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Editor-in-Chief

Contemporary Ecology Research in China

当代中国生态学研究

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Contemporary Ecology Research in China

Preface

China lies in the east of Asia with a vast expanse and extremely complex geographical and natural conditions. In the territory of China, highly diversified ecosystems with different plant species combinations had been formed and nurtured. These provide us an unusual natural laboratory to discover the rule of nature and find out the way to harmonize the relationship between nature and human beings. Thanks to our ancestors, during over 5000 years' history, the Chinese created a brilliant civilization in which the holistic thought and harmonic relationship between human and nature is the core of national philosophy. On the other hand, China's environment is characterized by its vulnerability and fragility, and the situation varies very much with geographical conditions. Due to the soaring population and the long history of cultivation in addition to the short-sighted approach in exploitation of natural resources, many natural hazards and disasters causing ecosystem degradation and destruction, soil erosion, desertification, pollution, species extinction and lowering of biodiversity, etc. have occurred. This situation is particularly severe since the last decades. Urgent need for ecological studies of China is aroused under such circumstances.

General Review of the Development of Ecology in China

In the course of China's long history, wealth of knowledge and theories on the interactions between organisms and their environment have accumulated. Looking back at the development of ecology in China, we may roughly divide it into the following four phases, namely: primitive embryonic phase, fundamental ecological study phase, ecosystem study phase, and contemporary ecological development phase.

Primitive Embryo Phase
The traditional integrated philosophical thoughts to understand the world have long existed since time immemorial. Quite a number of ancient treaties and books reflect

the great achievements of the ancient Chinese as regards their production and life. For instance, they use the "San Cai" theory to explain the relationship between "the heaven", "the earth" and "human being". The theory of "Ying Yang" has been widely used to study the relationship between different components of the systems. Many excellent ideas in this aspect were recorded in some early outstanding works. For example, the four essays in Lü Shi Chun Qiu (Master Lü's Annals) including "Shang Nong" ("lay stress on agriculture"), "Ren Di" ("Capacity of soil"), "Bian Tu" ("Work and ground") and "Shen Shi" ("Fitness of the Season"), completed in the third century B.C., can be claimed as China's earliest agricultural treaties. The book Qi Min Yao Shu (Important Arts for People's Welfare) written by Jia Sixie of the sixth century, summarized the systematic knowledge of farming, forestry, animal husbandry, side-line production and fishery. Treaties and books on agriculture written over 2000 years have been handed down to the present day. According to incomplete figures, 376 essays and books on agriculture in those 2000 years were published, but many of them were scattered or lost. They form a large set of treatises with deep system and ecological thinking. Primitive but valuable thoughts are important parts of brilliant Huaxia civilization and left us many world important heritages. A few examples include rotation and intercropping systems in agriculture, Dujiangyan Water Conservancy Project, and karez and check dam engineering, dike-ponds, rice-fish integrated system, terrace planting, pastoral nomadism, etc. Ecological thinking and many practices were not only important in the ecological development of China, but also had important influence on the world. Although a wealth of knowledge related to ecology had been accumulated and scattered as a result of research carried out by individual scientists, ecology had been in its embryo phase until the establishment of People's Republic of China in 1949.

Fundamental Ecological Research Phase

Ecology as an independent branch of science obtained its rapid development after 1949. At the early stage of development, ecological research focused mainly on autoecology, population, and community ecology. From the very beginning of ecological research in China, Chinese scientists centered their research on practices to solve the crucial problems of the country. These include the exploitation and assessment of the suitability of habitat for cultivation of rubber plantation in tropical areas; the research on rational exploitation and regeneration of forests in northeastern and southwestern mountain regions; the combating with desertification in arid and semiarid land of northwestern China, and the construction of shelterbelt in the Northern China plain; and to establish nature reserves in various regions to conserve natural ecosystems, etc. Important contributions were made by the interdisciplinary scientific expeditions organized by the Chinese Academy of Sciences to carry out comprehensive survey to fill the gap of information including all disciplines of biological and ecological conditions. In this period, many studies were conducted at the community level. Based on the research, a great number of articles and monographs were published. The publication of "Vegetation of China" was a great event in the history of China's ecology. It sums up the achievements of vegetation research covering all the provinces of China and has made the classification of the vegetation systems and the Vegetation Map of China with 1:100 million scale.

