

Editorial

# Ecosystem Observation, Simulation and Assessment: Progress and Challenges

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Ecosystems provide supply, regulation, culture and support services for human-being, and overall support human survival and sustainable development. As an open, dynamic and integrated system, the internal components of an ecosystem are constantly realizing the dynamic coordination of interaction to achieve a new balance through the process of material and energy exchange and actualizing the mutual adaptation and self-evolution of the ecosystem and the external environment. However, driven by multiple factors such as climate change, population growth, urbanization, and exploitation of mineral resources, global problems such as ecosystem degradation and biodiversity loss have affected the sustainable development of human beings. It has become a hot spot in ecology research to develop basic theories, model methods and technical means for ecosystem observation, simulation and evaluation, for the quantitative analysis of the structure, process and function of ecosystems, and for the improvement of the scientific understanding of the changing characteristics and evolution laws of natural ecosystems.

## 1. Ecosystem Observation Progress

According to the spatial distribution of ecosystem characteristics, the parameters of an ecosystem are measured on the spot by setting sample plots, quadrats, sample points and sample belts in the field investigation. Alternatively, quantitative analysis is carried out in the laboratory after ecological sample collection. By these representative investigation methods, the overall observation of a regional ecosystem can be realized. This field survey type exemplifies the earliest and most basic method of ecosystem observation. To obtain more continuous times ecosystem observation data so as to better understand the ecosystem process and its mechanism, the observation equipment is deployed at a fixed sample point to observe positioning or site. For the same ecological parameter, different observation methods can be selected according to different research purposes, such as the study of methane emission intensity in wetlands [1,2].

Due to the limitation of the continuity and representativeness of observation data, the long-term positioning observation data of a single site cannot reveal the universal law of ecology. To take a mountain ecosystem as an example, the observation data from a certain station on the sunny slope can be used to analyze the laws of the mountain's sunny slope ecosystem but cannot be used to analyze the laws of other mountain or shady slope ecosystems. If we aim to determine a general law of mountain ecosystems, we must establish up multiple observation stations across different mountains and ecosystems according to their distribution. Positioning observation has developed from a single position to a network, forming ecosystems observation networks on national, intercontinental and global scales. In particular, the International Biological Program (IBP) launched in the 1960s and the international symposium "Long-Term Ecological Research: Global Prospects" held in the 1980s played important roles in promoting the development of positioning observation worldwide. Over 40 years, a national-scale ecosystem observation network has formed which is represented by the United States, China, the United Kingdom, Japan, Canada and Australia. This is joined by intercontinental-scale ecosystem observation networks,



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represented by the Asian Flux Observation System and European Integrated Carbon Observation System, and series of globe-scale ecosystem observation networks represented by the International Long-Term Ecosystem Research Network, the Group on Earth Observations Bio-diversity Observation Network, and the Global Terrestrial Observing System.

In addition to ground observation, remote sensing observation has become an indispensable means of ecosystem observation. Since the launch of the first manmade satellite in 1957, Earth observation has changed. The era in which humans can only make local observations from the Earth's surface, which spanned millennia, has ended. Up to now, the spatial resolution of remote sensing observation includes kilometer-scale, meter-scale and sub-meter-scale resolutions, the spectral resolution of remote sensing observation includes multi-spectrum and hyperspectral resolutions, and the spectral resolution of remote sensing observation includes ultraviolet, visible light, infrared, microwave resolutions, etc. The increasing use of UAV (unmanned aerial vehicle) remote sensing platforms has significantly improved remote sensing observation ability. Remote sensing observation has the unique characteristics of large-scale synchronous observation, which significantly improves the capability of researchers to observe the ecosystem in a spatially continuous or synchronous manner. At the same time, based on historical images, we can carry out retrospective monitoring and assessments of regional ecological change characteristics. Remote sensing observation has been widely used in regional ecosystem change monitoring [3,4]. The use of high spatial resolution UAV remote sensing observation technology can better monitor and identify large animals, and significantly improve the efficiency and data accuracy of biodiversity monitoring and investigation [5]. For hyperspectral remote sensing data, refined spectral information can better identify ecosystem process indicators, such as soil carbon or nutrients [6].

## 2. Ecosystem Simulation Progress

Ecosystem simulation is mainly realized through the ecological principles model. Ecological model simulation is based on a good understanding of the ecological process, structure and function. Based on the basic elements and key processes of the ecosystem, an ecological model is put forward by the parameterized, digital and quantitative expression of the complex ecosystem. As a consequence, it is unrealistic to aspire to describe the ecosystem completely and accurately through model simulation. Simulation model construction is the trade-off between model accuracy and simulation efficiency. In general, the fewer the basic elements and key process nodes of the ecosystem, the higher the simulation efficiency of the model but the lower the accuracy of the model. On the contrary, the simulation efficiency of the model is low, but the model accuracy is high. If the ecosystem has more basic elements and key process nodes then the simulated model will be closer to the real and complex ecosystem.

