Xinyuan Wang · Jing Zhen · Qingkai Meng

Spatial Observation of Giant Panda Habitat

Techniques and Methods

科学出版社 Science Press

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ISBN 978-981-19-8793-9 ISBN 978-981-19-8794-6 (eBook)
https://doi.org/10.1007/978-981-19-8794-6

Jointly published with Science Press
The print edition is not for sale in China (Mainland). Customers from China (Mainland) please order the print book from: Science Press.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

Among the various types of multi-international designated areas, World Heritage sites can be considered the crown jewel. As of July 2019, a total of 1121 sites have been inscribed on the World Heritage List, of which cultural heritage accounts for 869, natural heritage for 213, and cultural and natural heritage for 39. Due to the impact of global changes, the conservation and sustainable development of these precious properties are greatly challenged. Among them, the endangered animal world heritage sites are particularly problematic, especially the habitats of these rare and endangered animals. The imminent or ongoing habitat changes due to climate change and the combined effects of accompanying disasters such as heavy precipitation, drought, and extreme temperatures have led to drastic changes in animal survival conditions, coupled with unreasonable human activities, making these rare and endangered animal habitats. Habitats of these rare and endangered animals face a sudden increase in disaster risk.

The Giant Panda, the flagship species of the biodiversity conservation, once a representative of the endangered species, was removed from the "endangered" category in 2015 thanks to the joint conservation efforts of the Chinese government and people from all walks of life around the world. On the one hand, this strongly proves that humans can make a difference in protecting these endangered creatures and can slow down or even change the situation; on the other hand, we must not take it lightly, as temporary removal from "endangered" does not mean that we are free of worries forever, and we still need to even further strengthen the monitoring of Giant Panda habitats and further enhance scientific and effective conservation measures. On the other hand, we can never be complacent, and the fact that we are temporarily out of "endangered" does not mean that we are always worried.

Monitoring, conservation, and research of World Heritage sites is a long-term process. Without continuous and long time-series observation, it is impossible to truly understand the impact of global changes on heritage sites. With its advantages of long time-series, macroscopic, timely, holistic, and accurate cognitive objects, space-air-ground integrated Earth observation technology provides a unique perspective and macroscopic view of World Heritage from space. In October 2009, the 35th UNESCO plenary session approved the proposal made by the Chinese Academy of

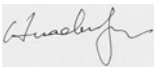
Sciences in May 2007 to establish an international space technology centre. The aim is to use space technology for work in the areas of natural and cultural heritage, biosphere reserves, climate change, and natural disasters, and to support education for sustainable development. In June 2011, UNESCO and the Chinese government signed an agreement to establish the International Centre on Space Technologies for Natural and Cultural Heritage (HIST), which was officially established in Beijing in July of the same year. HIST is the first space technology-based World Heritage research institute established by UNESCO in the world. The objectives of HIST are to help UNESCO Member States to apply space technology to the study and conservation of cultural and natural heritage, thus enhancing their management, conservation, promotion, and participation in UNESCO's activities related to world heritage; to strengthen the capacity of Member States to use Earth observation technology to acquire data to support decision-making for sustainable development; and to enable all research findings to become new educational materials, thus supporting the United Nations education for sustainable development activities. thus supporting UN activities on education for sustainable development. Due to the increasing impact of climate change and human activities, research on habitat conservation of rare or endangered species has become more urgent. Currently, the research on ecological health diagnosis methods and techniques of natural heritage sites, especially in the evaluation of biodiversity stability, habitat suitability assessment of important species, evaluation of natural landscape integrity, and the construction of technical standards and platforms for dynamic monitoring of heritage sites, has become a key focus of research, and the methods and models of related research have become a hot spot. In view of the different climatic, hydrological, vegetation, and soil characteristics of the habitats of important species, we study the spatial and temporal characteristics of the elements that characterize the outstanding universal values of natural heritage, combine the characteristics of different observation techniques of space-space-ground, obtain applicable spatial and temporal resolution remote sensing data, select suitable habitat suitability impact factors of important species with the guidance of dynamic data-driven paradigm, and construct a library of habitat suitability assessment models. The analysis of the factors affecting habitat suitability of important species and their interrelationships, the exploration of their change mechanisms and driving forces, and the search for applicable conservation measures and countermeasures are important elements of habitat-based natural heritage site conservation research, and are urgently needed for in-depth research. However, not much work has been done on this aspect of biological habitats by applying Earth observation techniques, especially in terms of comprehensive research.