During this period, the international exchange was limited to the Soviet Union and other socialist countries. It should be recognized that the joint expedition and training programs had played important roles in the initial stage of the development of ecology in China.

Ecological Research Phase
Since the 1960s, Chinese ecologists started their research on the ecosystem or biogeocenoses bases. With the help of experts from the former Soviet Union, China built its first biogeocenological experiment station in the tropical forest of Xishuangbanna, Yunnan Province in the early 1960s. With the suggestions of ecological scientists, China delineated 15 nature reserves. In some of these nature reserves, interdisciplinary observations and researches were conducted by experts of relevant Universities and research institutes. Since the late 1970s, experimental stations were established by the Academy of Sciences, Universities and some other organizations. Fragmental observations and systematical studies on the structure, function, and succession of these ecosystems were started. Although the development of such long-term research was carried out rather slowly and sometimes interrupted by some events, the ecosystem study did not stop and it was regenerated later in the 1980s by upgrading it into a series of nationwide networks to carry out observation and research on ecosystem. Special contribution was given to the construction of Chinese Ecosystem Research Network (CERN) under the Chinese Academy of Sciences. This program was started in 1988 and became prosperous in the 1990s. Now, CERN consists of 40 field research stations for various representative ecosystems involving agriculture, forest, grassland, lake, ocean, and city areas in different part of China. For effective coordination and management of the project, a general secretariat and several coordinating centers for water, soil, atmosphere, and biology and a synthesis center were established.

In 2006 the Ministry of Science and Technology of China began to establish the Chinese National Ecological Research Network (CNERN). Now a national network has been set up, which consists of 51 field observation stations for different types of ecosystems and one comprehensive research center. The project has carried out observations about ecosystem change covering the main region of our county and cross-department research and technology demonstration. Furthermore, the Chinese Forest Ecosystem Research Network (CFERN) has established 33 filed stations since March 2003. At the same time, works in the wetland and desert ecosystem station network also made some progress, relying on related state research projects. At present, the Chinese Wetland and Desert Ecosystem Research Network (CWERN) and CDERN have established five and four field stations respectively. The establishment of ecosystem network raised the study of ecology in China to a new level, which not only provides a long-term platform for the study of macro-scale ecological problems, but also promotes modernization of observation instruments and means. If during the period of IBP, China missed the opportunity of participation, then from the 1970s, during the implementation of the Man and the Biosphere Program (MAB) of UNESCO, China has already become a country with many active participants. The Cooperative Eco-Environmental Research Program (CERP) sponsored by UNESCO through the fund of BMFT of Germany was one of the biggest projects in MAB and played an important role in promoting the progress of ecology and training the personnels. Another important event was the establishment of Ecological Society of China in 1979.

Ecology for Sustainable Development

Since the second half of last century, especially during the first decade of twenty-first century, due to the drastic increasing population, escalating needs for consumption and short-sighted approach when exploiting natural resources, a long list of hazards and disasters became glaringly apparent. In exploring the solutions to the problems of sustainable development, contemporary ecological research experienced its revitalization and breakthrough, and a series of characteristic changes have occurred. These include:

- From natural ecosystems to nature-socio-economic-complex systems;
- Expansion of the scope of research both in space and in time;
- From short-term qualitative description to long-term quantitative and experimental research;
- From isolated plot study in limited areas to networking research covering many regions and ecological zones;
- Differentiation of disciplines and emerging new scientific branches in ecology;
- The modernization of research facilities and instruments.

