jointly launched MAWEC. On the basis of joining MA Conceptual Framework meeting in March 2002 in Paris, MA condition WG meeting in May 2002 in Rome and MA Scenarios WG meeting in October 2002 in Bangkok, MAWEC proposal in English was proposed and has been funded by MA. First Meeting of International Advisory Committee of

MAWEC was held in November 2002 in Beijing. The MAWEC framework was reviewed during the first meeting. The International Advisory Committee of MAWEC consists of Prof. Jerry M. Melillo from the Ecosystems Center in USA, Prof. Thomas Rosswall from ICSU in France, Prof. Masataka Watanabe from National Institute for Environmental Studies in Japan, Dr. Anthony C. Janetos from The H. John Heinz III Center for Science Economics and Environment in USA, and Mr. Marcus Lee from MA sub-global working group in Malaysia (Figure 1.5). After the MA Combined Working Group meeting in October 2003 in Prague, the MAWEC framework was improved and the MAWEC Working Summary was submitted to MA sub-global working group in December 2003. In May 2004 the second meeting of MAWEC International Advisory Committee was held in Xinjiang and Beijing of China (Figure 1.6), after which the MAWEC Working Summary was revised. The final MAWEC report has been completed in Chinese at the end of 2004 after a series of meetings participated by leaders from 29 research-teams and sub-research teams of MAWEC, academic authorities in China, policy-makers from relative department of Central government, and officials from local governments. During the MAWEC process, local governments have been joining relative activities at local level (Fig.1.6). Findings of MAWEC are going to be launched on 30th March of 2005 in Beijing with the MA launch activities together.

Figure 1.5. Prof. Guan Hua Xu, Minister of MOST and a member of MA Board, had an interview with MAWEC International Advisory Committee and principal investigators

MAWEC funded jointly by MOST and MA has been carried out under the charge of Institute of Geographical Sciences and Natural Resources Research of CAS, and Research Institute of Forest Resource Information Technique of CAF, Environmental Information Center of SEPA. The major leaders of research teams (Figure 1.7) are selected from the three leading institutions mentioned above, Research Center for Eco-Environmental Sciences of CAS, Xishuangbanna Tropical Botanical Garden of CAS, Institute for Environment and Engineering of Frigid and Arid Areas of CAS in Lanzhou of Gansu, Xinjiang Institute of

Ecology and Geography of CAS in Urumqi of Xingjiang, Chengdu Institute of Mountainous Calamities and Environment of CAS in Chengdu of Sichuan, and National Institute for Environmental Studies of Japan. MAWEC is contributing to successful implementation of the western development strategy and sustainable development of the selected typical areas at local level.

Figure 1.6. Collaboration of MAWEC International Advisory Committee and investigators with local governments

（left picture: a meeting with Xinjiang provincial government；

right picture：an investigation with staff of Qingyang local government of Gansu province）

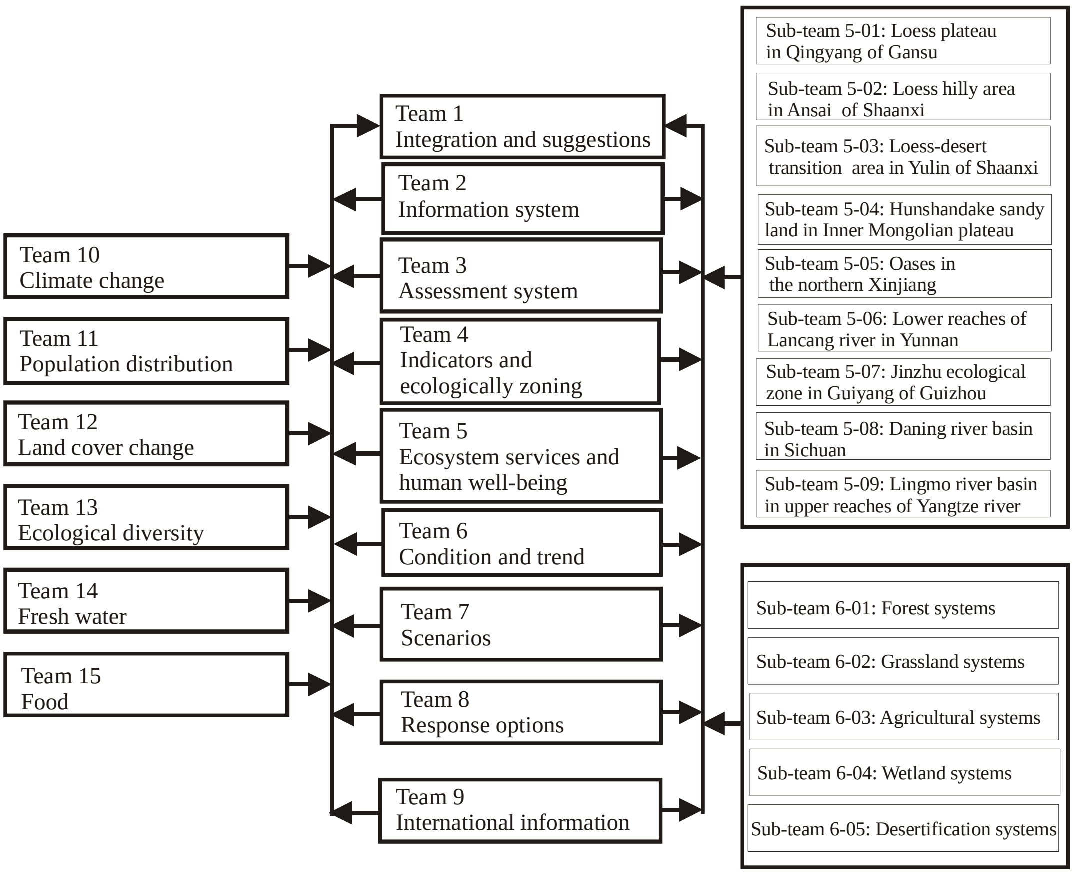

Figure 1.7. MAWEC organization structure

2. Assessment Method

To provide reliable scientific foundations for successful implementation of Western Development Strategy, and to support Millennium Ecosystem Assessment, the project of Integrated Ecosystem Assessment of Western China is carried out, by which overall assessment of the ecological systems in the western region of China and the possible impacts of ecosystem service change on human well being have been conducted. On the basis of ecological zoning, a method of high precision surface modeling is established by means of fundamental theorem of surfaces, surface modeling of population distribution is developed by means of grid generation method, a scaling index for ecological diversity is constructed by means of multi-fractal theory, and an ecological threshold model is developed by means of the theory of entropy production and excess entropy production. They are used to accomplish the specified contents of Integrated Ecosystem Assessment of Western China, analyze the change trend and future scenarios of ecological systems in the western region of China, evaluate the provisioning services (such as food and fresh water as well as biological diversity that affect the provisioning services of ecological systems) and regulating services (such as regulation of climate and soil erosion) and supporting services (such as preliminary productivity), simulate direct driving forces (such as climatic change and land cover change) and indirect driving forces (such as population growth and consumption pattern) leading to changes of ecosystem services, give a solution to the problems of relation between spatial scales and temporal scales, resolution transformation and cross-scale interaction, and analyze the relationship between ecosystem services and human well being. An integrated assessment system is basically developed, which is composed of information sources, data warehouse, HPSM platforms for information fusion, model-base systems, decision-supporting knowledge base, and person-computer interface (Liu et al., 2002).

2.1. Integrated Assessment System of Ecosystems in Western China

The multi-scale and error problems in applying geographical information systems to ecosystem assessment are solved by improving the method of high precision surface modeling. Integration of multi-source information is gradually achieved, taking geographical information system as a calculation platform, by means of gird generation method, domain decomposition method and grid computing method. Change trend and scenarios of ecosystems and ecosystem services are simulated on the basis of ecological thresholds and analysis of driving forces. The major components of the integrated assessment system include a data warehouse for standard control of data from various sources, a module of high-precision surface modeling for data fusion and transformation of multi-scale information, a model-base system concerning ecological thresholds and analysis of driving forces, and a decision-supporting knowledge base which is based on condition and trend evaluation and future scenario analysis (Figure 2.1).

The establishment of data warehouse involves data refinement, data conversion and data update (Han & Kamber, 2001). Since the integrated assessment system involves numerous data from various sources, many data have associated problems of incompletion such as loss of property values or source data, or problems of noise such as random deviation or abnormal variance, or problems of incompatibility such as data with the same property but different sources, different property names or conflictions with known data restrictions. All these problems have to be resolved through data refinement. To apply data from various sources, we often have to convert data into those formats or types easy to use. Because the final purpose of the integrated ecosystem assessment is to provide scientific foundations for implementing the Western Development Strategy, timely data update is an absolutely necessary content of data warehouse construction.

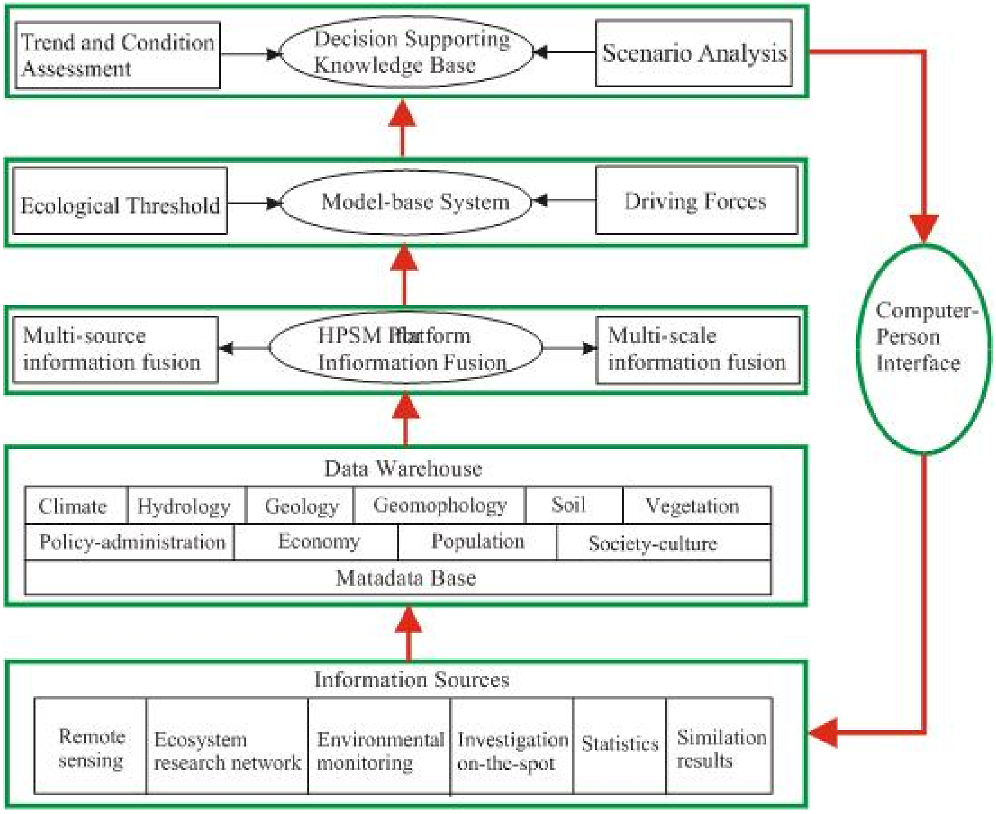

Figure 2.1. Integrated assessment system of ecosystems in the western region of China

The multi-scale issues are a hotspot in Millennium Ecosystem Assessment (MA, 2003) and challenges facing Integrated Ecosystem Assessment of Western China. The newly established method of high-precision surface modeling gives a solution to the error problems and multi-scale problems existing in geographic information system and realizes effective integration of multi-scale data (Yue et al., 2004, 2005). For instance, The major two existing approaches to monitoring ecosystem changes are observations at fixed positions (or spatial sampling) and retrieval using remotely sensed data (Yue and Liu，2001a，2001b). The approach of observations at fixed positions (or spatial sampling) can obtain high precision data at observation points. But observations at fixed positions or spatial sampling are confined within some limited dispersal points and not able to directly calculate relative parameters at regional scale. The parameters at regional scale can be estimated on the basis of the observation data at points by spatial interpolation. However, the direct description of regional properties by using data at points is not able to authentically reflect spatial distribution pattern because of the spatial heterogeneity of relative factors. Recent applications of digital remotely sensed data mainly focused on the development of ecosystem baseline conditions and investigation of coarse-scale vegetation dynamics. It is trying to apply remotely sensed data to monitoring dynamics of ecosystem structure and processes. Processes shaping different ecosystems operate over a hierarchy of temporal and spatial scales. Vegetation composition is hierarchically influenced by climate at regional to continental scales, by landforms at the landscape to regional scales, and by water redistribution and disturbance at local and patch scales. Satellite remote sensing can frequently supply surface information. But remote sensing description is not able to directly obtain process parameters that must be retrieved on the basis of combining remote sensing information with earth surface properties. With the method of high-precision surface modeling, the organic relation between the sampling points or observation points is established and thus effective integration of points-information and surface-information is reached.

Two important functions of the model-base system are model integration and operation. The users need to input data for models and provide parameters for model operation. The model-base system needs to provide the users with easy accesses to the various models, so that they can easily input parameters and data for operation and integration of models. It is necessary for the users to provide some specific commands to start up the process of operation of one or more models. Necessary command structure is established for the model-base system, and the models are put in the decision-supporting knowledge base. Meanwhile, the model-base system combines many necessary index models or modules together by providing necessary connections between models or controlling the sequence of model operation, so as to form the integrated models needed by the decision-supporting knowledge base. The model-base system must seamlessly combine the decision makers and the process of analysis, so that the model outputs are not only quantitative but also in allusion to the concrete issues, conditions and restrictions. The management sub-system of model-base system maintains the following six functions: ①allowing the users to produce new models on the basis of the existing models; ②providing multi-model connection mechanism for sequential processing and data exchange; ③allowing users to modify the existing models to meet their special requirements; ④having the rule system for storing, controlling, using and operating the models; ⑤ having the classification system and organization structure for the stored models; and ⑥having all functions similar to those of a database (such as operation, storage, search, deletion, and linking).

In the integrated assessment system, direct driving forces include land use and land cover change, climate change and natural disasters, and indirect driving forces include population growth, economic growth, consumption pattern, technical progress, policies, cultures and religions. The integration of driving force models, basic models, special models and threshold model with HPSM information fusion platform through the model-base system is a foundation of evaluating change trend and future scenarios of ecosystems in the western region of China.

In order that the users can utilize the decision-supporting knowledge base easily, an effective computer-person interface must be built up. The computer-person interactive interface directly affects utility of the integrated assessment system. A good computer-person interactive interface must be simple to be used and easy to be learned. Outputting must be featured by abundant contents and lively forms. Such inputting approaches as state-of-the-art manuscript and vocal inputting technology or widely used multi-window image interface technology can be adopted. Outputting may be in the form of text reports, sheets, visual graphics, and vocal composition, which bring out the best in each other to produce the most satisfactory effects. The computer-person interactive interface plays an important role in transmitting commands and data between users, the decision-supporting knowledge base, the model-base system, the information fusion platform, the database, and the sources of information. Users need an excellent dialogue interface, and servicepersons need a convenient software environment. Obviously, the computer-person interactive interface is a window of the integrated assessment system and its level indicates the level of the whole system.

2.2. Ecological zones in the western region of China

Ecological zones are geographically classified by the sensitivity of regional ecological environment, the importance of ecological services, and the similarity and difference of eco-environmental characteristics. For macroscopic guidance and classified management, the natural region must be divided into different areas (CAS Working Committee of Natural Zoning, 1959; Huang, 1989; Fu, 2001; Ouyang, 2002). Firstly, ecological zones are classified macroscopically, i.e. ecological zones are classified by climatic and geographic characteristics; secondly, ecological sub-zones are divided by ecological system types, and ecological function areas are classified by the ecological functions and environmental sensitivity; finally, on the basis of the ecological function, ecological function areas are specified.

Table 2.1. Ecological zones in the western region of China

Code of ecological zone		Name of ecological zone
I	1	Taiga Ecological Zone in Frigid-Temperate Area of Northern Da Hinggan Mountains
II	2	Ecological Zone of Deciduous Broad-Leaved Forest and Grassland in Central and Southern Da Hinggan Mountains
III	3	Ecological Zone of Typical Grassland in Central and Eastern Inner Mongolia Plateau
IV	4	Ecological Zone of Desertification Grassland in Central Inner Mongolia Plateau–Central Gansu
V	5	Ecological Zone of Grassland-Desertification in Central Inner Mongolia Plateau
VI	6	Desertification Ecological Zone in Central and Western Inner Mongolia Plateau –Beishan Mountainous area
VII	7	Ecological Zone of Forest and Grassland in Altai Mountain–Western Zhunge'er Mountainous area
VIII	8	Desertification Ecological Zone in Zhunge'er Basin
IX	9	Ecological Zone of Forest and Grassland in Tianshan Mountainous area
X	10	Desert Ecological Zone in Tarim Basin – Eastern Xinjiang
XI	11	Ecological Zone of Frigid Desertification Grassland in Pamirs—Kunlun– Aljin Mountains
XII	12	Desertification Ecological Zone in Caidam Basin
XIII	13	Ecological Zone of Forest and Frigid Grassland in Qilianshan Mountains
XIV	14	Ecological Zone of Frigid Grassland in River Headstream area—Southern Gansu
XV	15	Ecological Zone of Frigid Desertification Grassland in North Tibet Plateau
XVI	16	Ecological Zone of Temperate-Arid Desertification area in Ali Mountain
XVII	17	Ecological Zone of frigid grassy marshland in mountainous area of southern Tibet
XVIII	18	Ecological Zone of Tropical Rain Forest in the southern slope of Himalaya Mountains
XIX	19	Ecological Zone of Frigid-Temperate Taiga in East Tibet and West Sichuan
XX	20	Ecological Zone of Evergreen Broadleaf Forest in Southwest Sichuan and Central and North Yunnan Mountainous Area
XXI	21	Ecological Zone of South Subtropical Monsoon Evergreen Broadleaf Wood in Central Yunnan and Guangxi
XXII	22	Ecological Zone of Tropical Rain Forest in South Yunnan and Guangxi
XXIII	23	Ecological Zone of Subtropical Evergreen Broadleaf Forest in Nanling Mountains
XXIV	24	Ecological Zone of Subtropical Karst Vegetation in Central Guizhou
XXV	25	Ecological Zone of Subtropical Evergreen Broadleaf Forest in Wuling Mountain
XXVI	26	Agricultural-Forest Ecological Zone in Sichuan Basin
XXVII	27	Ecological Zone of Subtropical Evergreen Defoliate Forest in Qin-Ba Mountainous Area
XXVIII	28	Agricultural Ecological Zone in Fenhe River and Weihe River Basin
XXIX	29	Loess Plateau Ecological Zone in Shaanxi-Gansu-Ningxia
XXX	30	Agricultural Ecological Zone in Northeast China Plain

The ecological zones are named in terms of climatic and geomorphologic characteristics. Climatic characteristics include humidity, semi-humidity, aridity, semi-aridity, frigid-temperate zone, temperate zone, warm-temperate zone, subtropical zone, tropical zone, etc. geomorphologic characteristics include plain, mountainous region, hilly land, valley, etc.

The ecological sub-zones are named in terms of the ecological system types. The ecological system types include forest, grassland, wetland and farmland ecosystems.

The ecological function areas are named in terms of the importance of ecological functions and environmental sensitivity of the sub-zones. The characteristics of ecological functions include control of desertification, protection of biological diversity, conservation of water resource, hydrological control and soil preservation. The characteristics of environmental sensitivity include soil erosion, desertification, stony desertification, salinization and acid rain sensitivity.

The western region of China includes 30 ecological zones (Figure 2.2 and Table 2.1), 104 ecological sub-zones, and 686 ecological function areas. The 30 ecological zones are only involved in this summary.

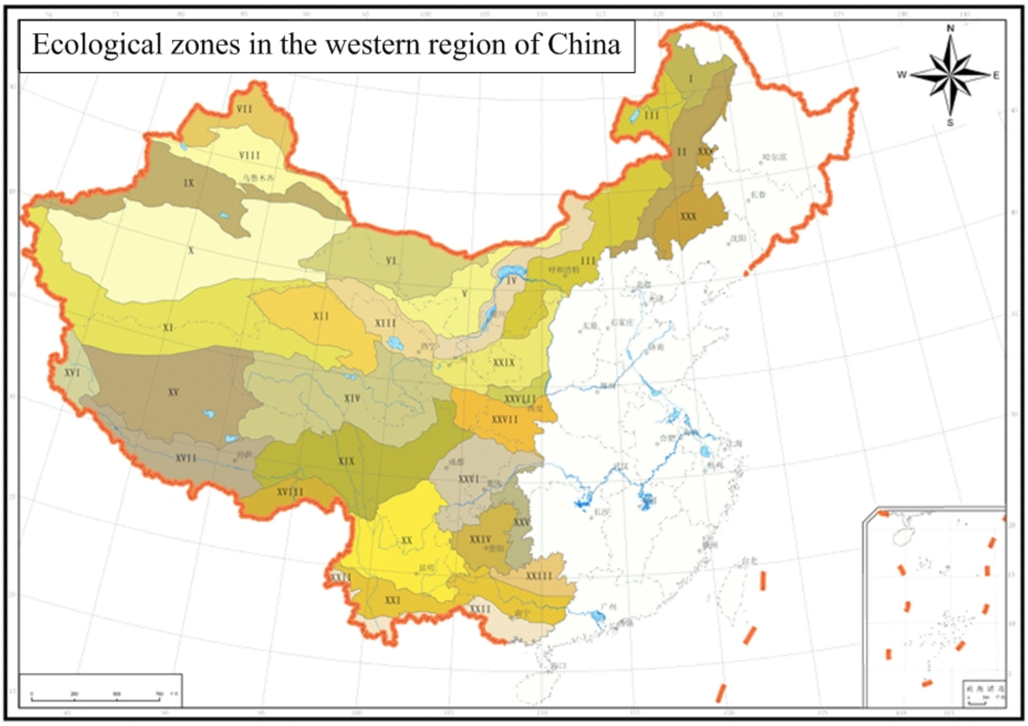

Figure 2.2. Ecological zones in the western region of China

2.3. Database integration

2.3.1. Data integration platform

Under the identical ecological data standard, technical rules for data acquisition are defined; special images are digitalized and a large amount of attribute data are collected; attribute database and spatial database are connected; key issues on data generation and integration technology are resolved; TM satellite image interpretation standards are developed for complex identification of information under the technological support of integrating remote sensing with geographic information system through surface analysis and multiple sampling; classification-quantification index system and data quality control system of remote sensing information of ecological systems in western China are established. In addition, there are database of natural factors and social-economic factors of terrestrial surface system, land observation database, national natural atlas database, and global dynamic database series. Database integration platform has been completed (Figure 2.3). The data resources have amounted to 1000GB.

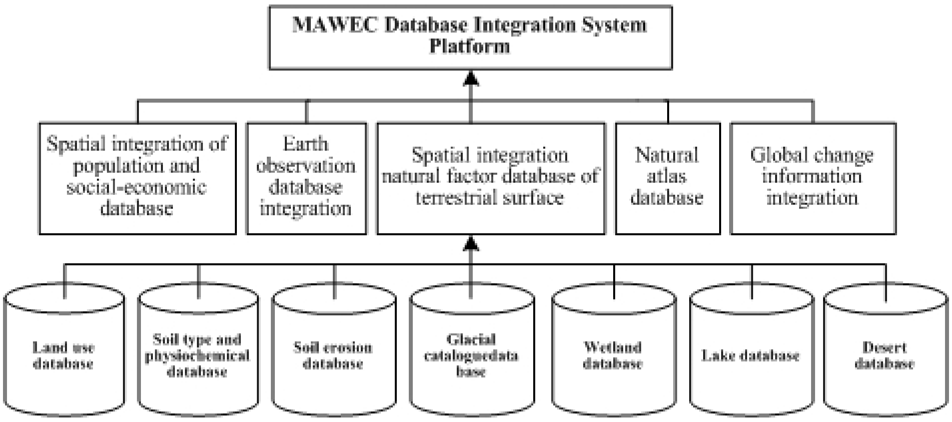

Figure 2.3. MAWEC database integration system platform

2.3.2. Technical platform for acquisition and share of data

The established 300TB online memory system can support storage of spatial data produced in five years; the system resources can guarantee that 1,000 users can log in to get necessary data at the same time; the system maintains complete user classification management function and strict security measures.

The regulation on share of geographic information has been developed; proposals on basic policy for and legislation on share of ecosystem information have been put forward; MAWEC database information classification and coding have been developed.

The historical accumulation, current status and future demands of ecological data are analyzed. Problems existing in acquisition, processing, analysis and application of MAWEC database are identified. Overall planning of the major research work concerning MAWEC database in the forthcoming years is carried out. In addition, we have conducted detailed planning in respect of construction of infrastructure facilities, organization structure, database construction and update, and team organization.

Wetland database website, soil database website and lake database website have been established, by which you can browse, through the web pages, and thus share the information freely.

2.4. Construction of special models

2.4.1. High precision surface modeling: a solution for multi-scale problems

Scale issue is an inherent part of ecology (Schumm, 1965; Stommel, 1963; Lv and Fu, 2001; Yue and Liu, 2003). Since 1990s, multi-scale problem becomes the central problem in ecology, for unifying population biology and ecosystem science, and marrying basic ecology and applied ecology (Levin, 1992). Multi-scale problem has become the new frontier of ecology (Allen, 2001). In order to find a solution for the multi-scale problem, the method of high precision surface modeling (HPSM) is developed (Yue et al., 2004, 2005). For the simulated surface $(x, y, f(x, y))$, HPSM is formulated as,

$$\begin{cases} f_{xx} = \Gamma_{11}^{1} f_x + \Gamma_{11}^{2} f_y + \dfrac{L}{\sqrt{E+G-1}} \\ f_{yy} = \Gamma_{22}^{1} f_x + \Gamma_{22}^{2} f_y + \dfrac{N}{\sqrt{E+G-1}} \end{cases} \tag{1}$$

where E and G are the first fundamental coefficients; L and N are the second fundamental coefficients; Γ_{11}^{1}, Γ_{11}^{2}, Γ_{22}^{1} and Γ_{22}^{2} are functions of the first and the second fundamental coefficients.

The numerical tests show that grid spacing and distance between sampling points have little impact on HPSM precision. It means that HPSM is to give a solution to multi-scale problem that have long perplexed ecological world (Yue et al., 2005).

2.4.2. Interpolation model for climate change in China

Daily temperature and daily precipitation data from 1960 to 2002 are selected from the 735 weather observation stations. Temperature surfaces are created on the basis of improving the interpolation method, gradient-plus-inverse distance squared (GIDS). The GIDS (Nalder and Wein, 1998) was developed on the basis of comparatively analyzing interpolation methods such as inverse distance weight (Lee and Angelier, 1994) and the Kriging (Olea, 1999). The application result of GIDS in interpolating every-ten-days and annual mean temperature in China showed that GIDS has a much less error than the inverse distance weight and the Kriging (Lin et al., 2002; Pan et al., 2004). GIDS is further improved on the basis of iterative simulation and formulated as,

$$T_{jk} = \left(\sum_{i=1}^{N_{jk}} \frac{T_i + [a(E_{jk} - E_i) + C_X(X_{jk} - X_i) + C_Y(Y_{jk} - Y_i) + C_E(E_{jk} - E_i)]/2}{d_{ijk}^2} \right) \Bigg/ \sum_{i=1}^{N_{jk}} \frac{1}{d_{ijk}^2} \tag{2}$$

where a is decreasing rate of temperature with elevation increase; C_X, C_Y and C_E are linear regression coefficients between temperature and longitude, latitude and elevation over; X_i, Y_i, E_i and T_i are respectively longitude, latitude, elevation and temperature at the weather observation station i; X_{jk}, Y_{jk}, E_{jk} and T_{jk} are respectively longitude, latitude, elevation and temperature at point (j,k) to be interpolated; N_{jk} is number of weather observation stations that are involved in the interpolation of the point (j,k); d_{ijk} is distance from the observation station i to the interpolation point (j,k).

Although the decrease rate of temperature with elevation increase, $a = -0.0065^oC/m$, has been adopted globally, it is incorrect to be applied in China. Our simulation results show that decrease rate of temperature with elevation increase has a great difference in different regions because of the considerable topographical variety over China (Table 2.2).

On an average, the decrease rate of temperature in China is $a = -0.0046^oC/m$ and the multivariate regression model of relationship between temperature T, longitude X, latitude Y and elevation E is simulated as,

$$T = 43.312 - 0.106X - 0.469Y - 0.00361E \tag{3}$$

where correlation coefficient is -0.9817.

Therefore, the improved GIDS can be specifically formulated as,

$$T_{jk} = \sum_{i=1}^{N_{jk}} \frac{2T_i - [0.0046 \cdot (E_{jk} - E_i) + 0.106 \cdot (X_{jk} - X_i) + 0.469 \cdot (Y_{jk} - Y_i) + 0.0036 \cdot (E_{jk} - E_i)]}{2d_{ijk}^2 \left(\sum_{i=1}^{N_{jk}} d_{ijk}^{-2} \right)} \tag{4}$$

In terms of formulation (2), all primary temperature surfaces of $1km \times 1km$ grid data are created by iterative interpolations, in which search radiuses for each temperature surface are respectively defined as 150km, 200km, 250km and 500km. Then, the primary temperature surfaces are corrected in terms of $1km \times 1km$ digital elevation model of China and relationships between temperature and elevation.

Table 2.2. The decrease rate of temperature with elevation increase in different regions of China

Regions	Correlation coefficients	Decreasing rate (℃/Meter)	Linear regression equation
Changbai mountains	-0.962828	0.0028	$T = -0.0028E + 9.3481$
Da-xiao Hinggan mountains	-0.84284	0.0040	$T = -0.0040E + 8.3638$
Qinghai_Xizang Plateau	-0.953225	0.0029	$T = -0.0029E + 14.442$
Hengduan mountains	-0.953959	0.0054	$T = -0.0054E + 24.542$
Loess plateau	-0.870578	0.0036	$T = -0.0036E + 14.111$
Nanling mountains	-0.909555	0.0060	$T = -0.0060E + 18.996$
Qilian mountains	-0.993717	0.0037	$T = -0.0037E + 14.787$
Qinling mountains	-0.764436	0.0040	$T = -0.0040E + 15.681$
Taihang and Lvliang mountains	-0.978394	0.0050	$T = -0.0050E + 14.530$
Tianshan mountains	-0.850741	0.0038	$T = -0.0038E + 13.858$
Wuling mountains	-0.945071	0.0055	$T = -0.0055E + 18.112$
Wuyi mountains	-0.905499	0.0044	$T = -0.0044E + 18.848$
Himalaya mountains	-0.852985	0.0064	$T = -0.0064E + 30.978$
Yanshan mountains	-0.984928	0.0046	$T = -0.0046E + 12.258$
Yunnan-Guizhou Plateau	-0.854687	0.0045	$T = -0.0046E + 19.979$

2.4.3. HLZ model for spatial distribution of terrestrial ecosystems

Holdridge Life Zone (HLZ) classification is a scheme that uses the three bioclimatic variables derived from standard meteorological data to formulate the relation of climate patterns and broad-scale vegetation distribution. It relates the distribution of major ecosystems (termed life zones) to the bioclimatic variables. The HLZ classification divides the world into over 100 life zones in terms of mean annual bio-temperature in degrees centigrade (MAB), average total annual precipitation in millimeters (TAP), and potential evapotranspiration ratio (PER) logarithmically. Bio-temperature is defined as the mean of unit-period temperatures with substitution of zero for all unit-period values below $0^{o}C$ and above $30^{o}C$ (Holdridge, et al., 1971). Evapotranspiration is the total amount of water that is returned directly to the atmosphere in the form of vapor through the combined processes of evaporation and transpiration. Potential evapotranspiration is the amount of water that would be transpired under constantly optimal conditions of soil moisture and plant cover. The potential evapotranspiration ratio is the ratio of mean annual potential evapotranspiration to average total annual precipitation, which provides an index of biological humidity conditions. In other words, MAB, TAP and PER at site (x, y) and in the t'th year have the following formulation:

$$MAB(x, y, t) = \frac{1}{365}\sum_{j=1}^{365} TEM(j, x, y, t) \quad (5)$$

$$TAP(x, y, t) = \sum_{j=1}^{365} P(j, x, y, t) \quad (6)$$

$$PER(x,y,t)=\frac{58.93MAB(x,y,t)}{TAP(x,y,t)} \tag{7}$$

where $TEM(j,x,y,t)$ is the value summing the hourly temperature above 0^oC and below 30^oC on the j'th day and dividing by 24; $P(j,x,y,t)$ is the mean of precipitation on the j'th day.

Suppose

$$M(x,y,t)=\ln MAB(x,y,t) \tag{8}$$

$$T(x,y,t)=\ln TAP(x,y,t) \tag{9}$$

$$P(x,y,t)=\ln PER(x,y,t) \tag{10}$$

$$d_i(x,y,t)=\sqrt{(M(x,y,t)-M_{i0})^2+(T(x,y,t)-T_{i0})^2+(P(x,y,t)-P_{i0})^2} \tag{11}$$

where M_{i0}, T_{i0} and P_{i0} are standards of MAB logarithm, TAP logarithm and PER logarithm at the central point of the i'th life zone in the hexagonal system of HLZs. When $d_k(x,y,t)=\min_i\{d_i(x,y,t)\}$, the site (x,y) is classified into the k'th life zone.

2.4.4. Scaling index for ecological diversity

The scaling index is formulated as (Yue et al., 1998，2001，2003b，2005e),

$$d(\varepsilon,t)=-\frac{\ln\left(\sum_{i=1}^{m(\varepsilon,t)}(p_i(\varepsilon,t))^{\frac{1}{2}}\right)^2}{\ln(\varepsilon)} \tag{12}$$

where t represents time; $\frac{1}{\varepsilon}=e+\frac{a}{s}$, a is area of studied region in hectares or area of the sampling quadrat, s is spatial resolution of land cover data or the smallest crown diameter of the sampled individuals, and e equals 2.71828; $p_i(\varepsilon,t)$ is probability of the ith investigation object such as species biomass or ecotope, which is a function of variables ε and t; $p_i(t)$ is probability of the ith investigation object, which is a function of time t; $m(\varepsilon,t)$ is the total number of the investigation objects, which is a function of variables ε and t; $m(t)$ is the total number of the investigation objects, which is a function of time t.

2.4.5. Index for patch connectivity

Landscape connectivity is distinguished into patch connectivity, line connectivity, vertex connectivity and network connectivity. Because the models for line, vertex and network connectivity have been studied for a long time, the index of patch connectivity is introduced and formulated as (Yue et al., 2004),

$$C(t)=\sum_{i=1}^{m(t)}\sum_{j=1}^{n_i(t)} p_{ij}(t)\cdot S_{ij}(t) \tag{13}$$

where $p_{ij}(t)$ is the area proportion of the *j*th patch in the *i*th land cover type to the total area under investigation at time *t*; $S_{ij}(t)=\frac{8\sqrt{3}\cdot A_{ij}(t)}{\left(\mathrm{Pr}_{ij}(t)\right)^2}$, $A_{ij}(t)$ and $\mathrm{Pr}_{ij}(t)$ are the area and the perimeter of the *j*th patch in the *i*th land cover type respectively. The coefficient $8\sqrt{3}$ is the ratio of the square of perimeter to the area of a hexagon. $0 \le C(t) \le 1.1$ When it is a circle, S_{ij} has a maximum value of $\frac{2\sqrt{3}}{\pi}$, approximately 1.1. When all patches are circles, *C(t)* is supposed to be 1.1. When all patches are hexagons (6-gon), $C(t)=1.0$.

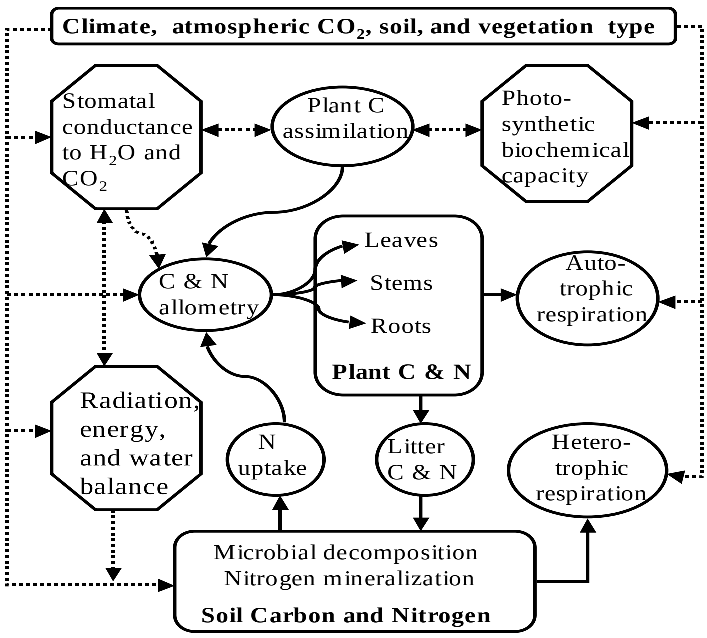

Figure 2.4. A schematic representation of CEVSA

2.4.6. The model of carbon exchange in the vegetation-soil-atmosphere (CEVSA)

CEVSA (Cao & Woodward, 1998) is a process-based ecosystem model that simulates energy (radiation and heat) transfers and water, carbon and nitrogen cycles in the vegetation-soil-atmosphere system. It is designed to quantifying the responses of ecosystem processes to global environmental changes such as in atmospheric CO2, climate, nitrogen deposition, and land use, and has been primarily used to quantify spatial and temporal variation in the terrestrial carbon sink.

The simulation of the carbon cycle is based on the processes of photosynthesis, autotrophic respiration, litter production, and heterotrophic respiration (HR) that are controlled by the eco-physiological characteristics of biomes (e.g. photosynthetic pathway, leaf form, and phenology) and by environmental conditions (e.g. radiation, temperature, and water and nutrient). To couple these biological and environmental controls over ecosystem carbon fluxes, CEVSA includes three modules, the biophysical module calculates the transfer of radiation, water, and heat to determine canopy conductance, evapotranspiration and soil moisture; the plant growth module describes photosynthesis, autotrophic respiration, carbon allocation among plant organs, leaf area index (LAI) and litter production; the biogeochemical module simulates the transformation and decomposition of organic materials and nitrogen inputs and outputs in soils (Fig. 2.4).

2.4.7. Models for assessment of food provisioning service

2.4.7.1. Agricultural ecosystems

Provisioning service of food in agricultural ecosystems is determined by potential unit grain yield, economic coefficient and cultivated area jointly. It is formulated as (Tian, 2004; Dang et al., 1999; Zhao,1999; Huang, 1985),

$$Y_{grain} = Y \cdot HI \cdot A_{food} \tag{14}$$

where Y_{grain} is grain yield; Y is primary grain productivity; HI is harvest index and $HI = 0.6$; $A_{food} = A_{gross} \cdot C_{net} \cdot C_{food}$ is efficient cultivated area, A_{gross} is gross cultivated area, C_{net} is net cultivation coefficient and C_{food} is efficient cultivation coefficient.

$$Y = Y(Q,T,W,S,M) = Y(Q) \cdot f(T) \cdot f(W) \cdot f(S) \cdot f(M) \tag{15}$$

where $Y(Q) = Q \cdot f(Q) = 0.219 \times Q$ is photosynthetic potential (kg/hm2), $f(Q) = 0.219$; Q, T, W, S and M are solar radiation, temperature, moisture, soil quality and capital input respectively; $f(T)$, $f(W)$, $f(S)$ and $f(M)$ are the corresponding efficient coefficients; $f(T) = \frac{1}{1+e^{2.052-0.161 \cdot T}}$, when T <-10, $f(T) = 0$; $f(W) = K(0.7C_{slope}C_{DEM} + 0.3C_{slopewater})$, K is humidity coefficient, C_{slope} is moisture modification coefficient of surface slope, C_{DEM} is moisture modification coefficient of elevation, $C_{slopewater}$ is hydrological modification coefficient; $f(S) = C_{SFI} \cdot C_{erode}$, C_{SFI} is modification coefficient of soil quality, C_{erode} is soil erosion coefficient; $f(M) = 0.6$.

In addition to grain, crop straw has potential for provisioning food.

$$Y_{mutton} = Y_{straw} \cdot C_{fodder} \cdot C_{strawmutton} \tag{16}$$

where Y_{mutton} is food that crop straw could provision (mutton unit); Y_{straw} is yield of crop straw; C_{fodder} is fodder coefficient of the crop straw; $C_{strawmutton}$ is conversion coefficient between mutton and crop straw.

2.4.7.2. Grassland ecosystems

Food provisioning potential of grassland ecosystems is formulated as fellows (Tian, 2004; Chen, 2001),

$$Y_{grassland} = G_{grass} \cdot C_{use} \cdot C_{grassmutton} \quad (17)$$

$$G_{grass} = Y(Q,T,W,S,M) \cdot A_{grass} \quad (18)$$

$$Y(Q,T,W,S,M) = Y(Q) \cdot f(T) \cdot f(W) \cdot f(S) \cdot f(M) \quad (19)$$

$$Y(Q) = PAR \times A \times CL \times G \times CH \times E \times (1-B)/F/(1-C) \quad (20)$$

where $Y_{grassland}$ is food provisioning potential of grassland ecosystems (mutton unit); G_{grass} is grass potential of grassland; C_{use} is utilization ration of forage grass; $C_{grassmutton}$ is conversion coefficient from forage grass to mutton; A_{grass} is grassland area; PAR is efficient photosynthetic radiation; A is maximum absorption ratio of PAR; CL is modification coefficient of vegetation coverage; G is modification coefficient of growth rate; CH is harvest coefficient of forage grass; E is quantum conversion ratio; B is modification coefficient of vegetation absorption; F is heat quantity of dry vegetation matte; C is ash ratio of forage grass; calculation of $f(T)$ and $f(W)$ is same as agricultural ecosystems; $f(w) = K = \frac{R}{E_0} = \frac{R}{0.0018(25+T)^2(100-F)}$, K is humidity index monthly, R is monthly precipitation, E_O is monthly evaporation rate, T is monthly mean temperature, F is relative humidity on an average; $f(M) = C_{Pop} \cdot C_{Scale}$, C_{Pop} is modification coefficient of population density, C_{Scale} is modification coefficient of grassland size.

2.4.7.3. Forest ecosystems

Food provisioning service of forest ecosystem is formulated as,

$$P_{ij} = A_i \times N_{ij} \times CT_{ij} \times CP_{ij} \times CS_{ij} \times CR_{ij} \times CV_{ij} \times CO_{ij} \quad (21)$$

where P_{ij} is potential of the jth type of food provisioned by the ith forest type; A_i is area of the ith forest type; N_{ij} is baseline yield of the jth type of food of the ith forest type; CT_{ij}, CP_{ij}, CS_{ij}, CR_{ij}, CV_{ij} and CO_{ij} are modification coefficients of temperature, precipitation, soil, solar radiation, vegetation and others respectively.

2.4.7.4. Aquatic ecosystems

Food potential provisioned by aquatic ecosystems is formulated as

$$P_i = \sum_{j=i}^{4} PA_{ij} \cdot A_{ij} \cdot C_{ij} \quad (22)$$

where P_i is fish potential of the ith pixel; PA_{ij} is natural fish potential of the jth type of water body within the ith pixel; A_{ij} is area of the jth type of water body within the ith pixel; C_{ij} is coefficient of the increasing fish production from artificial input; j=1, 2, 3 and 4 represents fishery paddy field, reservoir and pool, lake, and river.

$$PA_{i1} = 0.042 \cdot (\ln SFI_i)^{2.4} \cdot (\ln P_{mi})^{1.6} \cdot (\ln PD_i)^{0.72} \cdot (1 + t_i / 100)^{3.4} \quad (23)$$

$$PA_{i2} = 0.334 \cdot (\ln SFI_i)^{0.72} \cdot (\ln P_{mi})^{0.83} \cdot (\ln PD_i)^{0.45} \cdot (\ln SR_i)^{1.31} \cdot (1 + t_i / 100)^{2.42} \quad (24)$$

$$PA_{i3} = 3.94 \cdot (\ln SFI_i)^{0.55} \cdot (\ln P_{mi})^{1.21} \cdot (\ln PD_i)^{0.47} \cdot (\ln NDVI_i)^{0.18} \cdot (\ln S_i)^{-0.25} \cdot (1 + t_i / 100)^{3.4} \quad (25)$$

$$PA_{i4} = 0.179 \cdot (\ln SFI_i)^{0.81} \cdot (\ln P_{mi})^{1.87} \cdot (\ln PD_i)^{0.56} \cdot (\ln NDVI_i)^{0.21} \cdot (1 + t_i / 100)^{1.78} \quad (26)$$

where SFI is soil quality; P_m is precipitation coefficient; t is temperature; PD is population density; S is slope; NDVI is a vegetation index.

2.4.7.5. Total food provisioned by terrestrial ecosystems

Total food provisioned by all kinds of major ecosystems is calculated by,

$$TN_i = \sum_{j=1}^{m} P_j N_{ij} \quad (27)$$

where TN_i is potential of the ith kind of nutrients (i=1, 2 and 3 represent calorie, protein and fat); P_j is potential of the jth type of food; m is number of food types; N_{ij} is content of the ith kind of nutrients from the jth type of food.

2.4.8. Surface modeling of population distribution (SMPD)

The SMPD introduced in this paper is generally formulated as,

$$SMPD_{ij}(t) = G(n,t) \cdot W_{ij}(t) \cdot f_1(Tran_{ij}(t)) \cdot f_2(NPP_{ij}(t)) \cdot f_3(DEM_{ij}(t)) \cdot f_4(u_{ij}(t)) \quad (28)$$

where *t* is the time variable; $G(n,t)$ is a parameter determined by total population in administrative division *n* where grid cell (i, j) is located; $W_{ij}(t)$ is an indicative factor of water area; $f_1(Tran_{ij}(t))$ is a function determined by the condition of transport infrastructures of grid cell (i, j); $f_2(NPP_{ij}(t))$ is a function determined by the condition of net primary productivity of grid cell (i, j); $f_3(DEM_{ij}(t))$ is a function determined by the elevation of grid cell (i, j); $f_4(u_{ij}(t))$ is a function determined by contribution of urban areas to population density at grid cell (i, j); $u_{ij}(t) = \sum_{k=1}^{M(t)} \frac{(S_k(t))^{a_1}}{d_{ijk}(t)}$, $S_k(t)$ is size of the kth city, a_1 is an exponent to be simulated, $M(t)$ is the total number of cities, $d_{ijk}(t)$ is the distance from grid cell (i, j) to the core grid cell that has the highest population density in the kth city.