It is very pleased that the HIST research team has conducted more in-depth research on spatial observation and cognition of natural heritage with the support of the State and Chinese Academy of Sciences. In particular, the successive support from the International Cooperation Special Project of the Ministry of Science and Technology, the Key R&D Project of the Ministry of Science and Technology, and the Strategic Priority Research Program of the Chinese Academy of Sciences has enabled the research team to conduct continuous spatial observation and cognition research on natural heritage, especially the research on the impact of global change on

Giant Panda habitat based on space technology, and form some scientific cognition. Under the organization and leadership of researcher Xinyuan Wang, the research team explored the information implied by remote sensing images indoors and the true meaning behind the information in the field despite the high mountains and dangerous roads. As a result, all of us worked together and gathered the strengths of our research to write and assemble a book. The study showed that although the two earthquakes in recent years, Wenchuan and Ya'an, had less impact on the habitat and the Wenchuan earthquake had more impact, the natural recovery of vegetation had an obvious effect in 3–5 years. However, the impact of ongoing climate change requires great attention: in Giant Panda habitat, the vegetation boundaries of the mountainous vertical zone are rising due to warming temperatures, advancing northward in latitude, thus affecting the current suitability of giant panda habitat. In addition, excessive human activities (road construction, reclamation, mining, reservoir construction, etc.) have had different degrees of impact on the habitat suitability of giant pandas, resulting in some habitats even needing to consider relocation for conservation. Looking to the future, we should indeed prepare for the rainy days, especially for the long-term changes in the natural environment and the continuous high-intensity impact of human activities, and pay great attention to the scientific conservation and effective countermeasures for the Giant Panda habitat, and conduct in-depth research.

As HIST enters the second phase of construction, I sincerely hope that the HIST research team will continue to practice and innovate in the application of space technology to the conservation and recognition of natural and cultural heritage, and achieve more and greater scientific and technological achievements in the new round of journey.

This is the preface.



February 2020

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Preface

Space-based Earth observation is a science and technology that detects the Earth from space and conducts scientific analysis and research on the Earth's targets. By applying this technology, we can help achieve scientific and intelligent decision-making and management for the Earth in terms of detection and discovery, monitoring and assessment, and scientific cognition and response strategies.

In recent decades, space-based Earth observation has grown with the development of aviation and space platform technologies and optical, microwave, laser, and other payload technologies, as well as the progress of information processing methods. At present, space-based Earth observation systems for various applications have been established worldwide, constituting a multifaceted, three-dimensional observation system for all levels of the land, ocean, and atmosphere, playing an increasingly important role in resource and environmental investigation and monitoring, and promoting economic, social and sustainable development.

After nearly three decades of advancement, space technology has also played an increasing role in the monitoring and protection of natural and cultural heritage. For example, in terms of cultural heritage detection, in 1994, Guo Huadong, a Chinese scientist who participated in the Space Shuttle Radar Program, discovered the ancient Great Wall of the Ming and Sui Dynasties buried by dry sand by means of radar remote sensing, which was regarded as one of the "three major discoveries" of the scientific program. In 2013, Chinese scientists identified six ancient town ruins, two settlement sites, and one ancient road section of the Silk Road through optical remote sensing and historical maps. The six ancient towns, two residential areas, and one ancient river in the Guazhou-Shazhou section filled the gap of remote sensing archaeological discoveries of Han and Tang sites in the area west of the ancient city site of Bazhou. In 2018, 10 archaeological remains of the Roman period were discovered in Tunisia at the western end of the Silk Road using spatial archaeological technologies and methods, which revealed the layout of the military defense system and the structure of the agricultural irrigation system on the southern route during the Roman period, which was the first time that Chinese scientists used remote sensing technology to discover archaeological remains outside of China. In terms of using space technology for monitoring and evaluation of natural heritage conservation, Chinese World Natural Heritage sites such as Huangshan and Jiuzhaigou have made notable achievements in digital construction. On a macro level, space information technology is a very effective and objective technical tool in the conservation of world heritage sites, especially for places that are off the beaten track, such as giant panda habitats, with high mountains and overgrown trees and grasses, where human footprints need to make arduous efforts to reach.