In this period, remote sensing, geographic information system, global positioning system (3S system) are widely implemented for access to accurate information. Some ecological stations have been established as observation towers equipped with many automated continuous observation apparatus. Many manipulative experiments including free air CO_2 enrichment, Throughfall Displacement Experiment, Free air temperature enrichment, and ultraviolet-B variation are established to explore responses of ecosystem processes, structure and function to climate change. Isotope tracer method is used to study the rates of gross mineralization, nitrification, immobilization, and consumption of soil N. In addition, mini-rhizotron technique, dilution-plate method and denaturing gradient gel electrophoresis are used to measure root dynamics and species composition of microbial community in microbial ecology studies. Remote sensing satellites to detect the regional greenhouse gas concentrations, the lidar technique to measure atmospheric aerosol concentrations, as well as remote sensing inversion models are wide applied to research carbon cycle. These modern equipments lay a solid foundation for the continuous improvement of ecology.

In this phase, the hot spots of ecological research were concentrated on biodiversity conservation, global change, and sustainable development. These researches have been listed in the National Key Fundamental Research Program and were implemented by research institutes, universities, and related ministries/

administrations. With the advent of the twenty-first century, ecosystem rehabilitation, environmental protection, and afforestation had become an urgent and enormous strategic task and a fundamental plan for China in her seeking for survival and development for the nation and a series of key ecological construction programs had been implemented. These programs included the Natural Forestry Protection Program (NEPP), Conversion of Cropland to Forest Land, Sheltbelt Development Program in such regions as China's "Three-North Region" and the Yangtze River Basin areas; the Desertification Control Program in the vicinity of Beijing and Tianjin; The Wildlife Conservation and Nature Reserves Development Program; the Fast-growing and High-yield Timber Plantation Program. The above-mentioned programs have been incorporated into the national economic and social development plan and thus the ecology had increasingly become a bridge linking science and development. It is necessary to point out that the Chinese Society of Ecology, the National Natural Science Foundation of China, the National Committee of IGBP, and the National Committee of IHDP of China have played important roles in coordinating and promoting the ecological research in these fields.

Brief Introductory Description and Analysis on Selected Areas of Ecological Research

In recent years, the ecological research developed rapidly and covered a wide range of topics. In this paper, we just select a few of them to give more detailed introduction. These include biodiversity conservation, ecological research on global change, restoration of degraded ecosystems, and desertification control and promotion of sustainable development from concept to action, etc.

Biodiversity Conservation

China is a country with highly diversified fauna and flora. Since the funding of new China, much research work has been undertaken on domestication, cultivation, and breeding of wild plants and animals. The Chinese government attaches great importance to wildlife conservation and has organized a series of nationwide surveys focusing on conservation of wildlife and ecosystems. Much information and a great number of data have been accumulated. With the support of UNEP, and funded by GEF, a country-wide study on "China's Biodiversity" was carried out. It was a study of China's plants, animals, and microorganisms and their environment on the land and its marine waters. A comprehensive summary of accumulated information about biodiversity conservation related to agriculture, forestry, animal husbandry and fisheries, as well as the various activities involving many regions over China related to biodiversity conservation and evaluations of their economic, ecological, and social effects. More than 80 experts took part in the compilation and appraisal of the national report.

On the basis of long-term studies, a biodiversity-related database has been developed. In order to facilitate the study on flora and fauna, Chinese Academy of Sciences (CAS) has established a specimen collection system with 21 preservation units, containing 16.23 million specimen accessions. Based on the specimen data, CAS has established a comprehensive biodiversity information system (CBIS).

Since the beginning of the Eighth Five-year Plan, the Ministry of Science and Technology has taken the study of biodiversity conservation as a national key research program, and relevant departments have organized many researches on artificial of endangered animals and plants. During the period of the "Eighth Five-year Plan" (1991–1995), status quo and causes of damage to crucial ecosystems, including forest, grassland, freshwater, and coral reef ecosystems, have been carried out. A series of new methodologies of conservation biology such as population viability analysis, DNA sequence analysis, and others has been implemented in evaluating the threatened status of important species and its endanger mechanisms. The result of such research provided a scientific basis for biodiversity conservation especially for conservation of rare and endangered species as well as the life-supporting ecosystems. During the period of the "Ninth Five-year Plan" (1996–2000), the projects like "Study on Biodiversity Conservation in Key Areas of China" and "Biodiversity Changes, Sustainable Use and Regional Ecological Security in the Yangtze River Basin" have been included in the national key program of basic research.