2.4.9. Ecological thresholds

In summarizing the related research achievements, Odum concluded: (i) the optimum density of population sustainable over a long period of time in the face of environmental uncertainties is perhaps 50 percent lower than the theoretical maximum carrying capacity *K*; (ii) from the standpoint of sustainable development, the range between maximum carrying capacity and the optimum density seems to represent the sustainable growth range of population; (iii) the sustainable growth range of population is often skewed to the left (taking the $n = 0.5K$ as the central axis).

A further study on the Odum's conclusion shows that the sustainable growth range of population is [0.5*K*, *K*] after affected by a small perturbation; the sustainable growth range is, taking $n(t) = 0.5K$ as the central axis, skewed to the left and the possibly longest skewed distance is $\frac{K}{2\sqrt{3}}$, about 0.289*K*, under the effect of a great perturbation. In other words, for natural ecosystem, near-natural ecosystem and seminatural ecosystem, the sustainable growth range of population is [0.5*K*, *K*]; for anthropogenic biotic ecosystem and anthropogentic technical system, the sustainable growth range is ($0.5K - \frac{K}{2\sqrt{3}}$, $0.5K + \frac{K}{2\sqrt{3}}$) or approximately [0.211*K*, 0.788*K*]. Obviously, the width of sustainable growth range of the anthropogenic biotic ecosystem and the anthropogentic technical system is greater than those of natural ecosystem, near-natural ecosystem and seminatural ecosystem.

2.5. Model-base system

Since the latest several centuries, a large number of ecological models have been developed. These models are crystals of the scientists' knowledge about and experiences in ecological system. To prevent abuse of the models outside the effective range, fully and effectively utilize the existing model knowledge, reduce time and financial waste in repeated establishment of models, and develop necessary new models, we verified the relevant models published in major foreign and domestic periodicals. 3068 models in high practicability and theoretical value are collected in MAWEC model-base. By their application fields, these models are divided into 27 model groups: ecological theoretical models, individual and physiological models, population models, community and ecosystem models, behavior ecology and evolution ecological models, landscape models, global change models, biological diversity models, virus ecological models, ecological management and ecological recovery models, industrial models, agricultural models, communication models, urban models, tourist models, regional models, climatic models, physiognomic models, soil models, hydrological models, vegetation models, information transmission models, terrestrial spectrum and frequency characteristic models, remote sensing information processing and analysis models, atlas models, geographic information system models, and comprehensive integration models (Yue, 2003). All these models form the basic model-base of MAWEC model-base system.

2.5.1. Design of model-base system

The model-base system is composed of five parts: basic model-base, specific model-base, model-base management system, model dictionary, and model-base administrator. MAWEC model-base system adopts top-to-bottom integration design ideas on two levels. The design on the first level is mainly used in the overall framework of the general platform of the model-base system, while the one on the second level is mainly used in various sub-systems of the model-base system. Overall design of the sub-systems includes functional and structural design of each sub-system as well as design of the functions and tasks of the modules in each system. Eventually, the detailed designs of the sub-systems are integrated into the detailed design of the overall framework of the general platform of the resource and environment model-base system (Fan and Yue, 2004).

①First of all, sequence of the sub-systems of the model-base system is specified for design, and the sub-systems of the most priority are designed first. The advantages of this idea include that all sub-systems can be developed in order and that the development of the following sub-systems can borrow the previous experiences or even share some parts of the previously developed sub-systems. In addition, the following sub-systems can be used to test the previously developed sub-systems. This idea is a necessary pre-condition and reliable guarantee of sequence, operability, and high performance of the whole model-base system.

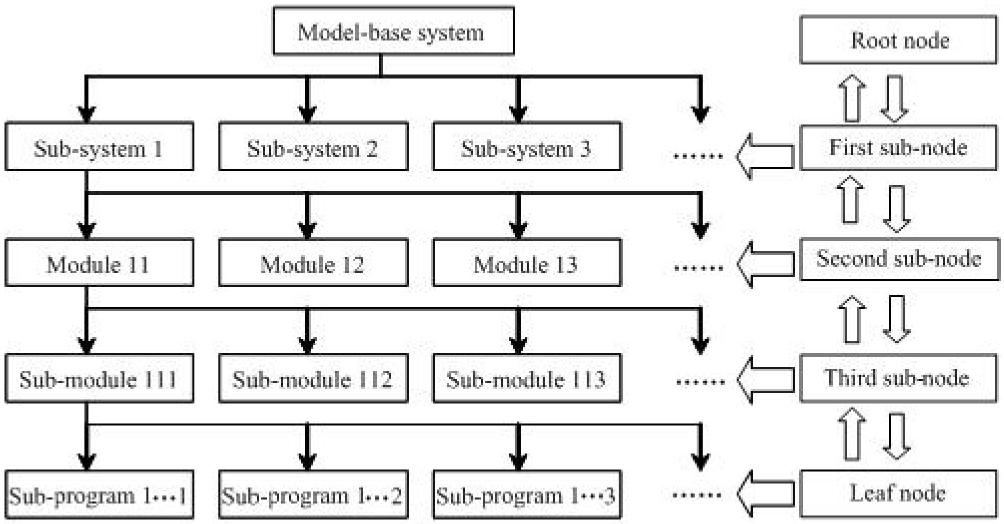

Figure 2.5. The model-base system

②When the sub-systems of the most priority are selected, the modules of each sub-system are sequenced, and the prior modules are selected for design.

③When the sub-modules of the sub-systems are selected for prior design, the sub-sub-modules of the sub-modules are sequenced for designed, till the final root nodes. When the above-mentioned works are done, the sequence specified in accordance with the principle of prior development is followed in implementation. Finally, when development of all sub-systems is completed, the sub-systems are integrated into the preliminary prototype of the model-base system (Figure 2.5). When there are sufficient software and hardware resources, human resources, and fund as well, you of course can choose to develop the sub-systems or sub-base of the model-base system simultaneously. However, before simultaneous development is started, the connection, communication standards, and interface protocol between various sub-systems as well as development work should be analyzed, studied and designed in detail. In short, the development teams of the sub-systems must cooperate with other very well, or there may appear incompatibility between the sub-systems, a great deal of repeated development work, impossibility to integrate the various sub-systems (or sub-bases) of the whole model-base system.

2.5.2. Model-base

Model-base is the core of the model-base system, and it includes basic model-base and special model-base (Figure 2.6). The models of the basic model-base will be designed in the form of base function with standard I/O interface, which involves two aspects (Fan and Yue, 2004): ①code base, source base, property base and index base of single–purpose models; ②code base, source base, property base, index base and general functions of modular units for constructing the comprehensive models. Code base and source base are text bases on sub-program level. The former is for storing the execution codes of the models, and the latter is for storing the source codes of the models. Property base and index base are organized in relations, and then express the relations between the basic model units (model source data). In other words, the former is for storing model dictionary, and the latter is for storing key words for search.

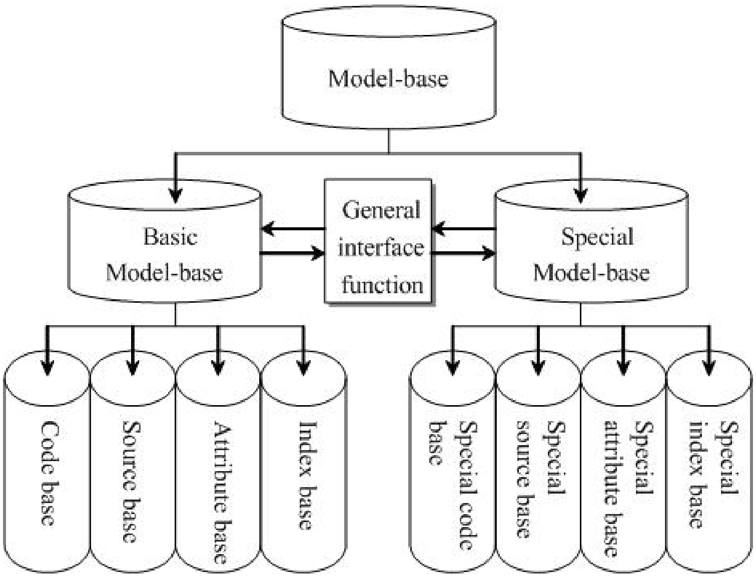

Figure 2.6. Composition and functional structure of the model-base

There is a general interface between the special model-base and the basic model-base, through which any basic model-base can be accessed and operated. Special model-base is also composed of code base, source base, attribute base and index base. However, the code base of the special model-base involves the model execution codes corresponding to the special part, and doesn’t share any content with other special model-bases. In addition, the source base stores only source codes corresponding to the special models, while the attribute base includes not only all information of the special models, for this reason it is called standard text base of the special model-base, but also all information about combination of the relevant basic model units of the basic model-base.

2.5.3. Model dictionary

Model dictionary is an important part of the model-base system, and the core of the model-base management system. Model dictionary contains all description and storage information about all models in the model-base. It is a special database about model description information. It is an information tool for controlling the relevant models during design, actualization, operation, maintenance, and expansion of the model-base system. As an important tool in model-base management, model dictionary is directly involved in the management of the model-base (including systematic design, analysis of demand definition range, design, actualization, operation and maintenance, update of the model-base, etc.).

The model dictionary is a metadata base of the model-base. It contains not only all description information about the model-base, but also the information about background for constructing the relevant models. It provides the users with query about effectiveness and hidden presumption of the relevant models (Fan and Yue, 2004). Uniform model description standard is a precondition of effective management of the models. It contains the following contents: ①overall information about the models, including name of model, model construction date, information about the modeler, time of being put into the base, and information for reference; ②model function; ③conditions and range for model application; ④mathematical equations; ⑤explanation about model parameters; ⑥model operation characteristics, including name of execution code, source code, coding and decoding system, and data format; ⑦model application cases; and ⑧illustration of the relevant models.

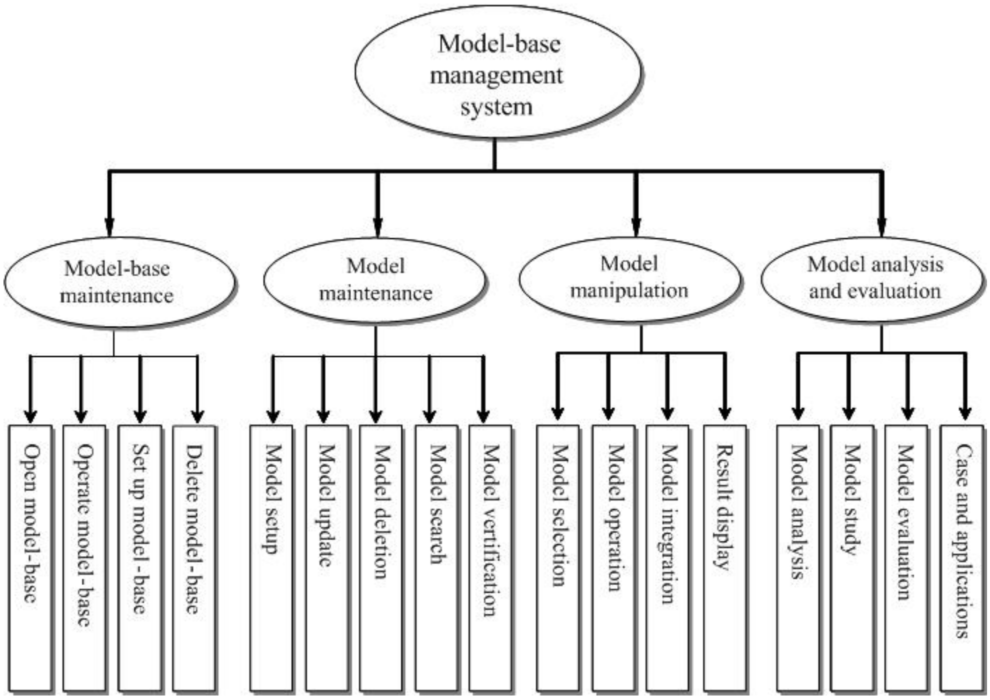

Figure 2.7. Composition and functions of the model-base management system

2.5.4. Model-base management system

The model-base system is used for analysis of temporal and spatial information about various ecological issues as well as simulation of their internal mechanism. For some complex ecological issues, it is necessary to effectively integrate various complementary models, and one single model may not work. Therefore, the model combination functions of the model-base management system must be taken into full considerations and designed in detail during the process of developing the model-base system. The composition and functions of the model-base management system include the following contents (Figure 2.7): ①providing maintenance operation of the model-base, including startup, operation, setup, and deletion of the model-base; ②providing the relevant operation about model maintenance, including setup, update, deletion, search and verification of models; ③providing the relevant functions concerning model manipulation, including selection of model, operation of model, display of results, and integration of models; ④providing the function of analyzing and evaluating models; ⑤providing basic tools for analysis and design of the model-base system; ⑥providing foundations for the model-base administrators in managing and inquiring; ⑦providing basic information for the users to understand the model-base system; ⑧providing design criteria of the general models or model-base interfaces.

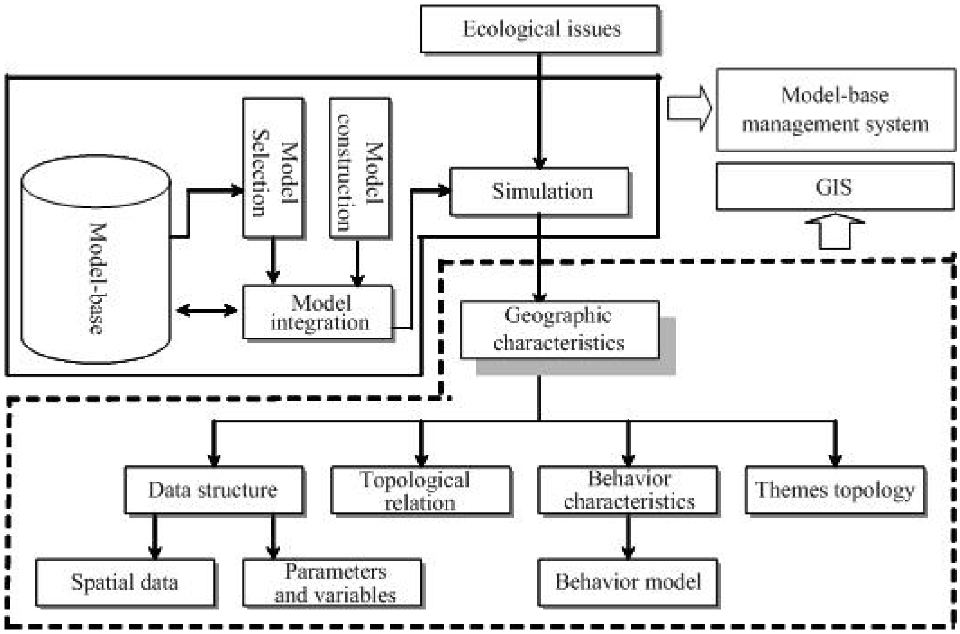

Figure 2.8. Integration of model-base system with GIS

2.5.5. Integration of model-base system with GIS

Seamless integration between the model-base system and GIS can satisfy the general requirements of users. Without knowing the special data structure in the GIS, the users can select the relevant models in the model-base system, and carry out the relevant operation according to the information provided on the visual user interface, and the results can be displayed on the visual platform of the GIS (Figure 2.8).

3. Conditions and trends

3.1. Trend of climate change

On the basis of observation data collected from 735 meteorological stations during the period from 1961 to 2000, the zonal variety law of temperature and precipitation is simulated in terms of elevation in different mountainous systems (Yue et al., 2005). The results show that the mean temperature rose from 8.45℃ in the 1960s to 8.75℃ in the 1990s, increased by nearly 0.075℃ every ten years; the mean annual precipitation rose from 531.54mm in the 1960s to 546.88mm in the 1990s, increased by 3.835mm every ten years; potential evapotranspiration ratio dropped from 2.70 in the 1960s to 2.40 in the 1990s, decreased by 0.08 every ten years. The change trend of the major climatic factors in the 30 ecological zones in the western region of China in the past 40 years can be concluded as three aspects.

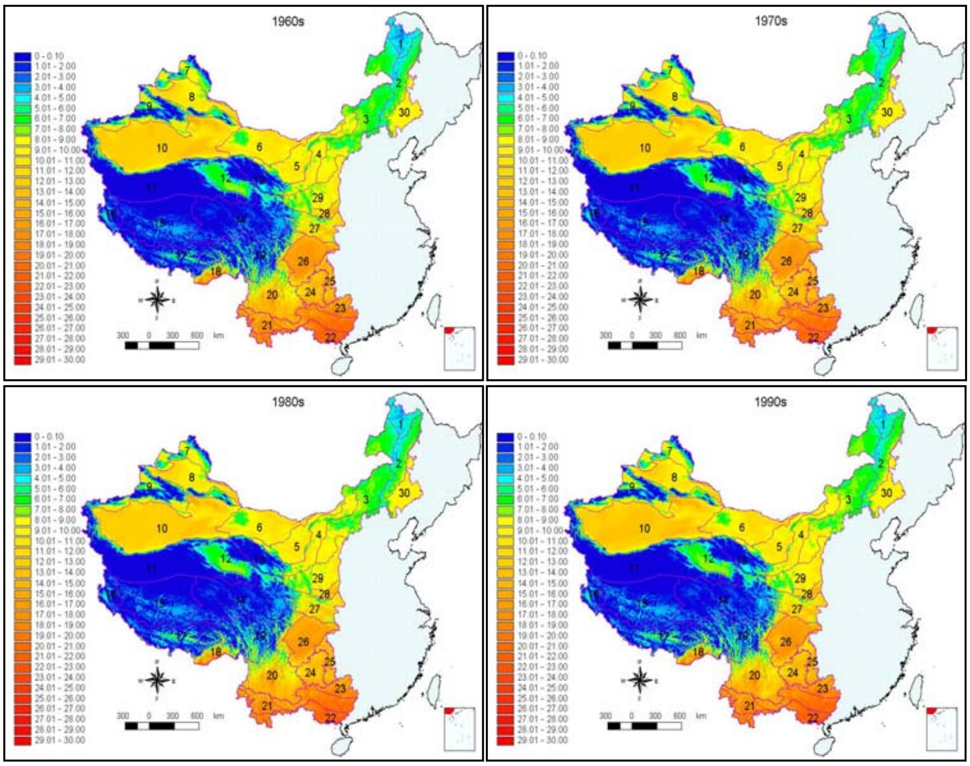

Figure 3.1. The mean decadal bio-temperature in 1960s, 1970s, 1980s and 1990s

① The mean decadal bio-temperature of the tropical rainforests and monsoon forests in the south of Yunnan and Guangxi was the highest one in western China. To be more exact, it was 19.42℃, 19.35℃, 19.52℃ and 19.81℃ in the 1960s, 1970s, 1980s and 1990s respectively. Except for certain drop in the 1970s, it rose by nearly 0.1℃ every ten years on an average in the remaining decades. This temperature rise rate was higher than that of any other part of western China. The mean decadal bio-temperature in the high frigid desert grassland zone along Pamir-Kunlun Mountain-Alkin Mountain was the lowest. To be more exact, it was 0.84℃, 0.88℃, 0.87℃ and 0.99℃ in the 1960s, 1970s, 1980s and 1990s respectively. Except for certain drop in the 1980s, it rose by nearly 0.04℃ every ten years on an average in the remaining decades (Figure 3.1-3.2).

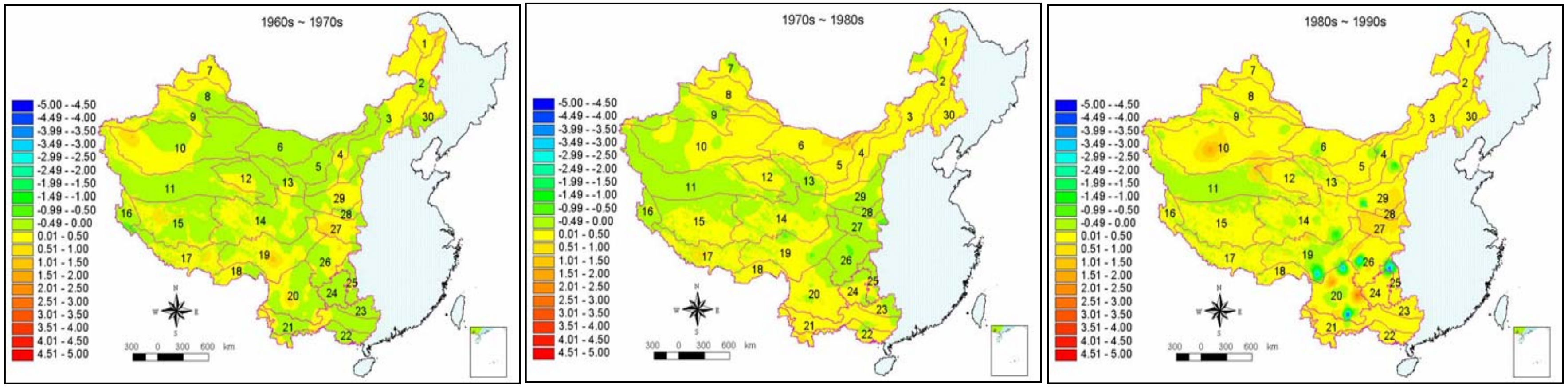

Figure 3.2. Changes of the mean decadal bio-temperature from 1960s to 1990s

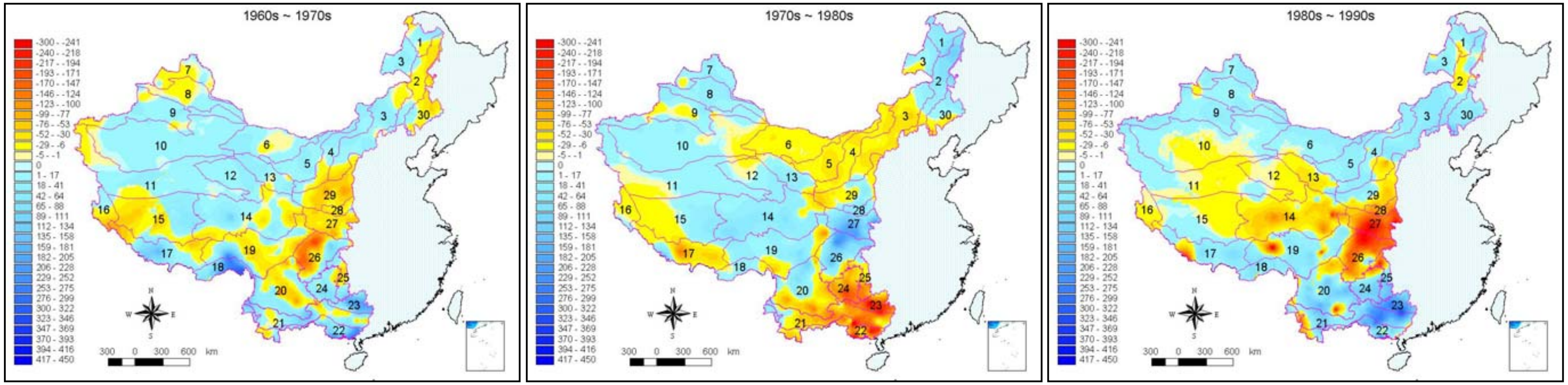

Figure 3.3. Changes of the mean annual precipitation from 1960s to 1990s

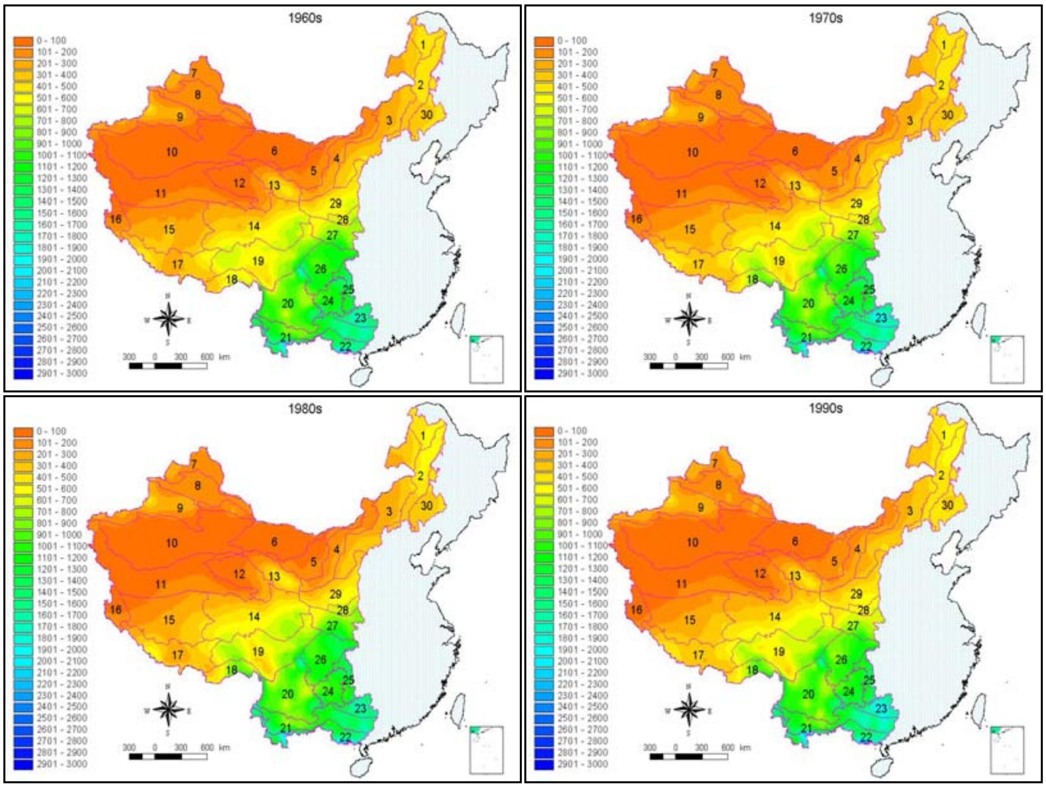

Figure 3.4. The average annual precipitation in 1960s, 1970s, 1980s and 1990s

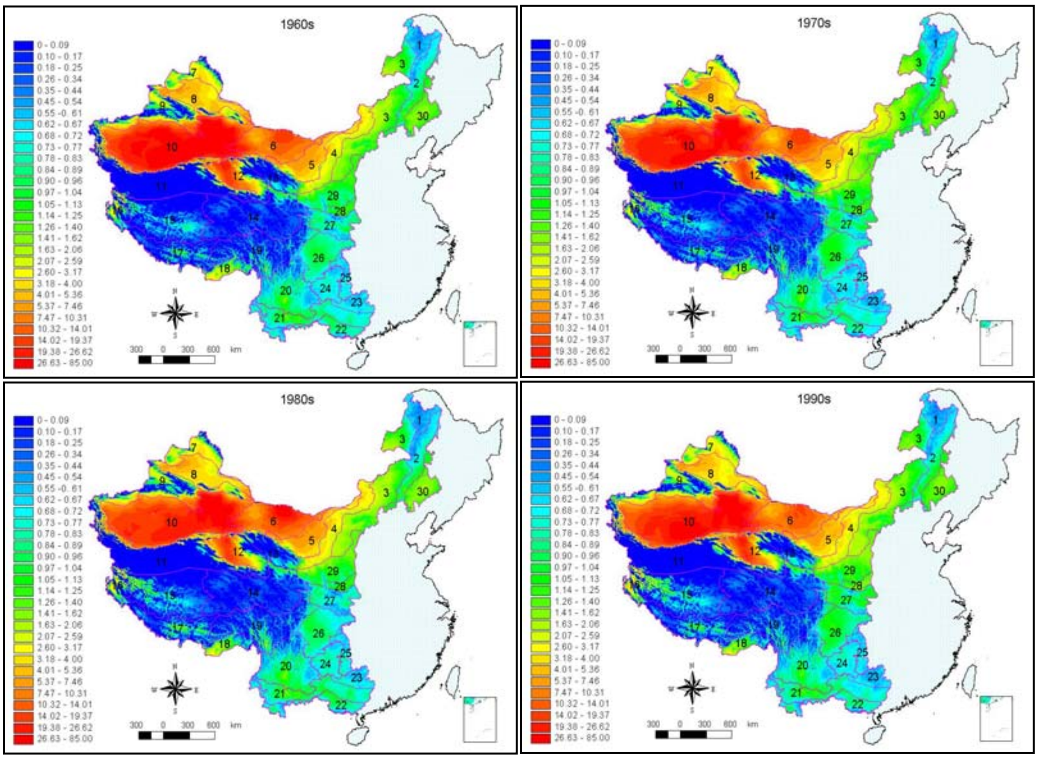

Figure 3.5. The average potential evapotranspiration ratio in 1960s, 1970s, 1980s and 1990s

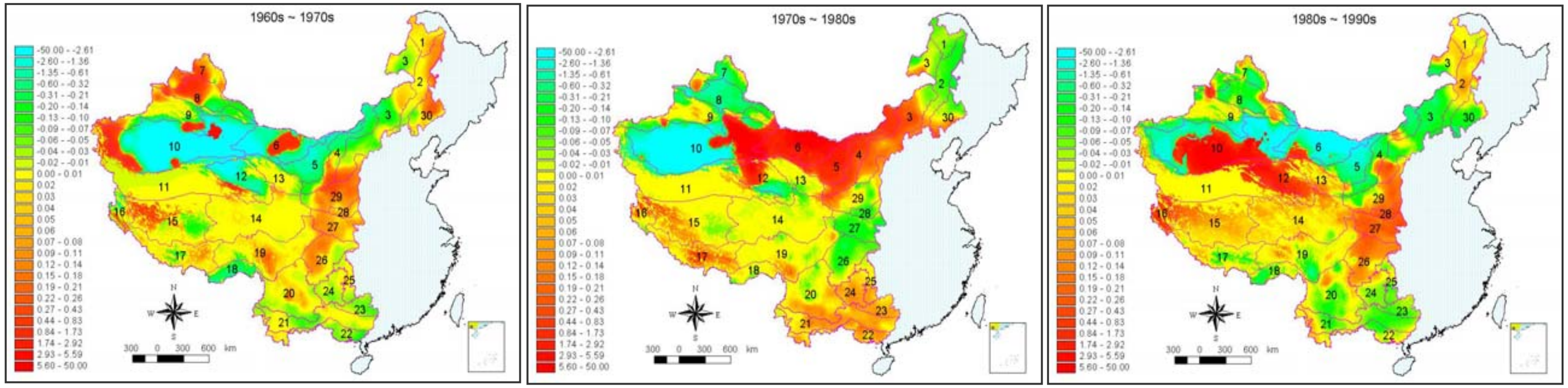

Figure 3.6. Changes of the average potential evapotranspiration from 1960s to 1990s

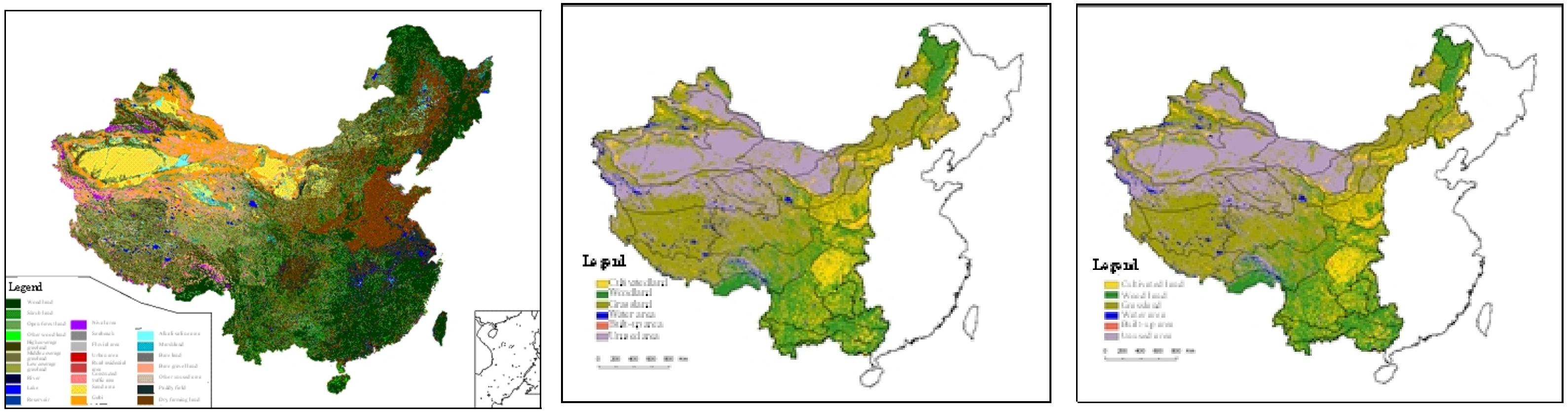

Figure 3.7. Land use maps based on TM data

(left figure: land use in 2000; middle figure: land use in 1980s; right figure: land use in 1990s)

② The average annual precipitation in the subtropical evergreen broadleaf forest zone in central Nanling was the highest one in western China. The average annual precipitation was respectively 1552.51mm, 1681.29mm, 1525.00mm and 1720.66mm in the 1960s, 1970s, 1980s and 1990s. Except for certain drop in the 1980s, it rose by 42.04mm every ten years on an average in the remaining decades. The rate was nearly eleven times of the average rate of the whole western region of China. The average annual precipitation in the Tarim Basin-Dongjiang Desert zone was the lowest. To be more exact, it was respectively 31.74mm, 38.11mm, 43.29mm and 44.49mm in the 1960s, 1970s, 1980s and 1990s. It constantly rose by nearly 3.19mm every ten years, slightly lower than that of the whole western China (Figure 3.3-3.4).

③ The average potential evapotranspiration ratio of the Tarim Basin-east Xinjiang Desert zone was the highest in the western China. To be more exact, it was respectively 29.72, 23.28, 21.55 and 22.58 in the 1960s, 1970s, 1980s and 1990s. It decreased as a whole by 0.51 every ten years. The average potential evapotranspiration ratio of the River Source Area – South Gansu frigid meadow zone was the lowest. In the 1960s, 1970s, 1980s and 1990s, the mean decadal bio-temperature was respectively 0.19, 0.19, 0.18 and 0.22℃. It kept the same in 1960s-1970s, decreased by 0.01 in 1980s, and increased by nearly 0.03 in 1990s. Generally, it rose by nearly 0.008 every ten years (Figure 3.5-3.6).

3.2. Change trend of terrestrial ecosystems in western China

3.2.1. Change trend of spatial distribution of the terrestrial ecosystems

Out of the 38 types of HLZ ecosystems (according to the definitions of HLZ models, hereinafter shortened as Life Zone), 28 types exist in China and 27 types in western China. The only missing one in western China is the tropical moist forest zone that exists at low latitudes. This indicates the complexity of the HLZ ecosystems in the western region of China. The tropical dry forest zone that appeared in the south of Yunnan in the late 1970s indicates the increase of precipitation and the rise of temperature. Other types of HLZ ecosystems in western China also went through a range of spatial changes as such climatic conditions as temperature, precipitation and potential evapotranspiration ratio changed in the periods (figure 3.8).

① The tropical desert zone is mainly distributed in the center of Tarim Basin and Turpan Depression, namely, Taklamakan Desert. The warm temperate desert zone is mainly distributed in Tarim Basin, the most part of Turpan depression, the center of Qaidam Basin, and Badain Jaran Desert of Alashan Plateau, which are generally sandwiched between the tropical desert zone and the cold temperate desert zone. The cold temperate desert zone is mainly distributed in the west and east of Alashan Plateau, the edges of Tarim Basin and Turpan Depression, and the peripheral areas of Qaidam Basin, which are just outside the warm temperature desert zone. The northern desert zone is mainly distributed in the center and west of Junggar Basin, and small part of the northwest of Alashan Plateau. The northern desert and scrub zone, the cold temperate scrub zone, and the warm temperate desert and scrub zone are mainly distributed in most part of Alashan Plateau and Junggar Basin, the northwest of Loess Plateau, and the southwest of Inner Mongolian Plateau. Both the cold temperate desert scrub zone and the warm temperate desert scrub zone show an expanding trend; particularly, the desert scrub zone in Loess Plateau and Inner Mongolian Plateau expands eastward and southeastward extremely apparently. The Boreal dry scrub is mainly distributed in the lower mountainous areas of Tianshan, the southwest of Qinghai-Tibet Plateau, as well as the lower mountainous areas in the north of Qilian Mountain.

② The nival zone is mainly distributed in most part of the northwest of Qinghai-Tibet Plateau, most alpine areas of the northwest of Qilian Mountain, the alpine areas in Hark Mountain and Bogeda Mountain of Tianshan, and the alpine areas of Altai. The alpine dry tundra zone, the alpine moist tundra zone, the alpine wet tundra zone and alpine rain tundra zone are mainly distributed in the alpine areas surrounding the nival zone, most alpine areas of the southeast of Qinghai-Tibet Plateau, the edges of Altai, Qilian and Tianshan outside the nival zone, as well as the alpine areas in the north of Daxing'anling. As the temperature rose and the precipitation increased during the period from 1961 to 2000, the nival zone in western China declined constantly; the alpine dry tundra zone and alpine wet tundra zone expanded gradually; the nival zone on Qinghai-Tibet Plateau retreated northwestward apparently, and the nival zone in other alpine areas retreated toward mountain tops with high elevations. The spaces where the nival zones retreated were gradually occupied by various alpine tundra zones.

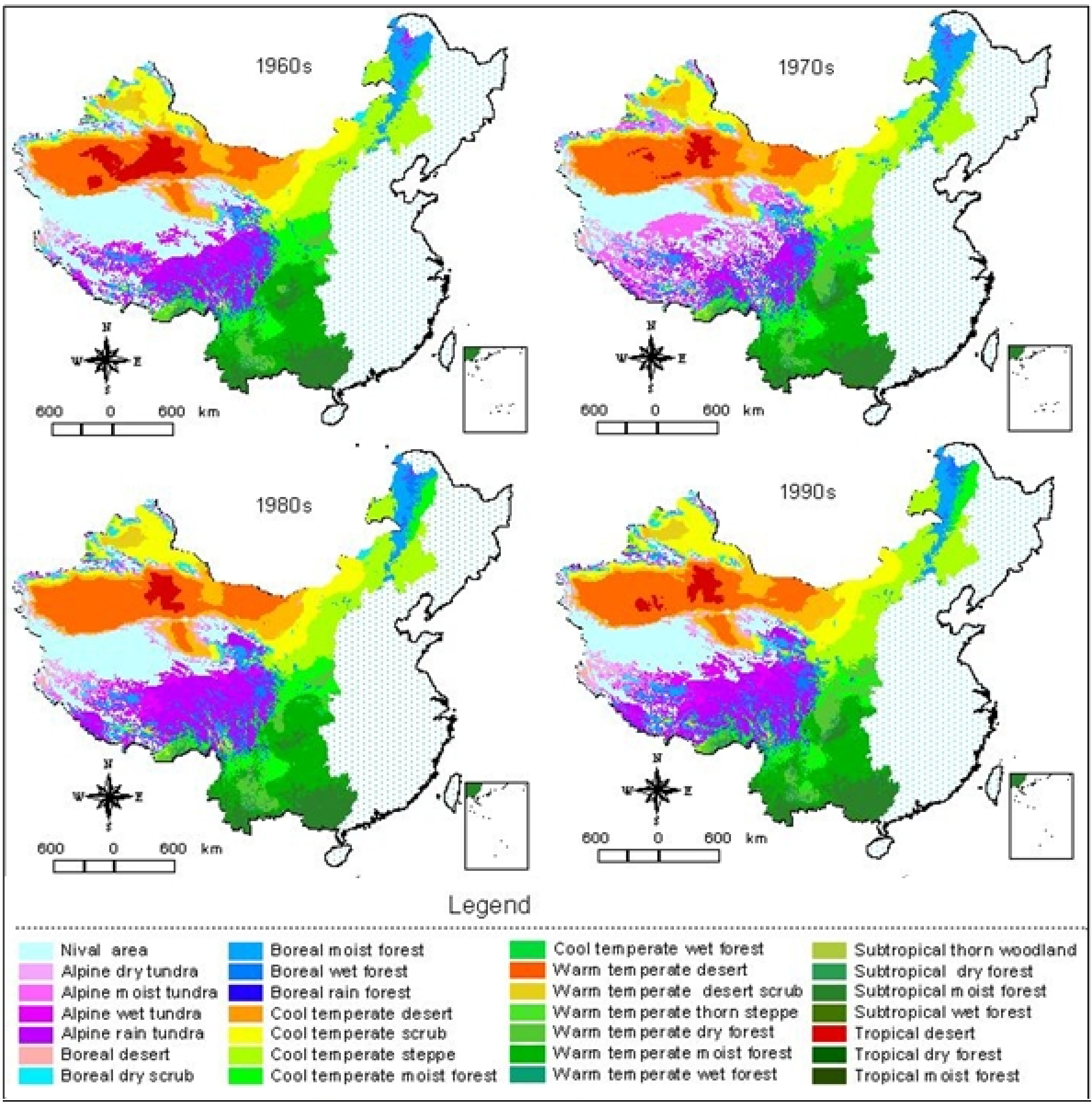

Figure 3.8. Change trend of HLZ ecosystems in western China

③ The cool temperate steppe was mainly distributed in Mongolian Plateau, Loess Plateau, and the west of Daxing'anling (the reaches of Baikal Lake and Hulun Lake). The warm temperate thorn steppe was mainly distributed in the lower mountainous areas in the southeast of Himalayas, and the reaches of Ili River in the west of Tianshan and Aibi Lake in the north of Tianshan.

④ The boreal moist forest, the boreal wet forest, and the boreal rain forest were mainly in the east of Qinghai-Tibet Plateau and Daxing'anling. The cold temperate moist forest zone and the cold temperate wet forest zone were mainly distributed in the alpine areas in the east of Qinghai-Tibet Plateau, most part of Qinling, and the northeast of Daxing'anling. The warm temperate dry forest zone was mainly distributed in the lower mountainous areas in the north of Qinling, the southeast of Qinling, the center of Sichuan Basin, and the alpine areas of Yunnan-Guizhou Plateau.

⑤ The warm temperate moist forest zone was mainly distributed in the east of Sichuan, Chongqing, most part of Guizhou, the south of Qinghai-Tibet Plateau, and the east of Yunnan. The warm temperate wet forest zone was mainly distributed in the west of Yunnan, and the lower mountainous areas in the south of Qinghai-Tibet Plateau. In the whole western areas, the warm temperate moist forest zone and the warm temperate wet forest zone were mainly distributed in most part of the upper reaches of the Yangtze River. As the temperature and precipitation fluctuated increasingly in Qinghai-Tibet Plateau, the types of HLZ terrestrial ecosystems fluctuated accordingly. The climatic conditions and physiognomic features were extremely complicated in Qinghai-Tibet Plateau (particularly, in the east of Qinghai-Tibet Plateau), and as a result of these complicated climatic and physiognomic conditions, the land cover types alternated frequently. Therefore, the ecosystems were unstable and fragile in Qinghai-Tibet Plateau, particularly, in the northeast, southeast and east of Qinghai-Tibet Plateau. The subtropical dry forest zone, the subtropical moist forest zone and the subtropical wet forest zone were mainly distributed in the lower mountainous areas in the southeast of Sichuan Basin, most part of Guangxi, and the southwest of Yunnan. In the late 1970s, the tropical dry forest zone appeared at the south end of Guangxi.

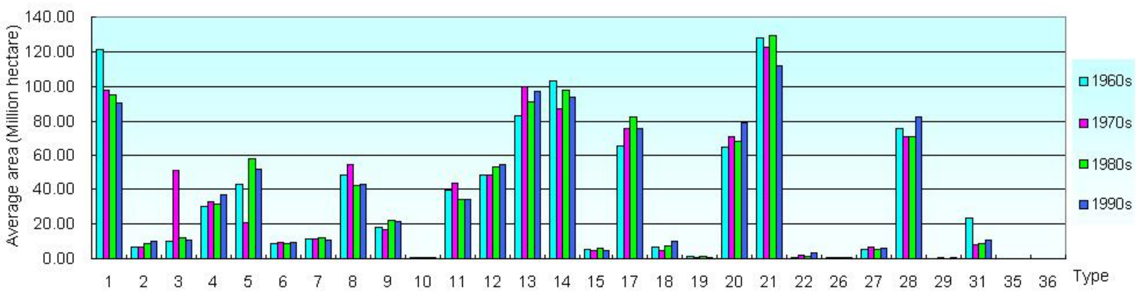

Figure 3.9. Area change trend of HLZ ecosystems in western China（abscissa code referenced in table 3.1）

3.2.2. Area change trend of HLZ ecosystems in western China

According to the analysis results of area change of the HLZ ecosystems in the western China (Figure 3.9), ①the area of nival zones constantly decreased by 6.3% every ten years on an average; to be more exact, it decreased by 2.33×10^7 hectares (or 19.2%) in the 1970s than in the 1960s, by 2.51×10^6 hectares (or 2.6%) in the 1980s than in the 1970s, and by 4.76×10^6 hectares (or 5%) in the 1990s than in the 1980s; ②the alpine dry tundra zones and the cold temperate dry scrub zones constantly increased respectively by 13% and 3.5% every ten years on an average; ③other types of HLZ ecosystems fluctuated dynamically. The subtropical wet forest zone fluctuated the most. It increased by 346.7% in the 1970s than in the 1960s, but decreased by 77.6% in the 1980s than in the 1970s, and increased again by 440.6% in the 1990s than in the 1980s. The subtropical wet forest zone fluctuated the second. It increased by 210.3% in the 1970s than in the 1960s, but decreased by 67.6% in the 1980s than in the 1970s, and increased again by 251.3% in the 1990s than in the 1980s; ④the warm temperate desert and scrub zone decreased by 1.81×10^6 hectares (or 26.7%) in the 1970s than in the 1960s, and increased by 2.52×10^6 hectares (or 50.8%) in the 1980s than in the 1970s, and by 2.83×10^6 hectares (or 37.8%) in the 1990s than in the 1980s. It can be seen that the warm temperate desert scrub increased more and more quickly in western China from the late 1970s. This reflects the continous desertification in China since the 1970s.