The giant panda is not only a national treasure of China but also a flagship species for biodiversity conservation globally, and in July 2006, at the 30th UNESCO World Heritage Conference, China's "Sichuan Giant Panda Habitat" was inscribed on the World Heritage List. The heritage site consists of Baoxing County, where the world's first giant panda was found, 7 nature reserves including Wolong Nature Reserve and 9 scenic spots including Qingcheng Mountain—Dujiangyan, Jiguan Mountain—Jiulonggou, Xiling Snow Mountain, and Tiantai Mountain in Sichuan Province, covering 12 counties in four cities and states, including Chengdu, Ya'an, Aba, and Ganzi, with an area of 9,245 km^2. Since then, the "Sichuan Giant Panda Habitat" has been included in the world heritage protection.

Historically, Giant Panda was widely inhabitated in China, with fossil remains found in the Yellow River, Yangtze River, and Pearl River basins, but with climate change, geological landscape changes, and the continuous expansion of human activities have led to a shrinking range of giant panda habitats. Nowadays, the habitat of giant pandas is limited to six narrow mountain systems in the western region of China at the junction of Sichuan, Shaanxi, and Gansu provinces: Qinling, Minshan, Qionglai, Daxiangling, Xiaoxiangling, and Liangshan. According to the results of the fourth national giant panda survey announced by the State Forestry Administration, the number of wild giant pandas nationwide reached 1864 and the habitat area reached 2.58 million hm^2 by the end of 2013. Spatial monitoring and overall conservation of Giant Panda habitats and prediction of future environmental changes will not only help improve the current situation of habitat fragmentation and islandization but also carry out habitat suitability assessment on a fine scale and future habitat adjustment. This will create favorable conditions for the establishment of nature reserves and the release of giant pandas. At the same time, it can also explore research ideas for the monitoring and evaluation of natural heritage sites for rare and endangered species, and how to study the change trends of habitats in the context of future global changes.

This book is the culmination of the research team's joint research, capturing relevant parts of Jing Zhen's doctoral dissertation. The sections are divided as follows: Outline Development, Preface, Executive Summary, Xinyuan Wang. Chapter 1, Sect. 1.1: Xinyuan Wang and Lei Luo; Sect. 1.2: Lanwei Zhu; Sect. 1.3: Xinyuan Wang and Jing Zhen. Chapter 2, Sect. 2.1: Ruixia Yang, Chuansheng Liu; Sect. 2.2: Fulong Chen, Lanwei Zhu; Sect. 2.3: Cheng Wang, Xiaohuan Xi; Sect. 2.4: Chun Chang, Lei Luo, Xinyuan Wang. Chapter 3, Sect. 3.1: Linhai Jing, Lanwei Zhu; Sects. 3.2, 3.3: Linhai Jing, Yunwei Tang; Sect. 3.4: Jingwei Song, Yunwei Tang, Lei Luo, Xinyuan Wang. Chapter 4, Wanchang Zhang, Ning Nie. Chapter 5, Sect. 5.1: Ruixia Yang, Lei Luo; Sect. 5.2: Fulong Chen; Sect. 5.3: Cheng Wang, Xiaohuan Xi. Section 5.4: Yunwei Tang, Linhai Jing. Chapter 6, Sect. 6.1, 6.4: Qingkai Meng; Sects. 6.2, 6.3: Fulong Chen; Sect. 6.5: Chuansheng Liu, Qingkai Meng. Chapter 7, Sect. 7.1: Jing Zhen, Lei Luo; Sects. 7.2, 7.3, 7.4: Jing Zhen. Chapter 8, Sect. 8.1, 8.2, 8.3: Jing Zhen; Sect. 8.4: Xinyuan Wang. The whole book is coordinated by Xinyuan Wang and Jing Zhen. Prof. Siyuan Wang made general revisions to Chaps. 1 and 2. Dr. Qingkai Meng unified the draft of Chaps. 1–6 of the English version. Graduate Students Li Li, Ying Liao, Chun Chang, Jingwei Song, Ning Nie, Shaobo Xia, and Yunqi Zhang participated in the work of data processing and analysis of heritage sites. Chuansheng Liu and Jing Zhen were successively responsible for contacting publication matters.