Until 2008, China had founded 2538 natural reserves with a total area of 148.94 million ha, accounting for 15.13 % of the total national land territory of China. It has now formed a well-coursing national natural reserve network. The gross area of the protected areas reaches to 17 % of the total territory land of China which includes forest parks, cultural and natural heritages, scenery areas, wetland parks, geological parks. Besides, an integrated ex-situ conservation system has also been built in China, which includes zoos, botanical gardens, arboretums, wildlife-breeding bases, crop germplasm banks, and animal germ cell banks.

Based on the ecological research, China has preliminarily established a system of biodiversity conservation policies and regulations, including "Law of Wildlife Protection" (1988), "Regulation on Nature Reserves" (1994), "Regulation of Wild Plant Protection" (1997), "Regulations on Administration of Import and Export of Endangered Wild Animals and Plants" (2006) and so on. In order to implement "the Convention on Biological Diversity(CBD)", the State Council established the CBD Implementation Steering Committee in 1993, headed by the Ministry of Environmental Protection (MEP) with 24 ministerial members. It is followed by "the Joint-ministerial Conference for Species Resources Protection and Management" founded in 2003 with 17 ministries, coordinated by MEP. Meanwhile, an affiliated scientific body of "National Expert Commission for Biological Species Protection" was established. Besides, China National Biodiversity Protection Action Plan was issued by the Chinese government in 1994 and the updated National Biodiversity Strategy and Action Plan was officially issued in 2010.

Global Change and Global Ecology

Research on alleviation and adaptation to global change has been a key area of global change science since the end of the twentieth century. Chinese ecologists have also actively taken part in relevant researches, such as the responses and acclimation of ecosystem to global change, ecosystem C storage, processes involved in the C cycle and their mechanisms, the observation and simulation of ecosystem carbon, nitrogen and water fluxes, and the interaction between human activities and global change, etc.

Chinese scientists have suggested to set up the Northeast China Temperate-Grassland Transect in 1993, which was officially registered as the Fifth Transect of the Global Change and Terrestrial Ecosystems (GCTE) by IGBP in 1994. Later, an assumption of creating the transect from the polar tundra to rain forests along the east coasts of Eurasia Continent was promoted and its sector in China was named the North-South Transect of Eastern China (NSTEC). In 2002, the conception of China Grassland Transect (CGT) was proposed after the extensive researches on terrestrial ecosystem C cycle and its driving mechanism in China. It covers the main grassland types across the Northeast Plain, Inner Mongolia Plateau, Loess Plateau and hinterland of Qinghai-Tibet Plateau from Northeast to Southwest of China. Recently, an initiative has been made in cooperation with Euro-Asian Continental Grassland Transect (EACGT) with AsiaFlux. An integrated observation and research network platform for ecosystem and global change in Asia has been established, with the carrying out and achievement of the A3 foresight program (CarbonEastAsia) among ChinaFLUX, JapanFlux, and KoFlux.

Research on ecosystem C storage, process and mechanism of C cycle, and C budget in China started basing on the inventory of vegetarian productivity, biomass, soil census and experiments on organic fertility effect in the early 1960s. Feng Zongwei, for the first time, quantified the biomass yield of main forest ecosystem types in China and characterized its distribution pattern in 1999, by comprehensively summarizing and analyzing the research data accumulated since the 1960s. Hence, a large number of studies assessed the C budget and C storage of forests as well as grassland ecosystems in China by using the data of soil census and forest inventory data. Recently, Piao Shilong analyzed the current terrestrial carbon balance of China and the mechanisms of the involved processes during the 1980s and 1990s using three different methods: estimation of biomass and soil carbon inventories extrapolated by satellite greenness measurements, ecosystem models, and atmospheric inversions.