Table 3.1. The classification standard of HLZ ecosystems

Code	HLZ	standard of MAB (℃)	standard of TAP (mm)	standard of PER
1	Nival	0.2670	88.3880	0.1770
1	Nival	0.5300	88.3880	0.3540
1	Nival	0.5300	177.7770	0.1770
1	Nival	1.0610	88.3880	0.7070
1	Nival	1.0610	177.7770	0.3540
1	Nival	1.0610	353.5520	0.1770
2	Alpine dry tundra	2.1210	88.3880	1.4140
3	Alpine moist tundra	2.1210	177.7770	0.7070
4	Alpine wet tundra	2.1210	353.5520	0.3540
5	Alpine rain tundra	2.1210	707.1070	0.1770
6	Boreal desert	4.2430	88.3880	2.8280
7	Boreal dry scrub	4.2430	177.7770	1.4140
8	Boreal moist forest	4.2430	353.5520	0.7070
9	Boreal wet forest	4.2430	707.1770	0.3540
10	Boreal rain forest	4.2430	1414.2130	0.1770
11	Cool temperate desert	8.4850	88.3880	5.6750
12	Cool temperate scrub	8.4850	177.7770	2.8280
13	Cool temperate steppe	8.4850	353.5520	1.4140
14	Cool temperate moist forest	8.4850	707.1070	0.7070
15	Cool temperate wet forest	8.4850	1414.2130	0.3540
16	Cool temperate rain forest	8.4850	2828.4270	0.1770
17	Warm temperate desert	14.2700	88.3880	11.3140
18	Warm temperate desert scrub	14.2700	177.7770	5.6750
19	Warm temperate thorn steppe	14.2700	353.5520	2.8280
20	Warm temperate dry forest	14.2700	707.1070	1.4140
21	Warm temperate moist forest	14.2700	1414.2130	0.7070
22	Warm temperate wet forest	14.2700	2828.4270	0.3540
23	Warm temperate rain forest	14.2700	5656.8540	0.1770
24	Subtropical desert	20.1810	88.3880	11.3140
25	Subtropical desert scrub	20.1810	177.7770	5.6750
26	Subtropical thorn woodland	20.1810	353.5520	2.8280
27	Subtropical dry forest	20.1810	707.1070	1.4140
28	Subtropical moist forest	20.1810	1414.2130	0.7070
29	Subtropical wet forest	20.1810	2828.4270	0.3540
30	Subtropical rain forest	20.1810	5656.8540	0.1770
31	Tropical desert	33.9410	88.3880	22.6270
32	Tropical desert scrub	33.9410	177.7770	11.3140
33	Tropical thorn woodland	33.9410	353.5520	5.6750
34	Tropical very dry forest	33.9410	707.1070	2.8280
35	Tropical dry forest	33.9410	1414.2130	1.4140
36	Tropical moist forest	33.9410	2828.4270	0.7070
37	Tropical wet forest	33.9410	5656.8540	0.3540
38	Tropical rain forest	33.9410	11313.7100	0.1770

3.2.3. Change trend of ecological diversity and patch connectivity

The ecological diversity and patch connectivity of HLZ ecosystems in western China respectively increased by 0.27% and 2.79% every ten years. The bio-temperature constantly rose in the past half a century, and tropical moist forest zone appeared in the south of Guangxi from the 1970s. The number of HLZ ecosystem types increased from 26 in the 1960s to 27 in the 1970s. According to the analysis above, as the air temperature continuously rises and precipitation gradually increases, the ecosystems in western China become more and more suitable for people to live in near future.

3.3. Condition and change trend of the major ecosystems in western China

In recent years, the farmlands, woodlands and grasslands have changed a lot in the western region of China. According to the statistics of eight western provinces (regions) (exclusive of Yunnan, Guizhou, Sichuan and Chongqing), the farmland area increased by $1.97\times10^6 hm^2$, or 7.7%, in western China in 1999 than in 1986, but cultivation of unused land and abandonment of farmland coexisted. In 1999, the total area of woodlands and non-timber wood lands increased to some extent in western China, but at the same time, the area of natural forests and protective woodlands with strong ecological service capabilities decreased. In 1999, the area of grasslands apparently decreased in western China. To be more exact, it decreased by $1.11\times10^7 hm^2$, or 4.5%, in 1999 than in 1986. Meanwhile, the area of degraded grasslands and those grasslands that suffered from rats increased a lot. The area of garden plots increased at a high rate, but the absolute area didn't change considerably.

From 1986 to 1999, the total area of farmlands, the area of irrigation lands, and the area dry farming lands all increased apparently in western China. The farmlands increased in western China in two ways. First, grasslands were cultivated into farmlands, and second, woodlands were cultivated or transformed into farmlands. The increase of farmlands by cultivating grassland accounted for 69.5%, while the increase of farmlands by cultivating woodlands or orchards accounted for 22.4%. Meanwhile, a great deal of farmlands was abandoned because of low yield each year, and the abandoned lands suffered from severe water and wind erosion. The ecological environment deteriorated sharply in western China due to a variety of factors, such as abandonment of farmlands, cultivation of sloping fields and dry farming lands, extensive ways of farming, and artificially created changes of temporal and spatial distribution of water resources due to increase of farmland area.

3.3.1. Forest ecosystems

Due to such conditions as moisture and heat, as well as their distribution, the vegetation of forests in China varies regularly from north to south as the latitude decreases (Figure 3.10). Vegetation belts in western China include the cold temperate coniferous forest, the temperate coniferous and broad-leaved forest, the warm temperate deciduous and broad-leaved forest, the subtropical evergreen broad-leaved forest, and the tropical monsoon and rain forest (Shen, 2000).

In addition to the above-mentioned belt-types of forest vegetation, there are some non-belt forest vegetation in China. The major factor that affects the distribution of the non-belt forest vegetation is the local eco-environment under certain physiognomic and geological conditions, not the local climatic conditions. That is why they are distributed in a non-belt way. The non-belt forests in China roughly fall into three categories that are forests in Qinghai-Tibet Plateau, forests in the temperate grassland zone, and mountainous forests in the temperate deserts. They are mostly distributed in western China.

In western China, the area of lands for wood purpose totals 1.43×10^8 hectares in western China, accounting for 54.4% of the whole of China; the area of woodlands amounts to 7.04×10^7 hectares, accounting for 44.3% of the whole of China; the forest coverage is 10.29%; the living stumpage amounts to

7.57×10^9 m^3, and the wood accumulation totals 6.97×10^9 m^3; the area of coniferous forests is up to 3.29×10^7 hectares, and the wood accumulation is up to 4.40×10^9 m^3; the area of broad-leaved forests is up to 3.04×10^7 hectares, and the wood accumulation is up to 2.58×10^9 m^3 (State Forestry Administration, 2002).

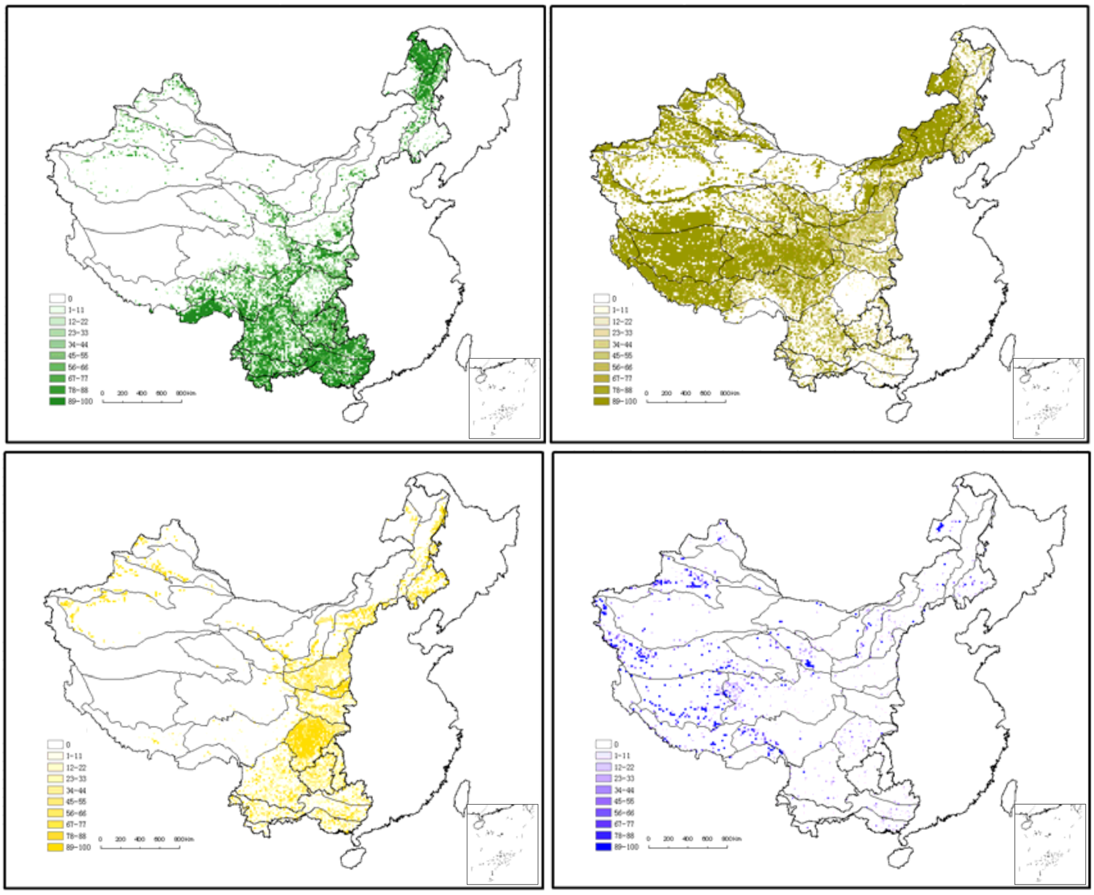

Figure 3.10. Major ecosystems in western China

(upper left: forest ecosystems and their coverage; upper right: grassland ecosystems and their coverage; lower left: agricultural ecosystems and their coverage; lower right: wetland ecosystems)

3.3.1.1. Timber provision

According to the fifth national survey of forest resources, the quantity of forest resources increases, but the quality decreases. Forest growth exceeds consumption, but the mature and over-mature forest resources constantly decline. Artificial forests increase, but natural forests decrease. The amount of actual consumption of forest resources has been in excess of the proper amount of forest resource consumption that is subject to the current structure of forest resources. Therefore, to achieve the timber supply-demand balance, the emphasis is not placed on cutting more forests, but on improving forest resource utilization efficiency, and reducing demands for timbers by promoting the development of the artificial board industry, improving the quality of timber products, and boosting saving and substitution of timbers. As the protection of natural forests is carried out, supply of timbers will drop accordingly. For these reasons, the amount of forest resource consumption will roughly be the same in the forthcoming years as that in the period from 1994 to 1998, namely, annual consumption of $3.71\times10^8 m^3$ (Yao, 2002).

3.3.1.2. Bamboo products

In the period from 1990 to 2001, the bamboo yield in western China increased from 1.94×10^7 pieces to 7.36×10^7 pieces, and the annual growth rate was 12.87% on the average; the per capita bamboo yield increased from 0.06 piece/person to 0.20 piece/person, and the annual growth rate was 11.57% on the average. The bamboo shoot yield increased from 3.2×10^7t in 1980 to 3.11×10^8t in 1998, and the annual growth rate was 13.46% on the average; the per capita bamboo shoot yield increased from 0.11 ton/person to 0.87 ton/person, and the growth rate was 11.98% on the average. The project of returning eroded farmlands to forests in western China has resulted in considerable growth of quality bamboo forest, which will surely boost the yield of bamboo and bamboo shoot to meet the social demands.

3.3.1.3. Non-timber forest products

In western China in the period from 1980 to1999, the output of forest products, including chestnut, turpentine, palm, Chinese tallow tree, oil-tea tree, and Chinese wood oil, increased from 5.35×10^9t to 9.50×10^9 t, and the annual growth rate was 3.07%. The per capita forest product output increased from 19.01 ton/person to 26.51 ton/person. As the rural society and economy develop quickly and the living standard of people improves constantly, the demands for non-timber forest products will grow fast. Meanwhile, the adjustment of industrial structure, the introduction of scientific and technological achievements, the development of market, and the improvement of management will surely lead to considerable improvement of the capability of supplying non-timber forest products.

3.3.1.4. Fuel wood

Fuel wood is still the major source of energy in the rural areas in China, particularly, in the outlying and mountainous areas. In the period from 1981 to 1993, the output of fuel wood increased from 3.35×10^7 t to 6.61×10^7 t, and the annual growth rate was 5.81% on the average. In 1993, the fuel wood demand-carrying rate in western China was 135%. At present, the demand for fuel wood far exceeds the carrying capacity of the forests in western China, which results in huge pressure on the future forest resources. Great importance must be attached to this problem; effective measures must be taken to resolve it; sustainable development must be achieved in respect of fuel wood.

3.3.1.5. Genetic resources

The biodiversity is exciting in western China. The diversity of animal species in western China is supported by the facts that the mammals account for 52% of the whole of China, reptiles a little less than 1/3, amphibians 50%, and special animals 50%-80%. The diversity of plant species in western China is more exciting. The mosses account for nearly 50% of the whole of China; special plant species account for 25%; there are over 1500 varieties of ferns in Yunnan; there are respectively 4600 and 3700 kinds of medicinal herbs in Sichuan and Guizhou, more than 2000 in Guangxi, Yunnan, Chongqing and Xinjiang respectively, and over 700-800 in Shaanxi, Qinghai and Tibet respectively. The diversity of ecosystems in western China is supported by the fact that, in western China, there are the northern coniferous forests, the sub-alpine coniferous forests, the warm temperate coniferous forests, the subtropical evergreen broad-leaved forests, the rigid evergreen broad-leaved forests, the coniferous and broad-leaved forests mainly containing hemlocks, tropical forests, grasslands, deserts, wetlands and so forth. In western China, there are more than 400 nature reserves covering a total land area of over 6.3×10^7 hm^2, accounting for 9.2% of the total territory of western China. The reserves protect the special biological environment of western China. For instance, the quantity of migratory birds has increased to 47 thousand since Qinghai Lake Nature Reserve was founded. In Yunnan, “the Kingdom of Animals and Plants”, and Qinghai-Tibet Plateau, “the Gene Treasury”, 15-20% species (world average of 10-15%) are threatened.

3.3.2. Grassland ecosystems

The natural grassland ecosystems in western China can be divided into four zones. They are temperate grassland ecological zone, the high frigid grassland ecological zone, the desert grassland ecological zone, and the southwestern grassland ecological zone. The temperate grassland ecological zone mainly includes the grassland ecosystems in the east of Inner Mongolian Plateau, Loess Plateau, and partial semi-arid areas of Xinjiang. The high frigid grassland ecosystems are mainly distributed in Qinghai-Tibet Plateau. The desert grassland ecosystems are mainly distributed in Xinjiang, Qaidam Basin, and the west of Inner Mongolia. The southern grassland ecosystems are mainly in mountains and slopes, and are mostly composed of secondary grassland ecosystems where the forests are ruined and alpine grassland ecosystems grows.

3.3.2.1. Spatial distribution of grassland ecosystems

At present, the total area of the natural grasslands in western China is 3.31×10^8 hm^2, accounting for 48.2% of the total territory of western China. 1.30×10^8 hm^2 grasslands have a coverage of 50% or more, accounting for 39.28% of the total grasslands in western China; 1.21×10^8 hm^2 grasslands have a coverage of 20-50%, accounting for 36.68%; 7.97×10^7 hm^2 grasslands have a coverage of 5-20%, accounting for 24.04% (figure 3.10). The grasslands with coverage of over 50% are mainly distributed in Qinghai-Tibet Plateau and the east of Inner Mongolia, where the moisture conditions are relatively good. The grasslands with coverage of 20-50% are mainly distributed in the west of Qinghai-Tibet Plateau, the center of Inner Mongolia, the center of Loess Plateau, the southwestern grassland area, and some parts of Xinjiang. The grasslands with coverage of 5-20% are mainly distributed in Xinjiang, Qaidam, the west of Inner Mongolia, and some parts of Qinghai-Tibet Plateau.

3.3.2.2. Grassland productivity

Western China have a vast territory, which accounts for 68.83% of the total territory of China, but the population of western China is just 27.41% of the total population of China. The poor natural environment results in poor productivity of the grassland ecosystems. Out of the grassland ecosystems in western China, the southwestern grassland area maintains the highest productivity per unit area; the temperate grassland zone comes the next; and the high frigid grassland zone has the lowest productivity per unit area. As for per capita area, the high frigid grassland zone takes the first place, the desert grassland zone and the temperate grassland the second, and the southwestern grassland the last. As for per capita production value, the desert grassland takes the first place, the temperate grassland and the southwestern grassland the second, and the high frigid grassland the last.

There are approximately 3.31×10^8 hm^2 natural grasslands in western China, but most grasslands maintain very low output per unit area. According to statistics, in western China, 1.1×10^7 hm^2 natural grasslands maintain a yield per unit area of 120,000kg/hm^2 or more, accounting for only 3.32% of the total natural grasslands in western China; 1.0×10^8 hm^2 natural grasslands maintain a yield per unit area of over 3000kg/hm^2, accounting for only 31.42%; 2.24×10^8 hm^2 natural grasslands maintain a yield per unit area of less than 3000kg/hm^2, accounting for 67.67%; natural grasslands maintaining a yield per unit area of less than 750kg/hm^2 account for more than 25% of the total natural grasslands in western China.

3.3.3. Farmland ecosystems

On the basis of the data obtained in the fifth national census, the per capita amount of land in western China is 28.52mu, 2.6 times of the per capita amount of land in the whole China; the per capita amount of farmland is 2.02mu, 1.4 times of the per capita amount of farmland in the whole country. In spatial distribution, Tibet Autonomous Region maintains the highest per capita amount of land, namely, 688.21mu, which is 24.1 times of the average of western China; Inner Mongolia maintains the highest per capita amount of farmland, namely, 4.7mu, which is 2.3 times of the average of western China; Sichuan Province maintains the lowest per capita amount of farmland, namely, 1.15mu, which is 56.9% of the average of western China.

Compared with those of the whole China, the farmland ecosystems in western China are featured with large quantity, poor quality, extensive cultivation, and less supported population.

3.3.3.1. Crop production

In 2002, the farmland ecosystems in western China supplied 1.27×10^8t of grains, which was 27.74% of the total amount of grain provisioned by the farmland ecosystems of the whole China. Out of the grains supplied by the farmland ecosystems in the twelve provinces, municipalities, and autonomous regions of western China, Sichuan province supplied the most, namely, 3.13×10^8t, which accounted for 24.70% of the total grain yield of western China; Guangxi came the next, and supplied 1.49×10^7t, which accounted for 11.72% of the total grain yield of western China; Qinghai Province supplied the least, namely, 9.13×10^5t. The grain supplied by the farmland ecosystems in western China increased from 4.56×10^7t in 1957 to 1.27×10^8t in 2002, and the annual growth rate was 3.96% on the average.

3.3.3.2. Fiber provision

In 2002, the farmland ecosystems in western China supplied 1.62×10^6t of cotton, which accounted for 32.9% of the total cotton provisioned by the farmland ecosystems in the whole China. Xinjiang province provisioned the most, namely, 1.48×10^6 t, which accounted for 91.2% of the total cotton yield of western China; Gansu came the next, and supplied 7.0×10^4 t, which accounted for 4.3% of the total cotton yield of western China; Shaanxi came the third, and supplied 4.3×10^4t. Chongqing, Yunnan, Tibet, Qinghai and Ningxia did not plant cotton.

3.3.3.3. Turning eroded farmlands back into forests or grasslands

In recent years, efforts have been strenuously made to return farmlands to forests and grasslands in western China. Particularly, after our government released the relevant policies on return from farmlands to forests (grasslands) in the second half of 1999 and in 2000 as well, the provinces (autonomous regions, and municipalities) made unremitting efforts in returning farmlands to forests and grasslands. According to the preliminary statistics made in 2000, more than 1.0×10^6 hm^2 sloping farmlands, including over 5.0×10^5 hm^2 of 25^o or above, have been returned to forests or grasslands in western China. Just in 2000, 4.2×10^5 hm^2 farmlands, including over 2.3×10^5 hm^2 of 25^o or above, were returned to forests or grasslands in western China.

According to some survey in 2000, in the Yangtze River drainage area, $2.24\times10^6hm^2$ farmlands that have a slope more than 25^o, should be returned to grasslands or forests step by step; about $6.7\times10^4hm^2$ terraces are not suitable for continuous farming any longer; $6.8\times10^5hm^2$ farmlands that have a slope between 15^o and 25^o, are not suitable for continuous farming any longer. Therefore, over $2.93\times10^6hm^2$ sloping farmlands should be returned to grasslands or forests step by step in the Yangtze River drainage area.

In Yellow River drainage area, $6.40\times10^5hm^2$ farmlands that have a slope more than 25^o should be returned to grasslands or forests step by step; about $3.93\times10^4hm^2$ terraces are not suitable for continuous farming any longer; over $9.0\times10^5hm^2$ farmlands that have a slope between 15^o and 25^o are not suitable for continuous farming any longer. Therefore, over 1.58×10^6 hm^2 sloping farmlands should be returned to grasslands or forests step by step in the Yellow River drainage area.

In addition to the Yangtze River drainage area and the Yellow River drainage area, western China have 8.0×10^5 hm^2 farmlands that have a slope more than 25^o, 16 thousand hm^2 terraces, and 3.1×10^5 hm^2 sloping farmlands not suitable for continuous farming any longer.

In western China, about 3.8×10^6 hm^2 sloping lands and terraces that have a slope more than 25^o and 1.9×10^6 hm^2 farmlands that have a slope between 15^o and 25^o are not suitable for farming, and 5.7×10^6 hm^2 farmlands that have a slope of 15^o should be returned to grasslands or forests step by step. These farmlands account for 40% of the total sloping farmlands that have a slope more than 15º in western China but maintain poor yield of less than 1.0×10^{10}kg per year, only 8% of the grain yield of western China, or 2% of the total grain yield of the whole China. Therefore, the return of these farmlands to forests or grasslands won't affect grain provision of China very much. Grain supply in China is relatively excessive at present, and return of farmlands to forests and grasslands will protect and improve the ecological environment, improve the fertility of these lands and other lands as well, and eventually improve grain yield. It is expected that 4.0×10^5-5.0×10^5 hm^2 can be returned in the near future. In case China government makes great efforts and takes effective measures, it is possible to return all sloping farmlands mentioned above to forests or grasslands in a short period of time.

3.3.4. Wetland ecosystems

Wetlands include swamps, peat bogs, wet meadows, lakes, rivers, flooded plains, river deltas, low beaches, coral reeves, mangroves, water reservoirs, ponds, paddy lands, and coastlines with water depth of less than 6 meters in time of low tide. In other words, wetlands can be regarded as ecosystems internally controlled by water over a long period of time (Yin and Ni, 1998). According to statistics on the basis of this definition, China has about 2.3×10^7-$2.5 \times 10^7 hm^2$ natural wetlands (Lu, 1990; She and Chen, 1997).

According to remote sensing data, the area of wetlands was 1.63×10^7 hectares in the 1980s, accounting for 2.43% of the total land area of western China; it increased to 1.66×10^7 hectares in the late 1990s, accounting for 2.47% of the total land area of western China. During the period from 1980s to 1990s, area of wetlands increased by 2.7×10^5 hectares.

3.3.4.1. Vegetation cover of wetland ecosystems

The most widely distributed wetland in western China is swamp, which plays an important role in wetland ecosystems in western China. There are various swamp vegetation types, mainly including various bryophytes, wool grass, thyme and sphagnum, kobresia humilis meadows and carex meadows; in the plain areas, there are reed, wild rice stem, bulrush, polygonum lapathifolium linn, star grass meadows, kikuyu grass meadows, and bluejoint meadows; in the lake areas, there are mainly hornwort, water weed and myriophyllum spicatum communities, duckweed and alga communities, wild lettuce and hydrocotylaceae communities, pottingeriaceae and pottingeriaceae natans communities, azolla imbricata and salvinia natans communities.

The forest swamps are mainly distributed in Daxing'anling area of Inner Mongolia and southwest China. In Daxing'anling area, there are mainly such forest swamps as Xing'an larch swamps, Taibai larch swamps, fir swamps, and alder swamps, while in southwest China, there are yew swamps and metasequoia swamps. Scrub swamp is also an important type of wetland in western China, and there are such types of scrub swamp as birch scrub swamps, willow scrub swamps, meadowsweet scrub swamps, caragana scrub swamps, arrow bamboo scrub swamps, baeckea scrub swamps, wide peony scrub swamps, thyme scrub swamps, and Indian azalea scrub swamps (China Wetland Vegetation Editorial Board, 1999).

In addition, there are mangrove swaps and sea grass communities in the coastal areas, and such salina as salty lakes in the western inlands.

3.3.4.2. Spatial distribution and ecological services of wetland ecosystems

In western China, the wetlands can be spatially divided into wetlands in northeastern Inner Mongolia, wetlands in northwestern arid area, wetlands in Qinghai-Tibet Plateau, and wetlands in coastal area (Figure 3.10). Northeastern Inner Mongolia wetlands, which are in the scope of western China, mainly refer to Daxing'anling wetlands, which, together with the surrounding Sanjiang Plain wetlands, Song-Nen Plain swamps, lakes, wet meadows as well as the wetlands widely distributed in Xiaoxing'anling and Changbai Mountain, provide the migratory birds with ideal food and shelters. These wetlands maintain flourishing brushwood and rich organic matters, and are very suitable for such water birds as red-crowned cranes, white-crowned cranes, white cranes, white storks, black storks, Chinese goosanders, snipes, gulls, gooses and ducks to live and breed. They are the water bird breeding center of Northwest Asia, and the inevitable course for water birds in North Asia to migrate southwards.

The wetlands in the northwestern arid areas are mostly inland or plateau wetlands, such as alpine meadow swamps and weed swamps with an elevation of 2500-5000m, as well as lakes including Bosten Lake and Sayrim Lake. Bayinbuluk Nature Reserve is right one of these wetlands, and is an important breeding place of big swans. Due to the outstanding natural conditions of the nature reserve as well as the natural habits of the water birds that migrate in a short distance or transversely, a lot of water birds such as black-neck cranes, big swans, bar-headed gooses, ruddy shelducks, black storks, brown-headed gulls, black-headed gulls, and redshanks live and breed in these wetlands in April and May each year. Tarim river drainage area is an important breeding place of black storks in China. The lakes in Mu Us Desert of Inner Mongolia support 40% relict gulls in the nature worldwide, and they are called Ordos community. Wuliangsu Sea in Hetao area is another important wetland in this drainage area. Due to poor stability, it is only important during the season when water birds migrate (Chen, 1998).

The wetland ecosystems in Yunnan-Guizhou Plateau are quite unique. There are both plateau lakes and wet meadows, which support a large number of migratory birds in winter. Napa Sea in the northwest of Yunnan, Qujing and Shaotong in northeast of Yunnan, and Cao Sea in the west of Guizhou are important places for the black-necked cranes to live through winter. In recent years, Dianchi lake of Kunming City has become a major place for black-headed gulls to live in winter.

Qinghai-Tibet Plateau wetlands are distributed in Tibet, Qinghai and the west of Sichuan, where there are low air temperature, little precipitation, but sufficient sunshine. With throngs of lakes, swamps, and wet meadows, these places are suitable for water birds to live. The Birds Island in Qinghai Lake is an important international wetland in the Plateau. In addition, Zhaling Lake, Eling Lake, and Namucuo Lake are of considerable importance. The northeast of Qinghai-Tibet Plateau, the place for black-necked cranes to breed, extends from Ruo'ergai in the northwest of Sichuan to Longbao Beach in Yushu of Qinghai, and approaches Qinghai Lake to the north. In Qinghai-Tibet Plateau, there are a great number of birds falling in few species, such as cormorants, bar-headed gooses, fish gulls, and brown-headed gulls.

The coastal wetlands in western China are distributed only in Beibu Bay sea area in Guangxi. Mangroves are the features of these wetlands, which are composed of estuaries of rivers, devious harbors, and a lot of islets close to the coastline. With climatic conditions completely different from those of the mainland, broad low beaches, a lot of shellfishes and water plants, the coastal wetlands draw a large number of seagulls, storks, egrets and ducks to live, breed and spend winter. They are the important posts to migratory birds, or places for them to live through winter.

3.4. Trend of land-use change

In the 1990s, remote sensing data were mainly used in comparative analysis of conditions and trend of land use change in China (Liu and Buhe, 2000; Liu, 1997). Of the lands surveyed by remote sensing (Liu et al., 2003a), cultivated lands (including paddy fields and dry lands) accounts for 18.94%, forest lands (including lands dominated by forests, scrub lands, thin forest lands and other woodlands) 23.61%, grasslands (including grasslands of high, medium and low coverage) 31.69%, water areas 2.87%, urban and rural areas, industrial and mining areas and residential areas 1.82%, and un-used lands 21.06% (Figure 3.7).

3.4.1. Characteristics of area change of land use in western China

Area of land use in Inner Mongolia changed the most by up to $5.23 \times 10^6 hm^2$, which was 25.53% of total changed area of land use in China. Area of land use in Xinjiang changed the second, and its changed area of land use accounted for 6.77% of the total. The changed area of land use in other provinces, municipalities and autonomous regions accounted for less than 2.77% of the total (Table 3.2).

In Sichuan Basin, the lands used for urban and rural construction increased apparently, and the lands used for this purpose were mainly high-quality cultivated lands. In the east of Inner Mongolia, forestlands and grasslands were brought under cultivation. In Loess Plateau and Qinling Mountain, grassland that is cultivated and farmlands returned back to forestlands and grasslands coexisted. In the mountainous areas surrounding Sichuan Basin, Guizhou and in the west of Yunnan, the woodlands decreased a lot. In the central part of Yunnan, return from farmlands to forestlands and grasslands and transformation from grasslands to woodlands were the major features. In the arid and agricultural oases in northwest China, partial lands on the edges of the oases were cultivated, while at the same time some previously cultivated parts inside the oases were wasted. In Qinghai-Tibet Plateau, the area of land use changed not much, and just water areas changed slightly.

Table 3.2. Characteristics of changed area of land use in western China during period from 1980 to 2000

(unit: hectare)

Province	Proportion to changed area of land use in China	Proportion to total land area of the province	Average size of dynamic pixels	Province	Proportion to changed area of land use in China	Proportion to total land area of the province	Average size of dynamic pixels
Inner Mongolia	25.53%	4.57%	146.58	Guangxi	1.52%	1.32%	92.99
Gansu	1.18%	0.60%	30.76	Sichuan	1.42%	0.60%	23.37
Qinghai	1.74%	0.50%	32.59	Chongqing	0.39%	0.96%	43.92
Ningxia	1.97%	7.81%	61.78	Guizhou	0.59%	0.69%	40.22
Xinjiang	6.77%	0.85%	42.48	Yunnan	2.77%	1.48%	85.36
Shaanxi	1.88%	1.87%	42.26	Tibet	0.09%	0.01%	47.68

3.4.2. Shrinkage and expansion of land use types in western China

Shrinkage of a land use type refers to the reduction of area of the previous land use type due to its transformation to other land use types. Expansion of a land use type is just opposite to the shrinkage. Since the total land area remains the same in a certain area, the shrinkage of one land use type means the corresponding expansion of the other. Therefore, the proportion of changed area of land use types in a province to the total changed area of land use types in the whole China can reflect the changes of the major land use types, and help figure out the major trend of the changes of land use (Liu et al., 1999).

Guizhou and Yunnan mainly saw the shrinkage of the scrub lands, which accounted for 21.45-43.68% of the total area of shrinked land use types; Inner Mongolia and Guangxi Zhuang Autonomous Region mainly saw the shrinkage of grasslands, and the proportion was about 23.90-34.38%; Chongqing and Gansu Province mainly saw the shrinkage of the grasslands of medium coverage, and the proportion was approximately 21.76-25.55%; Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region and Qinghai Province mainly saw the shrinkage of the grasslands of low coverage, and the proportion was 40.20-47.72%; only Shaanxi Province saw the shrinkage of sand lands, and the proportion was 36.33%.

Increase of dry lands was the main expansion of land use types. In those provinces that mainly saw the expansion of dry lands, such as Gansu Province, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region, and Inner Mongolia Autonomous Region, the area of expanded dry lands accounted for 21.67-50.68% of the total area of expanded lands in China; Guangxi Zhuang Autonomous Region mainly saw the expansion of lands dominated by woods; Chongqing mainly saw the expansion of scrub lands, and the proportion of area of expanded scrub lands to the total area of all expanded lands in China was 26.62%; only Yunnan Province saw the expansion of the grasslands in high coverage, and the proportion was 26.08%; Guizhou and Sichuan mainly saw the expansion of the grasslands in medium coverage, and the proportion was 21.44-34.68%; Shaanxi Province mainly saw the expansion of the grasslands in low coverage, and the proportion was 38.30%.

3.4.3. Changes of land use types in western China

From the end of 1980s to the end of 1990s (Figure 3.7; Table 3.3), the grasslands considerably declined in western China by up to $4.57\times10^4 km^2$. On the secondary classification of land use types, the grasslands in high, medium and low coverage all decreased. Forestlands also decreased by 3.45×10^3 km^2, and the decrease of forestlands was the result of balance between the decrease of lands dominated by woods and the increase of scrub lands, thin woodlands, and other woodlands. Farmlands, water areas, and lands for rural and urban construction, industrial and mining purpose as well as residential purpose increased. During the whole period of time, expansion of dry lands played the major role in changes of farmlands. The expansion reached up to 7.82×10^3 km^2, which accounted for 94.97% of the total expansion of farmlands. Paddy fields expanded by 4.10×10^2 km^2, which accounted for 5.03% of the total expansion of farmlands. Water areas also expanded slightly by 2.10×10^3 km^2. The lands for urban and rural construction, industrial and mining purpose and residential purpose increased by $3.23\times10^3 km^2$; the area of land for urban construction increased apparently by 1.63×103 km^2, accounting for 50.50% of the total area of increased lands for industrial and mining purpose and residential purpose; the area of lands for rural residential purpose increased by 1.37×10^3 km^2, accounting for 42.59% of the total area of increased lands for industrial and mining purpose and residential purpose; the area of lands for public communication construction increased by 2.23×10^2 km^2, accounting for 6.91% of the total area of increased lands for industrial and mining purpose and residential purpose. Un-used lands increased considerably. This is the result of the balance between the increase of sand lands, Gobi lands, swamps, naked lands, and naked stony lands and the decrease of saline-alkali lands and other un-used lands (Liu et al, 2002; Liu et al., 1999).

Table 3.3. Transformation between different land use types (hectare)

Land use type	Farmland	Forest land	Grassland	Water area	Building land	Unused land
Farmland	53692.19	130598.40	452656.36	37875.15	211733.34	61194.61
Forest land	378933.03	432253.13	481251.58	22314.58	67990.18	14147.77
Grassland	1833896.18	527432.29	1711569.28	149337.46	337523.93	832812.45
Water area	50081.07	15203.98	51579.29	133814.58	17334.57	80383.85
Biulding land	1033.36	22758.93	88253.24	9316.27	51193.55	12870.25
Unused land	127159.47	17978.89	558369.30	129765.69	36349.02	149444.29

From the 1980s to the end of the 20th century, the changes of land use in western China mainly embodied the decrease of grasslands and woodlands and the corresponding increase of farmlands, water areas, lands for rural and urban construction, and industrial, mining and residential purposes, and the un-used lands. The contradiction between the decrease of woodlands and grasslands and the increase of rural and urban construction, and industrial, mining and residential purposes led to the changes of land use pattern in western China in the late 1980s. Meanwhile, there existed great transformation from one land use type to another, particularly, the transformation from grasslands and woodlands to other lands. From the angle of transformation scale, the first ten transformations were successively the internal grassland transformation, the transformation from grassland to un-used land, the one from grassland to farmland, the one from un-used land to grassland, the one from grassland to woodland, the one from woodland to grassland, the one from farmland to grassland, the internal woodland transformation, and the transformation from farmland and grassland to lands for rural and urban construction, and industrial, mining and residential purposes (Liu et al., 2002b).

3.5. NPP and NEP change trend of terrestrial ecosystems in western China

The results from CEVSA model show that in period from 1981 to 2000, except that the NPP of the southeast of Tibet, Sichuan and Yunnan-Guizhou Area was high, the NPP of other areas was all below 200 g $C.m^2.a^{-1}$ (Figure 3.11). The NPP in western China averaged 1.63 Pg C. a^{-1} in twenty years, about 255 g $C.m^2.a^{-1}$, which was approximately 70% of the whole of China (363 g $C.m^2.a^{-1}$) that is simulated by CEVSA. As for NEP, western China was a carbon sink in the period from 1981 to 2000, and the total NEP in western China was approximately 0.83 Pg $C.a^{-1}$, accounting for 66% of the total in China. However, the average annual NEP in western China (0.041 Pg $C.a^{-1}$) was still lower than that of the whole China (0.0625 Pg $C.a^{-1}$).

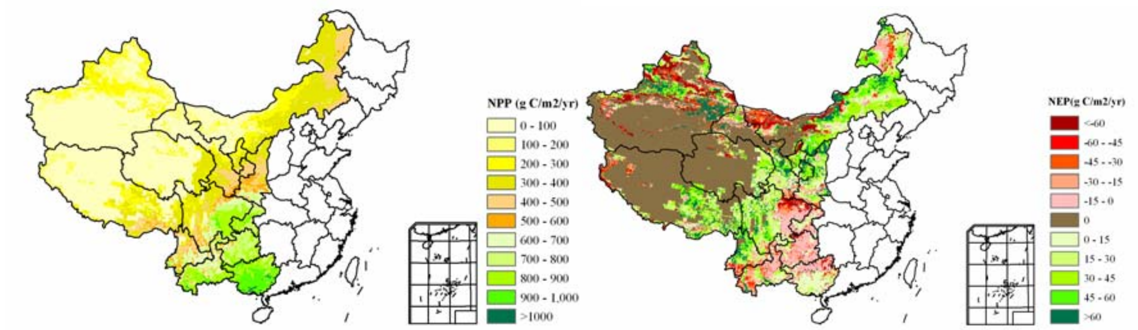

Figure 3.11. Spatial distribution of NPP (left map) and NEP (right map) during the period from 1981 to 2000

According to the average in the twenty years, it can be seen that carbon absorption mainly took place in the west of Southwest China, southeast of Tibet, Northeast China Plain, central and western parts of North China, and South China. Carbon release mainly took place on the southern edge of Sichuan Basin, Qin-Ba Mountainous Area (-45～-90 g $C/m^2/a$), Zhe-Min Hilly Area (-30～-45 g Cm^2/a), the northwest of Inner Mongolia, and partial areas of Xinjiang (less than -60 g $C/m^2/a$). The spatial pattern of NEP is closely related to the climate and the distribution of its corresponding NPP and HR. In the northern China, areas with high NEP are idential with areas with high NPP. However, the spatial pattern of NEP is not apparently related to HR. In Inner Mongolia, for instance, the correlation coefficient of the average annual NEP and NPP is up to 0.94 ($R<0.01$). In the past fifty years, it got apparently warmer and warmer in China. Particularly, in the past twenty years, the temperature rose by over 0.5℃ every ten years in North China, Northeast China and the central part of Northwest China, higher than the global average of 0.2℃ every ten years. Plus, the magnitude and scope of temperature rise in the 1990s was apparently higher or wider than those of the 1980s, and after the 1970s, the precipitation obviously decreased in some parts of Northwest China.

Generally, the past twenty years saw a relatively warm and dry period in China. As a result, the intensity of carbon absorption in terrestrial ecosystems was relatively low during this period, and the intensity of carbon absorption in western China was lower than the average of the whole China. In most parts of Loess Plateau and the northeast of Sichuan Basin, NPP dropped apparently (by about 10 g $C.m^2.a^{-1}.yr^2$); in the northeast of Inner Mongolia, NPP also dropped (by 2-6 g $C.m^2.a^{-2}$); in the southeast of

Tibet and Yunnan-Guizhou Area, NPP rose apparently. As for NEP, Loess Plateau is the carbon absorption area, but the precipitation apparently declined during the period. As a result, the past twenty years there was the most drastic drop of NEP in this area (Figure 3.12).

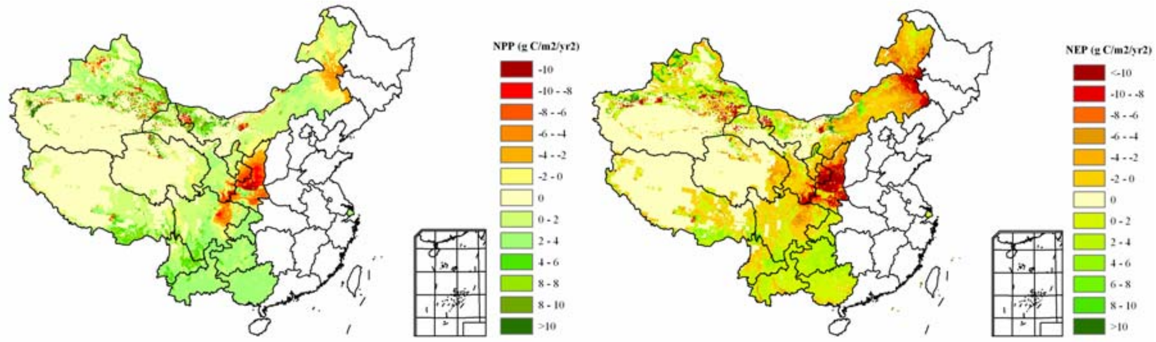

Figure 3.12. Change trend of NPP（left map）and NEP（right map）simulated by CEVSA

According to the 10-year anomaly sequences and changes of NPP and NEP in western China, NPP slightly increased in the period from 1981 to 2000 (Liu et al, 2003b), while NEP slightly decreased, which means the capability of carbon absorption declined. During the period from 1981 to 2000, there was the highest NPP in 1998, and NEP in 1998 was just next to that in 1993. In 1998, the precipitation in western China was higher than the average by 41mm.a^{-1}, and the average annual temperature was the highest in the period from 1981 to 2000. NEP and NPP are very sensitive to the change of precipitation and the impact of temperature rise on moisture utilization rate in western China.

3.6. Freshwater

The western region of China has a vast territory and apparent regional differences. In southwestern China, it is warm and rainy, and there is large area of rivers. Although area of southwestern China is only 26.48% of that of the whole China, its water resources account for 46.4% of those of the whole China. In northwestern China that is located in the center of the mainland, it is dry; 75% area is dry and semi-dry; there are few rivers; it is seriously short of water resources. Although area of northwestern China is 42.35% of that of the whole China, its water resources account for just 10% of that of the whole China (Qin, 2002).

3.6.1. Freshwater resources in northwestern China

3.6.1.1. Precipitation

The mean annual precipitation in northwestern China is 201mm, or $6.93\times10^{11}m^3$. In Yellow River area of northwestern China, mean annual precipitation is 422mm, or $2.56\times10^{11}m^3$. In the inland of northwestern China, mean annual precipitation is 145mm, or $3.66\times10^{11}m^3$; in the inland of Inner Mongolia Plateau, the multi-year precipitation average was 250mm, or $7.14\times10^{10}m^3$.

Seasonal snow accumulation is the important freshwater resource in the dry areas in northwestern China, and Xinjiang enjoys the richest snow resources in China. In winter, the average amount of snow accumulation (water equivalent) totals is up to $3.61\times10^{10}m^3$, including $2.12\times10^{10}m^3$ in North Xinjiang, $1.31\times10^{10}m^3$ in South Xinjiang, and $1.89\times10^{9}m^3$ in Qilianshan Mountainous Area (Qian, 2004).

3.6.1.2. River runoff

The river runoff in northwestern China is mainly composed of dissolved ice and snow, surface runoff, and supply of underground water. According to results of relevant scientific and technological projects under the Ninth Five-Year Plan as well as the Report on the Planning of Development and Utilization of Water Resources in northwestern China, the annual runoff in northwestern China (1956-1995) totaled

$1.44\times10^{11}m^3$, or 41.8mm deep. In Yellow River area of northwestern China, the annual runoff totaled $4.75\times10^{10}m^3$, or 75.5mm deep, accounting for 33% of the total of western China; in the inland river area of northwestern China, the annual runoff totaled $9.58\times10^{10}m^3$, or 38mm deep; in inland of Inner Mongolia Plateau, the annual runoff totaled $7.30\times10^{8}m^3$, or 3mm deep. The area of the inland rivers accounts for 67% of the total area of northwestern China.

The regional distribution of annual runoff is identical with that of precipitation in western China. The mountainous areas enjoy large runoff, and are supplied with water dissolved from ice and snow, so they are the major runoff cradles. Those areas with annual runoff of over 200mm include Altai Mountain, Tianshan Mountain, the south of Qinling in Shaanxi, and Qilian Mountain. Junggar Basin, Tarim Basin, and Qaidam Basin are areas with low runoff, and their annual runoff on the edges is less than 20mm, and disappears in the deserts in their centers.

3.6.1.3. Amount of underground water

The underground water is calculated by the amount of discharge in the mountainous areas, and by the amount of supplies in the plain areas. The underground water supplies to the surface water in the mountainous areas, and the surface water supplies to the underground water outside the mountain pass. Therefore, it is necessary to calculate the overlapped amount of water resulting from mutual transformation between surface water and underground water. The amount of underground water resources in northwestern China is $1.07\times10^{11}m^3$, including overlapped amount of $8.74\times10^{10}m^3$.

The amount of underground water resources in the Yellow River area of northwestern China is $3.26\times10^{10}m^3$, including overlapped amount of $2.68\times10^{10}m^3$. The amount of underground water resources in the inland of northwestern China is $6.95\times10^{10}m^3$, including the overlapped amount of $6.02\times10^{10}m^3$. The amount of underground water resources in inland of Inner Mongolia Plateau is $4.68\times10^{9}m^3$, including the overlapped amount of $4.22\times10^{8}m^3$, and the most underground water resources are supplied directly by precipitation in these inlands.

3.6.1.4. Gross amount of water resources and balance of water amount

In western China, the amount of precipitation totals $6.93\times10^{11}m^3$, or 201.1mm deep, to form river runoff of $1.44\times10^{11}m^3$, or 41.8mm deep; the amount of evaporation is $5.49\times10^{11}m^3$, or 159.3mm. In the whole region of western China, the amount of underground water resources totals $1.07\times10^{11}m^3$; the non-overlapped amount of underground water resources that can be obtained by the local vegetations in the form of evaporation is up to $1.93\times10^{10}m^3$, out of which $5.79\times10^{9}m^3$ are in the Yellow River area of northwestern China, $9.28\times10^{9}m^3$in the inland river area of northwestern China, and $4.26\times10^{9}m^3$ in inland of Inner Mongolia Plateau, accounting for 30%, 48% and 22% of the non-overlapped amount of underground water of northwestern China respectively.

3.6.2. Freshwater resources in southwestern China

There are rich surface water resources in southwestern China, namely, $1.27\times10^{12}m^3$, accounting for 83.7% of the total surface water resources in western China. The abundance of surface water resources in southwestern China results from a lot of precipitation. In southwestern China, the mean annual precipitation is 838.8mm, 30% higher than the average of the whole China. The precipitation is unevenly distributed. In the mountainous areas, it reaches 3000-5137mm, while in the east of Yunnan Plateau and Sichuan Basin, it is less than 900mm.

The amount of water resources is $4.48\times10^{11}m^3$. Tibet takes the first place in China. As for the average annual water generation modulus, Guangxi maintains the highest, namely, 8.17×10^5 m^2/km^2, and Tibet maintains the lowest, namely, 3.74×10^5 m^2/km^2; both are higher than the average of the whole China, which is 2.86×10^5 m^2/km^2. The amount of water resources just in the southwestern river drainage areas (exclusive of the upper streams of the Yangtze River and the Yellow River) is up to $5.85\times10^{11}m^3$, and the average annual water generation modulus is 6.88×10^5 m^2/km^2, including 1.48 m^2/km^2 and 1.25 m^2/km^2 respectively in West Yunnan and the river drainage areas of Tibet, which are one of the most moist areas with the most amount of water generation in China.