The publication of this book is jointly supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDA19030500), the National Key Research and Development Program of the Ministry of Science and Technology (2016YFC0503302), and the National International Science and Technology Cooperation Program "Spatial Fine Observation and Cognition of Global Change Impact on World Heritage" (2013DFG21640). This book was prepared under the guidance and preface of Academician Huadong Guo, Associate Professor Haiping Li of Renmin University of China, and Researcher Peng Luo of Chengdu Institute of Biology, Chinese Academy of Sciences have made many constructive modifications and suggestions to the content of this book.

Since the spatial observation of natural heritage sites is in a rapid development stage, some principles and technical methods are still being explored, and because of the limited level, omissions and errors are inevitable. In addition, during the preparation of this book, references from the Internet or other sources have been cited, and we would appreciate your correction if there are any references that have been omitted due to the oversight of the preparation.

February 2020

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Contents

Chapter 1
Natural Heritage Sites and Space Observations

1.1 World Natural Heritage

1.1.1 Overview of the World Natural Heritage

World heritage is recognized as a cultural relics and natural landscape with prominent significance and universal value by all mankind. It is a rare and irreplaceable wealth, and is also a "material evidence" to understand the evolution of the earth, the evolution and development of human beings, and the evolution of different ethnic groups and related history. They have the significance and role of natural protection knowledge education, civilization inheritance and spiritual motivation, and can make unique contributions to world peace and security.

In November 1972, the United Nations Educational, Scientific and Cultural Organization (UNESCO) passed the Convention Concerning the Protection of the World Cultural and Natural Heritage, stipulating that natural heritage includes the following: from a scientific or conservation perspective, geological and natural geographical structures with outstanding universal value, and survival zones clearly classified as endangered animals and plants. From an aesthetic or scientific perspective, a natural feature consisting of geological and biological structures or groups of such structures of outstanding universal value. From a scientific, protective or natural beauty perspective, natural attractions with prominent universal values or clearly delineated natural areas. There are four criteria for the selection of natural heritages: (i) Outstanding examples that represent important stages in the evolution of the earth; (ii) The composition represents ongoing Important geological processes and Biological evolutionary processes, as well as outstanding examples of the interrelationship between humans and the natural environment; (iii) Unique, rare or wonderful natural phenomena, landforms or areas with rare natural beauty; (iv) Remaining habitats of rare or endangered species of wild fauna and flora species. As of July 2019, the total number of world heritages reached 1121, including 869 world cultural heritages, 213 world natural heritages and 39 world cultural and natural mixed heritages. In terms of quantity, the number of world cultural heritage is far greater than the number of

X. Wang et al., *Spatial Observation of Giant Panda Habitat*,
https://doi.org/10.1007/978-981-19-8794-6_1

world natural heritage and mixed heritage, but in terms of distribution and protection area, the world natural heritage occupies a large proportion.

China has a vast territory, a long history, unique natural environment and rich historical and cultural heritage. In 1985, China acceded to the World Heritage Convention. By July 2019, China had 55 world heritages, including 37 world cultural heritages, 14 world natural heritages and 4 world cultural and natural mixed heritages. The total number of world heritages ranked first in the world and was a veritable world heritage power.

China's 14 world natural heritage sites are Wulingyuan Scenic Area, Huanglong Scenic Area, Jiuzhaigou Scenic Area, Three Parallel Rivers of Yunnan Protected Areas, Giant Panda Habitat in Sichuan, Karst in South China, Sanqingshan National Park, Danxia, Chengjiang Fossil Site in China, Tianshan in Xinjiang, Hubei Shennongjia, Qinghai Hoh Xil, Fanjingshan and Yellow Sea (Bohai) migratory bird habitat in China (Phase I). Four world cultural and natural mixed heritages are Mount Tai, Mount Huangshan, Mount Emei-Leshan Buddha and Mount Wuyi.