The Chinese Terrestrial Ecosystem Flux Observation and Research Network (ChinaFLUX) was established in 2001. A basic system of flux observations based on eddy covariance technique and gas chromatography has been developed. Continuous measurements on C and water vapor fluxes over typical terrestrial ecosystems have been made in the last 10 years. New efforts have also been made to make observations of atmospheric N deposition, biological N fixation, and the stable isotope nitrogen flux. ChinaFLUX has obtained long-term observation data of CO_2 fixation through photosynthesis, nitrogen fixation by bean root modules through biological processes, water evaporation through evapotranspiration, and energy fluxes in typical terrestrial ecosystems in China. The vegetation and soil inventory data around each flux site have also been collected. A series of datasets have been produced, including the spatiotemporal dynamic dataset and atlas of major climatic and meteorological factors, land resources, and LUCC since 1980 in China. Basing on the above datasets and modeling system, the spatiotemporal pattern of C sink or source of typical forest and grassland ecosystems in China were quantitatively evaluated, and the environmental and biological driving mechanisms of temperature, precipitation, radiation, and leaf area index on the C budget of different terrestrial ecosystems in the Asian Monsoon area were also investigated.

The research on C cycle simulation started later in China than that in European and American countries, but it progressed rapidly. In recent years, Chinese scientists have adopted and improved several terrestrial ecosystem C cycle models from abroad, such as CEVSA, GLO-PEM, BEPS, EALCO, etc. They also compared the performance of SIB2, BIOME-BGC, and BIOME3 models in simulating China's terrestrial C budget. Furthermore, Chinese scholars have also developed their own C cycle models for different ecosystem types; for example, the C budget model of forest ecosystems in China (FORCCHN), the biophysical process-based model for C budget in agro-ecosystem (Agro-C), the C budget model of grass ecosystems in China (DCTEM) based on IBIS model, and the atmosphere-vegetation interaction model version 2 (AVIM2). The rapid development and improvement of these models greatly promoted the simulation of C and water budget in China's terrestrial ecosystem.

Chinese scientists have carried out a series of experiments to test the ecosystem's responses to different warming, precipitation, CO_2 enrichment, and N deposition conditions. In 2007, National Natural Science Foundation of China (NSFC) launched a key research project focusing on the response and adaptation of China's typical terrestrial ecosystem to climate change and integrated the major observation sites in China. Important findings were obtained about the short-term response and long-term adaptation of ecosystem C and N processes, biological diversity, and ecosystem patterns to climate change. Currently, under experiments control were made focusing on the grasslands in Qinghai-Tibet Plateau and Inner Mongolia, where ecosystems are sensitive to climate change. Lately, simulation experiments on the effects of N deposition, precipitation change, and atmospheric CO_2 enrichment on plant growth have been carried out at the major forest ecosystems in eastern China.

Combating Desertification and Erosion Control

China is one of the countries most severely affect by desertification and soil erosion. According to preliminary estimation, 37.2 % of the country's territory—some 3.57 million km^2—is classified as drylands (including arid, semisarid and dry sub-humid arid areas). Of the drylands, 2.64 million km^2 falls under the category of desertified land in accordance with the definition of the UNCCD, and these desertified lands are distributed in 18 provinces and account for 27.5 % of the country's landarea. The desertified lands of China can be attributed to wind erosion, water erosion, salinization, and freezing-thawing processes. The life of over 400 million residents are affected by desertification, and the direct economic losses per year exceed 64 billion yuan.

China's desertification mitigation efforts began in the late 1950s. Through a number of high-profile programs, such as the Three-North's Shelterbelt Development Program was initiated in 1978, the National Program on Combating Desertification was initiated in 1990, the Sandification Control Program for Areas in the Vicinity of Beijing and Tianjin was launched in 2000, and the Conversion of Croplands to Forests and Grasslands Program initiated in 2000, the Government of China has poured on average 0.024 % of the country's annual gross domestic product (GDP) into desertification mitigation efforts and, as a result, some 20 % of the desertified lands have been brought under control.

Based on the result of scientific research, the scientists in field ecology put forward the following suggestions for further improvement the situation for policy making: (i) expanding the previous sectoral perspective to embrace a multi-stakeholder approach; (ii) setting priority zones within the restorable area, and establishing National Special Eco-Zones (e.g., forest farms, protected areas, and headwater areas); (iii) restructuring the state anti-desertification investment portfolio by changing the government direct investment in tree plantations to government acquisition of planted/greened areas; and (iv) introducing preferential policies against sandy-desertification, such as permitting land tenures for up to 70 years and compensating for ecological services.