In southwestern China, the precipitation is relatively sufficient, and the water resources are relatively rich. The major water systems belong to the Yangtze River drainage area, the Pearl River drainage area, the drainage areas of the four international rivers, as well as the inland Qiangtang River drainage area in North Tibet. The mean annual precipitation during the period from 1956 to 1979 is $1.10\times10^{12}m^3$. Deducting the annual flux from Qinghai to Jinshajiang River, which is $1.15\times10^{10}m^3$, the mean annual water generation is $1.08\times10^{12}m^3$ (Zhang and Lu, 2002).

3.7. Food

3.7.1. Food provisioning service of farmland ecosystems in western China

Western China has a vast territory, but few farmlands. Its area accounts for 71% of the total area of China, but the gross area of its farmlands is $6.68\times10^5km^2$, accounting for only 37% of the total in China. The paddy fields are mainly distributed in the southwestern provinces, particularly, in Sichuan Basin. The dry lands are mainly distributed in the east of western China, such as Inner Mongolia, Sichuan, and Shaanxi.

The grain supply capability of western China is $3.23\times10^{12}t$. Further, the stalk resources that can be used as feedstuffs in western China can result in a supply of 4.44×10^6 t of meat (mutton) to people. In the aggregate, people can get $1.14\times10^{15}m^3$calories, protein of 3.19×10^7t, and fat of 9.97×10^6t from the nutritious substances mentioned hereinabove.

Huge differences exist between different regions in the capability of food provision in western China (Figure 3.13). By the potential of gross output of grains, Sichuan, Guangxi, Yunnan, Guizhou, Shaanxi, Inner Mongolia and Chongqing have the highest potential, and their provision capabilities are all above 2.0×10^7t. Sichuan Province maintains the highest potential, which is 7.88×10^7t, accounting for one fourth of that of the whole western region of China. The total food potential of the seven provinces amounts to $2.93\times10^{12}t$ which accounts for 95.27% of western China. The total potential of grain supply of Tibet, Qinghai, Gansu, Ningxia and Xinjiang is less than 5% of that of the whole western China. Grain supply in western China is mainly from southwestern China. On the one hand, the farmlands are mainly in southwestern China, and on the other hand, southwestern China have good water and heat conditions, which result in much higher yield of grains than that of northwestern China. The average grain yield per hectare is all above 10t in Guangxi, Chongqing, Sichuan, Guizhou and Yunnan. Guangxi maintains the highest yield of grains, namely, 17.89t. However, the yield of grains is less than 5t/hectare in other places of western China (except for Shaanxi). Guangxi maintains the highest potential coefficient of 3.9, and Yunnan maintains 3.3. Due to much fog and insufficient sunshine, Chongqing, Sichuan and Guizhou maintain lower potential coefficient than Yunnan and Guangxi. Other provinces and autonomous regions except for Shaanxi and Gansu all maintain a coefficient of 2 or less.

Compared with the whole China, or East China, or Central China, western China have lower gross and unit output of grains. Its gross output of grains accounts for only 27.33% of the total in China, and its unit output of grains is 7.75×10^3 kg/hectare. However, the unit output of Central China, East China, and the whole China is 9.99 thousand kg/hectare, 11.99×10^3 kg/hectare, and 9.76×10^3 kg/hectare respectively. This is mainly because the general natural conditions in western China are not as good as those in Central and Eastern China.

3.7.2. Food provisioning service of grassland ecosystems in western China

Western China has 2.78×10^6 km^2 grasslands, which is 92.67% of the total in China. 8.74×10^5 km^2 grasslands are in high coverage, 1.01×10^6 km^2 grasslands are in medium coverage, and 8.98×10^5 km^2 grasslands are in low coverage. The grasslands are mainly distributed in the east of Inner Mongolia, Qinghai-Tibet Plateau, and Xinjiang.

The assessment results (Figure 3.13) indicate that the grasslands in different coverage in western China maintain greatly different production capabilities. The climatic productivity of the grasslands in high, medium and low coverage is 9.82×10^3kg/(hm^2.a), 4.16×10^3kg/(hm^2.a) and 936kg/(hm^2.a) respectively; the soil productivity of the three types of grassland is 4.57×10^3kg/(hm^2.a), 1.96×10^3kg/(hm^2.a) and 421kg/(hm^2.a) respectively. It can be seen that the capability value of the grasslands in high coverage is over ten times of that of grasslands in low coverage. The integrated productivity of the three types of grassland in western China is 2.05×10^3kg/(hm^2.a), and the unit productivity of Guangxi and Yunnan is much higher than that of other places. Guangxi maintains 9.95×10^3kg/(hm^2.a) and Yunnan maintains 8.62×10^3kg/(hm^2.a). Guizhou and Chongqing take the third and fourth places and maintain the unit productivity of 4.60×10^3kg/(hm^2.a), less than half of that of Guangxi. Xinjiang maintains the lowest unit productivity of only 769 kg/(hm^2.a).

The assessment also indicates that the grasslands in western China can produce 5.70×10^{12}t hay per year; the theoretic carrying capability is 4.49×10^{12} standard sheep units; they can provide 1.5×10^7 t of meats, including 3.68×10^{13} calories, 1.82×10^6t of protein, and 3.23×10^6t of fat. Compared with Central China and East China, western China has very low productivity. However, due to its vast area of grasslands, western China still maintain exciting food provisioning services, which account for 85.05% of the total of the whole China. Inner Mongolia, Tibet, Yunnan and Sichuan maintain the highest capabilities, and can provide meats of 3.68×10^6t, 3.06×10^6t, 1.98×10^6t and 1.76×10^6t respectively. Total meat provisioned by grasslands in western China is 10.48 tons, which accounts for 68.57% of the total of the whole China. In terms of regional distribution, the food provisioning capability of the grasslands in western China is mainly distributed in the east of Inner Mongolia, the east of Qinghai-Tibet Plateau (including the north and west of Sichuan, and the southeast of Tibet), and the east and west of Yunnan. The north of Qinghai-Tibet Plateau, Xinjiang and the east and west of Inner Mongolia have large areas of grasslands, but maintain low production capabilities, so they don't have much sufficient food provisioning services.

3.7.3. Food provisioning service of forestland ecosystems in western China

Western China has 1.11×10^6 km^2 forestlands, which is 49.60% of the total area of the forestlands nationwide. 5.39×10^5 km^2 are lands dominated by forests, 3.49×10^5 km^2 are scrublands, 2.01×10^5 km^2 are thin forestlands, and 1.69×10^5 km^2 are other types of forestlands, accounting for 48.75%, 31.55%, 18.18% and 1.52% respectively. These forestlands are mainly distributed in the northeast of Inner Mongolia, the southeast of Tibet, the west of Sichuan, the north of Guangxi, Yunnan, and Guizhou.

The assessment results indicate that the forestlands in western China can supply meats of 8.69×10^5 t, feedstuffs of 8.68×10^7 t, vegetables of 9.42 $\times10^6$ t, oils of 3.59×10^6 t, and grains of 1.20×10^{12}t, which respectively account for 46.97%, 50.74%, 37.60%, 17.60%, and 25.15% of the total in China. In the aggregate, all the foodstuffs can provide 6.53×10^{13} calories, 1.45×10^6t protein, 2.21×10^6t fat, which respectively account for 28.25%, 33.72% and 27.03% of the total in China.

In terms of regional distribution, forestland meats are mainly from Yunnan, Guangxi, Sichuan, Inner Mongolia, and Tibet, which all maintain a capability of over 1.0×10^5t. Yunnan maintains the highest capability of 1.97×10^5t. Forest feedstuffs are mainly from Yunnan, Guangxi and Sichuan, which respectively provide 2.11×10^7t, 1.51×10^7t, and 1.25×10^7t. Forest vegetables are mainly from Yunnan, Guangxi, Sichuan and Tibet, which respectively provide 2.28×10^6t, 1.74×10^6t, 1.31×10^6t, and 1.06×10^6t. Forest oils are mainly from Guangxi, which provides 2.50×10^6t, 69.75% of the total of western China. Forest oils are also from Inner Mongolia, Guizhou, Sichuan and Yunnan. Forest grains are mainly from Guangxi, Sichuan, Yunnan, Guizhou and Shaanxi, which provide 3.34×10^7t, 3.02×10^7t, 1.57×10^7t, 1.5×10^7t, and 1.08×10^7t respectively.

3.7.4. Food provisioning service of aquatic ecosystems in western China

There are over 600 kinds of freshwater fishes in western China, where the local heat and light resources are rich and favorable for fishes and aquatic lives to grow. In 2000, there was a total water area of 1.67×10^5km^2 (exclusive of paddy fields suitable for breeding) in western China, which accounts for 62% of the total water area in China. Unfortunately, most water areas are not fully used in western China. Since western China is in the upper streams of most rivers, the water is rarely polluted and suitable for breeding fishes.

3.7.4.1. Fish productivity of paddy fields

In western China, there are 2.34×10^4km^2 paddy fields suitable for fish farming, 93% of which are in the southwestern provinces, particularly, in Sichuan Basin and the basins of various sizes in Guangxi. In northwestern China, the paddy fields suitable for fish farming are mostly close to rivers, such as Hetao Plain of Ningxia. According to MAWEC assessment results, the paddy fields in western China maintain a fish farming capability of 4.08×10^6t, 25.05% of the fish farming capability of the whole China. Sichuan, Guangxi and Chongqing in southwestern China maintain the highest capabilities, to be more exact, 2.10×10^6t, 9.95×10^5t, and 4.43×10^5t respectively, which total 3.54×10^6 t, 86.73% of that of western China. Sichuan Province's fish productivity of paddy fields accounts for 51.47% of that in western China.

3.7.4.2. Fish provisioning service of pools, ponds, and water reservoirs

In western China, there are 6.38×10^3 km^2 pools, ponds and water reservoirs, which are mostly distributed in Guangxi and Sichuan. According to MAWEC assessment, the fish provisioning capability of the pools, ponds and water reservoirs in western China is up to 1.91×10^6t, 12.54% of the fish productivity of the pools, ponds and water reservoirs in the whole country. Guangxi, Sichuan, Yunnan, Xinjiang and Chongqing maintain the highest capabilities, to be more exact, 7.01×10^6t, 3.84×10^5t, 2.16×10^5t, 1.46×10^5t and 1.20×10^5t respectively, which account for 36.65%, 20.09%, 11.28%, 7.64% and 6.26% of that of western China.

3.7.4.3. Fish provisioning service of lakes

In western China, there are a lot of lakes, which unfortunately maintain poor fish productivity. Although area of the lakes is up to 5.28×10^4 km^2, accounting for 70% of that in China, the fish productivity is only 8.19×10^5 t, less than 17% of that of the whole China. The major reasons include location of the lakes in Qinghai-Tibet Plateau, where the water temperature is too low, and the nutrients are insufficient. In terms of regional distribution of fish productivity of the lakes in western China, Yunnan, Tibet, Inner Mongolia, and Qinghai maintain a fish productivity of over 1.0×10^5t, to be more exact, 2.59×10^5t, 1.66×10^5t, 1.21×10^5t and 1.06×10^5 t respectively, which total 6.52×10^5t, 79.66% of that of western China.

3.7.4.4. Fish productivity of rivers and channels

In western China, there are 1.48×10^4 km^2 rivers, which maintain a fish productivity of 3.29×10^5 t, 15.72% of that of the whole China. Guangxi and Sichuan maintain the major fish productivity of rivers and channels, and their joint capability is up to 1.86×10^6 t, accounting for 56.47% of that of western China.

3.7.4.5. Total fish provisioning services of the inland water bodies in western China

In western China, the fish productivity of the four kinds of water bodies above totals 7.14×10^6 t, which equal 9.42×10^4 t calories, 1.34×10^6 t protein, and 4.01×10^5 t fat, and accounts for 18.49% of that of the whole China. Sichuan, Guangxi, Yunnan, and Chongqing maintain a fish productivity of over 5.0×10^5 t, to be more exact, 2.62×10^6 t, 1.79×10^6 t, 7.15×10^5 t, and 5.88×10^5 t respectively, which are 36.68%, 25.09%, 10.02% and 8.23% of that of western China, and totally 5.71×10^6 t, accounting for 80.02% of that of the whole western China. In terms of geographic distribution (Figure 3.13), Sichuan Basin and Guangxi Basin play the major role, and that is mainly because the fish productivity of paddy fields in the two basins accounts for a high proportion.

3.7.5. Total food provisioning capacity in western China

According to summarization of a food provisioning capability of the major terrestrial ecosystems in western China by nutrients (Table 3.4), the quantity of heat of foods provisioned by western China totals 1.25×10^{15} calories, and the quantity of heat from farmland, forestland, grassland and aquatic ecosystems respectively accounts for 91.06%, 5.23%, 2.96% and 0.76% of the total in western China; the protein provision of the terrestrial ecosystems in western China totals 3.65×10^7t, and the four ecosystems' protein respectively accounts for 87.38%, 3.96%, 4.98% and 3.68% of the total; the fat provision of the terrestrial ecosystems in western China totals 1.58×10^7t, and the one from the four ecosystems respectively accounts for 63.03%, 14.02%, 20.40% and 2.57% of the total. Generally, the provision capability of various nutrients in western China accounts for low proportion to the total of the whole China, to be more exact, 27.87% for quantity of heat, 28.03% for protein, and 31.36% for fat.

Table 3.4. Food provisioning service of major terrestrial ecosystems in western China

Region	Heat (trillion calorie)					Protein (thousand ton)					Fat (thousand ton)				
	total	farm-land	forest land	grass-land	water body	total	farm-land	forest land	grass-land	water body	total	farm land	forest land	grass-land	water body
Inner Mongolia	98.4	86.4	2.9	8.9	0.3	3013	2432	100	438	43	1767	785	193	776	13
Guangxi	230.8	209.9	17.1	1.4	2.4	6657	5886	365	69	337	2900	1812	863	123	102
Chongqing	86.0	81.3	3.6	0.3	0.8	2488	2282	79	16	111	824	709	53	29	34
Sichuan	298.3	277.5	13.0	4.3	3.5	8775	7789	284	210	492	3222	2418	282	372	149
Guizhou	115.5	107.1	7.1	0.9	0.3	3258	3005	160	46	47	1230	933	202	81	14
Yunnnan	188.1	170.5	11.9	4.8	0.9	5406	4783	253	236	135	2270	1480	331	419	41
Tibet	13.2	3.7	1.9	7.4	0.2	583	103	83	364	33	809	33	122	645	10
Shaanxi	107.1	99.1	5.8	1.9	0.4	2995	2784	68	91	52	1137	874	86	162	16
Gansu	53.2	50.4	0.7	2.0	0.1	1554	1420	26	98	11	679	455	47	174	3
Qinghai	7.3	4.3	0.2	2.7	0.2	285	122	8	131	23	292	40	12	233	7
Ningxia	15.7	15.4	0.0	0.2	0.1	455	433	1	9	12	161	139	2	17	4
Xinjiang	34.8	31.2	1.1	2.2	0.3	1059	880	21	111	47	528	293	25	196	14
Western China	1248.4	1136.8	65.3	37.0	9.5	36528	31919	1448	1819	1343	15819	9971	2218	3227	407

In terms of regional distribution, the quantity of heat mainly comes from Sichuan, Guangxi, Yunnan, Guizhou and Shaanxi, which respectively supply 2.98×10^{14} calories, 2.31×10^{14} calories, 1.88×10^{14} calories, 1.16×10^{14} calories and 1.07×10^{14} calories respectively. Qinghai and Tibet supply the least, to be more exact, 1.32×10^{13} calories and 7.3×10^{12} calories respectively, far below that of Sichuan and Guangxi. Protein mainly comes from Sichuan, Guangxi, Yunnan, Guizhou and Inner Mongolia, which respectively supply 8.78×10^6t, 6.66×10^6t, 5.41×10^6t, 3.26×10^6t and 3.01×10^6t. Ningxia and Qinghai supply the least, to be more exact, 4.55×10^5 t and 2.85×10^5 t. Fat mainly comes from Sichuan, Guangxi, Yunnan, Inner Mongolia, Guizhou and Shaanxi, which respectively supply 3.22×10^6t, 2.90×10^6t, 2.27×10^6t, 1.77×10^6t, 1.23×10^6t and 1.14×10^6t. Qinghai and Ningxia supply the least, to be more exact, 2.92×10^5t and 1.61×10^5t respectively.

3.8. Sustainable population carrying capacity of the ecosystems in western China

3.8.1. Change trend of population distribution

In 1935, a critical line (Figure 3.14), of which two end points are Heihe city in Heilongjiang province and Tengchong city in Yunnan province, was introduced in a study on distribution of population in China (Hu, 1935). This Heihe-Tengchong line is located in the ecologically fragile zone where southeastern monsoon meets with westerlies. The area on the northwestern side of the Heihe-Tengchong line includes Qinghai province, Xizang autonomous region, Gansu province, Ningxia Hui autonomous region, and Xinjiang Uygur autonomous region. The area is about 5.25×10^6 km^2 and accounts for 54.9% of total area of China. An analysis combining relative research results (Hu, 1935, 1983; Zhang, 1997) with our simulation result shows that the ratio of population on the northwestern side of the Heihe-Tengchong line to total population of China was 3.3% in 1933, 4.9% in 1953, 6.1% in 1982, 6.2% in 1990, and 6.5% in 2000. The ratio has been increasing since 1930s.

It seems that population distribution in China has a slanting trend from the southeastern side to the northwestern side of the Heihe-Tengchong line since 1930s. Five causes can be found: ①in 1930s and 1940s, China-Japan war and China civil war led a large number of death and migration of inhabitants on the southeastern side of the Heihe-Tengchong line; ②in 1950s, the newly established government of China organized a series of massive immigration to bring wasteland under cultivation in the western region of China, such as production and construction corps in Xinjiang Uygur autonomous region, and immigration and reclamation bureau in Qinghai province; ③in 1960s, a large number of factories, scientific research institutions, colleges and universities were removed from eastern coast to western region; especially, about 1.7×10^7 middle-school students in cities were sent to rural areas for accepting peasant education and most of them came to western region of China; ④since 1970s, birth control policy, only one child for one couple, was carried out in China, which was rigorously implemented in eastern region and loosely in western region; ⑤in recent years, implementation of the western development strategy and massive construction of infrastructures in the western region of China have contributed to the increase of the ratio of population on the northwestern side of the Heihe-Tengchong line to total population of China.

In terms of the provincially mean values, Shanghai, Tianjin and Beijing have the highest densities that are respectively 2089, 861 and 843 persons/km^2 in 2000. Jiangsu, Shandong and Henan have higher densities that are respectively 7.20×10^5 and 559 persons/km^2. The mean densities of Hunan, Hubei, Hebei, Chongqing, Anhui, Zhejiang and Guangdong range between 304 and 481 persons/km^2. The lowest densities appear in Tibet, Qinghai, Xinjiang and Inner Mongolia. In general, the average population density of eastern China and middle China are respectively 7.4 times and 5.7 times the one of western China in 2000.

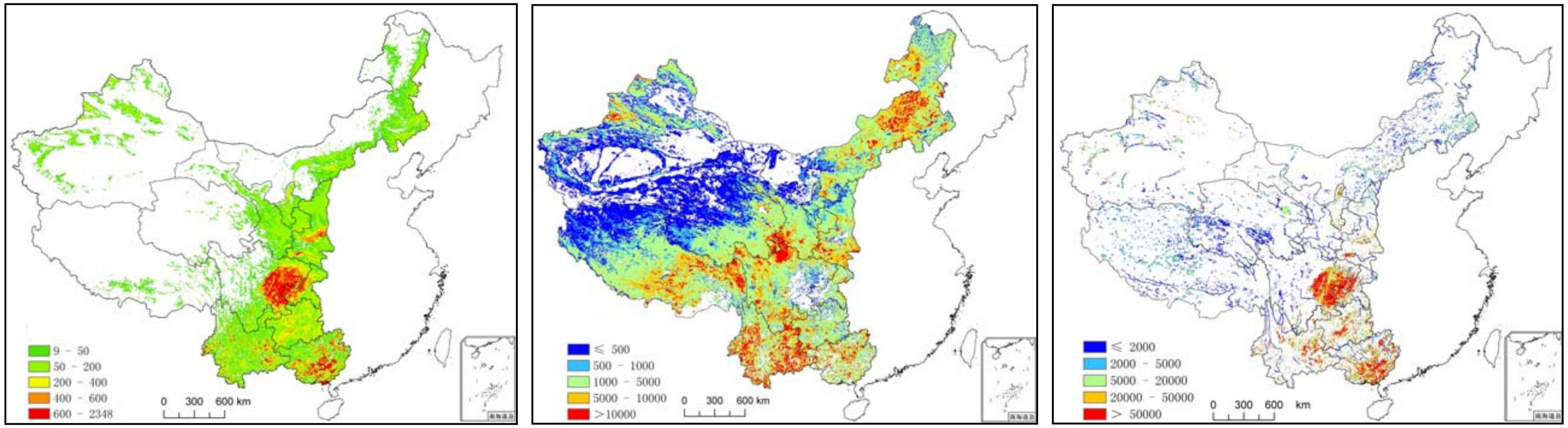

Figure 3.13. Ecosystem food provision services in the west region of China

(left map: farmland ecosystem (t/km^2); middle map: grassland ecosystem (kg mutton/ km^2); right map: water ecosystem (kg fish/ km^2))

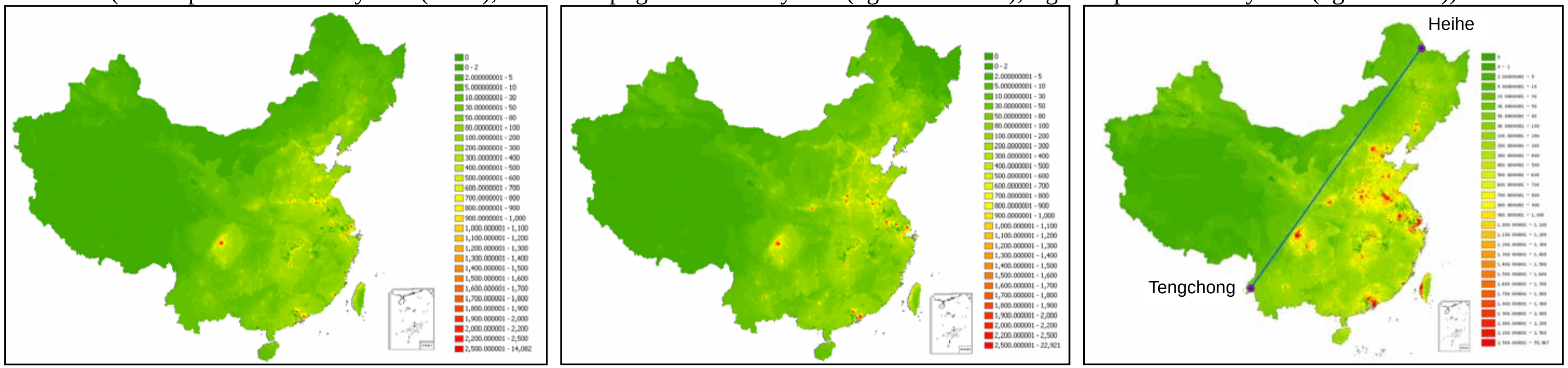

Figure 3.14. Trend of spatial distribution change of population in China

(left map: in 1930; middle map: in 1949; right map: in 2000)(unit: person/km^2)

3.8.2. Regional analysis of population carrying capacity

According to the population carrying capacity model under balanced nutrition, the ecosystems in western China can support 6.52×10^8 people on the well-off living standard. Sichuan, Guangxi, Yunnan, Inner Mongolia, Guizhou, Shaanxi and Chongqing maintain the highest population carrying capacity, to be more exact, 1.49×10^8, 1.19×10^8, 9.6×10^7, 5.9×10^7, 5.6×10^7, 5.2×10^7 and 4.1×10^7 respectively. These seven provinces can share 87.94% of the total population carrying capacity of western China. Ningxia and Qinghai maintain the lowest capacity, to be more exact, 7.54×10^6 and 7.01×10^6 respectively.

In terms of population carrying capacity on the average (Figure 3.15), Sichuan Basin and the basins in the central and southern parts of Guangxi can support over 1200 persons/km^2; the mountainous areas surrounding Sichuan Basin, Yunnan, Guizhou, the north of Guangxi, Shaanxi, the east of Gansu, Ningxia, Xinjiang and the east of Inner Mongolia maintain an average population carrying capacity of 100-1200 persons/km^2; the southeast of Qinghai-Tibet Plateau and most part of the east of Inner Mongolia maintain a population carrying capacity of 5-100 persons/km^2; the northwest of Qinghai-Tibet Plateau, the south of Xinjiang, the Northwest of Gansu and the west of Inner Mongolia maintain a population carrying capacity of less than 5 persons/km^2. In terms of the average population carrying capacity of the provincial region, Chongqing and Guangxi maintain a population carrying capacity of over 500 persons/km^2; Sichuan and Guizhou maintains a population carrying capacity of 300-500 persons/km^2; Yunnan, Shaanxi, and Ningxia maintain a capacity of 150-300 persons/km^2; Xinjiang, Qinghai and Tibet maintain a capacity of less than 50 persons/km^2.

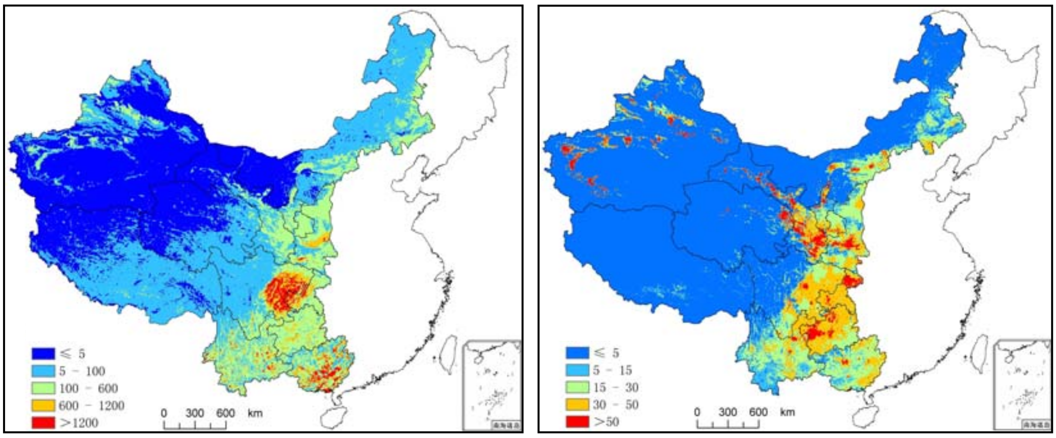

Figure 3.15. left map: ecosystem carrying capacity in the west region of China under well-off living standard (person/ km²); right map: population pressure in the western region of China

According to the ecological threshold model, the sustainable population carrying capacity of the ecosystems in western China ranges from 1.38×10^8 to 5.15×10^8 persons (Table 3.5). According to the population statistics of 2003 (State Statistics Bureau, 2004), the population of western China totaled 3.69×10^8, which is in the range of the sustainable population carrying capacity of western China. That is to say, western China still have great potential of population carrying capacity, although some individual places in western China suffer from overload of population.

3.8.3. Population pressure of the terrestrial ecosystems in western China

The population pressure index of western China is a geometric average of the percentages of population's demand for various nutrients to the provisioning capacity of ecosystems. The assessment results (Figure 3.15) show that the average population pressure index of western China is 8.93, much lower than 21.43 of the central China, 35.61 of the eastern China, and the average of the whole China, namely, 14.09. On provincial level, it can be seen that Chongqing and Guizhou suffer the highest population pressure, and their population pressure indexes are 27.80 and 25.15 respectively; Shaanxi, Ningxia, Guangxi, Yunnan, Gansu, and Sichuan suffer the second highest population pressure, and their indexes vary from 10 to 20; Inner Mongolia, Xinjiang, Qinghai, and Tibet suffer from the lowest population pressure, and their indexes are lower than 10. In terms of geographic distribution, most farmlands of Xinjiang, the east of Qinghai, Hexi Corridor of Gansu, the south of Gansu, the central part of Shaanxi, the Three Gorges area in the east of Chongqing, and the west of Guizhou suffer from the highest population pressure, and their population pressure indexes are bigger than 50; the population pressure index is greater than 15 in the east of Qinghai-Tibet Plateau, Shaanxi, Ningxia, the south of Gansu, and the central and southern parts of Inner Mongolia maintain; the population pressure index in other areas in western China is less than 5 (Table 3.5).

Table 3.5. Population carrying capacity and population pressure of terrestrial ecosystems in western China under well-off living standard

Region	Population in 2003	Range of sustainable population carrying capacity（million persons）	Population pressure index(%)
Inner Mogolia	2380	[12.39，46.33]	4.35
Guangxi	4857	[25.18，94.17]	17.18
Chongqing	3130	[8.72，32.61]	27.80
Sichuan	8700	[31.52，117.87]	10.57
Guizhou	3870	[11.9，44.49]	25.15
Yunnnan	4376	[20.32，75.97]	13.46
Tibet	270	[3.59，13.44]	0.26
Shaanxi	3690	[10.99，41.09]	19.31
Gansu	2603	[5.79，21.66]	12.90
Qinghai	534	[1.48，5.53]	1.94
Ningxia	580	[1.59，5.95]	17.82
Xinjiang	1934	[4.14，15.47]	3.42
Western China	36924	[137.62，514.59]	8.93

Western China has a vast territory, and extremely complex geographical pattern (Xi and Zhang, 2001). The natural eco-environment of northwestern China are featured by rich light and heat resources, long sunshine time, rare precipitation, dry climate, shortage of water resources, uneven temporal and spatial distribution of water resources, sparse vegetation, widely distributed deserts, physically underdeveloped soil, and high salt content in the soil. Over-cultivation of the sloping lands have caused damages to the vegetations, loss of surface soil, declination of farmland quality, and desertification of lands by 2640km^2 per year (Research Institute of Land Development and Regional Economy, 2003). In southwestern China, particularly, in territories of nationalities and poverty-stricken areas, the hostile living environment is the major factor that has affected the living and development of the local people. Overuse of natural forest resources and over-cultivation of sloping lands in the upper reaches of the Yangtze River have resulted in frequent big flood, aridity, rainstorm, landslide, mud-rock flow, rock fall, and other natural disasters. A lot of species face desperate situation or even extinct. According to simulation results of spatial population distribution (Yue et al, 2003a, 2005a, 2005b), the population of western China was 1.11×10^8 in 1930, and 1.75×10^8 in 1950, and it increased by 6.4×10^7; the population of western China was 3.55×10^8 in 2000, and it increased by 1.80×10^8 than that of 1950. The population of western China of our country has been increasing quickly, which intensifies the pressures on ecosystem services such as freshwater, food, and biodiversity. As a result of the quick population growth, the previously weak ecosystems have been further damaged, and the carrying capacity of the lands has dropped sharply.

4. Ecosystem services and human wellbeing in western China

Almost all of terrestrial ecosystem types are covered in western China, including forest ecosystem, grassland ecosystem, wetlands ecosystem, lake (river) ecosystem, desert ecosystem, frozen earth ecosystem, glacier/rock ecosystem, agricultural ecosystem and urban ecosystem, of which forest ecosystem, grassland ecosystem and agricultural ecosystem affected seriously by human activities take up a wide range of the area and are the typical ecosystems in western China.

For analyzing the conflicts of those ecosystems in typical regions of western China, the following three aspects should be considered: The first is to identify typical ecosystems in the research regions, analyze their structures and functions systematically, and then evaluate the ecological quality of all these ecosystems; The second is to ensure the types of ecosystem services, analyze the relationships and conflicts between them and calculate the ecosystem service values; The last one is to put forward the best ecosystem service mode which has maximum ecosystem service value. Sangong River valley in Xinjiang, Hunshandake sandlot in south central of Inner Mongolia, dam system of Qingyang city in Gansu province and Suomo River valley in the upper Yangtze River were discussed in this paper in order to analyze the present conditions and development trends of different ecosystems under the policy of western development, so as to provide scientific comments and proposals for the local governments.

4.1. Main conflicts among resources and ecosystems in the process of ecological construction in western China

4.1.1. Conflicts between the developments of primary forestry production and animal husbandry and the aggravating vegetation deterioration.

As a source of providing important raw materials for human lives, forest plays a significant role in human survival and development with the functions of oxygen making, wind prevention and sand fixation, water storage and farmland protection, ecological environmental improvement, etc. The forest coverage rate in western China is 9.98% that is 6.67 points lowers than the average of China. Among those western cities, forest coverage rate in Qinghai province is 0.3%, Xinjiang reaches to 0.79%, Ningxia Hui Autonomous Region reaches to 1.45% and in Gansu province the rate is 4.33%. From 1949 to 1984, the wooded area in Xinjiang decreased by 5.5×10^3 hm^2 because of provision of forest outputs from primary forestry production. The forest coverage rate of the upper Min River in Sichuan has decreased from 30% to 18% since the 1950's.

Western China is the main grass region that covers 84.4% of the total grassland area of the country. However, due to pursuit of short-term economic interests, the phenomena of overgrazing and overloading in western provinces cause pasture degeneration and quality reduction. At the same time, the species of beneficial plants drop heavily while the contaminated plants grow quickly. Up to now, the degraded pastures have reached to 3.31×10^6 km^2 occupying 23% of the available grasslands in western China.

4.1.2. Conflicts between industrial, agricultural and domestic water consumption and shortage of water resource.

Gross amount of water resource in western China is 1.5×10^{12} m^3 that covers 55.66% of the total water quantity in China. Water resource distribution in western China is uneven, which is more in the south and less in the north. Northwestern China is one of the most water-deficient areas in the world. It is dry with an average rainfall of 235 mm while evaporation reaches to 1000-2600 mm. Population increased sharply to 2.4×10^8 which is 1.6 times of 9.36×10^7 in 1949 in southwestern China, water quantity in the northwestern China occupies 82% of the total in the Western, but the per-capita farmland reduced from $1441m^2$ to 560

m^2. Human and nature can't keep harmonious relationship in this region because they all need much water for survival. In addition, this region gets low development on water resources development and utilization because water can't flow upwards against the particular physiognomy. In this water-deficient area, the per-capita irrigated area only amounts to 240m^2 and 56% of the lands are currently in water scarce irrigation.

4.1.3. Conflicts between rapid economic growth and spread of desertification

Most of the vegetation in western China is suffering from the severe destruction by rapid economic development and various irrational human activities; consequently the area of desertification is enlarging continuously, and become serious and harmful. The phenomenon of soil desertification in the west is characterized by saltification, desertification and stone-desert. Soil saltification and desertification mainly happened in the northwestern region, and stone-desert mainly appeared in the southwestern region. At present, soil saltification, desertification and stone-desert are still extending. The subduing area of rough lands in the west was added up to 2.43×10^7 hm^2 from 1949 to 1998, and the subduing area of saltification amounted to 6.13×10^5 hm^2. Agricultural and pastoral areas were the most degraded regions being affected mostly by agriculture.

4.1.4. The aggravation of soil and water erosion

The area of soil and water loss amounts to 1.05×10^6 km^2 and the ratio of soil and water erosion is 15.15% that shares 58.01% of the country. Silt that flows into the Yellow River and the Yangtze Rive owing to soil and water erosion amounts to more than 3×10^9 t, and 70% of these come from the western region. Soil erosion at the upper Yangtze reaches to 1.5×10^9 t in which 5×10^8 t into trunk streams and 1×10^9 t into branches; consequently the coarse sand and gravel which fill up the branch channel and the reservoir reduce the flood discharging ability of the channels.

4.1.5. Conflicts between wetland reclamation and protection

Wetlands especially natural wetlands have a lot of ecological functions such as impoundment, climate adjustment, soil and water conservation, water purification and biodiversity protection. There are many natural wetlands in western China. The areas of these wetlands shrink increasingly because of human doings such as reclamations.

4.1.6. Conflicts between intensive human exploitations and frequent disasters

Water resources suffer heavy losses due to vegetation deterioration. Drought occurrence in the west increased by 7.5% from the 1980s to the 1990s. Forest degradation and sedimentation were the basic reasons for inundation. Flood occurrence increased by 49% from the 1980s to the 1990s.

Slipstream, coal seam self combustion and surface subsidence are the main geologic hazards. Geologic hazards occur commonly and seriously in the west. Human activities such as mineral resources development, water table decrease, slope cultivation and construction activities without taking into consideration of soil erosion cause frequent occurrence of the geologic hazards of the region.

4.1.7. Conflicts between industrial development and environmental contamination

Western China is the origin of many rivers of the country. Stream flow in this region especially in northwestern region is relatively small in comparison with other areas, and the self-purification capacities of these rivers are poor. In the meanwhile, the industrial and mining businesses in this region are bringing serious pollution, which in turn cause increasingly stream pollution and lake eutrophication. The discharge of sewage to the Yellow River in the 1990s came to 4.2×10^{10} t, which has doubled that in the 1980s; water quality therefore show a sharp deteriorating trend. According to the results of the water quality monitoring in 1998, out of the 7.25×10^3 km of the Yellow River trunk stream and the main reach of its branch, 38% of which has water quality at Fifth Class and below. At the same time, lake eutrophication is getting steadily worse.

4.2. Conflicts of ecosystem services in Western China

4.2.1. Ecosystem services and human well being in the Sangong River valley of Xinjiang

Northwestern part of China includes all the districts of Xinjiang, Qinghai, Gansu and Guanzhong and Shanbei provinces and regions which lie in the north of Qinling mountain in Shanxi province, also includes Alashanmeng, Yikezhaomeng, Wuhai, Hetao of the western Inner Mongolia. The area of the northwestern region is 3.49×10^7 km^2 taking up 35% of the total land area in China. The average annual water resource in this region reaches to 2.34×10^{11} m^3 that makes up 8% of the total water resource in China, while the available water resource is less than 1.2×10^{11} m^3. Under the umbrella of the development of western China, major economic activities such as speeding up constructions of infrastructure, enhancing a strong ecological environment safeguards and constructions, adjusting industrial structure are related closely to water resources. Water problems in northwestern regions get even more severe compared to the southwestern region due to the differences of water resource availability and ecological environment between the two regions. The paper emphasizes on water resource problems in droughty region by taking the Sangong River valley in Xinjiang Fukang as an example.

It is well known that "no water, no hope" in northwest region. Water resource is linked closely to the development of human beings and society. Restricted by socioeconomic structure and the development stage, agricultural water consumption occupies 90% of limited water supply in the northwest region. The irrigation quota in northwest region is higher than the national average because of the restrictions of human factors and natural factors such as rainless and semiarid conditions of the region, and the efficiency of industrial water consumption approaches to the average of the country. The GDP output based on per m^3 water is lower than average level owing to a high proportion of agricultural sector in the GDP. On the other hand, regional distribution of annual average water resource is uneven due to relative concentration of economic development and popular distribution. The shortage of water has become more and more serious in northwest region such as the Yellow River in Ningxia Hui Autonomous Region and the Weihe River which is the branch of the Yellow River in Shanxi province. Water problem is increasingly becoming serious because of insufficient rainfall and unreasonable intervention and utilization of water resource. As a result, the whole ecological environment turn to be frangible and the soil and water erosion in the Loess Plateau become more and more serious. Desertification and water erosion tend to extend constantly. Stream break, lake shrink, water table subduction and unreasonable irrigation will continuously cause oasis salification and water resource deterioration.

Sangong River valley is located between 43°09′ to 45°29′ north latitude and 87°47′ to 88°17′ east longitude and lies in the west of Fukang city and belongs to rainless region in the middle latitudes of western China (Figure 4.1). The valley is 30 km long and 29 km wide, and the total area is 1.67×10^3 km^2 (Luo, 2002). Sangong River valley presents a typical rainless geomorphic feature and is divided into south mountainous area, middle oasis area and north desert area according to the gradient that is higher in the south and lower in the north. This region is characterized as drought climate, deficient water supply, exiguous plant, wide desert and weak ecosystems. There is a high potential for irrigation farming thanks to opulent sunshine. The main rivers in this valley are the Sangong River, the Sigong River and the Shuimo River and the annual average runoff of these rivers reach to 9.92×10^7 m^3 (Zhang, 1994).

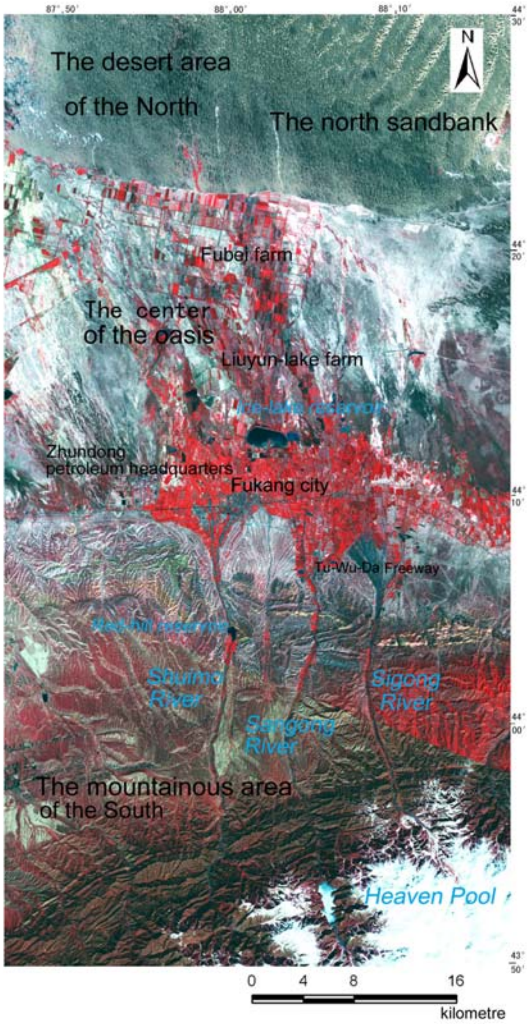

Figure 4.1. TM image of the Sangong River valley (Luo, 2002)

Although the proportion of agriculture industry dropped slightly and other industries increased slowly in 1998 compared with the one in 1990, agriculture still remains as the leading industry of the region. Saltification and desertification are the main environmental problems in the Sangong River valley owing to a preliminary level industrial structure. Following the development of soil and water resource in rainless region, the alluvial plain desert landscape, which developed from the low part of ground water overflow, turned into constructed oases landscape, and then secondary saltification happened on the land. Desertification is another environmental problem in this region and the sand dunes spread everywhere. On the other hand, the oases is far away from water resource and the stream runoff volume is lower than annual average at normal water years and low water years, so water couldn't be retained very well and desertification appeared on the edges of the alluvial plain oases. The increase of new oases and barren lands would bring not only great damage to the land but also threaten the stabilization of plain oases.

Reservoirs, marshes and riversides are main types of hydro-ecosystem in the valley. In general, hydro-ecosystem function degraded sharply because many riversides and marshes shrank quickly and degenerated to gravel soil or uneven ground from 1978 to 1998. According to the statistical results on the hydro-ecosystem service value of this region in 1978, 1987 and 1998, wetlands reached to the maximum service value in 1987 compared with the ones in 1978 and 1998; The statistical results also shown a improving trend of the total service function from 1978 to 1998. Human impacts on water resource stressed markedly in 1988 compared with the one in 1978. Ecosystem service of wetland is reinforced by increasing rainfall and the area of wetland. The service function of reservoir is embodied by water supply potential. The function reached to the best in 1998, and water supply potential and regulating function is also improved.

Based on the data of rainfall, annual average temperature and runoff volume in Fukang from 1961 to 2001, it was known that the runoff volume tended to reduce year on year while the snowmelt and the rainfall increased continuously (Liu, 2004). Among influential factors, climatic change, land utilization, land use change and water conservation project are listed as direct factors, while population change, water resources development and utilization etc. are indirect factors. Among these factors, land use change is the main driving factor. The main problems of water recourse utilization in Sangong River valley are as follows: low standard of power-operated wells construction, unreasonable arrangement, shortage of water in spring, lack of water project planning and reservoir construction plans, unrestrained exploitation for ground water. Therefore many measures should be adopted to reduce these environmental problems. Land development and utilization especially the farmland development and utilization in this area should be controlled firmly; agricultural development objectives should be determined according to water resource availability, and the internal structure of agriculture should be readjusted so as to increase the proportion of animal husbandry, and reduce water resources development and utilization degree and protect water ecosystem.

There were no significant changes on grass ecosystem and desert ecosystem in 1978, 1987 and 1998 according to the calculations of ecosystem service value. The forest ecosystem service reached to the top in 1987 and then fell down owing to shrinking of shrubbery area. Farmland service function was enhanced because of farmland extension from 1978 to 1998. Wetland ecosystem service function maximized in 1987 and then descended from 1988. Water service function reached the highest level in 1978 and began to descend because of increased demand for water resources. With water consumption grew constantly, many reservoirs were built to satisfy the development of industry and agriculture. But such human interventions make the service function of the natural ecosystem weakened.

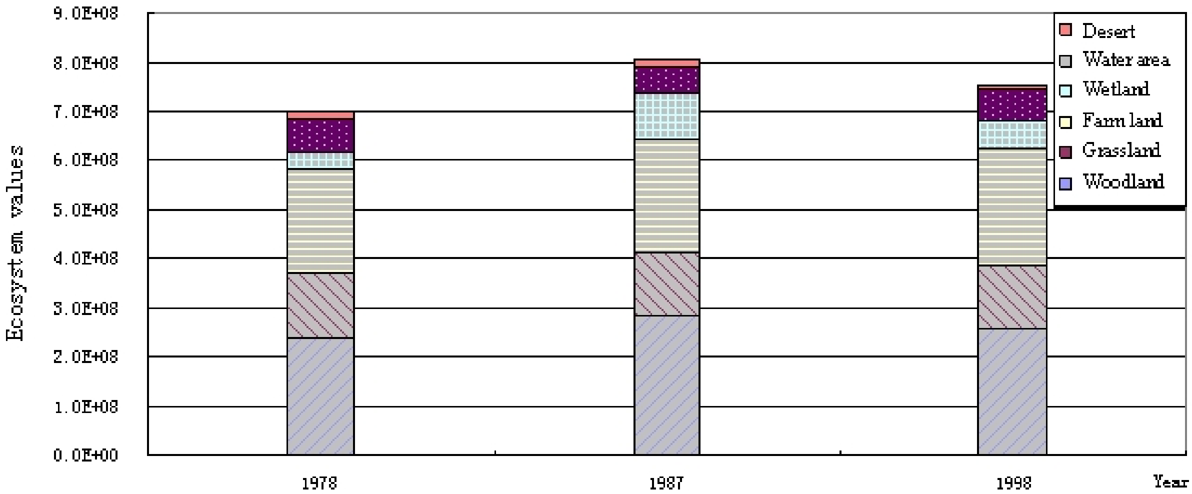

Figure 4.2. Ecosystem values of oasis ecosystems in SanGong River basin

It is shown from the analysis that the total service function of all kinds of ecosystems didn't reach the maximum value until 1987, and the total service of the Sangong River Oasis reached its highest value at that time (Figure 4.2). From this time on, the value fell down slightly, but it still kept a high level in 1998 compared with the one in 1978. A steady increase in artificial ecosystem value indicated a trend of human's constant stimulation on the ecosystem before 1987. However, the service function of the natural ecosystem such as native pasture, wetland, river and river banks and desert kept increasing from 1978 to 1987, and then touched the top in 1987. This analysis also indicated the relationship between natural ecosystem and artificial ecosystem. In a long run of interests and well being of human beings provided by the whole ecosystem, natural ecosystem and artificial ecosystem should be managed evenly so as to realize the maximum value of ecosystem service in this region.