China's world natural heritage is mainly distributed in the south of the Qinling-Huaihe line, and the characteristics of the distribution around large natural geographical units are very obvious. Sichuan Huanglong, Jiuzhaigou Scenic Area, Emeishan-Leshan Giant Buddha Scenic Area, Giant Panda Habitat and Three Parallel Rivers of Yunnan Protected Areas are distributed in the eastern margin of the Qinghai-Tibet Plateau in a strip along the north-south direction. Anhui Huangshan, Jiangxi Sanqingshan and Hunan Wulingyuan are mainly distributed in the hilly areas of Jiangnan. Wuyi Mountain in Fujian is distributed in hilly areas of Fujian and Zhejiang; Karst in South China is distributed on the Yunnan-Guizhou Plateau, across Guangxi, Yunnan and Guizhou Provinces (regions). Fanjing Mountain in Guizhou is also located in the transition slope zone from Yunnan-Guizhou Plateau to Xiangxi Hills. In terms of terrain, it is mainly on the second and third steps of the three major terraces, and each natural geographic unit presents significant differences and geographic gradients in terms of ground elevation, geomorphological combination, and bioclimatic aspects, with obvious edge effects, and non-equilibrium changes such as variation, disturbance, enhancement and weakening make the natural environment in these areas more complex in terms of geographical differentiation, thus becoming an important distribution area for many rare wildlife resources and peculiar natural landscapes.

1.1.2 World Natural Heritage Protection Research

The Convention on the Protection of the World Cultural and Natural Heritage sets forth the responsibility of the entire international community to participate in the protection of cultural and natural heritage of outstanding universal value through the provision of collective assistance. To develop scientific and technological research and to adopt appropriate scientific, technological and other measures for the effective protection, preservation and display of cultural and natural heritage.

Space-to-earth observation technology has the characteristics of macroscopic, timely and accurate, which provides a platform for mankind to understand the world heritage from the air. UNESCO list has a wide distribution, large area and many types of heritage, and space-to-ground observation technology plays a key role in this regard. Space-to-earth observation technology plays an important role and significance in monitoring and protecting the world list heritage sites for people to understand the changes of greenhouse gas concentrations, land use and land cover patterns, as well as the expansion of cities and other human settlements. Monitoring, protection and research of world heritage require spatial information technology. In October 2009, the 35th UNESCO assembly approved in May, 2007, Chinese Academy of Sciences, Suggestions, in the territory of China to establish an international space technology center, help it to use the technology to carry out the natural and cultural heritage, biosphere reserve, climate change and natural disasters in the field of education and support sustainable development. In June 2011, UNESCO and the Chinese government signed the establishment of the International Center on Space Technologies for Natural and Cultural Heritage under The Auspices of UNESCO, HIST), HIST was officially established in Beijing in July 2011. HIST is the first space technology-based world heritage research institution established by UNESCO in the world, supported by the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences. HIST is a type II center of UNESCO. Its objective is to help UNESCO member States apply space technology to the research and conservation of cultural and natural heritage, thereby strengthening their management, protection, introduction and promotion of world heritage and participating in UNESCO related activities. Strengthening the capacity of Member States to use earth observation technologies to obtain data to support decision-making on sustainable development; Enable all research findings to become new educational material in support of United Nations education for sustainable development activities. In addition, the spatial dynamic monitoring research on the changes of typical heritage sites is one of the main research directions of HIST. Based on the multi-scale and multi-source remote sensing data, the representative world natural and cultural heritage sites are monitored and evaluated on different platforms of "sky-sky-ground", so as to provide decision-making reference for the management department of heritage sites.