China is one of the nations with most serious soil erosion in the world. According to the second national remote sensing soil erosion survey in the 1990s, the area of soil erosion and wind erosion reached 3.556 million km^2. About 50 million tons of soil would be lost every year.

China, as a country with an ancient civilization, has a long history of soil and water conservation. Having summarized the experiences in history, considering the current situation of the country, a soil erosion prevention system with Chinese characteristics was formulated, mainly based on small watershed comprehensive management. Small watershed management has been carried out in 27 provinces, autonomous regions and municipalities. More than 9800 small watershed areas are made control, with a total area of nearly 40 million km^2, of which 22 million km^2 are soil erosion area. Nearly 3000 small river basin control projects have been completed.

Although the worsening trend of soil erosion in China has been controlled, water and soil erosion areas are still facing high population, densities, and environmental pressures. Several countermeasures are being taken: (i) recognizing that "soil erosion is a serious ecological degradation" and soil and water conservation as a national policy; (ii) implementing integrated technology systems; (iii) strengthening scientific research on soil and water conservation; (iv) strengthening the legal construction of soil and water conservation; (v) enhancing soil and water conservation; and (vi) constructing soil and water conservation mechanisms, especially investment practices, compensation, incentive, and restriction mechanism.

The Ecosystem Study on the Qinghai-Tibetan Plateau

The Qinghai-Tibetan Plateau, also called "The Third Pole", is a unique geographic unit with an average altitude over 4000 m. The plateau is one of the biodiversity hotspots over the world; on the other hand, it is the most fragile region due to its extreme climate and habitats.

The ecological research dated back to the natural resources survey since the 1950s. The large-scale multi-disciplinary scientific expeditions in Chinese Himalayas and Hengduan Mountains, were organized and carried out by the Chinese Academy of Sciences from 1973 to 1979. A wealthy of knowledge obtained in understanding the ecological conditions and distribution of vegetation and the productivity of ecosystems. The results of such expeditions were summarized in the book Geological and Ecological Studies on the Qinghai-Xizang Plateau. In 1980, an International Symposium on the Qinghai-Tibetan Plateau was held in Beijing. It was a milestone of international cooperation in ecological research in the high mountain regions. The Commission of Integrated Survey of Natural Resources, Chinese Academy of Sciences, played an important role in ecological research on the plateau in collaboration with international organizations such as International Center for Integrated Mountain Development in Nepal and the Woodland Mountain Institute, West Virginia, USA and International Development Research Center in Canada. In the period of "the Eighth-Five Year Plan" (1991–1995), the national basic research program of "Formation, Evolution, Environmental Change and Ecosystem Research on the Qinghai, Tibetan Plateau" was initiated. Some long-term ecological research stations, for example Gonggashan Mountain Forest Station in west Sichuan, Haibei Alpine Grassland Ecosystem in Qinghai, and Lhasa Agricultural Ecosystem Research Station were founded as research bases for ecosystem study. As a consequence, a book Ecosystems of Qinghai-Xizang (Tibetan) Plateau and Approach for Their Sustainable Management was jointly published to summarize the results of the research in this period.