Scenario analysis of social economic water demand and ecologic water demand in the Sangong River valley under the strategy of West Development should be focused on the following aspects: the balance between the river ecosystem and the natural or artificial ecosystem; the balance of water consumption between industrial, agricultural and domestic sectors and the balance between social economic water use and ecosystem water use. The results show that the following suggestions should be considered for the development of the Sangong River valley in the future: to build necessary impoundment project at mountainous pass so as to enhance the regulating ability for runoff; to development irrigation free vegetation and adjust environmental measures to local conditions; and to explore and utilize ground water properly and to strengthen the management of water resources.

4.2.2. Ecosystem service conflicts in the south central Inner Mongolia

The south central of Inner Mongolia is located between 113°22′ to 116°43′ east longitude to 41°37′ to 43°10′ north latitude and lies in the middle of Hunshandake desert (Zhao, 1991). The total area of this region is 2.9×10^5 km^2. It belongs to arid and semiarid continental climate in temperate regions characterized by a long winter and short summer, unevenness of precipitation, lack of rainfall, wind-drift sand and westerly winds prevalence.

The annual average wind speed trends to descend year on year since the 1970’s due to implementation of many measures such as agroforestry and wind-prevention and sand-fixation (Xu, 1996). Chestnut soil is the main soil type of this region and wind erosion is a major type of soil erosion (Zhao, 1996). Gramineous and composite plants are the representative vegetation types of the region. Drought resistant gramineous plants and sand shrubbery are the main plants in this field with simple structure of plant community and few species (Wang, 1996). Surface runoff does not develop very much in this area, but the groundwater is abundant, and distributes extensively, water table is shallow and the water yield is high, and available water resource is rich (Zhang, 1985). The area consists of dozens of nationalities including the Mongolia, the Han nationality, Hui nationality and the Man nationality. Population increased rapidly in the 1980s-1990s, slowed down after 1990. The various composition indexes of GDP increased obviously since 1985, and the increasing degree of output value from township enterprise was remarkable. In recent years, per capita water and soil resources are becoming scarcity due to population growth and continuous deterioration of environmental conditions. Overgrazing and intensive cultivation make the services function of the local ecosystem damaged constantly, and the structure and approach of land utilization are changing continuously.

Based on the result simulated by remote sensing over the past 20 years, changes of the ecosystem support and supply functions as represented by the Normalization Vegetation Index (NDVI) and the Natural Primary Productivity (NPP) show the same trend. From the mid- or late- 1980s to the middle 1990s, there is an improvement in the functions reflected by these two indexes; this is benefited mainly from ecological projects implemented in this district. (Liu et al., 2003；Deng, et al., 2004；Zhan, et al., 2004). However, after this, the ecosystem support function and the supply function showed a serious declining trend because of population growth and human’s interventions. This finding has been proved by the field research on the spot (Liu, 1988). Nevertheless, monitoring results over the past 20 years indicated that the regulating function of the district's ecosystem has been improved to a certain degree, which could be evidenced by the rising of forest coverage and the declining of precipitation variation.

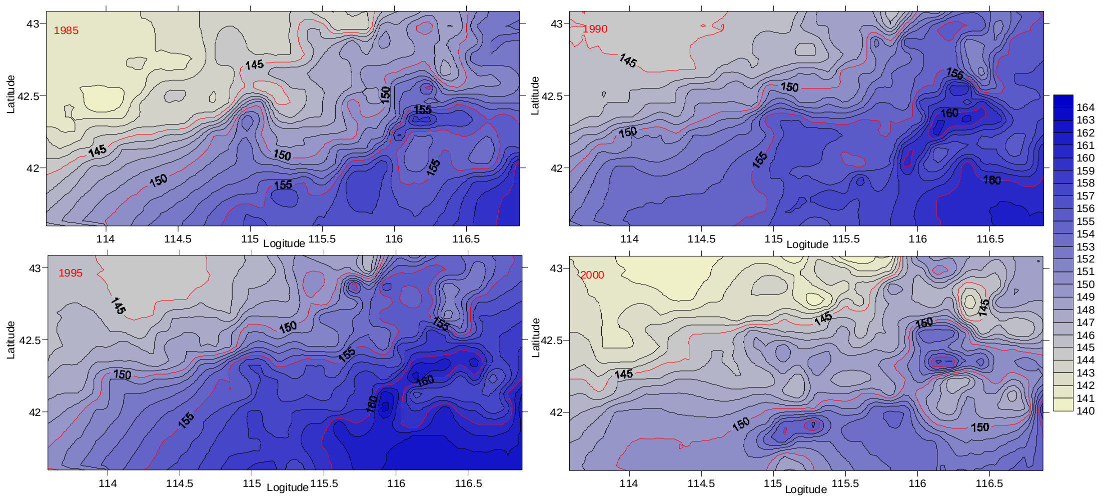

Figure 4.3. Spatial distribution of NDVI at the south central Inner Mongolia in 1985, 1990, 1995 and 2000

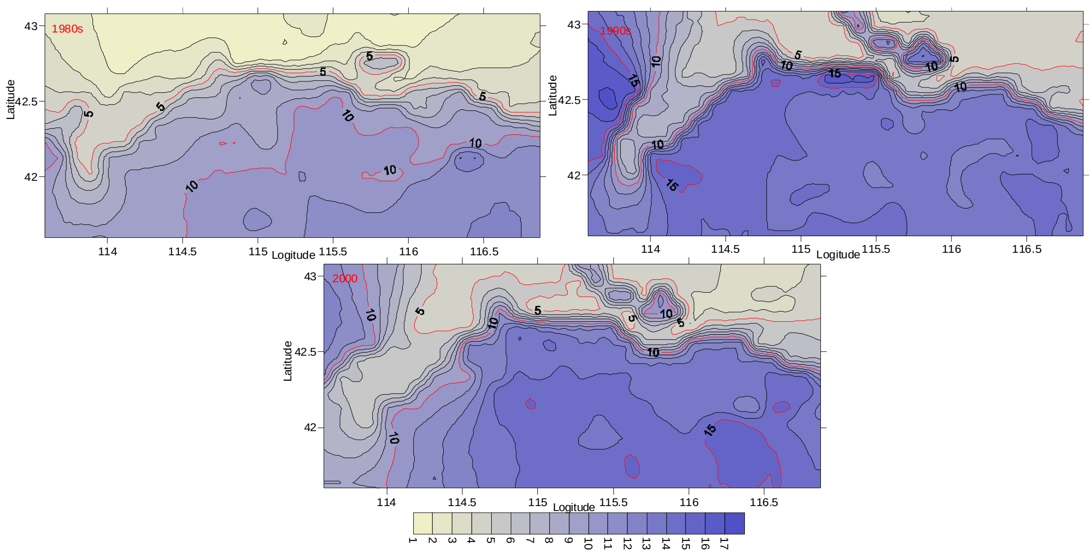

Figure 4.4. Changes of NPP at south central Inner Mongol in the 1980s, 1990s and 2000

Since 1980s, local economic activities exerted a great influence on the changes of ecosystem services. Land use is constantly intensified which has caused fragmentation of habitat conditions of the region and deterioration of the scale and quality of biological habitat in the ecosystem, and brought changes in composition of species and function of ecosystem. In addition, development of industry and agriculture and the combustion of fossil in some places deteriorated environmental quality and damaged the ability on maintaining bio-diversity and providing services.

Even worse, in some places of the district, constant aggravation of the human activities had even damaged directly the first class structure of the ecosystem (Cairns, J., 1980; Cairns, J., 1997), and reduced the ecological functions of controlling soil erosion and adjusting climate. Therefore, it is clear that the human's influence on the natural ecosystems is increasing in a nonlinear manner, and affecting negatively the support and supply functions of the system, which should be taken into consideration in the future.

Limited by water resources, the southern areas belong to the marginal land with very fragile ecological balance in the Inner Mongolia, the contradictions of fighting for land between agriculture and animal husbandry is very conspicuous, which is shown as follows: Fighting for land between agriculture and animal husbandry, and conversion of grassland into farm land happened everywhere (Meng and Guo, 1997); monocropping of grains causes a disconnecting pattern between agriculture and animal husbandry; development of intensive grassland animal husbandry is restrained by poor efficient fodder industry dawdling in grains; raising animal husbandry depending on God, traditional norms of the herdsman, fighting for the grains between human beings and animal husbandry through competition in land resources. Those conflicts have already become the basic crux for economic and ecological development of the southern grassland in Inner Mongolia for a long time. The contradiction of agriculture and animal husbandry in pastoral area of the grassland is a basic factor in sustainable development of grassland animal husbandry. Through analysis of American land satellite digital image from the middle of 1980s to the end of 1990s in the south central Inner Mongolia, it can be found that grassland quality shown a decreasing trend over the past 20 years.

The reasons for grassland degradation can be summarized as grassland cultivation, overgrazing, humans' damage and mouse and pests. Cultivation on the grassland is an important reason for grassland resource loss and quality degradation; While overgrazing is a direct reason causing degradation of grass quality and productivity (Zhang, 1994; Li, 1997; Liu, 2000; Yu, 2002). Besides, the area of desertification in the south central Inner Mongolia is expanding rapidly, such as sandy desertification (Wu, 1992). The areas of desertification have increased by 9.6% with the total desertification areas of 2.24×10^6 hm^2 during the past 20 years. Field investigation shows that not only the desertification area is increasing, but also the desertification degree is aggravating year on year.

Through establishing the model of land use changes in the Taipusi banner and using the principle and method of systematic dynamics, structural analysis of land use changes in 2000-2020 is done with the support of statistical data over the past 50 years ever since the foundation of the state, and field investigation in the Taipusi banner.

Using CLUE-S model and the simulation result of systematic dynamics, scenario analysis of land use changes has been conducted with the support of high-resolution data. And three scenario models the Taipusi banner have been established namely reference model, ecological model and economic model (Deng, 2003). Under the reference model, the expansion and shrink of various kinds of ecosystems is taking place near the original positions. By the year of 2020, barren land will decrease seriously due to cultivation activities; only those that are severely eroded and could no longer be cultivated will remain as barren land. Forestland will expand obviously and grassland keeps unchanged, and the spatial distribution of those land resources would remain the same. Settlements and industry areas will expend in a small scale around the existing areas, but the expansion range is limited. The area of water body will not change. The area change of ecosystem under the ecological mode reflects the increase of forestland mainly in the northwestern part and northeast part of the downtown during the prediction period. In addition, under this scenario, the area reduction of ecosystem is controlled at a rational level and the large-scale reduction of the area will not happen.

Under economic mode, almost all of the ecosystem area is converted into cultivated land, grassland and forestland, with a great decrease in barren land. And forestland decrease is very limited.

The simulation of spatial-temperate pattern and the scenario analysis on the area of ecosystem change under the three models have provided important basis for making land use plans and sustainable development strategies. First of all, with reference to the prediction of changes of ecosystems, and the fact of grassland degradation and desertification in the Taipusi Banner, it is suggested the local government should make a rational overall plan on land resource development, industrial structural adjustment, population control and economic development. Secondly, prediction results of the three models show that concentrative distribution of uncultivated land in the northeast and northwest Taipusi Banner will be becoming a sensitive area where the ecological environment degradation will be serious in the coming twenty years. Under different models, the competition between various kinds of ecosystems causes a large difference in succession of the ecosystems, which reminder us to focus on changes of the ecosystem services in this area and control strictly unreasonable transformation of ecosystem so as to improve the ecological environment of the region.

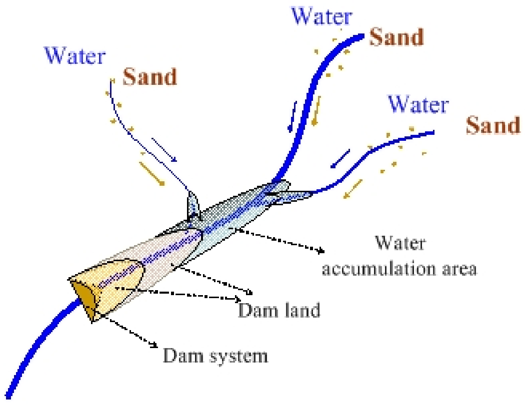

Figure 4.5. Sketch map of Ditch management

Figure 4.6. Major components of skeleton dam

4.2.3. Ecological and economic benefits derived from dam-for-siltation construction in Qingyang City of Gansu Province

China is one of the most serious countries on soil erosion in the world. The loess plateau is a typical area suffering from soil erosion. Among various kinds of projects on water and soil conservation, the dam construction has been got the remarkable effects and valuable for ecological rehabilitation and conservation. Dam system with a function of blocking mud running off is built along with ditches in the erosion-stricken regions. The land from siltation is called dam-land (Figure 4.5, Figure 4.6). According to historical record, the earliest dam -"Collecting Mud Naturally" - is traceable as far back in time as 400 years in Ming Dynasty. It is evident that building dam in ravine areas of loess plateau benefits greatly for preventing the mud from running off, controlling soil erosion, utilizing water and sand resources effectively, upgrading agricultural production, improving the local ecological environment, and promoting regional economic development.

Since the founding of the People's Republic of China, the dam system has been developed rapidly owing to the great efforts on demonstration and extension paid by water resources management agencies, and water and soil conservation agencies. The development of dam system experienced four stages: test and demonstration in the 1950's; extension and popularization in 1960's; construction and development in 1970's; and improvement and consolidation in 1980s. As of 2002, the area of dam-land accounted for 9% of the total cultivated land and grain yield from dam-land accounted for 20.5% compared with the total. Therefore, the dam-land has been very important component of farmland as well as important grain bowl in loess plateau. The problems on food and fiber shortage facing local residents have been solved increasingly; and slope lands have been made available for forestation and animal grazing.

Qingyang City, known as "Longdong", is located in the east of Gansu province, longitude from 106°45′ to 108°45′ east and latitude from 35°10′ to 37°20′ north. Total population in this area is about 2.5×10^6. Of which, rural population is 2.2×10^6, taking up 88.98% of the total. The physiognomy in the region is classified into three types: ravine area of loess plateau in the south; mixed area of hill and ravine of Loess Plateau in the north; and hill area of Loess Plateau in the east. This area is featured with inland monsoon climate with cold- and short-winter season, less warm summer season and rainy autumn season. Qingyang is one of the districts with rocky and sandy lands in the upper and middle reaches of the Yellow River. The area is characteristic of ravines, bare lands, loose soil structure, and intensive and relatively concentrated precipitation. Serious soil erosion (87.2% of the area being eroded) has already become the main restriction factor of local economic development.

Qingyang is a less developed area in the Northwestern region with poor resources and underdeveloped infrastructure facilities. Agriculture is dominating industry while enterprises confronting problems arising from capital shortage and out-of-date technologies. In light of natural resources, economic status as well as crop adaptability, Qingyang is segmented into four areas: hill area in the north planting benne; mixed area of ravine and terrace in the middle planting wheat and benne, ravine area in the south planting wheat and economic crops; and "Zhongshan" hill area in the east planting fruit trees, sugar beets and drug herbs as well as crops (Fig 4.7).

The average annual precipitation is about 400mm in this region. The precipitation is unevenly distributed on July, August and September. The soil is eroded badly thanks to the great variation of precipitation among years and the erosion-prone earth surface. Severe soil erosion greatly contributes to the decline of soil fertility and degradation of farmland, thereby causing decrease of agricultural production and declining carry capacity of land. Furthermore, the Loess Plateau is one of main habitat for communities of ethnic minority. Traditional living habits and religious customs of ethnic minority group have brought great difficulties to the enforcement of national family planning policy so that population in this area increased rapidly. Increased demands for food and other resources have put great pressures on ecosystem; especially grain production on steep land has directly contributed to severe soil erosion and brought irreversible impact on local ecosystem.

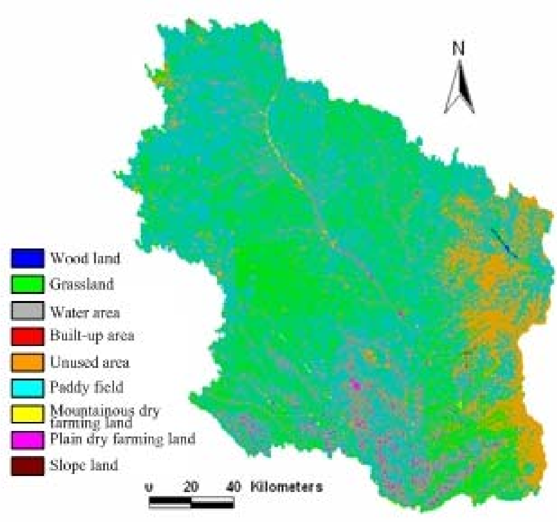

Figure 4.7. Map of land use in Qingyang City

(Source: Data Center for Resources and Environment of the Chinese Academy of Sciences)

Building dams for siltation changes the pattern of natural succession of ecosystem and enhances ecosystem services in terms of provisioning services, regulating services and cultural services. The specific embodiment of improved ecosystem services includes increases of soil fertility, soil organic mater, soil enzyme activation, efficiency of solar energy use, grain production; improvement of regulating function, soil capacity of water holdings, ventilation and soil moisture. As effectual mode for ecological restoration, dam system plays an important role in increase of siltation and improvement of ecosystem. The dam built in the ditch can elevate base of ditch, mitigate erosion of ditch border and ditch bottom, prevent front ditch from stretching forward. At the same time, the efficiency of dam system is so remarkable that muddy inflows will be retained, silting into land. The amount of mud and sands from siltation accounts for 67% of that from other measures. The amount of mud and sands retained by large-sized dam is about 8×10^3 t, which can be converted into one mu of dam-land; 6×10^3 t by middle-sized dam; and 3×10^3 t by small-sized dam. Grain yield in dam-land is three to five times higher than that in terrace and 5 to10 times higher than that in slope land. It is obvious that dam system constructions benefits greatly to ecological rehabilitation while associated with remarkable economic returns (Figure 4.8).

Figure 4.8. Map of comparison between slope cultivation and dam-land cultivation

With the construction of dam system in the Loess Plateau, indices indicating human well-being have increased dramatically and socio-economic development has been accelerated gradually. Achievements is embodying in improvement of agricultural production, reasonable adjustment of land use, upgrade of transportation and communication, increase of job opportunities, update of health care facilities, improvement of educational and scientific facilities, settlement of clean drink water for human and animals. Test, demonstration and extension conducted by water resources management agencies, water and soil conservation agencies have accelerated development of dam system, experiencing process of development from small scale to large scale, from disorder to order, from unsystematism to systematism, from voluntary practices to officially organized actions, from focusing on construction to integration of construction, management and maintenance.

By the end of 2002, the Loess Plateau has built 1.14×10^5 of dams, of which there are 1500 large-sized dams, 1.12×10^5 medium-and small-sized dams and 3.2×10^8 hm^2 of dam-land have been converted into farmland while 1.87×10^4 hm^2 of mesas have been protected.

Over the last decades, construction of dams for siltation in the Loess Plateau had achieved notable success in prevention ecological environment from deterioration to a certain extent. The chronicity and complexity on ecological construction, however, requires that well-planned and step-by-step actions must be paid to it. A series of problems faced with ecological construction must be solved as soon as possible in order to ensure smooth implementation of the ecological construction and to achieve the anticipated results. Special emphasis must be paid to water and soil conservation; and ecological rehabilitation must be put into central agenda.

The first problem is planning. Not only scale and benefit should be integrated into the construction of the dam system, but also a long-term and short-term benefit. The construction scale of silt ground dam influences directly the investment in economy and technology. Therefore, sand-reduce and silt should be taken as important objectives and relationships between scale and benefit should be coordinated based on the situation of the large coverage of the project areas, their lagged economy and difficulties in the implementation of the projects. In addition, ecological construction is a tough and long-term task in the Loess Plateau due to its backward socio-economic conditions and serious “countryside, farmer and agricultural” problems. To achieve a large-scale construction target of silt dam in the Loess Plateau, scientific planning and demand analysis must be developed according to local situation under strategic guidance of China's economy and society development policy. Relationships between scale and benefits, long-term and short-term targets should be taken into consideration.

The second problem is overall planning for dam system of small river basin. It is a main direction that silt dam construction should be concentrated in the watershed and a relatively stabilized dam system be constructed. It is important to solve the “countryside, farmer and agricultural” problems in soil erosion areas and promote conversion of farmland into forest and grassland and therefore socio-economic sustainable development through comprehensive planning in the watershed, periodic construction and construction of relatively stable dams.

In addition, income right in the management of river basin is a major issue during Silt Dam construction. For the sake of improving ecological environment and production condition, the local government has started to control water-and-soil preservation by taking loan from the World Bank. There are 32 newly built large-sized dams, 60 Silt Dams, and 3.1×10^4 hm^2 farmlands, 6.99×10^4 hm^2 afforestation, 4×10^4 hm^2 artificial grassland, 1×10^4 hm^2 orchard, all those have improved ecological environment of the area. Vegetation coverage ratio increased from 15.8% to 40.8%, and silt reduced 8.70×10^6 t per year, blocked 3.35×10^7 m^3 runoff water. However, Qingyang prefecture has not obtained economic benefit in comparison with the investment although ecological environment is improving. The total loan taken by Qingyang is 4×10^7 USD, and 4.78×10^8 RMB of which should be paid off. After the project is completed, the local farmers will only gain from terrace, garden and part of artificial grass. It is unable to produce the economic benefits in a short time for most of the measures are used to improve ecological environment such as artificial forest and dams. However, Qingyang prefecture acquires remarkable ecologic benefit, which benefits the developed areas down streams. It is obviously unfair that Qingyang has to bear the total cost but share benefit only from environment improvement.

The establishment of the compensation mechanism should consider the following aspects: ①To establish management mechanism under the framework of the law; ②The government should prioritize financial support to ecological protection project in line with ecological construction compensation policy; ③Development of energy alternatives and ecological migration should be considered as the focus for government support in establishment of ecological compensation; ④The government should set up uniform ecological environmental compensation tax system as soon as possible, and eliminate overlapping of governmental institutions; ⑤To perfect "Green GDP" system, and reveal the economic meaning of ecological environment compensating system, make "win-win" blue print of economy and ecological protection. The basic policy and measure for implementation of participatory watershed management is as follow: ①Self- dependence with assistance from the government in term of the investment; ②During the management process, to take up multi-duty system including polluter, local organizations and the public; ③The governments at all levels make a series of preferential policies in order to attract the peasants to participate in the management of the watershed. Based on establishment of ecological compensation system and relevant policies and measures, continuous construction of the Dam system in the Loess Plateau will play an important role in recovery and construction of the ecological environment, and in improving human's well being and even regional economic and social development.

4.2.4. Conflicts of ecosystem services in the Suomo River valley

Suomo River, belonging to Dadu river Qingyi water system in the Yangtze River valley, rises in Wenbu ditch, Xiangkou village, Hongyuan county of Sichuan province. The total length is 182.5 km. The valley covers Maerkang and Hongyuan counties and the total drainage area is 3015.6 km^2 (Fig 4.9). For the river, the average annual runoff at outfall is 1.80×10^9 m^3; the sand transfer amount is 3.17×10^9 m^3 annually; the average sand content is 267.7g/m^3 and the sand lose rate is 13.10 kg/s annually. The area belongs to the monsoon climate of the plateau continent. Grassy marshland, forest and shrub forest are the main vegetations in the valley. The pastures and grassland lying in the upper reaches of the Suomo River valley belongs to Chuanbei grassland that is one of the largest grassland in China. The grass area in Hongyuan county takes up 91.8% of the whole areas of the county. The grass area in Maerkang county takes up more than 40% of the total area of the county.

In the past 20 years, the change of ecological system has been embodied by grassland degradation at the upper reaches and the changes of forest system in the midstream and downstream. The reason of grassland degradation is mainly overgrazing and mouse calamity and excessive excavating of Chinese herbal medicine, which cause directly decrease in grass yield, mouse and insect overflows, harden and compaction of soils, soil salinity and alkali and desertification. The trend of grassland degradation has been mitigated since the implementation of governmental policy on livestock rearing inside the farmyard. The change of forest system is also related closely to the relevant policies. The forestry of the basin was comparatively developed because of the impacts of market economy. However, it was suffered from destruction for a certain degree in the 1980s. And the situation is being improved since the 1990s due to implementation of several projects such as protection of natural forestry, and prohibition of illegal encroachments into the forest.

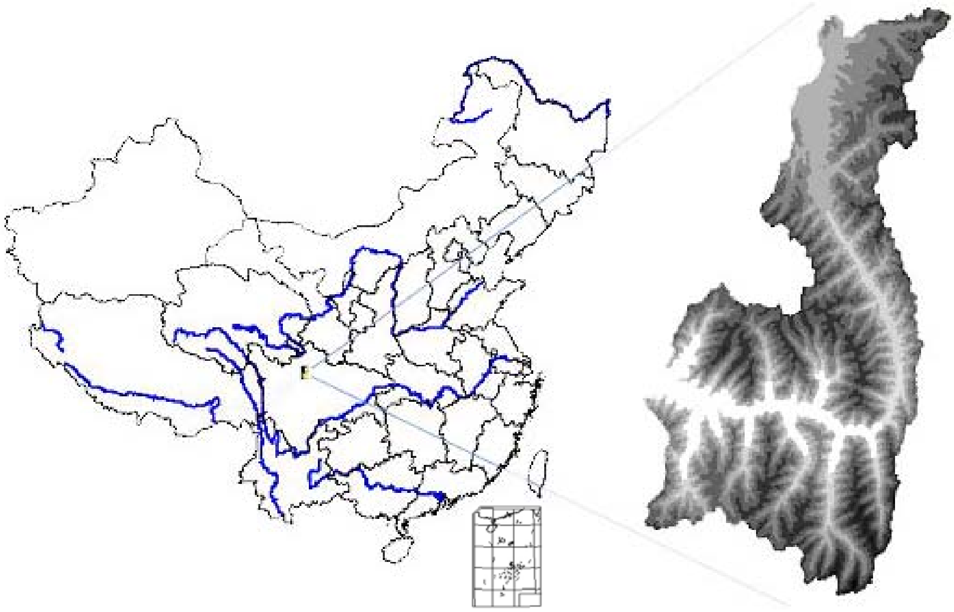

Figure 4.9. Situation and figure of Mosuo River basin

The main ecosystem service functions in Suomo River valley are regulating function and provisioning function. Regulating function includes water regulating (the change of the runoff volume), the atmosphere regulating (the change of urban air quality), the climate regulating (regulates regional temperature, rainfall, etc.), water treatment (the change of water environmental quality), the soil loss controls keeping with the sediment; provisioning service function includes food supply, material supply (forestry products), and water supply (runoff volume and water quality) etc. There are a lot of unavoidable contradictions in ecosystem service functions because of its multifunction, limitation and various scales. The contradiction of ecosystem in the Suomo River valley exists in the balance between regulating function and provisioning function. The main service function of ecosystem in the watershed is the regulating service function. Local people depend heavily on agriculture because of relatively low economic development levels, and they wish to obtain direct income from limited farm and forest land in a short run, therefore, their irrational behavior such as cutting down the forest and cultivating on the hillside fields leads to the deterioration of ecological environment of the watershed. The contradiction between regulating service function and provisioning service function lies in the difference of ecosystem service function at different spatial scales in the Suomo River valley. Resident within the region prefer provisioning function of the ecosystem such as provision of food, wood while the people outside the region prefer the regulating service function such as slowing down flooding calamity of the downstream area of the Yangtze Rive, protecting river water quality and regulating regional climate.

The Suomo River valley is located in the western of Sichuan province in China. The economic development level has been improving to some extent thanks to the development of the tertiary industry, but the local people still depends on the ecosystem to maintain their life. Main factors related directly to human well being in the Suomo River valley are: the abilities to survive in a clean and safe circumstance, to gain resources for making money and supporting themselves, and to get enough clean drinking water and fresh air. Besides, the chance to enjoy aesthetics and entertaining value, the chance to observe, investigate and understand cultural and spiritual value of ecosystem are also the important factors correlated with human well being in this region.

The major ecological problem in the Suomo River valley is insufficient water supply, and land use and land cover are major factors affecting water resources of the region. In this paper, three types of scenarios are proposed including current development situation, ecological protection and coordinated development, and quantitative change of water resource and change of flood frequency are simulated using the SWAT model. The results indicate that land cover under different scenarios affects not only the total quantity of water resources in the Suomo River, but also the flood occurrence frequency. The latter is concerned directly with well being of the residents in this valley. Compared to the first scenario of the current development situation, flood occurrence frequency reduced obviously under the scenarios of ecological protection and coordinated development. In the same reoccurrence period of the flood peak, its peak flow quantity under these three scenarios reduced significantly. For the same peak flow quantity of the flood, its reoccurrence period is different. Taking flood peak flow of $250m^3/s$ as an example, its reoccurrence period under the scenario of present development condition is three years; and reoccurrence period under the scenario of ecological protection is five years; and four years under the scenario of coordinated development. The results show that ecological protection is the most rational way among the three scenarios in terms of ecological safety and human being's safety.

4.2.5. Analysis on environmental benefit of Grain For Green in Jialingjiang River Watershed

Though the annual total sediment load at Yichang hydro-station increased from the 1950s to the 1980s, it tended to decrease gradually in the 1990s. The reason of increase is due to violent deforestation and rapid land-use change, while that of decrease may be due to countermeasures taken to control sediment yields and lots of dams built on the upstream basins. The Jialingjiang River watershed is one of the main sources of sediments in the Yangtze River watershed, and the annual total load in the 1990s from the Jialingjiang River basin discharged into the Yangtze River reduced to about 36% of that before 1988.To clarify the reason of decrease of annual sediment-inflow rate in this basin is of great significance to sediment control related forest planning, reservoir sedimentation prevention at the Three Gorges Dam and habitat and ecosystems preservation in the Yangtze River (Murakami et al., 2004). In this study we developed a sediment yield model for surface erosion of watershed slope, applied it to Jialingjiang River watershed in 1987, and investigated its applicability (Figure 4.10).

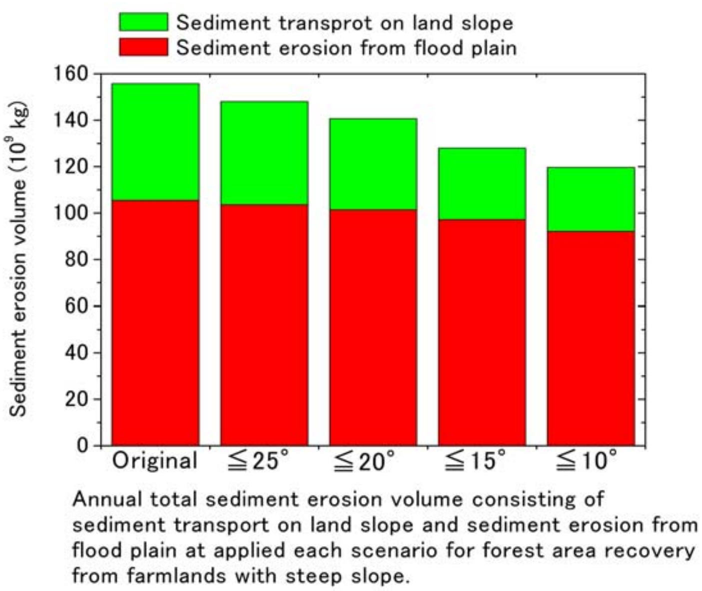

Figure 4.10. Gross soil erosion of grain-for-green areas on different slope in Jialingjiang River watershed
(including sediment transportation on slope and sediment erosion on alluvial plain)

5. Scenarios

5.1. Scenarios of climate change

On the basis of simulating the zonal variety law of bio-temperature and precipitation with elevation change in different mountainous systems (Yue et al., 2005), climate scenarios of terrestrial ecosystems in western China are analyzed in term of data of HadCM3 model (Johns et al., 2003).

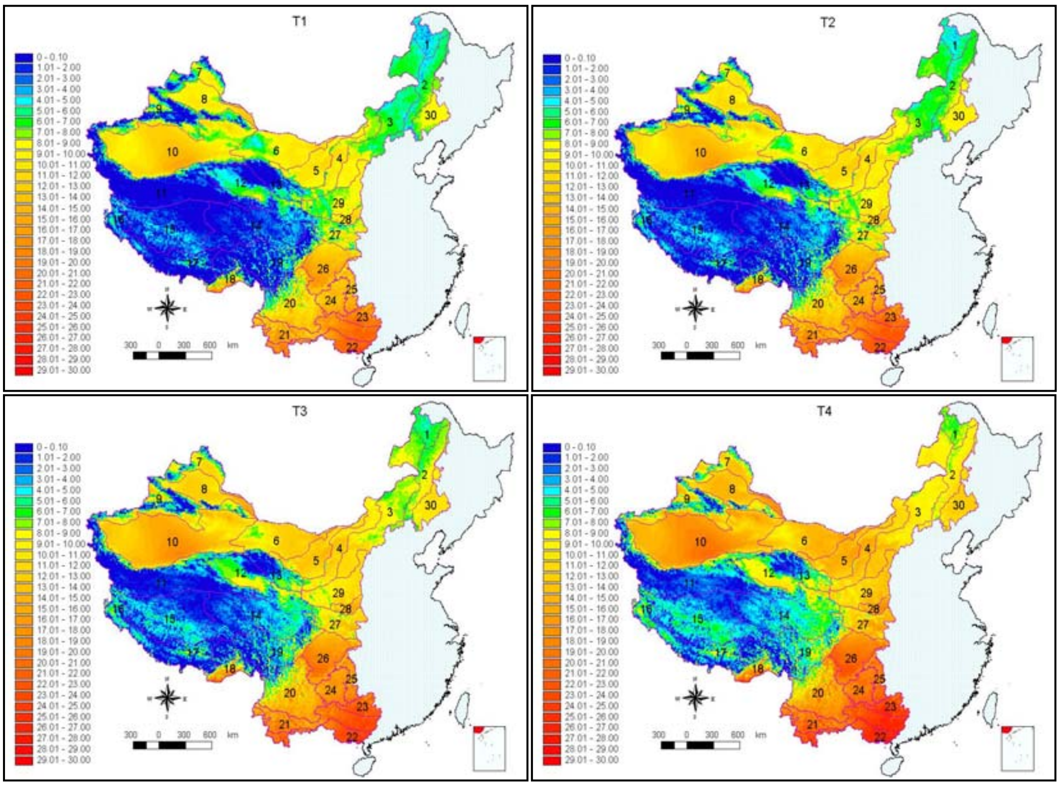

Figure 5.1. Mean annual bio-temperature based on HadCM3 A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively; each code in these maps represents an ecological zone, as seen in Table 2.1)

5.1.1. Scenarios based on HadCM3 A1FI

The simulation results based on the HadCM3 A1FI scenario data show that the bio-temperature in western China presents a continuously rising trend in the future 100 years. The mean annual bio-temperature would rise from 7.99℃ in the period T1 up to 11.97℃ in the period T4 with an average rise of 0.28℃ for every decade. The mean annual precipitation would go up from 844.73 mm in the period T1 to 1044.17 mm in the period T4 for an increase of near 14.25 mm averagely for every decade. Potential evapotranspiration ratio would increase from 1.12 in the period T1 to 1.34 in the period T4, an average 0.02 rise in every decade.

In the 30 ecological zones (as seen in table 2.1), the rain forest ecological zones in the southern Guangxi and Yunnan would have the highest mean annual bio-temperature in the period T1 and period T2, which would be 18.62℃ and 19.73℃ respectively; the subtropical evergreen broad-leaved forest ecological zone in Nanling Mountain Area would have the highest mean annual bio-temperature in the period T3 and period T4, which would be 21.31℃ and 23.76℃ respectively. Both these two types of the ecological zones show a continuously increasing trend, of which the bio-temperature would be increased by

0.36℃ and 0.37℃ in every decade. The bio-temperature in these two ecological zones would be higher than the rising rate in the whole western region of China in the future 100 years. The Frigid Desertification Grassland Ecological Zone in Pamirs-Kunlun-Arjin Mountain would have the lowest mean bio-temperature in the periods T1, T2, T3 and T4, which are 1.16℃, 1.42℃, 2.17℃ and 3.23℃ respectively and show a continuous rising trend; The increase rate is about 0.15℃ on an average in every decade.

The tropical monsoon rain forest ecological zone would have the highest mean annual precipitation in the periods T1, T2, T3 and T4, which would be 1678.89mm, 1790.05mm, 1915.58mm and 2144.34mm respectively and have an increasing trend; the increase rate would be 33.25 mm in every decade, which is 2.33 times of the average rate in western China. The desert biological zone in Junggar Basin would have the lowest mean annual precipitation in the periods T1, T2, T3 and T4, which are 133.97mm, 146.99 mm, 152.02mm and 160.10 mm respectively. The increase rate would be 1.87mm in every decade and much lower than the increase rate of the whole western region of China (Figures 5.3-5.4).

The desert ecological zone in Tarim Basin and eastern Xinjiang would have the highest potential evapotranspiration ratio, which are 6.67, 5.50, 6.95 and 7.69 respectively in the period T1, T2, T3 and T4. The increase rate is about 0.07 on an average in every decade, which is much higher than that of the whole western region of China. Frigid meadow ecological zone in the source areas of the Yangtze River and the Yellow river and southern Gansu would have the lowest potential evapotranspiration ratio, which are 0.12, 0.14, 0.20 and 0.25 respectively in the period T1, T2, T3 and T4. The increase rate is about 0.01 in every decade, only 50% of the rising rate of the whole western region of China (Figure 5.5-5.6).

5.1.2. Scenarios based on HadCM3 A2a

The simulation results based on HadCM3 A2a scenario data show that the bio-temperature in western China presents a continuously rising trend in the future 100 years. The mean annual bio-temperature would rise from 7.94℃ in the period T1 up to 11.08℃ in the period T4, of which the increase rate on an average would be 0.22℃ in every decade. The mean annual precipitation would go up from 849.08 mm in the period T1 to 1002.20 mm in the period T4, of which the increase rate would be about 10.94 mm on the average in every decade. The potential evapotranspiration ratio would increase from 1.12 in the period T1 to 1.27 in the period T4 and the average increase rate would be 0.02 in every decade (Figures omitted).

The rain forest ecological zone in the southern slope of Himalaya Mountains has the highest mean annual bio-temperature, which are 18.52℃, 19.46℃, 20.84℃ and 22.53℃ in the periods T1,T2, T3 and T4 respectively. The mean annual bio-temperature would increase by 0.29℃ for every decade and the increase rate would be higher than that of the whole western region of China in the future 100 years. Frigid Desertification Grassland Ecological Zone in Pamirs-Kunlun-Arjin Mountain has the lowest mean annual bio-temperature, which would be 1.16℃, 1.45℃, 1.86℃ and 2.69℃ in the periods T1, T2, T3 and T4 respectively and show a continuous rising trend; the rising rate would be about 0.11℃ in every decade.

Ecological zone of tropical rain forest and tropical season rain forest in the southern slope of Himalaya Mountains would have the highest mean annual precipitation, which are 1752.28mm, 1709.41mm, 1932.77mm and 2094.55mm in the periods T1, T2, T3 and T4 respectively. Precipitation would be increased by 24.45 mm in every decade on the average; the rising rate would be 2.23 times of the average rate in the whole western region of China. Desert biological zone in Junggar Basin would have the lowest mean annual precipitation, which would be 131.71mm, 146.84 mm, 159.52mm and 157.55 mm in the periods T1, T2, T3 and T4 and have an increase of 1.85mm in every decade on an average.

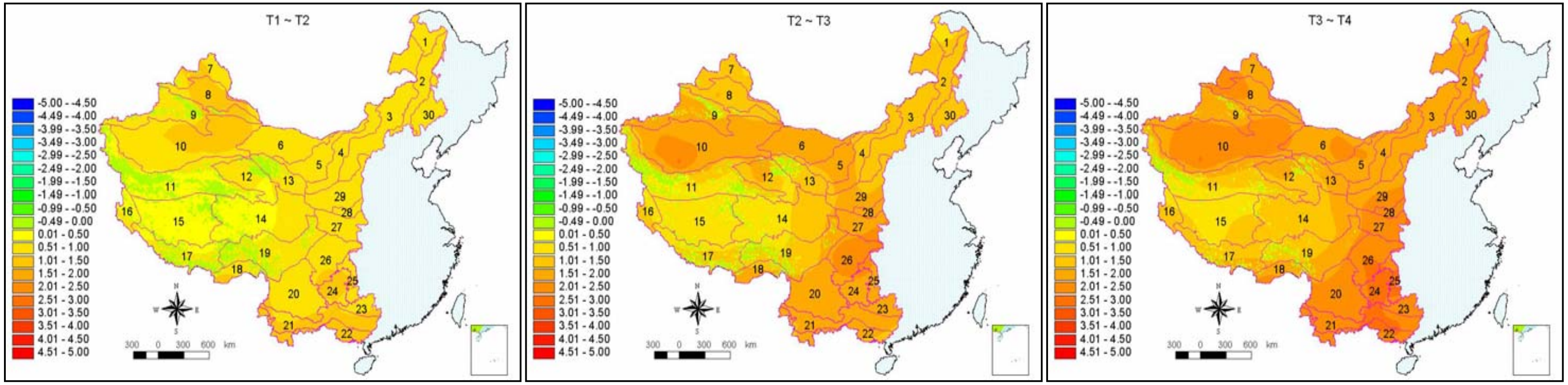

Figure 5.2. Bio-temperature change based on HadCM3 A1FI

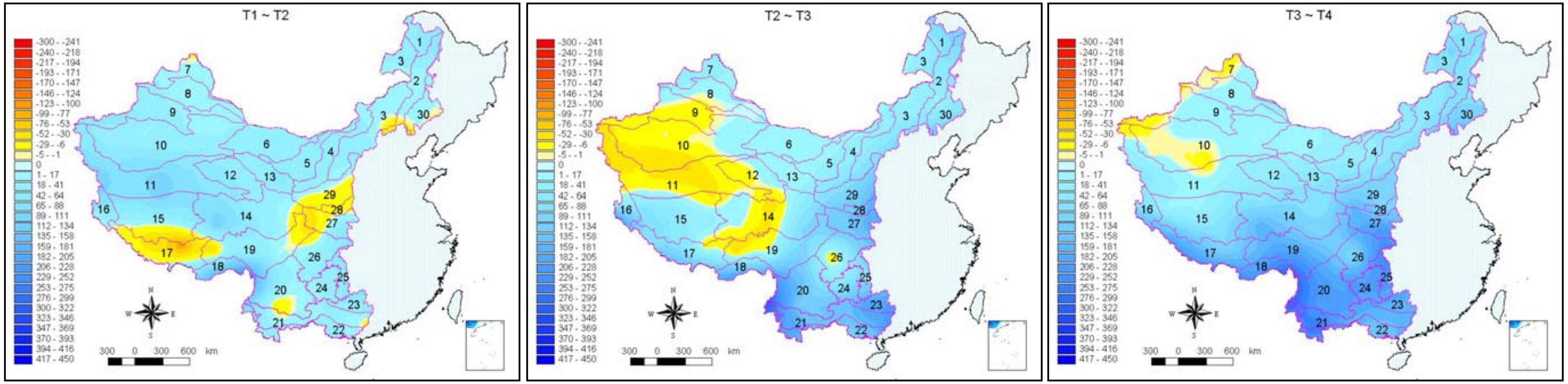

Figure 5.3. Precipitation change based on HadCM3 A1FI

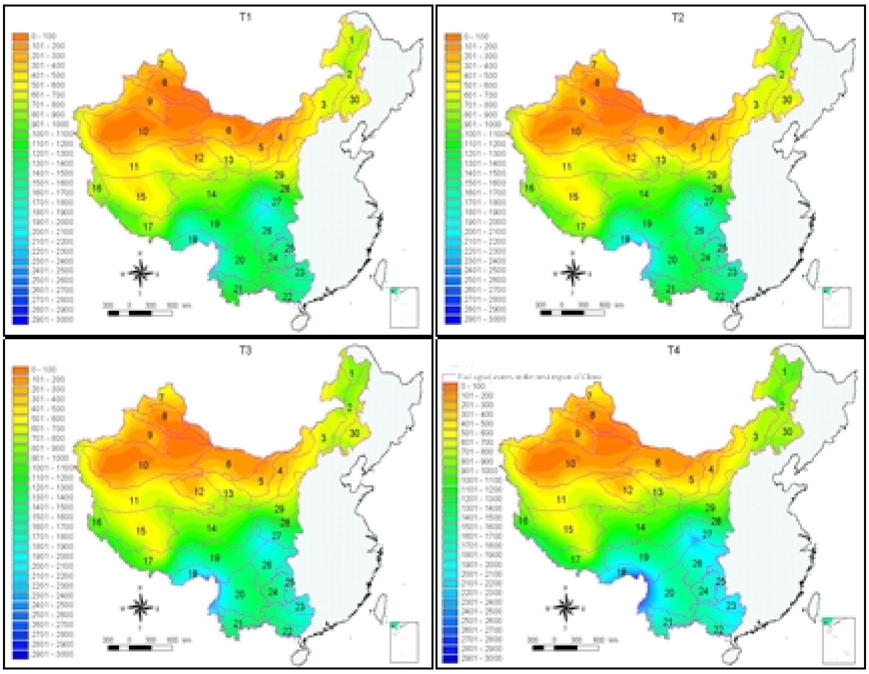

Figure 5.4. Mean annual precipitation based on HadCM3 A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively; each code in these maps represents an ecological zone, as seen in Table 2.1)

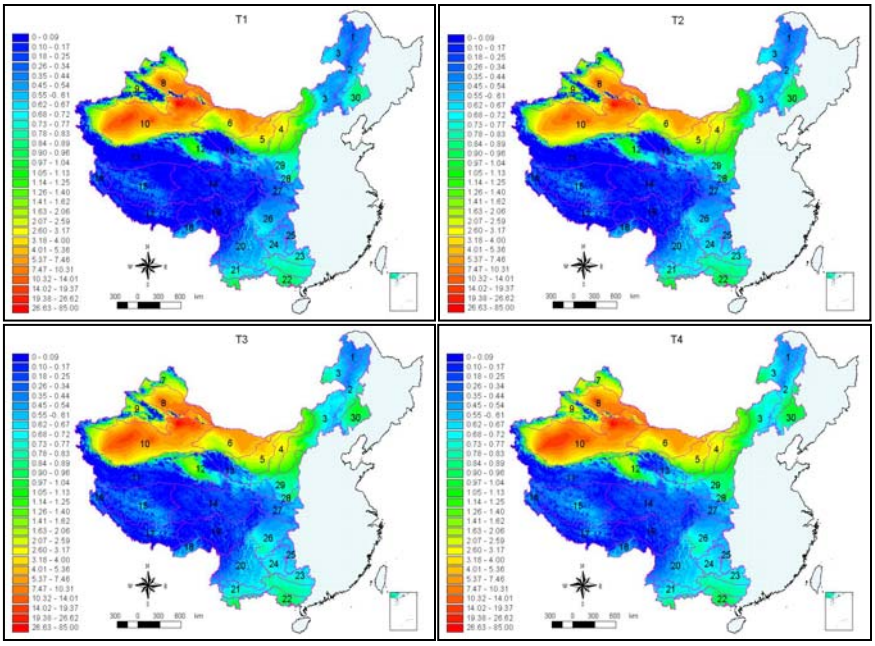

Figure 5.5. Potential evapotranspiration ratio based on HadCM3 A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively; each code in these maps represents an ecological zone, as seen in Table 2.1)

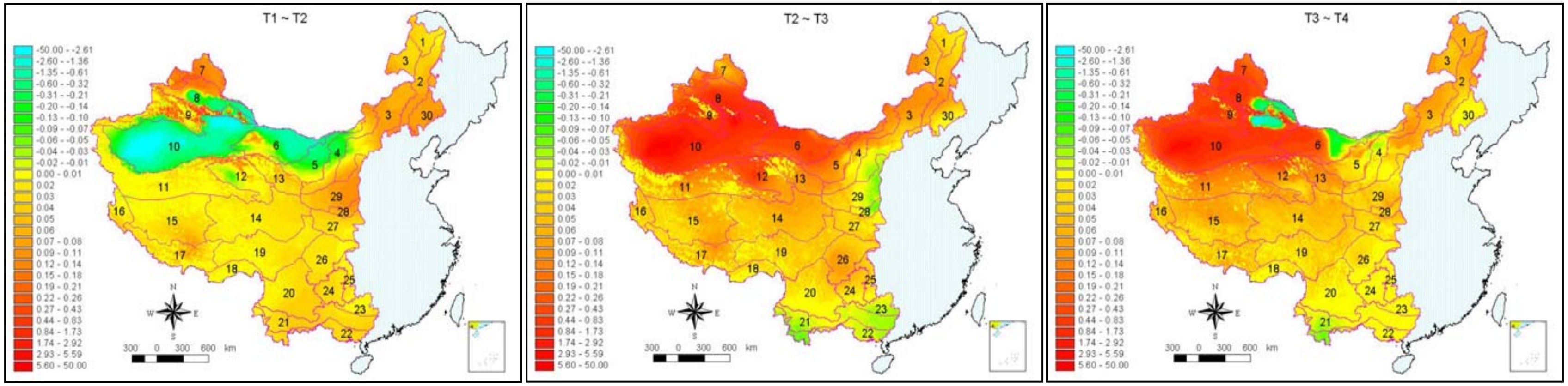

Figure 5.6. Change of potential evapotranspiration ratio based on HadCM3 A1FI

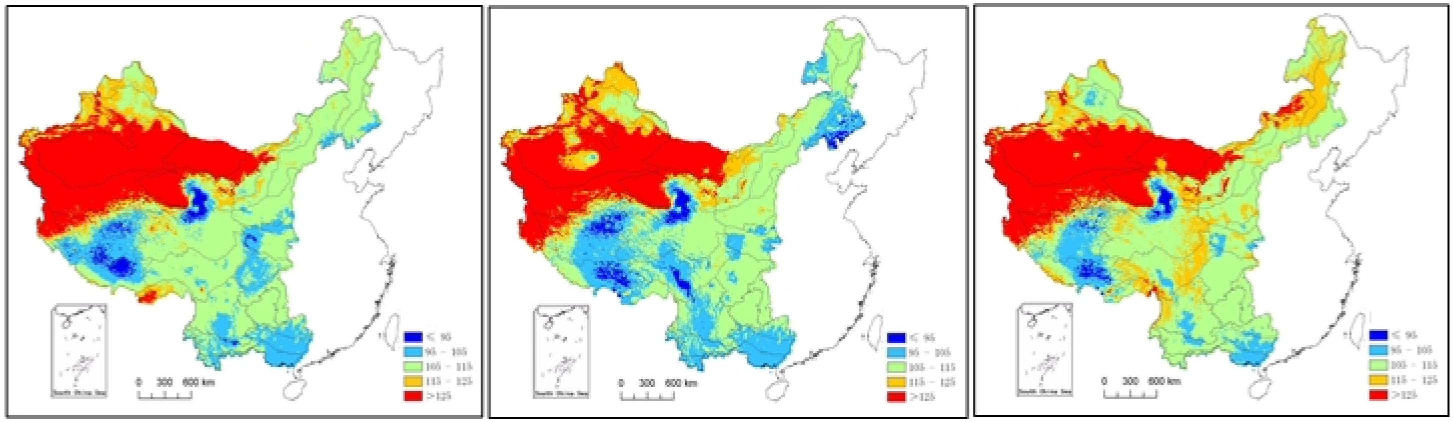

Figure 5.7. Effect coefficient of climate change on ecosystem food provisioning capacity (%)

(left map: scenario based on HadCM3 A1FI; middle map: scenario based on HadCM3A2a; right map: scenario based on HadCM3B2a)

The desert ecological Zone in Tarim Basin and east Xinjiang would have the highest potential evapotranspiration ratio, which would be 6.32, 6.14, 6.20 and 6.93 respectively in the periods T1, T2, T3 and T4; during the period from T1 to T3, it would have a falling trend and in the period T 4 an upward trend. The lowest potential evapotranspiration ratio would appear in frigid meadow ecological zone in south Tibet mountainous area, which would be 0.07, 0.09, 0.12 and 0.17 in the periods T1, T2, T3 and T4 respectively; there would be an ascending trend; the ascending rate would be about 0.01 in every decade as same as the one in the whole western region of China.