Natural heritage is faced with the dual impacts of changes in natural environment (especially catastrophic mutations) and human activities. Natural threats are mainly due to environmental changes caused by floods, diseases, natural extinction of species and global changes. However, most of the threats come from human activities and their effects. At present, illegal hunting and fishing have become the primary threat to natural heritage sites, and the most important and direct human activities of species disappearance. Grazing, agriculture and deforestation affect animal and plant populations and natural landscapes by altering habitats; mining and acquisition change the surface morphology and destroy the ecological balance; alien species invasion directly changed the ecological balance of the original species; the construction of water conservancy facilities has directly changed the water cycle and ecological process in the heritage site, so the threat to the heritage site is fatal. Poor management cannot control the adverse factors of heritage protection, and further aggravate the destruction of heritage sites. The surrounding development is mainly due to the influence of surrounding urbanization, population growth and industrial development, making the heritage site in the isolated state of peripheral development. Heritage sites are generally more or less affected by tourism development, which is manifested in the influx of tourists and the construction of tourism facilities that destroy the ecological balance and landscape of heritage sites. Fire is due to backward agricultural production methods or natural fire, resulting in ecological imbalance. Roads, airports and engineering pipelines cut the ecological links of the heritage sites. The destruction of heritage sites in troubled areas caused by armed conflicts and military incursions is also a serious concern (Thorsell and Sigaty 1997).

Due to the increasing impact of climate change and human activities, especially for rare or endangered animal and plant species habitat protection of natural heritage research, is of great urgency. At present, the research on the methods and techniques of ecological health diagnosis in natural heritage sites, especially in the evaluation of biodiversity stability in natural heritage sites, the evaluation of habitat suitability of important species, the evaluation of the original integrity of natural landscape, and the standard specification and platform construction of dynamic monitoring technology in heritage sites have become the focus of attention. Related research methods and models have also become a research hotspot. Based on the characteristics of different climate, hydrology, vegetation, soil and other characteristics of important species' habitats, the time-space characteristics of elements representing outstanding universal value (OUV) of natural heritage are studied and combined with the characteristics of different sky-air-ground observation technologies. And choose the right time—spatial resolution remote sensing data, guided by the dynamic data driven model, select the appropriate important species and habitat suitability factor, construct the habitat suitability assessment model base. By analyzing the factors influencing the habitat suitability of important species habitat and its mutual relations, to explore the change reason and driving force, looking for suitable protection measures and countermeasures, is an important part of the habitat class natural heritage sites protection research.

1.2 Global Change and Space Observation Technology

1.2.1 Spatial Observation and Cognition of the Impact of Global Change on World Heritage Sites

Global change refers to the global-scale changes in the function of the Earth system caused by natural and human factors, including atmospheric and marine circulation, water cycle, biogeochemical cycle, and changes in resources, land use, urbanization and economic development. Global warming is a prominent symbol of global change (Xu et al. 2013).

Global change is increasingly becoming a major issue of concern to all countries in the world, including China. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007), the average temperature in the Northern Hemisphere in the second half of the 20th century is likely to be higher than any 50-year period in the past 500 years and may be the highest average temperature in at least 1300 years; atmospheric concentrations of CO_2 and CH_4 in 2005 far exceeded the natural range of variation for the past 650,000 years. At the same time, a series of major global environmental problems such as environmental pollution, land degradation, species extinction and resource scarcity are becoming more and more serious, threatening human lifestyle and survival (Foley et al. 2005). Global change has the characteristics of large-scale and long-period spatial and temporal evolution. It is a complex system and needs to be studied by various theories and methods. Earth observation technology has a unique advantage in the study of global change due to its characteristics of macroscopic, dynamic, rapid and accurate detection. From the assessment report of the Intergovernmental Panel on Climate Change, the Earth System Science Partnership (ESSP), the World Climate Research Programme (WCRP), From the Climate Change Science Program (CCSP) of the United States, the development and application of space observation technology has been the priority of global change research (Alonso et al. 2008). After more than half a century of development, it has formed a three-dimensional earth observation system covering land, sea and atmosphere. The working band of the sensor covers the band range from visible light, infrared to microwave. The multi-system integrated network observation provides a very effective technical means for the fine observation of global change phenomenon. Among the 50 essential climate variables (ECVs) proposed by Global Climate Observing System (GCOS), 28 depend on satellite observation. Satellite observation has provided rich data for global change research (Xu et al. 2013).

Since the 1950s, many observed climate changes have been unprecedented in previous decades to thousands of years. In recent decades, climate change has affected natural and human systems on all continents and in the oceans, indicating that natural and human systems are very sensitive to climate change. Climate change, together with other pressure sources such as habitat loss and fragmentation, will lead to changes in species distribution, population composition, phenological period and ecosystem function. For species with small population size, narrow distribution, weak migration ability, single diet and weak genetic ability, they may face the risk of extinction due to climate change. How to interpret these changes and put forward targeted measures and suggestions is the current concern of domestic and foreign experts and scholars.