Through physiological studies it was discovered that the slow growth and small stature of alpine plants including crops is not associated with low rate of carbon uptake and high loss per unit of tissue. The carbon fixation rates were not lower than those at lower altitudes. On the contrary, the alpine plants have higher capacity for carbon assimilation in comparison with their lower populations or plant heights. The higher carbon investment into roots, but nothing significant difference in leaf mass ratio, guarantees carbon supply of alpine plants. The duration of active growing season appeared to be the overwhelming factor to constrain plant production. The net primary productions (NPP) of alpine plants in terms of production per growing day are not necessary lower than the low-altitude plants, even for the tropical or subtropical ones. However, NPP at the community level is lower than lower ecosystems due to lower leaf area index (LAI). Low temperature is the prominent factors limiting plant growth rather than photosynthesis, which is indicated by higher nonstructural carbohydrate concentration in alpine plant tissues in comparison with the growing at lower altitudes. Therefore, it is lower carbon use rather than poorer carbon source of alpine ecosystem boundaries such as treeline and grassland upper limit. The results of eddy covariance measurement of net ecosystem CO_2 exchange (NEE) indicate that alpine meadow and scrubs have weaker carbon sink or even source. Lower LAI is the key factor to cause lower carbon uptake. Rainfall patterns in the growing season and pulse rainfall in the beginning and at the end of the season affect the ecosystem respiration and thereby the carbon balance of ecosystem. Soil respiration is the main component of ecosystem respiration. Although temperature is the key factor controlling respiration, plant phenology modifies the temperature dependence of soil respiration in the season. Seasonal distribution of precipitation greatly affects the sink–source relation. Grazing and reclamation are the main disturbances that cause carbon loss due to enhancement of soil respiration. On the contrary, enclosure-pasturing system and recovery of degraded grassland might alleviate carbon emission and even accelerate carbon sequestration.

Global warming tended to be accelerated in the past decades in the high alpine area. Experimental warming caused rapid species extinction in alpine meadow, which was dampened by simulated grazing. Higher species losses occurred at the drier sites where N was less available. The indirect effect of climate warming on species richness was mediated by plant–plant interactions. Heat stress and warming-induced litter accumulation are potential causes. Grazing might reduce the risk of loss of species under the global warming scenarios.

Addition of nitrogen increases productivities of alpine N-limited ecosystems, but simulated nitrogen deposition often causes loss of species not only via increase of competition between plants species, but between plant and microorganisms. CO_2 enhancement ecosystem increases number of wheat tillers and stochastic photosynthetic rate of leaves. However, the wheat yields and biomass are not necessarily increased partly due to nitrogen supply shortage while the growing period.

Promoting Sustainable Development from Concept to Action

Unlike other biological communities, human society is a kind of artificial ecosystem dominated by human behavior, sustained by natural life support system, and vitalized by ecological process. It was named as Social-Economic-Natural Complex Ecosystem (SENCE) by Ma Shijun in 1984. Its natural subsystem consists of the five elements of Chinese tradition: metal (minerals), wood (living organism), water, fire (energy), and soil (nutrients and land). Its economic subsystem includes the essentials factors of production, consumption, reduction, transportation, and regulation. While its social subsystem includes technology, institution, and culture, the scientific study on sustainability in China is to coordinate the temporal, spatial, structural, and functional relationships among and within the three subsystems.

Grounded in ancient Chinese human ecological philosophy and SENCE approach, a campaign of Ecopolis development has been undergoing in some Chinese cities and towns since the 1990s. Ecopolis is a kind of administrative unit having productive and ecologically efficient industry, systematically responsible and socially harmonious culture, and physically beautiful and functionally vivid landscape. It is a kind of adaptive process toward sustainability through cultivating five facets of eco-sanitation, eco-security, eco-landscape, eco-industry, and eco-culture. The essential idea of ecopolis development is to plan, design, manage, and construct the ecosystem's function of production, living, and sustaining according to ecological cybernetics. It is a healthy process toward sustainable development within the carrying capacity of local ecosystem through changing the mode of production, consumption behavior, and decision instruments with three legs of Circular Economy, Harmonious Society, and Safe Ecology. Integration, demonstration, citizen's participation, and scientist's and technician's catalyzing are the keys in its development. The term "ecopolis" is used to imply an ecologically sound city region and its immediate periphery. The development of ecopolis needs five ways of motivation, i.e., administrative authorization, scientific supervision, industrial sponsorship, participation by the community, and motivation by media. There are four development stages: concept initiation and comprehensive planning, ecoscape planning and legislation, development through eco-engineering design, and ecosystem monitoring and management.