5.1.3. Scenarios based on HadCM3 B2a

The simulation results based on HadCM3B2a scenario data show that mean annual bio-temperature in western China would present a continuously rising trend in the future 100 years. The mean annual bio-temperature would rise from 7.95℃ in the period T1 up to 10.29℃ in the period T 4 with an average rise of 0.17℃ in every decade. The mean annual precipitation would go up from 849.03 mm in the period T1 to 948.31 mm in the period T4; the increase rate would be about 7.09 mm in every decade. The potential evapotranspiration ratio would increase from 1.12 in the period T1 to 1.16 in the period T4, an average 0.01 rise in every decade (figures omitted).

Ecological zone of the tropic rain forest and the tropic season rain forest in the southern Guangxi and Yunnan would have the highest mean annual bio-temperature, which would be 18.51℃, 20.04℃, 20.86℃ and 21.95℃ in the periods T1, T2, T3 and T4 respectively. The mean annual bio-temperature would increase by 0.25℃ in every decade and higher than that of the whole west region of China in the future 100 years. Frigid desertification grassland ecological zone in Pamirs-Kunlun-Arjin Mountain would have the lowest mean annual bio-temperature, which would be 1.17℃, 1.51℃, 1.81℃ and 2.12℃ in the period T1, T2, T3 and T4 respectively and show a continuous increase of 0.7℃ averagely in every decade.

Ecological zone of tropical rain forest and tropical season rain forest in the southern slope of Himalaya Mountains would have the highest mean annual precipitation, which are 1755.68mm, 1722.63mm, 1808.26mm and 1967.41mm in the periods T1, T2, T3 and T4 respectively. The mean annual precipitation would have an upward trend of 15.12 mm in every decade and the rising rate is 2.13 times of the one in the whole western region of China. The desert Ecological zone in Junggar Basin would have the lowest precipitation, which would be 131.34mm, 143.98 mm, 154.25mm and 158.26 mm in the period T1, T2, T3 and T4 respectively; there would have an increase of 1.92mm in every decade averagely, which is much lower than the increasing rate in the whole western region of China.

The desert ecological zone in Tarim Basin and east Xinjiang would have the highest potential evapotranspiration ratio, which would be 6.38, 5.56, 5.95 and 5.95 respectively in the periods T1, T2, T3 and T4; from T1 to T2, there would appear a decreasing trend and from T2 to T4 an upward trend. Frigid meadow ecological zone in South Tibet mountainous area would have the lowest potential evapotranspiration ratio, which would be 0.07, 0.11, 0.13 and 0.15 in the periods T1, T2, T3 and T4 respectively and show an ascending trend for nearly 0.01 in every decade.

5.2. Scenarios of terrestrial ecosystems

It is studied how are about climate variety with elevation change in Changbai Mountains, Da-xiao Hinggan Mountains, Qinghai_Tibet Plateau, Hengduan Mountains, Loess plateau, Nanling Mountains, Qilian Mountains, Qinling Mountains, Taihang and Lvliang Mountains, Tianshan Mountains, Wuling Mountains, Wuyi Mountains, Himalaya Mountains, Yanshan Mountains and Yunnan-Guizhou Plateau. In terms of the research results of climate variety in different areas, data from scenarios of HadCM2d1 and

HadCM3A1FI are used to analyze scenarios of HLZ ecosystems in the west region of China during periods of T2 (from 2010 to 2039), T3 (from 2040 to 2069) and T4 (from 2070 to 2099).

5.2.1. Spatial distribution of HLZ ecosystems

5.2.1.1. Results based on HadCM2d1

According to HadCM2, there were 30 types of HLZ ecosystems in the period T1. Subtropical desert scrub would appear in the north of low Altun Mountains in the period T2, subtropical desert appear in the eastern Tarim Basin in the period T3, and tropical wet forest appear in archipelagoes of China South Sea in the period T4 (Figure 5.8).

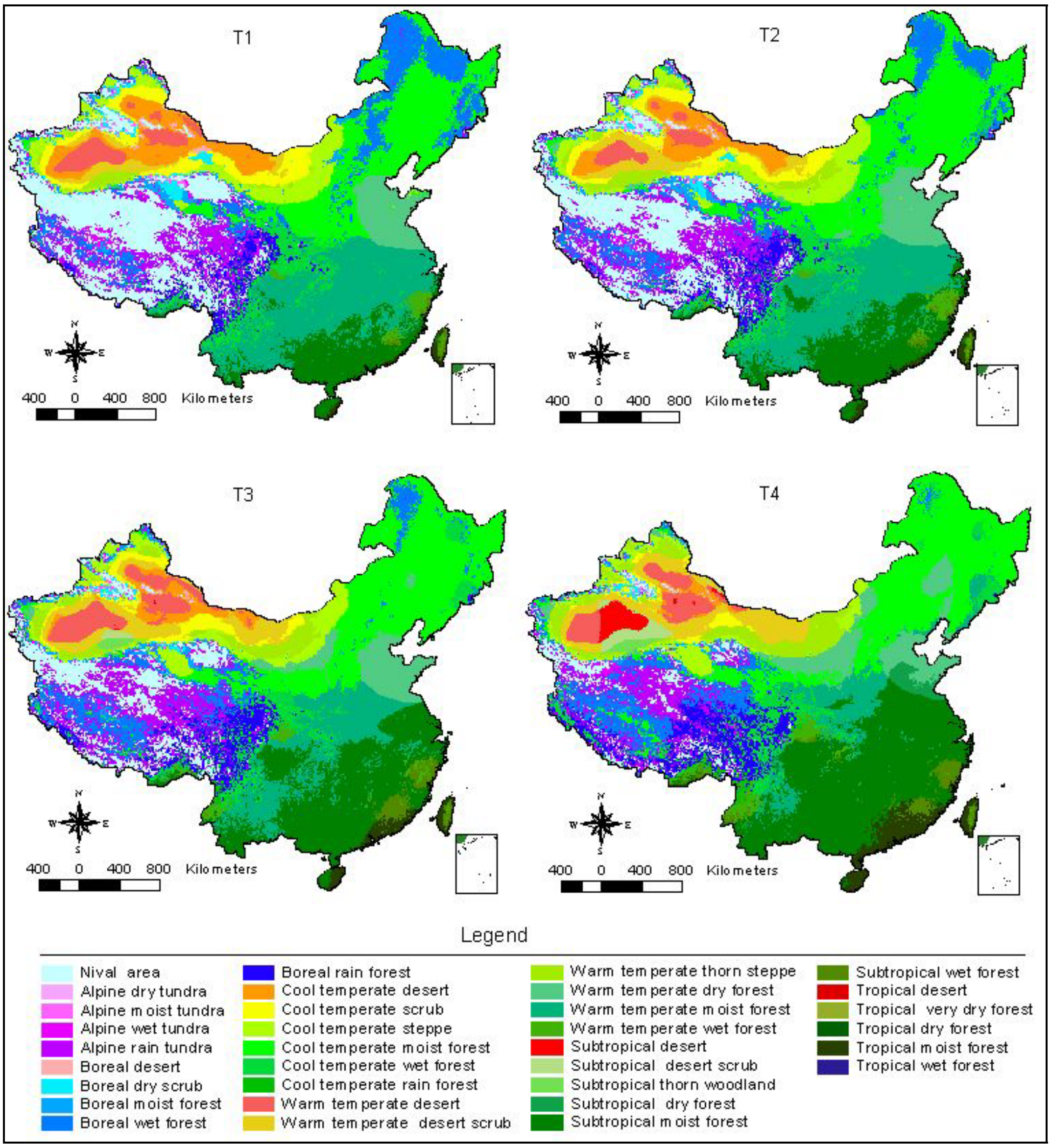

Figure 5.8. Spatial distribution of HLZ ecosystems in China based on HadCM2d1

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

5.2.1.2. Results based on HadCM3A1FI

According to HadCM3, there existed 28 types of HLZ ecosystems in the period T1. Tropical dry forest would appear in the southwestern Yunnan and the southwestern Hainan in the period T2. In the period T3 subtropical desert would appear in the eastern Tarim Basin and would have a rapid expansion trend;

subtropical thorn woodland would appear in the north of low Altun Mountains; subtropical desert scrub would appear in the area between the subtropical desert and the subtropical thorn woodland that newly appeared in the period T3. Subtropical dry forest distributed in southwest Yunnan in the period T1, which would disappear in T2 and T3, and would appear in Taishan Mountain area of North China plain in the period T4 once again (Figure 5.9).

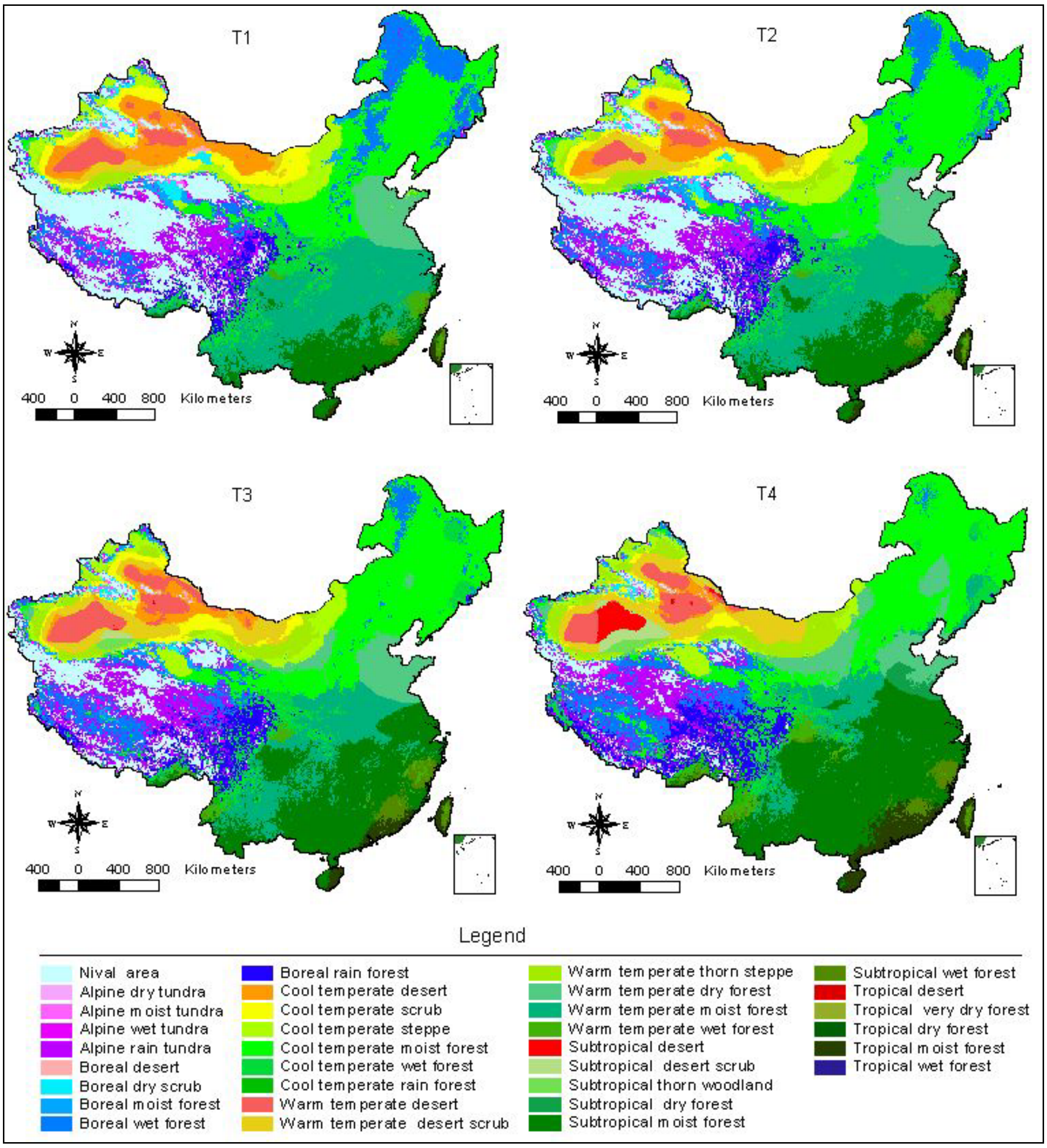

Figure 5.9. Spatial distribution of HLZ ecosystems in China based on HadCM3A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

Boreal desert would mainly distribute in Beishan Mountain area of the northern Qinghai-Tibet Plateau, Tarim Basin and the north of Turpan Basin; tropical desert would mainly distribute in centric areas of Tarim Basin, Turpan Basin and Junggar Basin; warm temperate desert would mainly exist around tropical desert and inner cool temperate desert that would mainly distribute in the middle of Alashan plateau and Junggar Basin.

Cool temperate scrub, warm temperate desert scrub and subtropical desert scrub would mainly distributed in peripheries of the northern Qinghai-Tibet Plateau, the western Tarim Basin, the western and northeastern Junggar Basin as well as the southeastern Alashan plateau and the southwestern Inner Mongolian plateau. Boreal dry scrub would mainly distribute in low mountain areas of Qinghai-Tibet Plateau, Tianshan Mountains and Qilian Mountains. Cool temperate steppe would mainly distributed in Mongolian plateau, loess plateau and the southwest of Northeast plain; warm temperate thorn steppe would mainly distribute in the southeast of Himalaya Mountains, the northwest of Tianshan Mountains, Qarqan river area of the northern Altun Mountains and Yarkant river area of the western Tarim Basin.

Boreal moist forest, boreal wet forest, boreal rain forest, cool temperate moist forest and cool temperate wet forest would mainly distribute in the east and the south of Qinghai-Tibet Plateau, Da Hinggan Mountains, Xiao Hinggan Mountains and Taihang Mountains; warm temperate dry forest mainly distribute in the most part of North China plain. Warm temperate moist forest and warm temperate wet forest would distribute in the north of Yunnan-Guizhou plateau and the most part of lower reaches of Yangtze River. Subtropical dry forest, subtropical moist forest and subtropical wet forest would mainly distribute in the south of Yunnan-Guizhou plateau, Nanling Mountains, Jiangnan hills and its south, and high mountains of Taiwan. Tropical dry forest would distribute in the western Hainan; tropical moist forest distribute in the eastern Hainan, Hong Kong and low mountains of Tainwan; tropical wet forest mainly distribute in archipelagoes of China South Sea.

In terms of HadCM2 and HadCM3, the nival areas in Qinghai-Tibet Plateau would shrink towards northwest rapidly and the ones in Tianshan Mountains and Qilian Mountains would shrink back to mountaintops with bio-temperature and precipitation increase. The shrinking speed simulated on the basis of HadCM3 is more rapid than the one simulated on the basis of HadCM2. Except for desert and desert scrub, warm temperate types of HLZ ecosystems and subtropical types of HLZ ecosystems currently distribute in the south of Yangtze River, while they would cross Yangtze River and shift towards the north in the future. Tropical dry forest and tropical moist forest would expand from southeast coastal area towards the north, of which the expansion speed based on HadCM3 would faster than the one based on HadCM2. Arid types of HLZ ecosystems such as warm temperate desert scrub and warm temperate thorn steppe would continuously increase, which means that desertification might become more serious in the 21st century in China.

5.2.2. Average area scenarios of HLZ ecosystems

Area of arid and cold types of HLZ ecosystems would gradually decrease, into which types of HLZ ecosystems living in arid and warm environment such as warm temperate desert scrub, warm temperate thorn steppe and warm temperate dry forest would expand. Nival areas, cool temperate moist forest, warm temperate moist forest, subtropical moist forest and boreal wet forest would be the first five types of HLZ ecosystems that have the biggest areas according to both HadCM2 and HadCM3; area of the five types of HLZ ecosystems is greater than 50% of the whole terrestrial land of China. Among these five types of HLZ ecosystems, nival areas, warm temperate moist forest and boreal wet forest would continuously decrease by $3.8\times10^7 hm^2$, $4.3\times10^7 hm^2$ and $1.6\times10^7 hm^2$ respectively during the four periods; subtropical moist forest and cool temperate forest would continuously increase by $6.0\times10^7 hm^2$ and $2.5\times10^7 hm^2$ respectively (Figure 5.10 and 5.11). These changes would make a considerable modification to terrestrial ecosystem services in China.

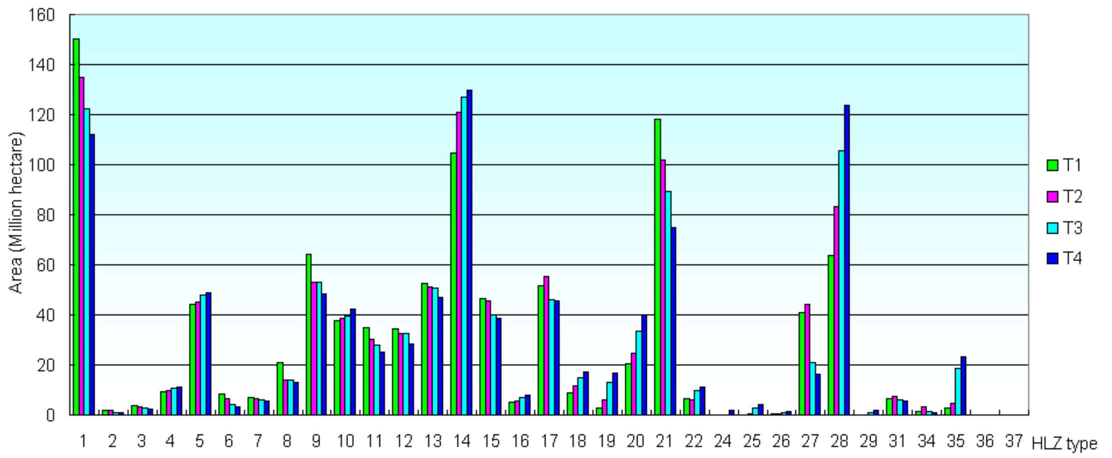

Figure 5.10. Area change of HLZ ecosystems in China based on HadCM2d1

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

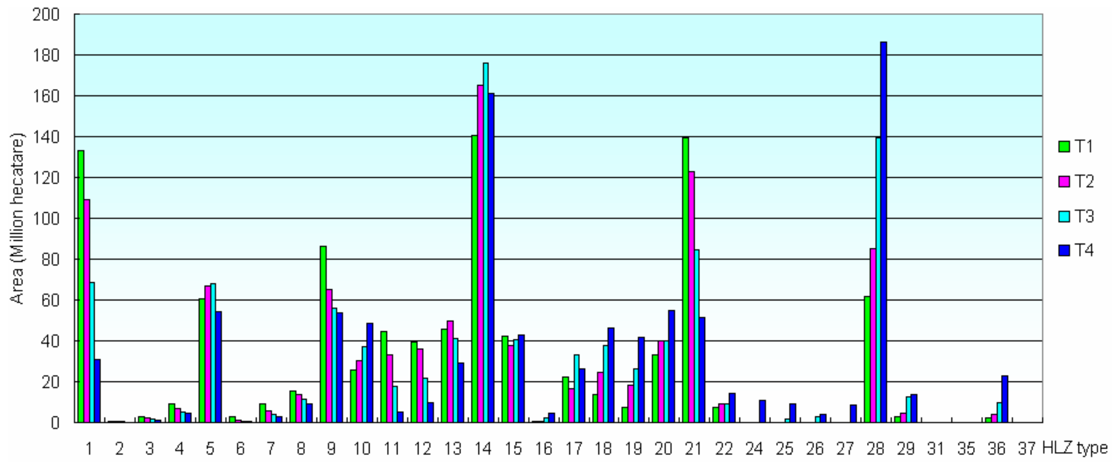

Figure 5.11. Area change of HLZ ecosystems in China based on HadCM3A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

5.2.3. Mean center of HLZ ecosystems

In terms of the mean center model, the shift ranges of mean centers of HLZ ecosystems simulated by HadCM3 data are obviously greater than the ones simulated by HadCM2 in general. The results from both HadCM2 and HadCM3 show that boreal wet forest, subtropical moist forest, tropical dry forest, warm temperate moist forest and subtropical wet forest have a bigger shift range, which means that these types of HLZ ecosystems are much more sensitive to climate change (Figure 5.12). The continuous shift of both boreal dry scrub and cool temperate scrub towards northwest in the 21st century means that types of HLZ ecosystems living in arid environment would evolve towards northwest with temperature and precipitation increase in northwest China. Mean centers of alpine moist tundra and cool temperature wet forest would shift towards north in general, which is caused by area expansion of the two types of HLZ ecosystems in high mountains of north China with precipitation increase in north China. Types of HLZ ecosystems living in cold and frigid environment such as alpine moist would be replaced by other types of HLZ ecosystems such as boreal wet forest so that relative ratio of area of boreal forest living in Qinghai-Tibet Plateau to the one living in Da Hinggan Mountains, Xiao Hinggan Mountains and Changbai Mountains would become greater in the 21st century because of temperature and precipitation increase in Qinghai-Tibet Plateau, which would lead to the great shift of mean center of boreal forest towards southwest. In short, climate change would cause a considerable change to spatial pattern of terrestrial ecosystems in China, to which human activities have a great contribution.

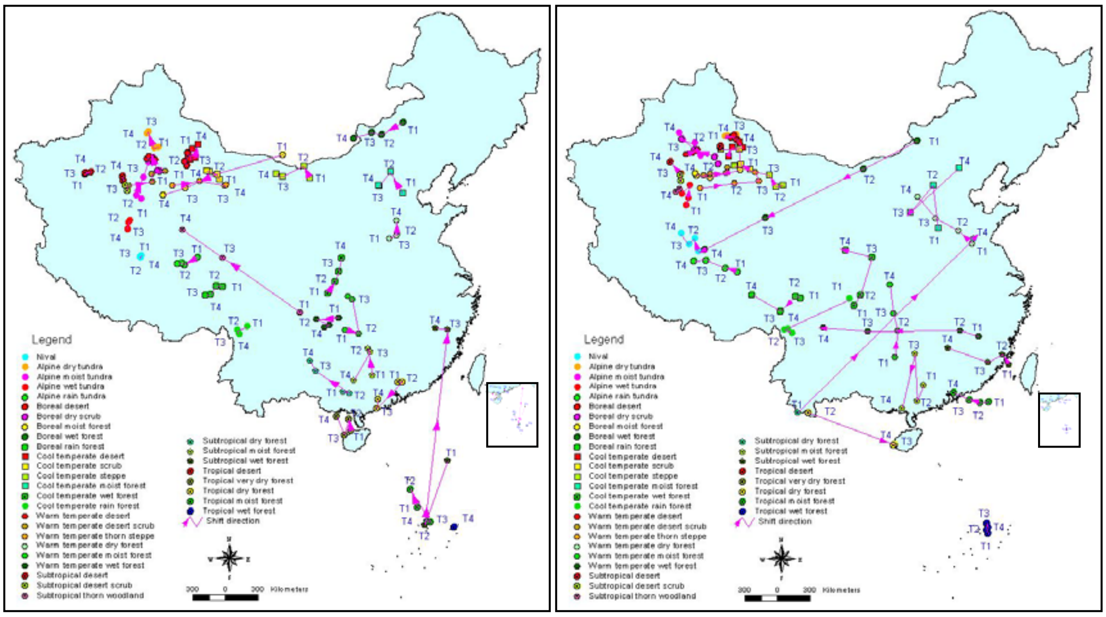

Figure 5.12. Shift trend of HLZ ecosystems in China

(left map: based on HadCM3A1FI; right map: based on HadCM2d1)

5.2.4. Ecological diversity and patch connectivity

Results from operating diversity index and patch connectivity index show that HLZ diversity and patch connectivity would continuously increase during the four periods. The increase rates of HLZ diversity and patch connectivity in terms of HadCM2 would respectively be 0.22 % and 0.14% per decade on an average; the ones in terms of HadCM3 would respectively be 0.38% and 0.42% per decade. The continuous increase of HLZ diversity and HLZ patch connectivity might imply that climate change would make the terrestrial ecosystems favor human wellbeing in China according to the relative research conclusions (Yue et al., 2001, 2003).

5.3. Scenarios of Land Cover

Land cover types show very apparent regional diversity in China because of the regional discrepancy on spatial hydrothermal distribution and the influence of the continental monsoon climate. In addition, the discrepancies in bio-temperature and precipitation between southern China and northern China and between eastern and western China results an apparently zonal distribution in agricultural land, forest land, grassland and other land cover types. In the future 100 years, with the continuous change of the climate factors such as bio-temperature, precipitation and potential evapotranspiration ratio and the intensification of the human activities, the land cover in China would take a series of changes. Because the three land cover scenarios, simulated on the basis of HadCM3A1FI, HadCM3A2a and HadCM3 B2a, have their similar patterns (Figures 3.13-3.15), the general conclusions among them are presented.

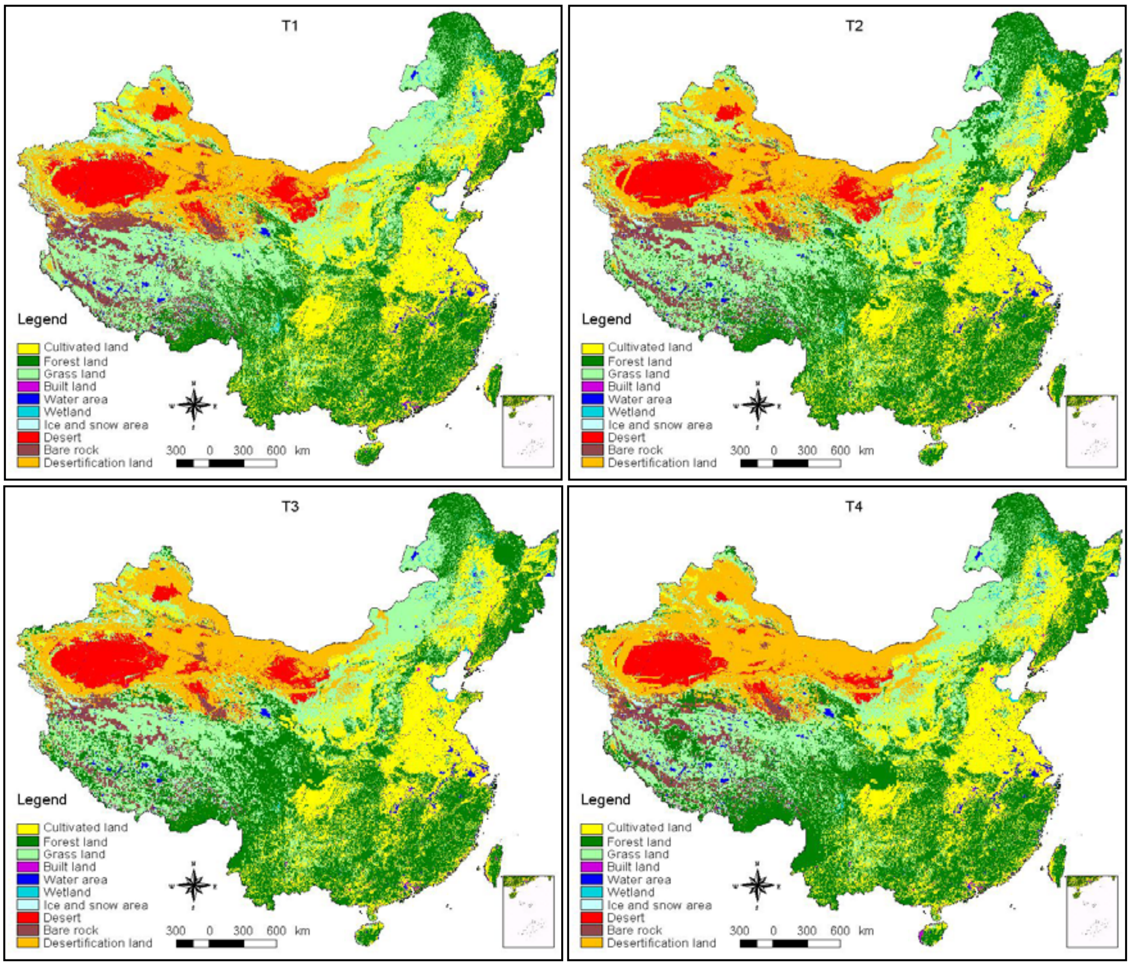

Figure 5.13. Land cover scenarios based on HadCM3 A1FI

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

5.3.1. Spatial distribution of land cover types

5.3.1.1. Spatial distribution of cultivated land

In future 100 years, the cultivated land in China would be in principle divided into two production areas, agricultural region and livestock farming region taking Da-xiao Hinggan Mountains-Yulin-Lanzhou-the east Qinghai-Tibet Plateau and its southeast edge as their border. The cultivated land in China mainly would distribute in northeast Plain, north China Plain, middle and lower reaches of Yangtze River, Sichuan Basin and Guanzhong Basin. Hexi Corridor of Gansu and alluvial fan in the north and south of Tianshan Mountain would have the relatively concentrated cultivation land. In addition, a plenty of cultivated land would be distributed broadly and discontinuously in hilly areas of southern China, with other land cover types together, such as forest and meadow.

5.3.1.2. Spatial forest distribution

The complicated terrain characteristics and diversified climate lead to great different characteristics of spatial forest distribution. In the future 100 years, forest in northeast China would mainly distribute in Da-Xiao Hinggan Mountains, Changbai Mountains and East Liaoning Basin; in southwestern China, forest would mainly distribute in areas of Himalaya Mountains and Hengduan Mountains in the east and south of Yalu Tsangpo river in Tibet, mountainous range around Sichuan Basin, Yunnan-Guizhou plateau and most hilly areas in Guangxi. In southeastern China, Forest would mainly distribute in the low mountainous and hilly areas such as Wuyi Mountains, Nanling ridges, Hills and Taiwan Mountains. In northwestern China, the woodland would mainly distribute in the mountainous areas of Tianshan Mountain, Altai Mountains, Qilian Mountains, Ziwu Mountain, Helan Mountain, Liupan Mountain and Yinshan Mountain, In short, forest and woodland in China would mainly distribute in mountainous and hilly areas.

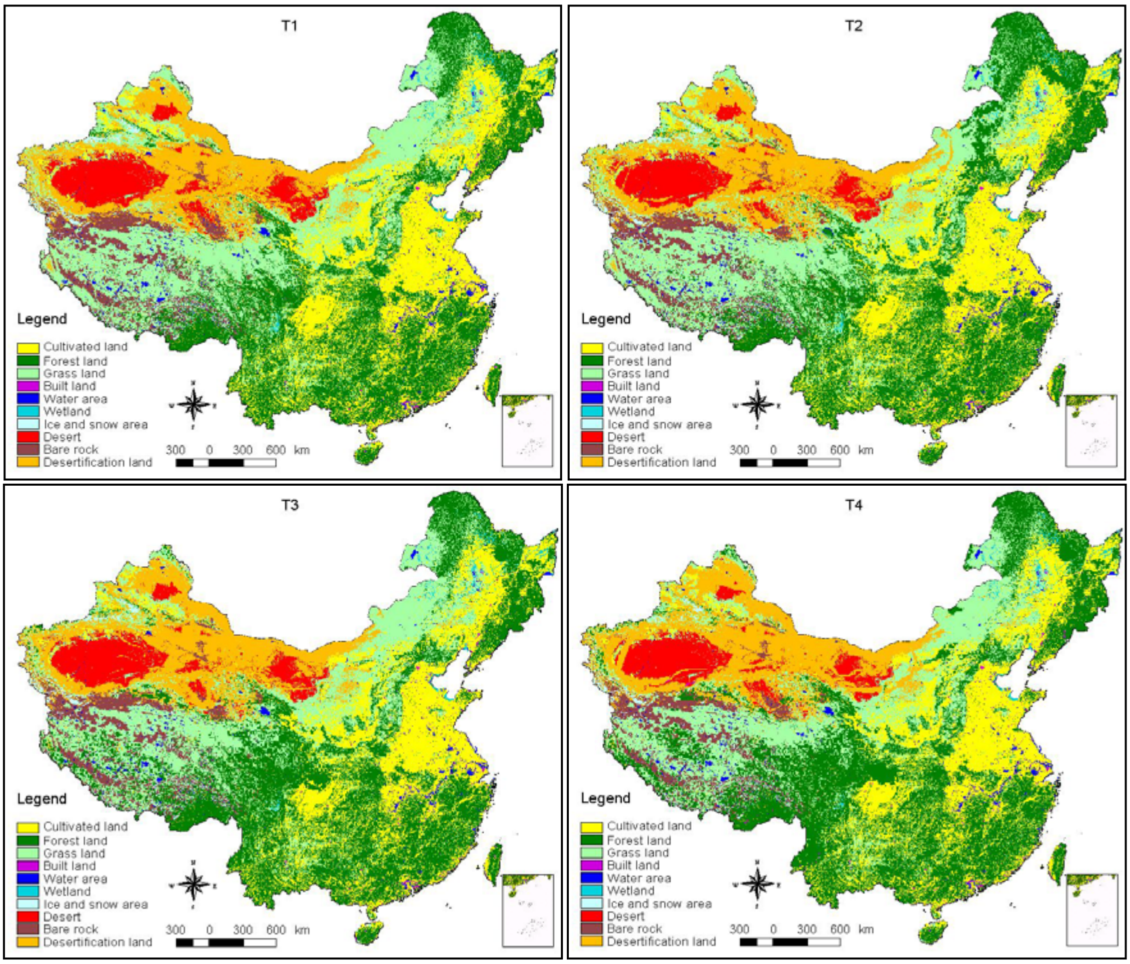

Figure 5.14. Land cover scenarios based on HadCM3A2a

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

5.3.1.3. Spatial distribution of grassland

In future 100 years, grassland would mainly distribute in western China and comparatively less in eastern China. Geographically, the grassland would mainly distribute in Qinghai-Tibet Plateau, Inner Mongolia plateau, Loess Plateau, Tianshan Mountains, Altai Mountains and areas around Tarim Basin. In the meanwhile, some grassland would scattered in hilly areas of Hunan, Hubei, Anhui, Fujian, Yunnan, Guizhou, Sichuan, Guangdong, Guangxi and Taiwan and mix with woodland.

5.3.1.4. Spatial distribution of water systems

Water systems in China, which include rivers and lakes, have a considerable effect on human population distribution. Rivers can be divided into oceanic ones that discharge into oceans and inland ones that start in mountainous areas and disappear in conoplain or flow into inland lakes. The oceanic system can be sub-divided into Pacific, Indian and Arctic drainage basins, accounting for 64% of the total land area in China. The inland system includes a few perennial rivers and has large tracts with no runoff, accounting for 36% of the total land area in China (Zhao, 1986).

The Pacific oceanic subsystem accounts for 88.9% of the total oceanic system; rivers flowing into the Pacific ocean include Heilongjiang river, Liaohe river, Luanhe river, Haihe river, Yellow river, Yangtze River, Qiantangjiang river, Zhujiang river, Yuanjiang river, Lancangjiang river. The Indian oceanic subsystem accounts for 10.3% of the total oceanic system; rivers flowing into the Indian ocean have only their upper reaches located in China, including Nujiang river, Longchuan river, Yarlu Zangbujiang river, and Shiquan river. The Arctic oceanic subsystem has only one large river, Ertix river that is a tributary of the ob river; it accounts for 0.8% of the total oceanic system.

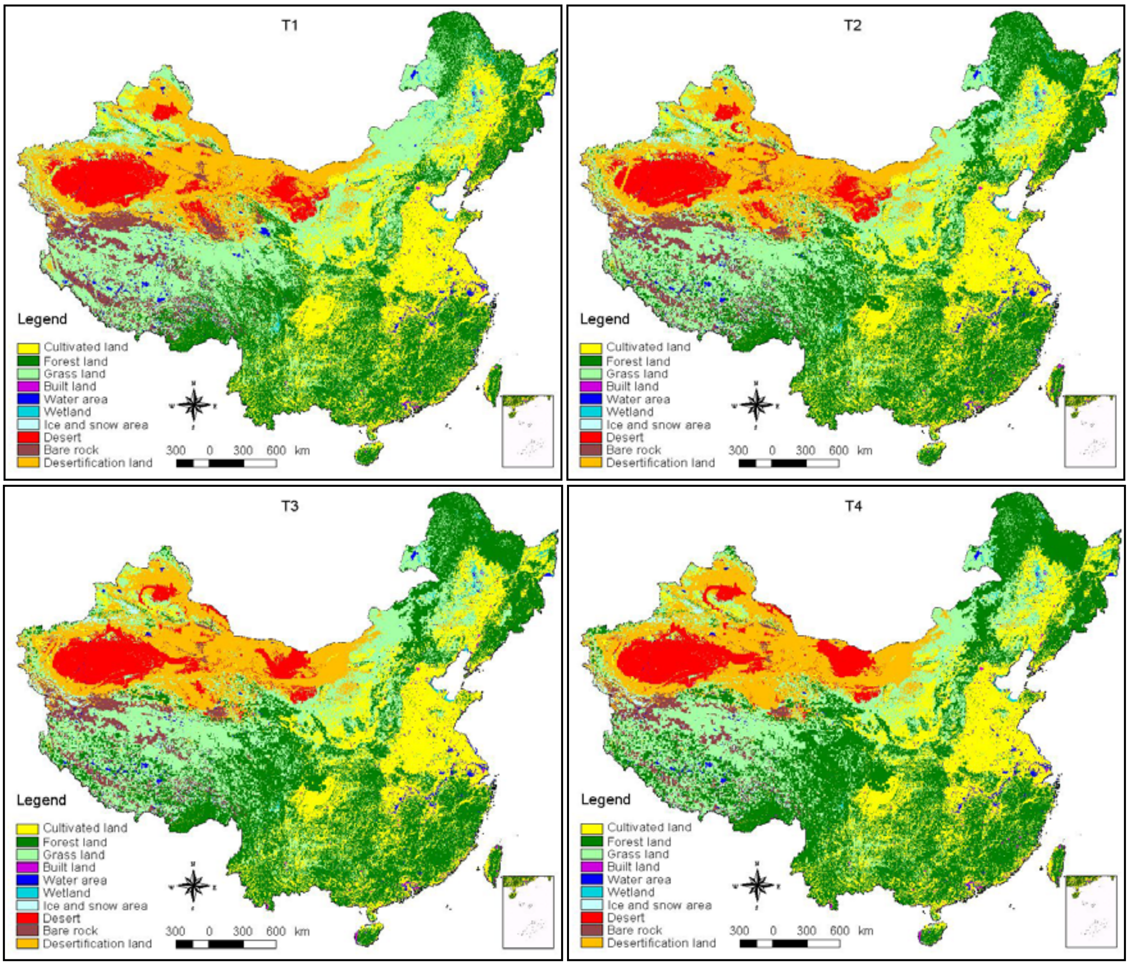

Figure 5.15. Land cover scenarios based on HadCM3B2a

(T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively)

The inland river system is mostly located in arid and semiarid Northwest China, the northwestern Qinghai-Tibet Plateau, and the central Ordos plateau. The great divide between inland and oceanic river systems runs essentially northeast-southwest, starting from the southern end of Da-Xing-An-Lin Mountains, passing through Yanshan, Helanshan, the eastern Qilian, Bayan Har, Nyainqentanglha, and Gangdise Mountains, and up to the southwestern margin of Qinghai-Tibet Plateau.

Five major lake regions can be identified, which are the northeast lake region, the northwest lake region, the Qinghai-Tibet lake region, the eastern lake region and the southwest lake region. They include 2800 natural lakes approximately, each with an area greater than $1km^2$ and many reservoirs that are artificial lakes. In the northeast lake region, there exist large tracts of marsh and numerous small lakes with a total lake area $3.72\times10^3km^2$. The northwest lake region is located in extensive arid and semiarid northwest China; there are numerous inland lakes with a total area of 2.25×10^4 km^2. In the Qinghai-Tibet lake region, the lakes are fed by melting snow and the lake basins are mainly controlled by tectonic structure, with a total lake area of 3.10×10^4 km^2. The eastern lake region is mostly located in the middle and lower reaches of the Yangtze River, Huaihe River, and Zhujiang River, with a total lake area of 2.22×10^4 km^2. The southwest lake region is located in Yunnan-Guizhou plateau, mostly in Karst area, with a total lake area of 1.189×10^3 km^2.

5.3.1.5. Spatial distribution of construction land

Construction land mainly distributes in the areas near rivers or valleys, with abundant water resources, convenient traffic, fertile soil and plentiful products, which are determined by characteristics of urban development and built land. Because of joint affection of various factors such as geographical features and social-economic conditions, in eastern China, the construction land would mainly distribute in Northeast Plateau, North China Plain, Plain in the middle and lower reaches of Yangtze River, Yangtze River Delta and Pearl River Delta in the future 100 years. In western China, construction land would mainly distribute in the areas with good climatic, social-economic and traffic conditions, which would include Sichuan Basin, Guanzhong Basin in Shaanxi, Hetao Plain in Ningxia, Hexi Corridor in Gansu and Xinjiang Oasis. In general, construction land would comparatively centralize in provincial and prefectural capitals.