Ecology is a wide range of contents, and there are many types of ecosystem models. Representative models include eco-geographic and biogeochemical models. Eco-geographic models mainly simulate the spatial distribution of terrestrial ecosystem and its relationship with geographical environment, as in a Holdridge life zone system model. Ecosystem biogeochemical models, such as the CASA vegetation net primary productivity model, CENTRY biogeochemical cycle model, or BIOME-BGC carbon and water flux model, mainly simulate ecosystem processes and functions including net primary productivity, carbon and nitrogen water cycle, nutrient circulation, etc. With the development of remote sensing and geographic information system technology, the spatial and geographic development trend of ecological models is obvious. At the same time, with the increasingly obvious impact of climate change and human disturbance on the ecosystem, the model simulation of the impact of climate change and human disturbance on the structure and function of the ecosystem has received more attention.

### 3. Ecosystem Assessment Progress

The main content of ecosystem assessment is the analysis of the spatio-temporal change process of the ecosystem and of the interaction between the ecosystem and human society, climate, hydrology, etc. The Millennium Ecosystem Assessment, carried out by the United Nations organization, has promoted the development of integrated ecosystem assessment in landmark fashion. Different organizations or countries have carried out many comprehensive ecosystem assessment practices at different scales, such as global, regional and national. The assessment framework models can be summarized into four categories: First is the “Ecological Pressure–Policy Response” ecosystem assessment framework, represented by the DPSIR (Drivers–Pressure–State–Impact–Response) framework adopted by the Global Environment Outlook of the United Nations Environment Programme. Second is the “Ecosystem Services–Human Welfare” ecosystem assessment framework, represented by the “Ecosystem Services–Material Supply Human Welfare–Change Driving Force” adopted by the United Nations Millennium Ecosystem Assessment. The third is the “Natural Benefit–Ecosystem Management” ecosystem assessment framework, represented by The Economics of Ecosystems and Biodiversity (TEEB) project plan promoted by the United Nations Environment Programme. The fourth is the “Comprehensive Status–Change Trend” ecosystem assessment framework, represented by China’s regular national ecosystem survey and assessment.

In addition to the comprehensive assessment of ecosystems, there have been some new research hotspots in ecosystem assessment focusing on global challenges and sustainable development of human society. In terms of sustainable development, measured by progress towards the 2030 Sustainable Development Goals proposed by the United Nations [7], the coordinated development of ecological protection and social economy [8–10] has attracted much attention. In the realm of climate change challenges, some researchers have assessed ecosystem responses to climate change, especially the response of ecosystem services [11] and production functions [12] to climate change. In terms of the challenges of biodiversity and ecological degradation, the biodiversity conservation assessment [13,14] and implementation effectiveness assessment of ecological conservation and restoration policies or measures [15–17] are becoming popular.

### 4. Challenges in the Future

Although people have made significant progress in the research and cognition of ecosystems, the cognitive level remains very limited in the face of complex and comprehensive ecosystems. There is no doubt that scientific research of ecosystems is needed.

The observation of ecosystem structure, process and function cannot be realized by using any existing ecosystem observation means alone. In the future, it will be necessary to build an intelligent ecosystem observation network by integrating three observation methods with the help of networks, IOT (Internet of Things), improving ecosystem observation ability and realizing fine observation. At present, due to the relatively mature observation technologies and methods for the main ecological parameters including vegetation and hydrology, there are many observation and research methods for natural ecosystems such as forests, grasslands and wetlands. However, for ecosystems that are not dominated by vegetation, such as deserts and glaciers, the observation technologies and methods need to be strengthened to better serve the challenges of climate change.

The ecosystem parameter data obtained by multi-observation means are multi-source heterogeneous and differ in space–time scale. Developing a means to process data from different observation methods and achieve the matching of a space–time scale is the most important and basic objective in ecosystem research. The accuracy of spatio-temporal matching of observation data directly affects the reliability and accuracy of ecosystem research conclusions. However, due to the significant difference in data scales, such as the spatial matching between the ground survey data in 1 square meter samples and the satellite remote sensing data with tens of meters or kilometers of spatial resolution, the current models and methods for processing these basic data still have great limitations. Of

course, the scale problem not only exists in data processing, but persists across wide areas of ecological research, such as evaluation and simulation, and represents a fundamental topic in ecological research. For the same ecological problem, with different space-time scales, the research conclusions may be inconsistent, and contradictory conclusions may even appear. Spatial scale includes both spatial scope and spatial granularity (or resolution), and time scale includes both time span and time frequency. A means of choosing and determining the best space–time scale is the basis and key of ecological research. Other scale concepts also constitute the object of ecological research: cells, tissues, organs, systems, individuals, populations, communities, ecosystems and biosphere.

Ecological research is not only a scientific problem, but also a management problem relating to the sustainable development of human beings. How to quantitatively analyze the interaction between ecosystems and human society, ecosystems and climate change, establish a universal “natural ecology human society” ecological assessment framework, and establish a high-accuracy “natural ecology climate change” ecosystem process model are the major challenge ecosystem assessment. In the face of major challenges such as current ecosystem degradation, biodiversity loss and climate change, many questions still require scientific explanation and accurate answers. Examples of such issues include developing a means to quantitatively understand and establish the driving effect of protection and restoration measures on ecosystem change, the prediction of impacts of human disturbance and destruction on ecosystems, the contribution of ecological protection and restoration to mitigating climate change, the impact of ecosystem change on natural disasters, the simulation and prediction of global large-scale ecological change, and the high-accuracy simulation and evaluation of local scale ecological processes. The in-depth study and solution of these problems are of great scientific significance to the sustainable use of nature, the optimization and adjustment of ecosystem protection, and to restoration strategies for human society.

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