During the past two decades, 510 eco-demonstration zones have been appraised and named by the Ministry of Environmental Protection, 14 provinces/autonomous regions/directly governed city regions (Hainan, Jilin, Heilongjiang, Fujian, Zhejiang, Shandong, Anhui, Jiangsu, Inner Mongolia, Shanxi, Hebei, Guangxi, Sichuan, and Tianjin) were approved to carry on eco-province development. By February 2010, there were already 108 state comprehensive experimental districts toward sustainability approved by the Ministry of Science and Technology, including towns, counties, middle/small-size cities, and districts of large cities distributed in 93 % of China's provinces and autonomous regions.

Compared with foreign countries, China's ecopolis development is rather through top-down than bottom-up encouragement. The advantages of this way is that if the decision makers are smart enough, the ecopolis plan will be strongly implemented; otherwise, it will be just an oral promise or an utopian ideal. While main lessons and challenges are also gained such as institutional barrier, behavioral bottleneck, and technical malnutrition, the Sino-Singapore ecocity planning in Tianjin, and a quite few other cases of ambitious ecocity planning in China, show the public a dream of a sustainable city. To realize it, however, an adaptive process is needed to meet the local natural and human ecological condition needs, to reshape our production mode, consumption behavior, the goal of development, and the meaning of life, to reform the fragmented institution in legislation, organization, governance, decision making, planning and management, and to renovate the reductionisms based and chain-linked technology.

After entering the new century, eco-agricultural development entered into its new stage. There are some mile stones like the publication of Agro-ecological Farming Systems in China by Parthenon Publishing in 2001 and Eco-agriculture—Theories and Practices of China's Sustainable Agriculture by (Beijing) Chemistry Press. These two monographs, all compiled by Li Wenhua together with nearly 100 specialists in eco-agriculture, got excellent responses from both in China and abroad.

In 2005, The Food and Agriculture Organization (FAO) of the United Nations launched a program on the Conservation of Globally Important Agricultural

Heritage Systems (GIAHS). FAO defined GIAHS as "remarkable land use systems and landscapes which are rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development". The Traditional Rice-fish Culture in Qingtian County, Zhejiang Province, was selected by FAO as one of the first group of pilot sites of the GIAHS project. Up to now, some researches on biocultural diversity conservation, eco-tourism development, eco-compensation mechanism, organic agricultural development, and multi-participatory process on the pilot site were carried out and many papers published.

Evaluation of Ecosystem Services and Eco-Compensation

Since the middle 1990s, global assessment of ecosystem services and the launching of the Millennium Ecosystem Assessment (MA) on a regular basis at national and sub-national scales have attracted great attention and interest of Chinese scholars in joining the cooperation with international organizations and conducting the assessment work at home.

In China, since the late twentieth century, researchers have done some preliminary explorations on the evaluation theory, methods, and applications of ecosystem services. Especially after entering the twenty-first century, a lot of works on the evaluation of various ecosystems in different regions were done. Ecosystem services of different spatial scales such as national, watershed, provincial, municipal, and district have been studied, as well as different natural and artificial ecosystems such as forest, grassland, farmland, wetlands, desert, marine and reservoirs, etc. At the same time, much attention has been paid to some single functions and services like water and soil conservation, carbon sequestration and oxygen release, air purification and landscapes, too. These achievements have played important roles in decision-making process related to ecosystem management and environmental protection in China.

Recently, scientists in the field of forestry worked on the standardization of the indicators of ecosystem service assessment and the value of ecosystem services were calculated on the basis of the forest inventory data, which covers all the forests in China.

In 2008, a Joint US-China Center on Ecosystem Services (JUCCES) has been established. The establishment of the Center was based on a series of discussions and meetings between National Service Foundation of China (NSFC), Chinese Academy of Sciences (CAS), and National Science Foundation of USA (NSFA), aiming to establish a long-term mechanism for promoting cooperative research and exchange information in the field of eco-service and eco-compensation studies. The mission of JUCCES is to provide a platform for facilitating collaboration, communication, and coordination between scientists engaged in studies on natural resources, ecosystem services, eco-compensation, impacts of ecosystem changes on human well-being, and response options for developing a harmonious relationship between human being and nature.

Research and practice on eco-compensation mechanism are of great strategic significance in the new period of implementing full-scale scientific development