5.3.1.6. Spatial distribution of other land cover types

In the future 100 years, nival cover would mainly distribute in areas of mountainous ridges in Tianshan Mountains, Qilian Mountains, Kunlun Mountains, Himalaya Mountains and Hengduan Mountains. Deserts would mainly distribute in Junggar Basin, Tarim Basin, Qaidam basin and Alashan Plateau. Bare rocks would mainly distribute in Qinghai-Tibet Plateau, the east of Turpan Basin, and Karst area in the southwest China. Desertification land would mainly distribute in outside areas of deserts in the northwest and inside areas of meadows.

5.3.2. Change of land cover types

In the future 100 years, with the continuously rising bio-temperature, increasing precipitation and strengthening human activities, cultivated land that would distribute in the north and the south of Tianshan Mountain, Hexi Corridor of Gansu and the south of Inner Mongolia Plateau would gradually decrease with the desert expansion. Cultivated land would continuously decrease in Loess Plateau.

Grassland, wetland, water area and nival area would decrease, while woodland would increase in Qinghai-Tibet Plateau. With the increasing precipitation and rising bio-temperature, bare rocks would decrease and some of them would convert into grassland.

Deserts would expand, in which desertification in Tarim Basin and Junggar Basin would spread out with the irregular circle shape. Desertification in Inner Mongolia Plateau would extend towards the east and the southeast. Desertification in Loess Plateau would become more serious.

Woodland density all mountains in northern China would increase and spatial scope of forestland would have an expanding trend with the rising bio-temperature and increasing precipitation. Woodland and grassland in hilly areas would have an increasing trend with decrease of cultivated land in southern China.

Construction land would show a continuously increasing trend. Urban construction areas would continuously enlarge in Northeast Plateau, North China Plain, Plain in the middle and lower reaches of Yangtze River, Yangtze River Delta and Pearl River Delta. Built land would increase in countryside. Land for transportation would expand.

5.3.3. Area changes of land cover types

Results of three land cover scenarios based HadCM3A1FI, HadCM3A2a and HadCM3B2a show that in the future 100 years land-cover types, of which area would increase, include woodland, construction land

and desertification land. Land-cover types that area would decrease include cultivated land, grassland, wetland, nival area, desert (except increasing desert shown by B2a scenario), and bare rock.

From period T1 to T4, woodland would have the greatest increasing rate that would be 2.34% in every decade on an average. Bare rock would have the fastest decreasing rate that would be 2.38% in every decade on an average. The rate of cultivated land converting into woodland would slow down gradually from the period T1 through T2 and T3 to T4. The rate of converting grassland into desert would speed rate from the period T1 to T4.

5.3.4. Ecotope diversity and patch connectivity of land Cover

In the future 100 years, ecotope diversity of land cover would show a decreasing trend, while patch connectivity would increase continuously. The simulation result based on HadCM3 A1FI shows that the decease rate of the ecotope diversity would be 0.16% in every decade on an average and the increasing rate of the patch connectivity would be 2.16% per decade. The result based on HadCM3 A2a indicates that the decrease rate of ecotope diversity would be 0.11% per decade on an average and the increasing rate of patch connectivity would be 2.15% per decade. The calculation result based on HadCM3 B2a represents that the decrease rate of ecotope diversity of land cover would be 0.25% per decade on an average and the increasing rate of patch connectivity would be 3.83% per decade.

5.3.5. Mean center shift of land cover types

The simulation results (Figure 5.16) based on HadCM3A1FI, HadCM3A2a and HadCM3B2a show that the mean center of cultivated land would wander about Nanyang of Henan province in the southwest of North China Plain with a trend shifting towards the southwest. The mean center of woodland would wander about the range from Yichang of Hubei province to Wanxian county of Chongqing with a trend shifting towards the southwest. The mean center of grassland would wander about the area around Qinghai Lake; in terms of simulation results based on HadCM3A1FI and HadCM3A2a the mean center would shift towards the northeast; mean center based on HadCM3B2a would shift towards the west. The mean center of construction land would wander about the adjacent area of Anhui, Henan and Hubei with a trend shifting towards the southwest. The mean center of water area would wander about upper reaches of Weihe River in the south of Gansu with a trend shifting towards the east. The mean center of wetland would wander about Tongliao in Northeast Plain with a shifting trend towards the east. The mean center of nival areas would wander about the adjacent area Kunlun Mountains and Arjin Mountains with a shifting trend towards the southwest. The mean center of desert would be wander about the eastern area of Tarim Basin with a shifting trend towards the west. The mean center of bare rock would wander about the around area of Kekexili Mountain in Qinghai-Tibet Plateau with a shifting trend towards the west. The mean center of desertification land would wander about the northwest of Qaidam basin with a shifting trend towards the southeast.

In the periods T1 and T2, the shift distances of the mean centers of the land cover types would be shorter than the one in other periods, which shows land cover change would be faster and faster in the future 100 years with the rising bio-temperature and increasing precipitation. The shift distance of the mean center of cultivated land would be shorter than the one of other land cover types.

In short, in the future 100 years, ecosystems in western China would have a pattern of healthy cycle after efficient ecological construction and restoration. If human activities would exceed regulation capacity of ecosystems themselves, the ecosystems in western China might be deteriorated more seriously.

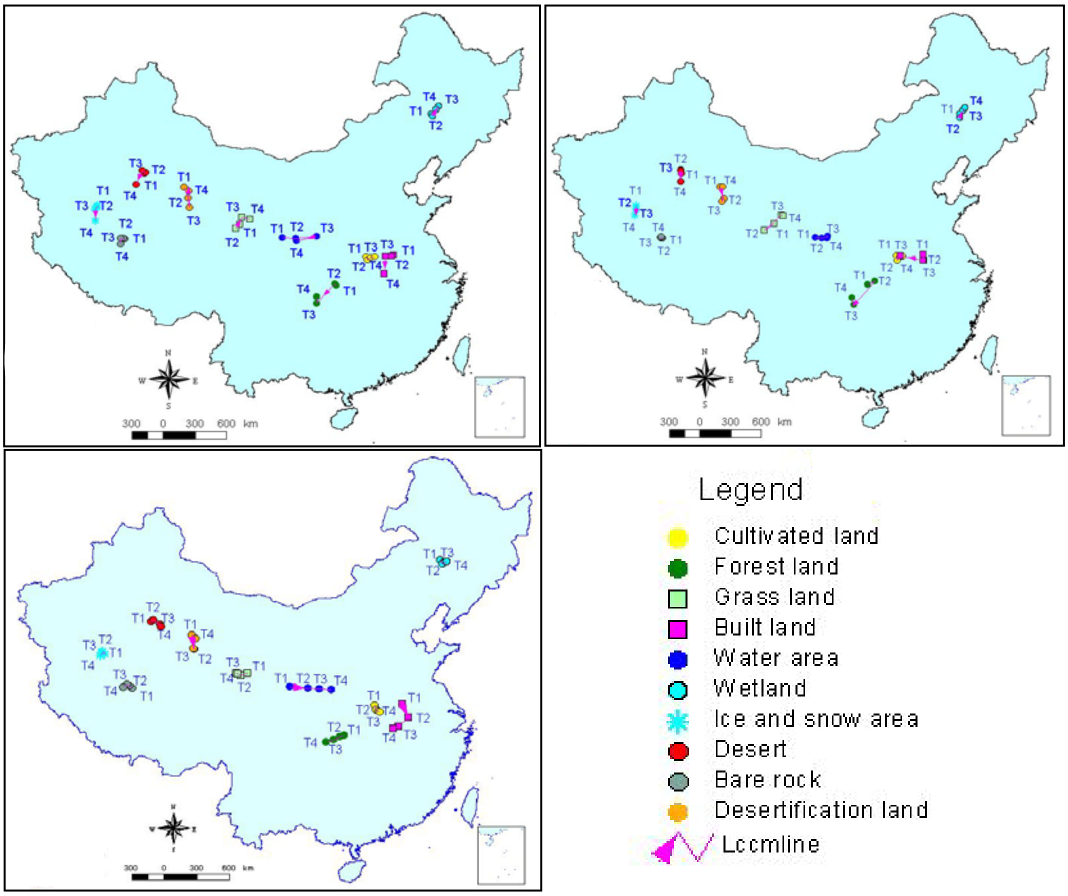

Figure 5.16. Shift trend of mean center of land cover types

(upper left map: based on HadCM3 A1FI; upper right map: based on HadCM3 A2a; lower left map: based on HadCM3 B2a. T1, T2, T3 and T4 represent the periods from 1961 to 1990, from 2010 to 2039, from 2040 to 2069 and from 2070 to 2099 respectively.)

5.4. Food provision

5.4.1. Scenarios of climatic change effects on food provisioning service

In terms of simulated results about the zonal climate variations of China, three climate scenarios of HadCM3 during the period 2010 to 2039 are modified. On the basis of the simulation of climatic scenarios, scenarios of food provisioning capacity of terrestrial ecosystems in western China are developed (fig5.7)

It can be seen from the figure that food provisioning capacity of the ecosystems in the western areas would be on the rise under the three different scenarios, and that the spatial distribution pattern would be similar in general. In the northwestern China including the western Inner Mongolia and western part of it, the Tianshan Mountain and the southern part of Tianshan Mountain, and the northern Qinghai-Tibet Plateau and the northern part of it, there would be a relatively high increasing degree. In the eastern Inner Mongolia, Guangxi, Yunnan and some parts of the Qinghai-Tibet Plateau, the food supply capacity drops slightly or changes little. Although there would be a certain increase in the other areas of the western China, the increasing degree would be obviously lower than that in the Northwestern. The fast growth pattern of the food supply capacity in the arid area of the northwest China would basically be similar to the patterns as influenced by precipitation, reflecting that precipitation would play a leading role in food supply capability in these regions.

Comparing the changes of food provisioning service in the three scenarios, we can find out many differences among them. In general, the change of the food supply would be relatively higher under scenario B2, while scenario A1 would take the second place, and scenario A2 would rank the last. Under B2 scenario, the food supply capacity would drop in Caidamu Basin and few other areas of the southwestern China, and would not vary too much in the middle and south Guangxi, middle Yunnan and west Qinghai-Tibet Plateau, the influential coefficient of the other areas would be all below 105%. In the eastern Qinghai-Tibet Plateau, Hengduanshan mountainous area, and east part of Inner Mongolia, the influential coefficient would reach over 115%. Under scenario A1, the number of the areas with an increasing trend in the food supply capacity would be increasing, while those with increasing potentials would have a slight annual increase or decrease trend. In the Northeast and southwest of Qinghai-Tibet Plateau, the range of capacity receding would expand further on the original basis, and in the northern Sichuan and some areas south of Yunnan, food supply capacity would begin to drop to some extent. There would be other areas with less changes including Sichuan Basin, the entire Guangxi, the south of Gansu and some parts in the east of Inner Mongolia; in the middle and east of Inner Mongolia, it can be found scarcely that the potential influential coefficient would be higher than 115%. Under scenario A2, the areas with the influential coefficient greater than 125% distributed mainly in the Northwest China, and the areas with receding capacity include southeast Qinghai-Tibet Plateau and northern territories of the Hengduanshan mountainous areas and the Chifeng and Tongliao areas in Inner Mongolia. Compared with scenario A1, the potential influential coefficient would be relatively lower in the southeast of the Qinghai-Tibet Plateau, and most parts of Yunnan, but it rises a little in Sichuan Basin, mostly above 105%.

Statistics of food provisioning capacity changes with each ecosystem as affected by climatic changes in western China demonstrated that potential of ecosystems would vary at different areas, and under different scenarios of climatic change. On the whole, the food provisioning potential of the aquatic ecosystem in the western China would present a downward trend, while the food provisioning potential of the farmland ecosystem, the grassland ecosystem and the forest ecosystem all would rise to some extent.

In the last three ecosystems, influential coefficient of food provisioning potential in grassland ecosystem would be greater than that in the farmland ecosystem, while forest ecosystem would be the least. At different scenarios of climatic change, the change under scenario B2 in the aquatic ecosystem would be slightly smaller than that in scenarios A1 & A2, in the other three ecosystems, changes of scenario B2 would be greater than that of scenario A1, and A1 would be greater than that of scenario A2. However, the difference would be not big under different scenarios of the same ecosystem in the same area. Taking the western region of China as an example, it would differ by 0.03 between B2 and A2 in agricultural and forest ecosystems, while in grassland ecosystem, the difference between B2 and A2 would be 0.05, and in the aquatic ecosystem, difference between B2 and A1 and A2 would be only 0.02 respectively.

The results above reflect a general situation of the western region of China. As far as different ecosystems are concerned, the difference between the areas is huge. The regional disparity of different ecosystems will be analyzed according to average changes in the three climatic scenarios.

As for agricultural ecosystems, except that there would be decrease in frigid meadow ecological zone in south Tibet mountainous area, food provisioning potential would increase in other 29 ecological zones (Figure 2.2 and Table 2.1). Five of them including frigid desertification grassland ecological zone in the Pamir-Kunlun-Aerjin Mountains, desert ecological zone in Tarim Basin and the east Xingjiang, desertification ecological zone in the west of the Inner Mongolia plateau and the North Mountain, desertification ecological zone in the middle part of the Inner Mongolia plateau; and forest and grassland ecological zone in Tianshan Mountain, would share the highest increasing rate. And the five ecological zones including tropical seasonal rain forest and rain forest ecological zone in the south of Guangxi and Yunnan, taiga ecological zone in eastern Tibet and the south of Sichuan, ecological zone of subtropical evergreen broad-leaved forest in the Nanling, ecological zone of subtropical monsoon evergreen broad-leaved forest in the middle of Guangxi and Yunnan, and agricultural ecological zone in the Fenhe river and Weihe river Basin would have the least increase rate of food provisioning potential.

As to grassland ecosystems, the food provisioning potential of every ecological zone would increase to some extent, but the increasing degrees differ greatly from each other. The five ecological zones that would have the biggest increasing rate include Desert ecological zone in Tarim Basin and eastern Xinjiang, ecological zone of frigid desertification grassland in Pamirs-Kunlun-Aljin Mountains, ecological zone of temperate arid desertification in Ali mountain, Desertification ecological zone in central and western Inner Mongolia Plateau and Beishan Mountainous area, forest and grassland ecological zone in Tianshan Mountainous area, of which potential influential coefficient would be greater than 1.20. The five ecological zones that would have the least increasing rate include frigid grassland ecological zone in mountainous area of the southern Tibet, ecological zone of frigid desertification grassland in the north Tibet plateau, ecological zone of tropical monsoon evergreen broad-leaved forest in the middle Guangxi and Yunnan, and ecological zone of tropical seasonal rainforest and rainforest in the south Guangxi and Yunnan, of which their potential influential coefficient would be smaller than 1.06.

For the forest ecosystems, spatial change characteristics of food provisioning potential would be similar to grassland ecosystems. Food provisioning potential in all ecological zones would increase. The five ecological zones that would have the highest increasing rate include ecological zone of frigid desertification grassland in Pamirs-Kunlun-Aljin Mountains, desertification ecological zone in Tarim Basin and eastern Xingjiang, desertification ecological zone in Caidamu Basin, Desertification ecological zone in central and western Inner Mongolia Plateau and Beishan Mountainous area, and ecological zone of forest and grassland in Tianshan Mountainous area, of which their potential influential coefficients would be greater than 1.25. The five ecological zones that would have the least increasing rate include frigid grassland ecological zone in mountainous area of the southern Tibet, ecological zone of frigid desertification grassland in the north Tibet plateau, ecological zone of tropical monsoon evergreen broad-leaved forest in the middle Guangxi and Yunnan, ecological zone of tropical seasonal rainforest and rainforest in the south Guangxi and Yunnan, ecological zone of subtropical evergreen broad-leaved forest in Nanling Mountains, agricultural ecological zone of in northeast China plain, of which potential influential coefficients are smaller than 1.06.

For aquatic ecosystems, spatial variations of food provisioning potential would be quite different from that of the other three kinds of ecosystems. The most outstanding feature would be that a lot of areas would be affected negatively. The five ecological zones with the highest increasing rate of food provisioning capacity include loess plateau ecological zone in Shaanxi-Gansu-Ningxia, desertification ecological zone in the middle of the Inner Mongolia plateau, desert ecological zone in Junggar Basin, ecological zone of forest and grassland ecosystem in Altai Mountains and the west of Junggar Basin, and Desertification Ecological Zone in Caidam Basin, of which their potential influential coefficients would be greater than 1.28. The five ecological zones that would have the greatest decreasing rate include taiga ecological zone in frigid-temperate area of northern Da Hinggan Mountains, ecological zone of deciduous broad-leaved forest and grassland in central and southern Da Hinggan Mountains, ecological zone of frigid and temperate taiga in the east of Tibet and the west of Sichuan, ecological zone of frigid grassy marshland in mountainous area of the southern Tibet, and ecological zone of subtropical evergreen and deciduous broad-leaved forest the ecosystem in the Qinba mountain, of which potential influential coefficients would be smaller than than 1.06.

In summary, the climatic change would influence significantly food provisioning potential of ecosystems. But it should be noted that the above-mentioned scenario analysis only considers the influence of temperature, precipitation, and evaporation on food provisioning potential, but the negative effects such as disaster weather and other uncertain factors on the food provisioning capacity has been not considered.

5.4.2. Scenarios of population carrying capacity in western China

Calculation of population carrying capacity is based on both capacity of food provision and population consumption. The amount of food consumption varies with different living standards. Referring to the research results from China Nutrition Society, the Chinese medium- and long- term nutrition development research group and some other organizations, and considering of actual demand from population in western China, well-off living standard and adequate food and clothing living standard are chosen to calculate the population carry capacity in western China (Table 5.1).

Table 5.1. Demand for nutrition under different living standards

Living standard	Adequate food and clothing	Well-off living standard
Calori（Cal）	2400	2750
Protein（g）	64	85
Fat（g）	58	81

Under the well-off living standard and adequate food and clothing living standard, population carrying capacity in western China would be 158-163 persons/km^2 and 114-118 persons/km^2 on an average respectively (Figure 5.17 and Figure 5.18). Population carrying capacity would vary greatly from one area to another. In Sichuan Basin, for instance, per square kilometer of land would be able to carry 950 persons under well-off living standard and 1200 under adequate food and clothing living standard. In Pamir, Kunlun and Aerjin Mountainous area with frigid desertification grassland ecosystems, population carrying capacity would only be 2 persons/km^2. Under well-off living standard in western China, in addition to Sichuan Basin, the ecological zones that would have population carrying capacity more than 400 persons/km^2 include ecological zone of tropical seasonal rainforest and rainforest in the south of Guangxi and Yunnan, agricultural ecological zone in Fenhe river and Weihe river basin, ecological zone of subtropical evergreen broad-leaved forest in Nanling Mountains, ecological zone of subtropical monsoon evergreen broad-leaved forest in the middle of Guangxi and Yunnan, ecological zone of subtropical Karst vegetation in the central part of Guizhou. The areas, in which population carrying capacity would it be less than 18 persons/km^2 under adequate food and clothing living standard and less than 15 persons/ km^2 under well-off living standard, include desertification ecological zone in central and western Inner Mongolia Plateau and Beishan Mountainous area, desertification ecological zone in Caidamu basin, ecological zone of temperate-arid desertification area in Ali Mountain, frigid desertification grassland in northern Tibet plateau, and desert ecological zone in Tarim Basin and eastern Xinjiang.

5.4.3. Scenarios of population distribution

Three scenarios, which are distinguished into I, II and III, are developed under a general assumption that railway construction planning would have been successfully carried out, increase rate of NPP would be 0.49gC·m-2/yr, and water system and elevation have little change on national level

In the scenario I, it is supposed that the urban population proportion would be 73.82%, total length of highway 1.54×10^6km, total length of railway would be 1.14×10^5km, and population 1.60×10^9 persons in 2020.

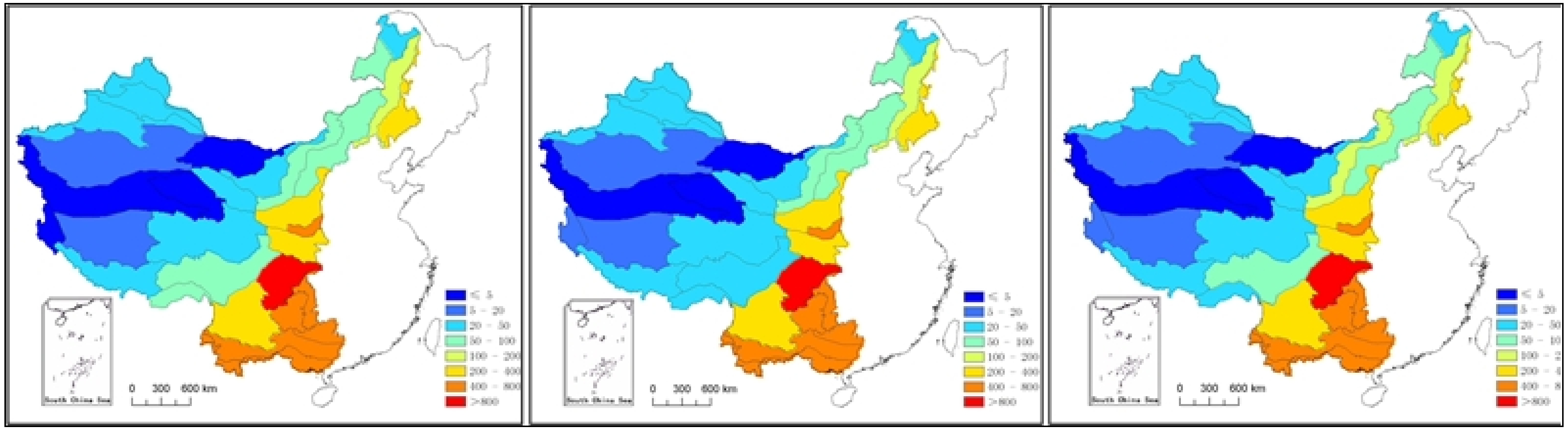

Figure 5.17. Population carrying capacity under living standard of adequate food and clothing (person/km^2)

(left map: based on HadCM3 A1FI; middle map: based on HadCM3 A2a; right map: based on HadCM3 B2a)

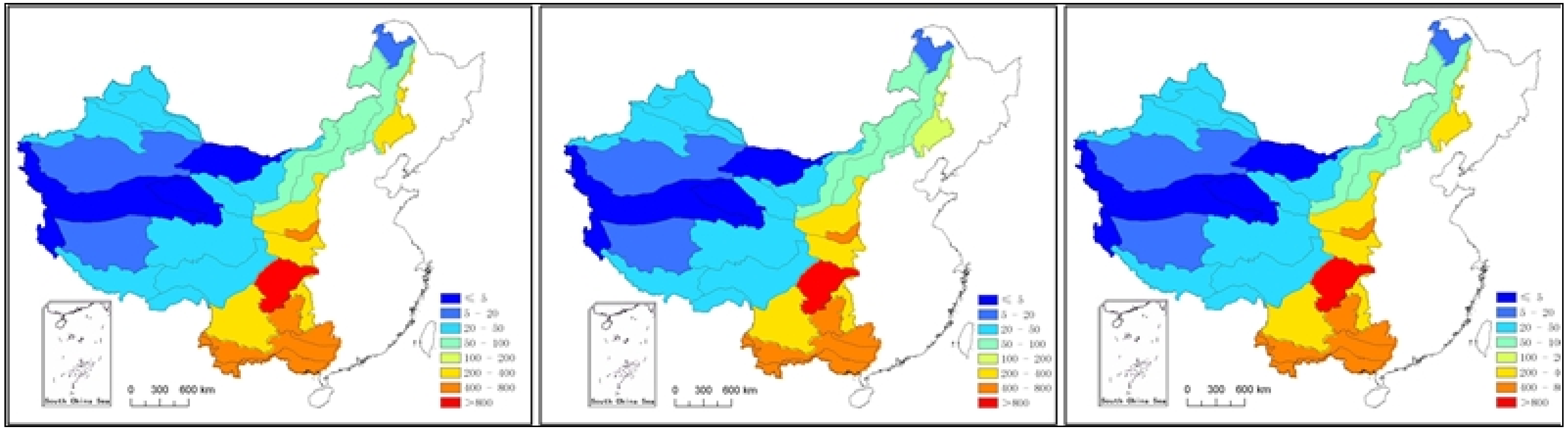

Figure 5.18. Population carrying capacity under well-off living standard (person/ km^2)

(left map: based on HadCM3 A1FI; middle map: based on HadCM3 A2a; right map: based on HadCM3 B2a)

In the scenario II, the urban population proportion would be 65.02%, total length of highway would be 1.47×10^6km, total length of railway 1.0×10^5km, population 1.51×10^9 persons in 2020.

In the scenario III, the urban population proportion would be 56.22%, total length of highway 1.47 million km, total length of railway 8.60×10^4km, population 1.46×10^9 persons in 2020.

All scenarios show that, if population migration in China would be no any limitation, population might greatly float from the western and middle regions to the eastern region of China. In fact, simulation of population trend during the period from the years 1930 to 2000 implied that population migration had a limitation from provincial administration (Yue et al., 2003, 2005). If population could freely migrate within the whole China, the balanced ratios of population in the western region, the middle region and the eastern region to total population in the whole China would be 16%, 33% and 52% respectively. Because the three scenarios of population distribution in 2020 have a very similar pattern, we only present scenario II as an example in this section (Figure 5.19).

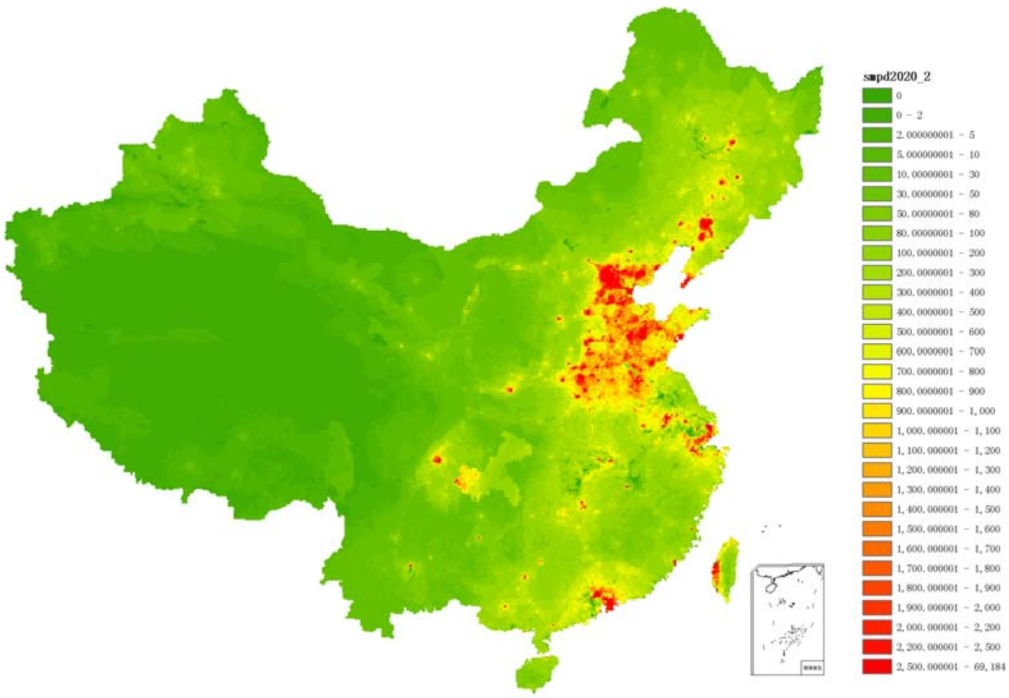

Figure 5.19. Scenario II of human population distribution in 2020 (unit: persons per square kilometer)

5.4.4 Comparative analysis between scenarios of population carrying capacity and population growth in western China

In terms of ecological threshold model (Yue, 2000), under living standard of adequate food and clothing, the ranges of sustainable population carrying capacity based on HadCM3 A1FI, HadCM3 A2a and HadCM3 B2a would be from 2.11×10^8 to 7.89×10^8 persons, from 210 million to 7.85×10^8 persons and from 2.16×10^8 to 8.09×10^8 persons respectively. Under well-off living standard it would range from 1.63×10^8 to 6.09×10^8 persons, from 1.62×10^8 to 6.06×10^8 persons, and from 1.67×10^8 to 6.24×10^8 persons respectively. According to the simulation results of SMPD, under the scenario of population freely flowed within the county without any restriction, the balance ratio of population in the western China to total population in China would be 16% (Yue et al., 2005a). Under assumption of population freely migrating within provinces without any restriction, the maximum of balance ratio (in 1930, 1949, 2000) was 32%. A relevant research result (Jiang, 1998; Yue et al., 2005b) suggests that three scenarios of total population in China would be 1.60×10^9, 1.51×10^9 and 1.46×10^9 in 2020. The six scenarios of population in western

China all would be kept within sustainable ranges of population carrying capacity under well-off living standard and living standard of adequate food and clothing (Table 5.2). In other words, population carrying capacity of ecosystems could meet the needs of future population growth in western China.

Table 5.2. Comparative analysis of sustainable population carrying capacity and population growth

（million persons）

Range of sustainable population carrying capacity	Adequate food and clothing			Well-off living standard		
	Climate scenario A1	Climate scenario A2	Climate scenario B2	Climate scenario A1	Climate scenario A2	Climate scenario B2
	[211， 789]	[21, 785]	[216, 809]	[163, 609]	[162, 606]	[167, 624]
Population scenario 1	511					
Population scenario 2	483					
Population scenario 3	466					
Population scenario 4	256					
Population scenario 5	241					
Population scenario 6	233					

5.5. Scenarios of western development

In the process of the scenario analysis of western China, the scenarios were taken into consideration with implementation of western development strategy and without implementation of western development strategy as well as the different prioritized degree of social, economic and ecological policies. Many factors, such as ecological construction, allocation of water and land resources, energy consumption, infrastructure construction, restructuring the industry, technical progress, regional development level, educational level, and labour quality are studied in the scenarios of western development. These factors are classified into three groups (Table 5.3).

Table 5.3. Major factors considered in the scenarios of western development

Infrastructure construction, industrial structure, capital investment, and technical progress	Ecological construction, land and water resources, energy consumption	Regional development level, educational level, and labour quality
Excellent	Excellent	Excellent
Excellent	Excellent	Bad
Excellent	Bad	Excellent
Excellent	Bad	Bad
Bad	Excellent	Excellent
Bad	Excellent	Bad
Bad	Bad	Bad
Bad	Bad	Excellent

Through previous qualitative analysis of the future development in western regions, the conclusion came into being that the policy is main driving forces for the western region development. Therefore, the influencing factors mentioned above and the policies on Western Region Development are proposed to be the major components for future development scenarios. In order to target the research objectives more accurately, picturing process of future scenario was simplified with great concerns on balanced development between regions, polarization of development, prioritization of environmental improvement and focus of economic development (Figure 5.20).

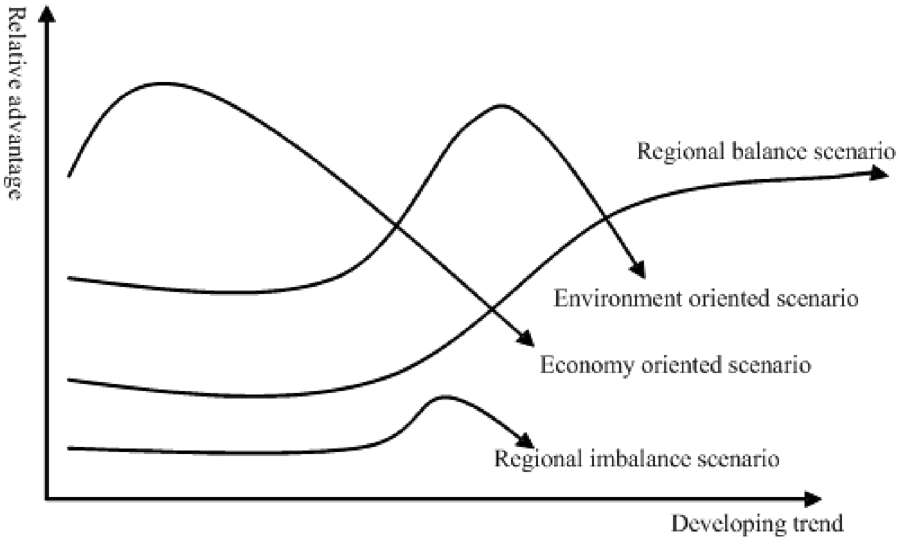

Figure 5.20. Scenarios of western development

5.5.1. Scenario of regional imbalance development

Economic development would be guided by market. If western development strategy would not be implemented, western China would turn to be disordered, the social-economic development would be lagged, ecological environment would deteriorate rapidly, and human well-being would decrease gradually. Moreover, the backward development of the region would affect the national security in a long run. The provisioning, regulating, supporting and cultural services of ecosystems would be weakened. Fresh water and food shortage would become severe increasingly. Ecological diversity would decrease. However, this scenario would not become true according to the opinions of the general publics.

5.5.2. Scenario of regional balance development

The successful implementation of western development strategy would keep ecological deterioration within limits in the future 50 years. Socio-economic development would be fasted. Regional disparity would be narrowed. Ecosystem services be recovered and reconstructed. A sustainable development future with coordinated development between resources, environment and society could be realized.

5.5.3. Scenario of environment oriented development

The deteriorating ecological environment is one of main causes of the backward development in western China. The economic growth should mainly focus on improvement of ecological environment, rather than solely on economic development. The scenario of environment oriented development could be described as that ecological environment policy such as conversion of cultivated land into forest and grassland would be successfully implemented; but readjustment of industrial structure, science and technology, and education policy are not been emphasized; ecological environment and ecosystem services would be improved, but slow economic development and poverty problem would strike regional disparity between western China and eastern China. Also, increasing disparity between the regions would directly cause conflicts between regions, nationalities, and social classes, and those would be potential risks for national security and social stability.

5.5.4. Scenario of economy oriented development

The economy oriented development would only pay attention to the economic development but ignore ecologic construction. The economic development would be improved greatly and regional difference would be reduced. However, the ecological environment would continue to deteriorate as a result of intensive resource utilization and development activities. Under this scenario, oasis in western China would disappear, river flows would be disconnected, environmental pollution would become more serious, and natural disasters would happen frequently, and deterioration of ecological environment would hamper economic development and human wellbeing.

According to the scenarios of western development, it could be concluded that both ecosystem services and human wellbeing in western China would obviously be improved if western development strategy would be successfully implemented. Policy-makers should have to take those scenarios into consideration in order to ensure a long-term ecologically benign and economically and socially sound development.

6. Response options

6.1. Aims of ecological construction in the western China

Western development had been carried out several times in history, but they had all caused damages on ecosystems. The western development strategy proposed nowadays will possibly aggravate the deterioration of ecological environment, if not paying attention to the harmonious development between economy and ecological protection. Therefore, we should carry out sustainable development strategy strictly, and take feasible measures to promote beneficial cycle of ecological environment.

From the view of development strategy, because carrying capacity of western China is limited, the emphasis of ecological construction should be put on the recovery of ecological environment. The first step is to stop manmade damages and restrain the worsening tendency; the second step is to carry out major ecological construction, and realize the target of superior ecological environment. In about 50 years, through mobilizing and organizing whole society and relying on technological innovation, institutional innovation and managerial innovation, to speed up improving environment when developing economy of western China. It would take the recovery of vegetation as major target, promote the adjustment and optimization of land use pattern, and realize the beneficial cycle of ecological systems. To accomplish this strategic objective, it should make overall plans, adjust environmental measures in accordance with local conditions, harness ecological environment in terms of individual ecological zones, give priority to the key points and improve environment step by step.

In future 50 years, ecological construction will be carried out in three steps. At the first stage from 2001 to 2015, investment will be increased on infrastructure and ecological construction. Ecological deterioration in western China is to be basically restrained. The treatment of soil erosion in areas along Yellow River and upstream of Yangtze River, desertification and salinization in grassland area should take effect. The ecological situation of Loess Plateau would be greatly improved and the oasis in Northwest China would be improved. The economic operation would step into beneficial cycle.

At the second stage from 2016 to 2030, on basis of the achievements at the first stage, ecological treatment of Northwest China would have great effect. Soil erosion and land desertification would be harnessed to a different extent. The ecological environment of Loess Plateau, Tarim River basin and Qinghai-Tibet Plateau would be obviously improved. The ecological environment of southwest China would step into beneficial development.

At the third stage from 2031 to 2050, on basis of the achievements at the second stage, ecological environment in Northwest China would be fully improved. The land suitable for forest and grass would get afforestation. Vegetation coverage would reach or close to the highest one in history. An effective forest and grass vegetation system would be established to prevent soil erosion and land desertification. The target of State Ecological Construction Planning will be basically realized.

6.2. Suggestions on ecological treatment

The western China is rather broad. It has a great spatial variation and diverse ecosystem types. The ecological construction in western China should give priority to the key points. On one hand, the regions with severe ecological problems but having development prospects are taken as the key points of ecological construction; on the other hand, the regions with developed economy but having fragile ecological environment are taken as the key points of ecological treatment (Wang et al., 2002).

According to ecosystem services, fragility and similarity of environmental characteristics, western China is divided into 5 ecological functional zones (Fig. 6.1).

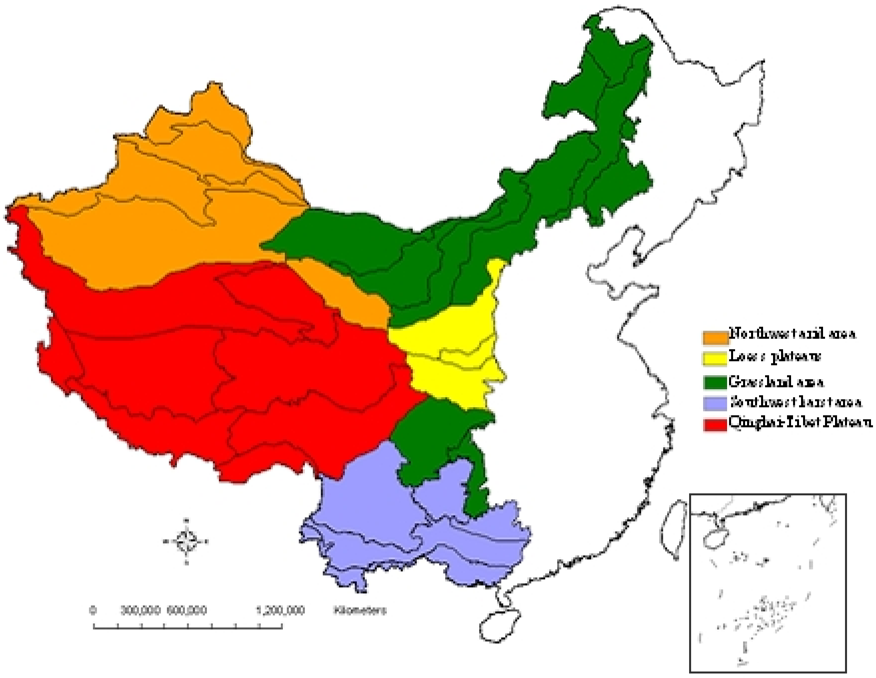

Figure 6.1. Spatial distribution of ecological zones

6.2.1. Loess Plateau

Loess Plateau is the most important area of ecological construction in western China. The ecological construction of Loess Plateau should combine with the policies of enriching the farmers and increasing their income. The Grain-for-Green policy, turning the severely eroded farmland back into forest and pasture, is earnestly implemented. Adjustment of land use structure is promoted by harnessing soil erosion.

The ecological construction projects should be first carried out in contiguous area of northern Shaanxi, western Shanxi and Inner Mongolia, where exists severe soil erosion problem. This area, named as the "Dark Golden Triangle", is a boom coal base of China, but the soil erosion has become more and more severe because of bad environmental protection and vegetation damage. This region should emphasize on preventing wind erosion and water erosion as well as ensuring the ecological safety of mineral resource exploitation, and take the recovery of vegetation and establishment of protected agriculture as main measures. The north Shanxi, northwest Shanxi should emphasize on preventing soil erosion, restoring vegetation, planting forest and orchard trees, and developing animal husbandry.

Great importance should be put on conservation of natural vegetation. In Loess Plateau, except the hillside farmland, eroded natural meadow accounts for more than 25% of total severe erosion area. Some severe deterioration areas are difficult to be used as farmland. It is not so easy to restore vegetation artificially according to current manpower and finance in western China. The only way is to close the mountain for vegetation conservation.

The Grain-for-Green Project is planned by "two belts and three zones" according to the zonal regularity of vegetation distribution. The area with annual precipitation more than 550mm in Loess Plateau, the south of Yan'an in Shaanxi province, can plant manmade forest extensively. Coniferous forest and broad leaved forest or bushes, such as Chinese pine, acacia, sallow thorn, little leaf peashrub and Astragalus adsurgens Pall can be mixed. For areas with an annual precipitation less than 450 mm, from the north of Yan'an in Shaanxi province to Great wall, the high forest can be only planted at the foot of ditch and slope with better moisture condition, while the vegetation in this region should center on meadow and bushes, such as Astragalus adsurgens Pall, lemon grass. According to the efficiency of water and soil conservation of vegetation, vegetation coverage should reach 60%-70%, which can reduce the soil erosion more than 60%. Proper ways of restoring vegetation cover are selected according to different local conditions, such as artificial seeding, sowing tree seeds by plane, enclosing the hills for natural conservation combined with manual supplemental seeding. Policies for environmental protection are drawn up to ensure the restoring vegetation target.

The economic development of Loess Plateau should choose a leading industry according to the local resource superiority and market demand. Loess Plateau can be self-sufficient in food after effort for several years. On one hand, the Grain-for-Green Project is promoting the improvement of ecological environment; on the other hand, the adjustment space for agricultural production structure has been enlarged. An important product base of merchandise animal husbandry is becoming possible in Loess Plateau. Management mode has been changed from previously single pasture to barn feeding or barn feeding combined with pasture. In the meanwhile, meatpacking industry of multiply animal husbandry product is developed. The high quality processed products will put into home and foreign markets. The development of economy strengthens capacity to manage ecosystems sustainability for human wellbeing.

6.2.2. Grassland zone

There are about 2.60×10^8 hm^2 of grassland in western China, in which major pastoral areas in China are distributed. However, the meadow conditions of pastureland are very different. The seasonal yields of grasses in pastureland are disequilibrium. Drought, blizzard, wild rat damage, and insect pest are obstruction to the stable development of animal husbandry.

Most of pastoral areas follow traditional pasture style, pursuing the increase of livestock number, but seldom selling animal husbandry product beyond pastoral area. Overburden grazing has deteriorated the meadow and makes ecosystems having weak disaster-resist capability. It is a common problem for each pastoral area. It is advised to keep on improving natural grassland, establishing artificial diet base, increasing enclosure facility around pastoral area, developing barn feeding or semi-barn feeding, and carrying out assorted construction and management. Different measures should be taken in different areas.

The arid and semiarid grassland in North China, including semiarid grassland in Inner Mongolian Plateau, arid desertification area and mountainous grassland in Gansu and Xinjiang, are short of water resources. The ecological environment is very fragile. Overburden and heavy gazing is serious and productivity of animal husbandry is low and unstable. The main development focus should be the protection of natural grassland. In the areas with annual precipitation less than 250 mm and in grassland having severe degeneration, desertification and salinization problems, enclosure and rotation grazing in divided zones should be carried out. In serious deteriorated grassland, annual fallow should be adopted and in medium deteriorated grassland, seasonal fallow during regreening and productive phase should be adopted to favor natural restoration of grassland. Ecological construction should center on artificial feeding, air seeding and grassland improvement. Forage grass base for barn feeding in winter should be established to stabilize the livestock breeding number. Xeric meadow and bushes should be planted on border of sand land or desert to increase the vegetation cover rate and to inhibit grassland desertification.

The interlaced farming-grazing areas, including northern Shaanxi, eastern Gansu, western Inner Mongolia and eastern Qinghai, are mostly grazed in history, where have the most severe ecological problems such environmental damage and soil erosion. For such severe situation, great adjustment should be implemented. The tradition of single food grain production in the interlaced farming-grazing areas should be abandoned. The damaged and eroded farmland should be turned back to meadow on basis of self-sufficient in food. During full protection and utilization of natural grassland, forage grass should be introduced into farming system to carry out ternary planting structure. Artificial seeding should be encouraged and animal husbandry should be developed as major industry.

Qinghai-Tibet Plateau frigid grassland takes animal husbandry production as principal part, but the animal husbandry production has a low level because of cold weather, inconvenient transportation, undeveloped and technology. As poor infrastructure, the forage grass supply is not enough in winter and spring and the disaster-resistant and livestock-defend capacity is very weak. On business operation mode, the composition of livestock herds is improper with an extensive management, and herdsman is short of merchandise mind. About 33% of grassland has been severely deteriorated because of long-term overburden grazing and improper utilization. Serious soil erosion has directly affected the ecological safety in upstream of Yangtze River and Yellow River. Therefore, this area should sincerely implement the guideline of "protecting and developing animal husbandry", through improving infrastructure construction, protecting grassland, improving livestock species and promoting the development of animal husbandry. The treatment of degeneration, desertification and salinization should be strengthened, grazing rotation, seasonal grazing inhibition and grazing rest should be carried out. In the area with good water condition, artificial high yield pasture should be established to improve anti-disaster capacity.

Hilly areas in southwest China have a mild climate and plenty of precipitation. Secondary grassland scattered with high grass yield but bad grass quality. About 30% is over-utilized, 30% gently-utilized and 40% underutilized. Flood happens in part of the areas frequently because of severe vegetation damage and soil erosion. The farming land on abrupt slope should be turned to meadow and existing grassland should be improved. Artificial pasture in high yield and quality should be constructed. The grassland improvement mode in low economic cost and low ecological cost should be adopted in the hilly areas, such as bushes-meadow-goat system, planting grass between commercial trees and ternary planting structure of grain-cash crop-forage grass. Animal husbandry base should be developed in the hilly area of southwest China.

6.2.3. Arid area in northwest China

Arid area in northwest China is an important component part of combating desertification and sandstorm in China. This area is short of water resources, has a large area of sand land. The sand storm occurs frequently and some oases are deteriorating. The key points of ecological treatment are to restore vegetation close to the boarder of oasis, to plant forest around large and medium cities, factories and mines, to select proper dam site to construct mountain reservoir that can retain water for generating electricity as well as balancing the water supply, to improve the plain reservoir according to practical situation, to take effective measures to improve oasis environment on premise of saving and balancing the water resources, to constitute oasis development planning and properly determine the land use structure of oasis.

Hexi Corridor in Gansu province is one of the severest desertification areas in China. Deserts surround oases in this area. The peripheries of oases are ecologically fragile, and irrational land-use could cause desertification in the peripheries and further endanger other parts of the oases. Especially, the blindly expanded oases in the middle and upper stream have already endangered oases in the downstream. Considering the environmental characteristics of Hexi Corridor, following biological measures are suggested: In the northern desertification area, wind-erosion and sand-fixing treatments, such as combining biological and engineering measures to increase forest and grassland proportion by protection and cultivation, promoting the restoration of natural vegetation, and forming a forest-grassland belt to fix the sand, should be put on the most important place. In the edge of desert, integrated measures should be taken to fix and control sand, to recover natural vegetation and to control the desertification trend in this farming and grazing interleaving area. In the periphery of oases, measures should be carried out to maintain the stability of oasis ecosystem. There are still 1.34×10^6 hm^2 arable land in this area, but constrained by water-resource blindly reclamation and expansion without considering ecological consequence should be strictly forbidden.

Measures should be taken to enforce the ecological recovery and protection, and to protect the natural mechanism of water resource formulation in Qilian mountainous area. Qilian mountainous area is conservation and supply area of rivers, and natural grassland and forest are distributed at different altitude. The natural vegetations are the outcome of special climate, and they impact on water cycle and maintain a stable ecosystem at the same time. Therefore, effective measures should be carried out to recover and protect natural vegetation by expanding the area for vegetation protection and enclosing and strengthening ecological construction. It is the only approach to keep sustainable development in Hexi Corridor area.

In order to stabilize existing oases, intensify the ecological construction and keep sustainable development of agriculture in Xinjiang, forest shelterbelt should be in proper proportion of all vegetation coverage, water supply should be considered in crop layout, and the development of high water-consumption crops should be limited. Except the Ili River, Erjisi River drainage area in north Xinjiang, oases in South Xinjiang should take ecosystem protection problems into consideration, and form oasis-characteristic production base by combining of farming and grazing.

For ecosystem construction and sustainable agriculture development in north Tianshan mountainous area, two shifts should be taken: the first is to transfer the timber forest from natural conifer forest to fast-growing forest in basin; the second is to transfer animal husbandry from the natural grassland to cultivated pasture in basin. The alluviums of the north Tianshan Mountains form the alluvial apron plain, which is several ten kilometers in width and inclining to the basin. The plain is the location of traditional oasis agriculture as well as population, towns and industry center. The improvement of the ecological and economic structure of oasis agriculture should center on forming a rationally integrated system of farming, gardening, forest industry, animal husbandry and water resources. The edges of alluvial apron are transition zones of oasis and desert, and they can be constructed as animal husbandry bases. The Guerban Tonggute Desert of Junggar Basin has the most abundant biological resources, and it is the gene treasury of temperate arid zone. It is proposed to strengthen the protection of the whole Guerban Tonggute Desert and establish national natural reserves or desert parks. Based on the protection, it is further proposed to breed wild ungulates herbivore and develop ecological tourism and hunting. The mountain-basin structure of north Tianshan Mountains is a typical ecosystem structure of arid area in central Asia. The Tarim Basin between Kunlun Mountains and Tianshan Mountains, the Caidam Basin between Kunlun Mountains and Qilian Mountains, and the Hexi Corridor in north Qilian Mountains all have similar mountain-basin structure and similar biogeochemical circumstance as well as land use pattern. Therefore, after localization and optimization, the mountain-basin developing model of in north Tianshan Mountains can be applied for the other mountain-basin system in northwest China.

6.2.4. Karst area in southwest China

Karst terrain is widely distributed in Guizhou, Guangxi and eastern Yunnan, where is also one of the largest continuous Karst areas in the world. Karst terrain is mountainous limestone area, with barren soil, severe water-soil erosion, fragile ecosystem and frequent drought and flood disasters. The eco-environment construction in severely deteriorated mountainous area should take integrated measures. In order to relieve water-soil erosion and rocky desertification, improving the capability of resisting natural disaster by afforesting and increasing the forest and grass coverage should be emphasized.

Strengthening eco-environment construction in this area should be focused on afforestation and enclosing, and these measures can be supplemented by engineering measures such as transferring slope land to terrace. In eco-environment construction area, different measures should be carried out according to farming situation, rocky desertification degree and land type. In areas with rock bareness more than 70% and very thin soil layer, enclosing, afforestation and grass-cultivating should be taken; in dolomitic-rock mountain areas with very thin soil layer (less than 2-3 cm), afforestation and enclosing should be taken; in areas with rock bareness from 30% to 70% (semi-rocky), afforestation or afforestation and enclosing should be taken according to site condition; in reclaimed areas, soil-water erosion and rocky desertification are very serious, an integrated farming-forestry mode should be implemented to increase vegetation coverage and prevent water-soil erosion. In general, slope fields with gradient more than 25 degree have severe soil-water erosion problem and rocky desertification inclination. In these areas, afforestation supplemented by enclosing and protection should be carried out. And it is necessary to gradually realize returning farmland to facilitate afforestation or implement an integrated farming-forestry model.

Ecological poverty alleviation measures should be enforced. The first step is to adjust and optimize industry structure, by developing ecological agriculture, especially the characteristic animal husbandry, economic forest and orchard, Chinese herbal medicine and high quality fruit production, by widely-adopting high quality species and promoting advanced technology, by combining ecological construction with agriculture development and economic development, and by building high quality, high productivity and high efficiency agriculture. The second step is to improve the working and living condition of farmers by applying feasible integrated measures, such as implementing rain-collection irrigation project, preventing soil-water erosion by transferring slope farmland to terrace and building soil wall, changing the energy structure in rural area by popularizing methane utilization, building small hydropower stations, transferring fuel from timber to gas or coal in feasible area, publicizing firewood-saving oven etc.

The Karst terrain in southwest China has formed special tourism resources because of the peculiar physiognomy and geologic environment. The Karst natural scenery combined with minority nationality custom as well as folk architecture makes the tourism very attractive, and the tourism industry should become the leading third industry.

6.2.5. Qinghai-Tibet Plateau

Qinghai-Tibet Plateau has a very special natural environment. Under the cold and arid condition, the ecosystem is very fragile and sensitive, and responds to global climate change very quickly. The existing wild animal and vegetation resources are vulnerable to excessive exploitation and human disturbance. However, in recent decades, overgrazing, reclamation, timbering, mining and herbdigging have caused the decreasing of forest area, grassland deterioration, desertification, rapid decreasing of wildlife resources, and severe environment pollution in parts of the plateau. Therefore the ecological reconstruction in this area should focusing on protecting existing natural ecosystem, on strengthening the protection of natural grassland in upper stream of Yangtze River and the Yellow River, and on establishing the policy of constructing natural reserves in Qinghai-Tibet Plateau. At the same time it is urgent to enforce the disaster prevention capability for earthquake, landslide, slide-debris flows, heavy snowing etc., and to set up specific fund to improve the respond and prevention ability to unexpected natural disaster.

Based on stable food production, it is important to develop the characteristic animal husbandry industry in Qinghai-Tibet Plateau: The first step is to adjust the planting structure of Qinghai-Tibet Plateau. In the Plateau food self-support is realized, and the farming area should publicize forage grass planting, expand animal husbandry by combing farming and grazing and relieve grazing pressure on natural grasslands. The second step is to develop meatpacking industry. The beef and mutton from Qinghai-Tibet Plateau are green food, which are welcome in mainland and Hong Kong Municipal District. And their price is 50%-80% less than similar products in international market. After the entry to WTO, the market can be expanded with improvement of transportation facilitates. Border trading with neighboring countries such as Nepal, Pakistan and India should be encouraged.

The adjustment of energy-consumption structure and reduce the consumption of biological energy is encouraged. In the farming and grazing area of the Plateau, on one hand crop straws, bushes and cow dung are used as fuel destroy the vegetation, on the other hand abundant water power, geotherm and solar energy are not fully utilized. Therefore middle or small size hydropower station should be constructed to establish a stable, rationally distributed power system, as well as county-level solar energy station in areas with less residents and inconvenient transportation. Beneficial power investment policy and price policy should be implemented, and solar heater, solar furnace, solar heating houses and sheds should be widely constructed.

Tourism with Qinghai-Tibet Plateau characteristics should be developed as leading industry. Tourism resources are dominant resources of Qinghai-Tibet Plateau, and developing tourism industry is the key for industrial restructuring and upgrading in the plateau. To develop tourism, it is required to intensify the construction of following key touristy areas and spots: ①Lhasa and adjacent areas have many world-famous religion temples, plateau lake, plateau grassland, pastoral camps, and the construction of tourist facility and form regional tourist center in this area should speeded up; ②On north side of Himalayas, the tourist region consists of 5 mountains higher than 8×10^3 and the Everest nature reserve. An international tourism line should be built relying on traditional international business road; ③The "Tea, Horse and ancient roads" tourism topic is starting from Shangrila of Yunnan province, passing through Changdu brine well, Ranwu Lake, Bomi, Brahmaputra Canyon to Lhasa. Furthermore, the number of climbing mountains can be added, mountaineer cost reduction and simplification of procedures for examination and approval can also facilitate expenditure and investigation tourism around Lhasa, the Everest, Xixiabangma Mountains, Linzhi, Changdu, Fengrenboqi Mountains and Shenshan St. lake.

The headstreams of Yangtze and Yellow River are strategically important to eco-environment safety in China. Therefore it is extremely important to protect the eco-environment of these areas by controlling overgrazing, rationally utilizing and protecting grassland resources, enclosing the summer and autumn pasture and cultivating grassland, and protecting the wetland ecosystem in lake area of the Plateau. The three-river drainage area of Tibet has assembled about 80% of the total population where the economic center of Tibet is. Therefore it is necessary to strengthen ecological monitoring and management in this area. The treatment should emphasize on serious eco-environment problems in serious area; integrate biology and engineering measures; and aim to protect biological diversity resources and prevent desertification, grassland forest deterioration, and.

Qaidam Basin is arid and short of water resources and it is also threatened by sandstorm. Therefore the following measures should be taken to protect the environment: ①Rationally utilize and protect natural grassland, speed up the construction of forage pasture, improve the quality of grass and livestock, control livestock number and prevent overgrazing and grassland deterioration. ②Intensify technology research on integrated utilization of salt lake resources and solve the environment pollution in brine discharge. ③Take integrated measures to protect the eco-environment of Qinhai Lake drainage area, and prevent the vegetation deterioration around the lake to stop and the tendency of desertification in lake areas.

6.3. Analysis and suggestion on returning farming land to facilitate afforestation in western China

6.3.1. Background and adjustment of the project of returning farming land to facilitate afforestation

Since the middle of 1990s, in order to restrain soil-water erosion and desertification tendency our government has started up the project of returning farming land to facilitate afforestation. But by the end of 2003, the government decides to reduce the area for returning farmland from 3.33×10^4 km^2 to 6.67×10^3 km^2.

The high subsidy, simplified subsidy standard and quick expansion of the project of returning farming land to facilitate afforestation have profound system and policy reasons; especially it has a close relation with the food policy and regional management problems in recent years. The policy of returning farming land to facilitate afforestation accelerates the transition of supply and demand relation in food market. Purchasing food in protective price and its incontinence will lead to decreasing of food price, and as an important policy to change the unbalance relation between food supply and demand and to reduce deficits in food department, the beginning and speedy expansion of the returning farming land to facilitate afforestation policy accelerate the decreasing of gross food yield and national food stock. As an important eco-environment protection project proposed during the period of food surplus, the returning farmland to facilitate afforestation project must be regulated along with the changing of food supply and demand relation. (Xu ji-tao, Cao zhi-ying, 2002)

6.3.2. Regional analysis of returning farming land to facilitate afforestation

The modeling result of returning farming land to facilitate afforestation considering factors such as population carrying capacity, population pressure (Fig. 6.2) show that the severe area in western China is 1.42×10^5 km^2, which accounts for 81.77% of the total severe area. And in severe area, the first-level is 1.61×10^4 km^2, the second-level is 2.93×10^4 km^2, the third-level is 9.60×10^4 km^2, which accounts for 11.39%, 20.73%, and 67.89% of total area in western China respectively. In addition, there is 1.22×10^5 km^2 less severe area in western China, which accounts for 66.60% of total less severe area. The total area which should be returned to facilitate afforestation is 2.63×10^5 km^2 in western China, which meets 73.98% of that in the country. Therefore, we can conclude that the main area is distributed in western China.

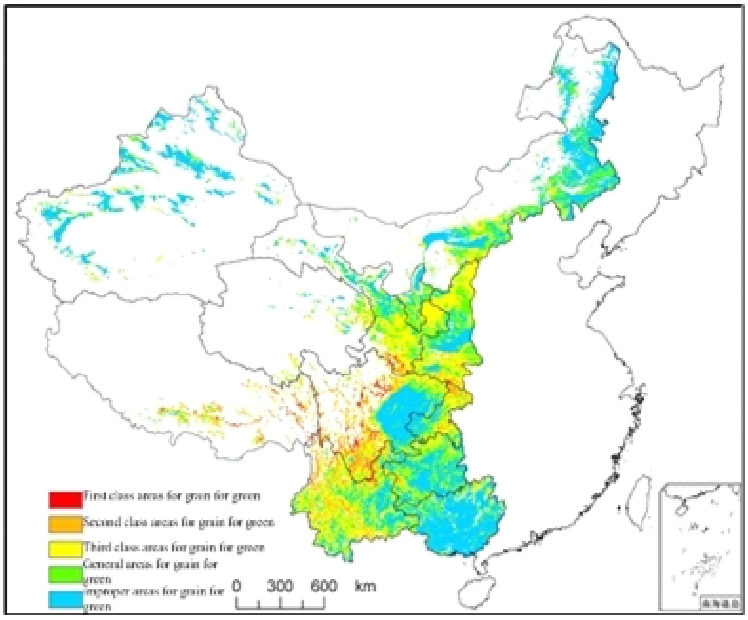

Figure 6.2. Distribution of returning farming land to facilitate afforestation in western China

From the distribution of returning farmland (Table 6.1), we can see that the first-level severe regions are located in Sichuan, Yunnan, Chongqing, Gansu etc; the second-level severe regions are located in Yunnan, Sichuan, Shanxi, Inner Mongolia, Gansu, Chongqing, Guizhou etc; the third-level severe regions are located in Gansu, Shanxi, Yunnan, Sichuan etc; less severe regions are located in Inner Mongolia, Shanxi, Gansu, Yunnan, Sichuan, Guizhou etc. Gansu, Shanxi, Yunnan, Sichuan and Inner Mongolia have the biggest returning farmland area, which is more than 30 km^2.

6.3.3. Risk analysis of the project of returning farming land to facilitate afforestation and grassland

From the implementation process of the project, risks may exist because of the rapid expanding and lack of experience.

Table 6.1. Area and influence of turning farmland back to forest or grassland (Units: km^2, %)

Regions	The most important areas of returning farmland								Important areas of returning farmland		Total	
	First class		Second class		Third class		Subtotal					
	Area	Influ.	Area	Influ.	Area	Influ.	Area	Influ.	Area	Influ.	Area	Influ.
Inner Mongolia	231	0.12	3034	1.90	8525	6.47	11790	8.49	22700	19.86	34490	28.35
Guangxi	38	0.04	217	0.29	1007	1.46	1262	1.79	2373	3.78	3635	5.57
Chongqi	1826	3.30	2915	5.90	6819	15.02	11560	24.22	7520	18.15	19080	42.37
Sichuan	5839	3.34	6478	4.08	12034	8.17	24351	15.59	14498	10.66	38849	26.25
Guizhou	646	0.97	1975	3.08	7625	12.82	10246	16.87	11475	21.15	21721	38.02
Yunna	4490	4.90	7151	8.71	13742	17.87	25383	31.48	14850	20.77	40233	52.25
Tibet	602	10.17	833	14.63	1299	25.56	2734	50.36	854	19.04	3588	69.40
Shanxi	884	1.06	3129	3.79	19477	21.23	23490	26.08	18463	23.34	41953	49.42
Ganshu	1470	2.12	2960	4.30	20871	31.63	25301	38.05	18359	29.84	43660	67.89
Qinghai	55	0.56	302	3.37	1419	16.82	1776	20.75	2378	29.00	4154	49.75
Ningxia	2	0.01	82	0.35	2450	11.79	2534	12.15	5190	27.31	7724	39.46
Xinjiang	26	0.02	249	0.14	780	0.79	1055	0.95	2883	4.41	3938	5.36
Western China	16108	2.15	29325	3.94	96047	12.19	141480	18.28	121542	16.32	263022	34.60
Central China	531	0.05	2430	0.24	19352	1.78	22313	2.07	38084	3.90	60397	5.97
Eastern China	111	0.02	978	0.16	8138	1.18	9227	1.36	22880	3.37	32107	4.73
China	16749	0.67	32733	1.32	123538	4.70	173020	6.69	182506	7.44	355526	14.13

6.3.3.1. Fiscal risk

At present our central government has invested RMB 5×10^{10}, however fiscal expenditure will reach RMB 2×10^{10} for 7.2×10^{3} km^2 returning farmland in 2003, which will continue to increase even if further control of the rapid increase of returning land (it will increase by about RMB 2×10^{9} in 2004). From this point of view, in 2004, the decision of central government to adjust the area of returning farmland is absolutely necessary. Considering the cost and benefit of the project, the plan for the following years must be established cautiously.

The economic situation is bad and educational level is low in most area where need to implement the project of returning farming land to facilitate afforestation. Employment opportunities for non-agriculture industry are relatively few in these areas. Expected income from afforestation is pessimistic because of the slow speed of forest growth; low market value of wood, as well as the uncertainty existed in woodcutting. Penned animal husbandry is straightly faced with the problem of feeding stuff (especially after the food subsidy), which will make the farmers stop breeding, or change back to grazing. As the result, the prospect of transferring farmers to continuous non-agriculture industry is also not optimistic. If these situations continue, the farmers will probable reclaim the farmland after the subsidy period is finished

6.3.3.3. Food security risk of farmers

Returning farmland to facilitate afforestation will surely affect the food supply function of ecological system. From statistical result, returning farmland will have a great effect on food supply in western China. If severe areas return completely, it will cause 18.28% reduction of food supply in western China, in which, the first, second and third level areas will cause food reduction to 2.15%, 3.94%, and 12.19% respectively. Less severe areas will cause food reduction in a degree of 16.32%, and the amounts of severe and less severe area will reach 34.60%. More than 40% of total food supply will be affected in Tibet, Gansu, Yunnan, Qinghai, Shanxi, Chongqing. Therefore the implementation of returning farming land to facilitate afforestation in western China must be carried out step by step. And the ecological environment in many areas (especially northwest areas) is always very adverse, and climate disaster occurred frequently that one normal year always accompanied by 2-3 arid years. Under such conditions, farmers need to keep food storage for 2-3 years, and it is very important to keep relatively large farmland for each person. From this point of view, even though the project will not bring food security problem, it might cause food supply problem of farmers if the area of returned farmland is excessive. Once subsidy for returned farmland is finished, reclamation of farmland will be inevitable unless government continues to provide food for them.

6.3.3.4. Regional ecological risk

Because of the regional difference of climate, soil, physiognomy and relief, vegetation construction measures must suit local environment. But presently the returning farmland to facilitate afforestation policy always set a unified requirement (such as all counties were required to returning 80% of the all returning farmland to plant timber tree; and setting the afforestation density without scientific ground). In some area, afforestation is carried out in steep sloping land (which is already enclosed and in which natural vegetation has already recovered). These activities destroy the remanent vegetation and violate the vegetation reconstruction law.

Therefore, in the northwest arid area, climate determines that the highest-level community is grassland and it is also the best soil-water conservation system. But afforestation is still irrationally carried out on sloping land in this area without considering the terrain and climate condition. Unreasonably high planting density will not only make trees die, but also destroy the soil layer, and lead to desertification. At the upper stream of Yangtze River, in order to solve soil erosion and prevent sediment accumulation in reservoir in middle stream, it is necessary to afforest on steep sloping field. But current measures have problems such as the simplification of tree species (only spruce, chamaecyparis pisifera, eucalypt had been planted). And these problems would lead to humdrum forest communities, and increasing the probability of insect and fire disaster.

6.3.4. Suggestions on the project of returning farming land to facilitate afforestation and grassland

In the north and northwest China, the irreversible ecological problems caused by over-exploitation agriculture and overgrazing should be pain great attention. And by increasing financial investment by government, biological restoration measures should been carried out. For instance, in the northwest, especially in Xinjiang, irrational irrigation in upper stream areas has caused water shortage, river course drying up, vegetation perishing, even desertification in downstream areas. In Inner Mongolia, overgrazing caused by blindly seeking profit had also leaded to grassland deterioration and desertification. The desertification and deterioration not only form an irreversible ecological deterioration process in these areas, but also cause sandstorms which affecting other parts of China. Therefore, it is necessary and urgent to improve the deteriorating environment. In the treatment, the output of water resources for irrigation and the benefit of ecological protection should be carefully calculated, profound fiscal transferring plan should be designed, and animal husbandry policy should be established considering the short-term income of animal husbandry and long-term loss of grassland destruction.

The Loess Plateau is most important cause of soil-water erosion in upper stream and midstream of Yellow River, and current engineering technology could alleviate soil-water erosion in midstream and downstream of the river. Treatment for soil-water erosion of Yellow River is a middle or long-term task, and the key is to reduce population pressure on farmlands by gradually emigrating the rural population to cities, eastern and central China. As analyzed ahead, without non-agriculture employment, it is very difficult to restore the eco-environment only by returning farming land to facilitate afforestation.

6.4. Key measures to achieve beneficial circulation of ecosystems in western China

6.4.1. Biological diversity protection

The biological diversity includes species diversity, heredity diversity, and ecosystem diversity. Enforcing the protection of biological diversity is an important part of ecological construction, and it is also very important in preventing desertification, soil-water erosion and sandstorm, and reducing natural disasters such as flooding, drought, slide-debris flows etc. In addition, clothing, food supply, housing, traveling of human being could not go without biological diversity.

6.4.1.1. Set up natural conservation

According to current ecological situation and ecological development targets, natural conservation should include the upper stream of main rivers such as Yangtze River, Yellow River, Lantsang River and Pearl River, the main original areas of sandstorm in Inner Mongolia and Ningxia, natural forest areas (such as Tibet) etc. And main wildlife species should also be protected. The western China is the habitat of panda, Dian golden monkey and Tibet antelope etc. Qinling Mountains is the transitional zone from warm temperate zone to subtropical zone, with different altitudinal belt for different wildlife. Consequently, the abundant wild life species in Qinling Mountains should be protected carefully.

6.4.1.2. Intensify investigation and protection of wildlife resources

Wildlife resources in western China had been abundant, but it has been destroyed seriously in recent years by human activities. Therefore it is urgent to investigate and protect wild biological resources in western China. Recent scientific discover of wild couple-hump camel species and Mongolian wild horse species have played an important role in investigating and strengthening protection of these wild animals. Liquorice is an important floral species survived in arid fragile ecosystems, which is a valuable genetic resource. Therefore predatory exploitation on liquorice resources in western China should be strictly prohibited. If destruction continues, the wild liquorice will extinct in 5 years, and cause irretrievable loss.

6.4.1.3. Control invasion of exotic species

In 1992, the convention on biologic diversity was put into effect, and “biological diversity day” has been regulated every year. In the year of 2001, the topic of “biological diversity day” is “the management of biological diversity and exotic invaded species”, which illustrates that exotic species invasion had destroyed, even extinct biologic diversity, and it had become a worldwide issue. The Mad-Cow Disease discovered in the United Kingdom in 1980’ had caused great economic and social loss, and it not only threatened the development of animal husbandry in most European countries, but also human safety.

Invasion of exotic species is the main cause of the losing of biologic diversity. The serious result caused by the introducing of cord grass from the United Kingdom and its widely planting in the beach in Fujian province is a typical example. The ecological effect resulted from exotic species invasion could not be discovered in short-term, and it may break out in several decades. And the negative effect of species invasion will be difficult to eliminate. Since 1990, our country has introduced in many kinds of grass species from foreign countries. According to statistical data, the imported grass seeds reached 6×10^3 t in 2000, and 75% of which came from Oregon, the United States. Because irreversible loss may be caused by exotic species, investment on scientific research is advised to verify and experiment exotic species before widely adopted.

6.4.2. Reasonable exploitation and utilization of water resources

6.4.2.1. Constitute and implement water conservation strategy in western China

Water conservation is the basic measure to solve the problem of water resource shortage in western China, especially in northwest area. It is the basic policy of China to establish water-conservation agriculture, water-conservation industry, and a water-conservation society. Agriculture irrigation accounts for more than 70% of the total water utilization, and it is even higher in western China. But effective irrigation water is only one third of total agriculture irrigation water. From these data we can see the potential of water conservation in agriculture. Improving the water utilization efficiency should emphasize on agriculture water-conservation by improving water-conservation irrigation technology, establishing water-conservation rotation system and cultivating drought-resisting crop species etc. Technology innovation should be taken to develop water-conservation industry. Due to the water shortage in northwest China, water-consumption projects should not be implemented. For important projects, sewage treatment measures should be carried out to improve utilization efficiency.

6.4.2.2. Strengthen water reserve, management and allocation in western China

The precipitation is plentiful in southwest area, with annual precipitation exceeding 1000 mm, but its distribution is not even spatially and temporally. Because it is very difficult to build reservoirs in mountainous Karst area, the water utilization problem in agriculture is relatively sharp. In order to fully utilize water resources in this region, following measures should be carried: building soil reservoir, forest reservoir and engineering reservoir; transforming sloping field to terrace; afforesting and conserving water resources; constructing small water pools in fields to conserve rainwater; constructing small reservoirs and underground reservoirs.

Northwest China is located in arid or semiarid zone, where evaporation exceeds precipitation greatly, and the water resources only account for 8% of gross water resources of China. While the distribution of water resources is not even spatially and temporally in Northwest. Desertification, salinization and water pollution accelerate conflicts between water supply and demand. It is remarkable that because of reclamation and industry development water for ecological environment has been occupied even deprived. Ecological water consumption in northwest China is only 2.84×10^{10} m^3 currently, however, the minimum ecological water requirement is 3.88×10^{10} m^3. And it will deteriorate the vulnerable ecosystem. Consequently, water resources should be well planned to achieve balance and reasonable allocation between regions according to economic development and ecological construction.

6.4.2.3. Develop and utilize international river water resources actively and firmly

The runoff of rivers originated in China to abroad is over 4×10^{11} m^3, most of these rivers are in the western China. Due to the lag of economic development, water resource utilization is insufficient this area. The international rivers exploitation in southwest water-abundant area should focus on electricity generation and shipping. And the exploitation of international rivers should given prominence to water resource utilization in water-shortage northwest areas. Erqisi River, Yili River, AKeSu River play a very important role in the development of Xinjiang. Therefore, we should amend and censor the exploitation plan of the three main international rivers scrupulously, design the controlling engineering plan elaborately, and prepare future negotiation about water resource distribution among countries. The exploitation and utilization of international rivers influence the relationship between circumjacent countries, so we should follow the guideline that will not only maintain the rights and interests of water resources in our country, but also deal well with the neighborly and friendly relationship with circumjacent countries.

6.4.3. Prevent desertification and alleviate the influence of sandstorm

6.4.3.1. Emphasize on prevention and strengthen the management of sand treatment

The formation of desertification and sandstorm is an extremely complex process. The process has a close relationship with global warming, ocean circumfluence changing, and irrational utilization of natural resources. The desertification and sandstorm in our country, has a relation not only to the natural environment of arid, semiarid areas in northwest China and human activities, but also to the ecological environment in Mongolia, Siberian and Central-Asia. First of all, human damages should be forbidden, and limiting fiscal capital and human resources should be used in area where is easier to be recovered and require less input. To supplement the target presented 21^{st} Century Agenda of China of reduction the desertification area to 1×10^3 km^2 per year, State Ecological Construction Planning has brought forward short, middle and long-term targets of 50 years for desertification treatment. The whole target of treatment and the imperative targets should be established scientifically.

The treatment of desertification such as enclosing and protecting should be strengthened in areas deteriorated seriously. Harmful human activities should be punished strictly.

6.4.3.2 Strengthen the treatment for desertification and sand-storm in western China

Sand treatment project should focus on the protecting and reconstructing of vegetation, protecting the existing vegetation, strictly forbidding random hewing, reclaiming and grazing. The treatment should be strengthened in the semiarid areas by forbidding reclamation in areas with annual precipitation less than 300 mm and building basic farmland and stop irrational reclamation. In areas with non-irrigation farming, autumn, summer and no-plough sowing should be publicized to avoid wind erosion by prevailing of northwest wind when ploughing in spring.

6.4.3.3. Constitute special action plan to alleviate the occurrence of sandstorm and its influence on Beijing

It had been brought forward to construct ecological zone around Beijing and Tianjin in national “the tenth five-year” plan, which is aimed to alleviate the occurrence of sandstorm and its influence. This project has a close relation to prevent desertification in western China. The sand-dust climate in Beijing and Tianjin has a long history, and it is not easy to get the sandstorm eradicated, but as long as the measures were powerful, it is possible to alleviate the occurrence and its influence.

At present there are four source areas of sandstorm, which are: Hexi Corridor and Alasa Plateau in Inner Mongolia; Huishandake, Hulunbeier, Keerqing Sandland northeast to Beijing, where is the farming and grazing staggered areas Inner Mongolia; periphery of Takemagan desert in Tarim Basin of Xinjiang; sand land and desert arid barren farming area along the northwest of Great Wall in Shaanxi, Ganshu, Ningxia, Inner Mongolia, Shanxi. Among these areas, Hexi Corridor and Alasa Plateau in Inner Mongolia is the major source. By reserch, the cold air resulted in sandstorm weather in Beijing comes from three directions: west direction (Alashanmengejinaqi→Helan mountain→Baotou, Hohehot Municipality →Beijing); northwest direction (Alashanmeng Erjinaqi→Bayanzhouermeng, Baotou, Wulanchabumeng, west part of Xilinguolemeng →Beijing and its surrounding area); north direction(Beijiaer lake and middle

Mongolia, Xilinguolemeng of Inner Mongolia in China→Hunshandake sandland→Beijing). Meteorologic satellite imagery shows that, Bashang in the southeast of Neimenggu Plateau and in the windward of Beijing is the main source of sandstorm in Beijing. And most sand-dust in Beijing are flying dust and floating dust, which account for 74% and 21% of all sand-dust days. Sand-dust is from: the sand sediment from old alluvial plain such as Yongding, Chaobai, Yuqi River etc and discarded dust from construction, which are local sources; farming and grazing staggered areas and grassland in middle Inner Mongolia, which are exotic sources. Research shows that sand-dust resulted in sand storm weather of Beijing mainly comes from Beijing and Bashang. Main sand-dust sources in Beijing should be treated urgently, not only to prevent the enlargement of sand-dust storm, but also to make sand-dust semi-fixed and fixed. In order to eliminate local construction dust, civilized construction should be advocated, and construction management should be enforced.

The state Ministry of Forestry has drawn up "the implementation scheme of integrate treatment project on sandstorm sources of Beijing", the scheme can act as the base or constituent of special action plan to prevent and alleviate sandstorm of Beijing region. To prevent desertification in Beijing is a long-term task, which should be improved gradually though the implementation of action plans to achieve the maximum treatment benefit.

6.5. Macro policy and measures to realize beneficial circulation of ecosystem in western China

The core of the western China Development strategy is to obey and follow above ecological economy principles, to optimize ecosystem structure and reinforce the ecosystem function considering the bearing capacity of water, soil and environment, and to follow the principle of ecological economic structure-function-equilibrium-efficiency. Policies, such as combining the ecological environment construction with economic development, improving agriculture industrialization, building ecological economy system, breaking up the vicious cycle of vulnerable-poverty-vulnerable, and achieving win-win development of eco-environment and economy is advocated. The economy reproduction, population reproduction and eco-environment reproduction should be developed in harmony. The benefit of economics, society and eco-environment should be considered integrated to maximize the function of the ecological economy system, and to realize the sustainable regional development.

6.5.1. Suggestions on ecological policy

Although the ecological restoration activities in western China of China had gained social agreements and support, and get many praises at present, many problems had also arisen, which can be concluded into following 5 aspects: ①Development of the western China might increase the pressure for ecological protection, the large-scale exploitation of natural resources might result in new ecological damage in central and western China, which will worsen the existing vulnerable eco-environment. ②The planning of ecological construction is relatively unreasonable, and the scale of project is emphasized but the scientific base and feasibility are ignored. ③The speed of eco-environment construction cannot catch up with the speed of deterioration. It is the basic reason of environment deterioration that ecological restoration is carried out in small scale, while reclamation and production is carried out in large scale. ④The eco-environment construction cannot reach the anticipate target because of errors in or deviation from planning, implementation, because of the lack of scientific and technical support and economic policies, or because of natural disasters. ⑤It is difficult to consolidate eco-environment construction achievements. Some farmers had excessively relied on government subsidy for their returned farmland, and it can be foreseen that the ecological damage will continue as long as the government stops the financial subsidy. As the restoration of ecosystem structure and function is a long-term course, eliminating the poverty in vulnerable ecological areas will also be a long-term course.

6.5.1.1. Ensure area of basic farmland

To ensure the living standard and basic food demand of farmers, and to make sure the returned farmland will not be reclaimed, it is necessary to keep integrated capacity of agricultural production. According to existing integrated agricultural production capacity, people in Yangtze drainage area should have at least 0.067 hm^2 per capita, and people in Yellow River drainage area should have at least 0.133 hm^2 per capita.

6.5.1.2. Adjust land use structure, and developing substitute industry

On basis of guaranteeing the amount of basic farmland, it is necessary to adjust land use structure, and develop substitute industry. Under traditional land use mode, the reclamation of steep slope land and other marginal land had caused the damage of natural vegetation, and brought severe ecological environmental problems. Therefore, in order to restore forest and grassland, we should transform traditional sloping field mode to sustainable land use mode. Ecological restoring plan should be supplemented by following policies: transforming of land use mode and industrial structure; strengthening local economic development; establishing self-support mechanism, and combining economic benefit with ecological benefit.

6.5.1.3. Implement eco-environment construction by economic means

Currently, ecological restoration plans such as returning farmland to facilitate afforestation (grassland), enclosing mountain for afforestation, substitute aid with grain, and individual contract are implemented in western China. And “substitute aid with grain” is a measure of ecological compensation, which shows the transformation of government policy on ecological restoration from merely administrative means to economic means. As the adjustment of land use structure and the development of substitute industry is time-consuming, government financial subsidy can guarantee basic living standard of farmers, and ensure the ecological restoration to be developed in the direction as government wished. Similar policies shall be implemented in related ecological restoration plans such as sand control and sand treatment. Besides financial subsidy, further economic means on taxation, credit, financial transfer payment and so on shall be applied to develop and perfect eco-environment construction, and realize management and construction of eco-environment by economic means.

6.5.1.4. Improve the policy system for ecological restoration

Eco-environment construction is a long-term and complicated project. And it involves millions of farmers and undeveloped local government in ecological vulnerable areas. The government investment and financial subsidy is not enough, and it is necessary to establish a set of policies to ensure the eco-environment construction. Refer to recommended methods of the World Bank, the policies of sustainable development include marketing means, administrative means, information publication and public participation etc.

6.5.2. Suggestions on economic policy

Although the target of market-oriented economic structure reform is to realize rational resource allocation, and make the regions get equal chance of benefit, in past 20 years, the regional differentiation in China had been increased, especially the differentiation between coastal area and inland area. Generally speaking, at the beginning of reform and opening, the regional differentiation in China tended to decrease, but it increased quickly soon later, and reached the maximum by the end of 1990s. The Chinese government had fully recognized the severity of regional differentiation, and established series of measures to promote the economic development of western China (Dong Suocheng etc, 2000).

6.5.2.1. Fiscal transfer

Fiscal transfer payment system aims for equilibrium in development among regions, and it is an important means to relief the fiscal differentiation between regions and to ensure the public services in undeveloped regions. Facing with vulnerable ecological environment, weak economic base and low sustainable development capacity in western China, it is necessary to refer to overseas experience of fiscal transfer payment, and establish a normalized Fiscal transfer payment system that is scientific and effective and meets national conditions. Profound fiscal system is established to ensure developing opportunities and diminish the area differentiation gradually.

For environmental protection in western China, the Fiscal transfer payment policies should include: ①Establishing the development fund for supporting environmental protection in western China, which is mainly subsidized by state revenue and developed regions. ②Enhancing the macroeconomic control of state environmental protection departments on environmental protection of western China. Nowadays, the state environmental protection departments only have the capacity of policy guiding, but are not able to give more economic supports. Therefore, it is necessary to establish “the development fund of supporting environmental protection in western China”, and the state environmental protection departments shall represent the government to arrange the funds. ③Matching pairs for developed regions and undeveloped regions in western China. The projects signed up contract between matched regions divides into two parts: non-reimbursable part, and reimbursable part.

6.5.2.2. Direct investment policies

Direct investment may affect the development progress of a region, and it is an important regional policy. The project of “three line” construction in China is a typical example of state direct investment. State direct investment can play an important role in environment protection in western China. The state direct investment on environment protection in western China include following two aspects:

Firstly, the infrastructure construction for environmental protection should be considered at the first place. Many infrastructures, such as roads, drainage facility, sewage treatment plant and so on, are commonweal facilities, which cannot produce economic benefit directly. And these facilities should be constructed through the investment by financial departments. But the limit fiscal capacity of local government in western China cannot afford them. Under this circumstance, the state direct investment on the coordination and development of western China should put the improving of the infrastructure for environment protection in the first place. The concept of investment law includes: ①The state direct investment is non-reimbursable assistance. ②The important cross-region projects are undertaken by the state. ③For infrastructure within the region, the state and local government shall share investment together with local government acting as main player.

Secondly, we should invest technology innovation related to environmental protection. The key point of the green development in western China is to realize economic development as well as environment protection. For existing enterprises, it means technical transformation; for new enterprises, it means adopting advanced technology. Different from infrastructure construction, technology innovation is economically reimbursable, but it needs large investment. Therefore, firstly, the central government should invest on related technology innovation for environment protection in western China to help regions in western China change economic growth mode. Secondly, instead of non-reimbursable assistance the central government can provide a loan from national bank or make use of foreign investment.

6.5.2.3. Ecological compensation mechanism

The midstream and upper stream areas of rivers had been invested large amount of manpower, funds, and material resources on treatment of desertification, soil-water erosion, and protecting vegetation and water resources. And the treatment improves the ecological safety for the whole drainage area. But it sacrifices economic benefit of midstream and upper stream areas. Nowadays, the midstream and upper stream areas of Yellow River, especially Loess Plateau had implemented eco-environment construction projects of returning farming land to facilitate afforestation (grassland), which gained ecological benefit for the whole drainage area, but damaged their own economic benefits. Therefore, the rights and obligations of midstream and upper stream areas as well as downstream areas should be considered comprehensively. The principles of ecological economics and environmental economics show that rivers are common property of people along the drainage area, and the whole area has the rights of sharing the resources as well as the obligations to protect the resources. In our country river resources are partitioned according to administrative regions. It splits the mutual relation and organic integrity among upstream, middle stream and downstream, and will cause accidents such as rapping resources and damaging environment. And the ecological economic system of drainage area will be trapped in a vicious circle. As a consequence, the eco-environment protection and construction of river are not only the responsibility of upstream, but also that of midstream and downstream.

Referring to experience of developed country, resources should be allocated in the whole drainage area, Chinese characteristic compensation mechanism unifying the rights and responsibilities of upper stream, midstream and downstream should be established, and administration institution should be organized for resource allocation, environment utilization, protection and management. The related departments in government should establish accounting policy of benefit compensation for the whole drainage area; Fiscal and taxation departments should constitute a practical financial transfer payment scheme, operation instructions and matching policies; National People's Congress should establish the laws and regulations for promoting the compensate mechanism and harmony development of upper stream, midstream and downstream, and guarantee the beneficial development of eco-environment protection project and sustainable development of whole drainage area.

In order to change the development mode and keep sustainable development, funds for eco-environment construction and protection in western China should be established, referring regional coordination development fund. The funds are from government investment and from the charges through compensate mechanism for using eco-environment resources and restoration of eco-environment. The fund will mainly be used in fundamental construction and protection of ecological environment, and it has strict regulation. And the fund can alleviate the pressure of fiscal expenditure, and provide stable capital recourses for eco-environment construction and protection.

6.5.3. Suggestions on administrative policy

The western China centralizes a large population of poverty residents, and most of poverty counties of the country are in the western China. The economic development speed of western China is slow, and amount financial revenue of local government is small. In 2002, the financial revenue of western China accounts 7.31% of GDP, which is 1.01% lower than country average, while the local financial expenditure of western China is only 26.82% of whole country financial expenditure, which is 18.29% lower than that of East Regions. In addition to the vulnerable eco-environment, the social accumulate capacity is very weak and individual paying ability is low in western China. If sacrificing ecological environment for improving living in western China, the eco-environment of the whole country will be affected.

6.5.3.1. Readjust industrial structure

Many researches show that the most impoverished people usually live in the areas with most severe environmental problem. It is because that the development of necessitous people is dependent on the consumption of natural resources. The vicious circle between poverty and eco-environment deterioration is the main reason for the underdeveloped of western China. The only way out to realize win-win of economic benefit and ecological benefic is to propel the readjustment of industrial structure. Therefore, it is necessary to get following work well done.

①Build up new concept for food safety, readjust planting structure and develop special agriculture.

Generally, regions with relatively serious eco-environment problems are mostly short of food. At present, the food production is relatively rich in gross amount in the country. And it provides advantages for adjusting agriculture production structure and crops allocation, and is favorable for local eco-environment development. The food balance mode of supply and demand should change from taking provinces, cities and towns as basic elements to a larger scope. The western China should enforce the construction of food base, and seek different food sources. In the food shortage regions, the food consumption for industry should produce food substitute. Local people and government should make full use of natural advantage and develop characteristic agriculture, such as tobacco, flower and herb in Yunnan, cotton, sugar beet, melon and fruit in Xinjiang, Pteridium aquilinum, jelly fungi, black melon seed, and malting barley in Gansu. The characteristic agriculture should be specialized, industrialized, and in certain scale, by means of creating agricultural products brands, enhancing the popularity of agricultural products, and increasing the quantity sold of products.

②Develop modern animal husbandry industry

Main grasslands of China are distributed in western China, and animal husbandry industry development in this area has grate potential. Large-scale vegetation construction will provide good conditions for the development of animal husbandry in western China, while the development of animal husbandry will also promote the grassland construction. Western China should improve grassland construction, increase sown pasture and improved pasture, introduce good grass species, adopt advanced meatpacking technology, and establish modern animal husbandry industry.

③Develop local non-agricultural industry and characteristic economy

We should develop local non-agricultural industry and characteristic economy, and create new points in economic growth. And the key points are concentrating on developing industry based on local raw material, developing transportation, construction and service industry for large energy, chemical industry base, developing handicraft products with local characteristics, transferring surplus labor of countryside, adjusting product structure according to market structure, and increasing business market competing power.

6.5.3.2. Control the growth of population, improve population quality and implement necessary ecological emigration project

The cause of vicious economy and environment circle “vulnerability-poverty-vulnerability” in western China is the reproduction population exceeds the reproduction speed of economy and environment, which result in severe overpopulation. And low education level had become great resistance to intensified economy development and ecological environment construction. Therefore, it is necessary to constitute strict and reasonable population policies, develop education and science, keep improving the quality of human resources, impel urbanization and improve efficiency of administration, implement ecological emigration project, strengthen the management of labor export, and release the land pressure.

①Control population growth

According to the estimation of UNESCO in 1997, the Tibet population had overburdened with 1×10^6, which accounts for 49.3% of total Tibet population. According to the study of Chinese Academy of Sciences in 1997 “production potential and population bearing capacity of land resources in China”, Yunnan, Guizhou, Gansu, Qinghai are all population overloaded regions, and Sichuan, Xinjiang, Shanxi, Ningxia are tend to be overloaded. The high speed of population growth and low education are serious handicap to the economic development and eco-environment construction in western China. To change the situation, besides the Han nationality the population policy in minorities regions should also be adjusted, and measures shall be taken to encourage minorities reduce fertility rate. At the same time, we should also increase investment on family planning, and implement free service of family planning for minorities.

②Increase investment on human resources of western China, improve population quality

There are 39% of population in western China are illiterate or semiliterate. The enrollment rate of children at the right age did not reach the national standard, and so does the publicizing nine-year compulsory education. T0 improve population quality we should take following measures: First, to enforce investment on basic education and speed up publicizing nine-year compulsory education. And it is necessary to reform the education investment, eliminate the embezzlement of education funds. Second, to take measures to incent scientific and technical innovation. It can be advised to establish a special fund improve the remuneration of scientific and technical personnel. Third, to encourage graduates from colleges and universities to participate the development of western China, and for the subsidied students from western China, and they can be free of repayment if they serve in western China for prescriptive years after graduation.

③Implement ecological emigration project

For a long time, the custom, system and policies had fixed the farmer from migrating, and now the situation needs breakthrough. The government should gradually emigrate people in national and local natural reserve, regions with frequent natural disaster, with abominable eco-environment to better regions. The area ready for emigration include poverty area in Loess Plateau, desertification grassland in Bashang, the severe arid area in Alashan Meng of Inner Mongolia, desertification area in Northwest with severe water shortage and desertification, deterioration regions in Qinghai-Tibet Plateau, Karst area with severe soil erosion in southwest. Emigration is a social ecological project, involving the psychology of emigrant and the conditions of areas receiving immigrants, which needs detailed investigation and careful planning.

6.5.3.3. Establish and improve the scientific research mechanism for the development of western China, and promote technological innovation

Advantages and restricts confronted by the development of western China should be analyzed thoroughly. Scientific and technical development planning which meets the requirements of economy, social development and ecological construction in Western China should be put in an important place. Based on the principle of long-term target and guidance, it is necessary to select research topics on eco-environment construction, industrial restructuring, special resource development, small town construction, especially on agricultural technology, water resource utilization, resource exploitation, energy utilization and conservation, population and health, environmental forecasting and protection, natural hazard precaution and hazard reduction, climatic change and effect, ecological evolution and forecasting, human activities and interaction with eco-environment etc. And the research on fundamental, applicable great science and technology projects should be organized thoroughly.

The western companies should be driven by science and technology, and center on improving competitive ability. For sustainable development the companies should follow: ①Organize scientific research, analysis the scientific restriction and handicap in western China, determine main research direction, introduce in advanced technology, and implement technology. ②Establish science and technology innovation system, set companies as the base for scientific and technological transformation, and establish a production-education-research integrated innovation system. ③Establish and improve market mechanism and incentive mechanism for scientific development. ④Establish scientific and technological service system in western China, speed up the transfer of scientific and technical achievement, technical service and consultation, technical contract and foster??new??points??of??economic??growth.?? ⑤Constitute preferential policy, establish special funds, and found risk investment technology institute according to the characteristics of high risk, high investment, high profit and fast upgrading of product. ⑥ Market research institute and research system, provide scientific support for the development of western China.

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