World heritage is a treasure with outstanding universal value in the process of natural evolution and human development. Its natural, cultural, economic and social value is immeasurable. The protection of world heritage is related to the sustainable development of national culture, ecological environment and social economy. Global change, especially climate warming, has brought great damage to the world heritage sites, and posed serious challenges to heritage protection, ecological system security and global biodiversity. Global climate change affects almost all organisms, and 80%

of species are under the stress of climate warming. The scale and impact of global climate change is already affecting wildlife, from the polar regions to the equatorial tropics, from the oceans to the interior, showing signs of change. At present, a large number of studies and observations have shown that the distribution pattern of species has changed due to climate change, and migration to high latitudes or high altitudes is the adaptation strategy of most species. The reason for this may be that with global warming, wildlife in search of similar cooler environments will move north in latitude as a whole, and the distribution of animals and plants is relatively dense mountains will show the move to a higher place on the elevation direction. On the whole, global warming will make more wildlife at a loss. Climate change will be more pronounced in alpine regions than in low-altitude areas, especially with rising temperatures, changing precipitation patterns and other extreme weather events. Therefore, how to rely on the rapid development of earth observation technology to study and analyze the change trend of species habitat under the background of climate change, whether the existing protected areas can continue to maintain the integrity of species and ecosystem, and how to adjust to mitigate and reduce the impact of climate change on species are the urgent problems to be solved in the field of ecological protection.

UNESCO world heritage convention is put forward: world heritage protection aims to protect and sustainable resource utilization, to ensure the integrity and authenticity of the current and future of the world heritage. In order to achieve this goal, all the most effective and appropriate methods must be used to collect, collate, retrieve, maintain and communicate data on the nature and spatial distribution of world heritage sites. Spatial information technology can meet this requirement by describing the status of world heritage sites and obtaining the most up-to-date and accurate data on their nature and location. With the help of spatial information technology, the physical condition, cultural characteristics, social and administrative system environment of world heritage sites can be evaluated to prepare for the formulation of corresponding conservation planning; The effectiveness of resources and their conservation and management measures can be monitored and evaluated. Therefore, spatial information technology has extensive and practical application value for world heritage monitoring and protection.

The primary concern of natural heritage monitoring is the prominent universal value of heritage. Natural heritage monitoring is divided into: (i) Systematic monitoring, which includes comprehensive monitoring of the implementation of conservation planning, heritage protection, management, display, publicity, etc.; the key monitoring contents include the monitoring of the solutions and effectiveness of the protection problems; (ii) Reactive monitoring. Reactive monitoring is a special monitoring for the problems in protection management, including the monitoring of abnormal situations or risk factors that threaten heritage protection.

Global change, especially climate warming, has brought great damage to world heritage sites and posed serious challenges to heritage protection. By using space-to-ground observation technology, we will develop algorithms for spatial monitoring, information extraction and multi-source data fusion of ecological and environmental changes of heritage sites based on medium and high resolution remote sensing data combined with ground observation, and the theory and technology system from data to information acquisition and knowledge discovery are gradually established. Focusing on biodiversity in ecologically fragile areas, it is extremely urgent to study the acquisition, analysis and evaluation of time-space fine-change information of biological habitat in the context of global change, which can be explored in the following four aspects.

(1) To carry out the research of fine spatial change analysis method of heritage site based on GIS spatial analysis, artificial intelligence and fuzzy mathematics discrimination. Deepen the understanding of the process and mechanism of the impact of global change on world heritage and realize the technological breakthrough of the identification and extraction of detailed spatial change information of specific objects.
(2) To develop data-intensive time-varying information analysis techniques for heritage sites. Develop a model for vegetation and ecological information extraction from remote sensing data with medium and low spatial resolution, and use the characteristics of high temporal resolution of remote sensing data with medium and low spatial resolution to study the data fusion algorithm with high spatial resolution data, so as to achieve dynamic information acquisition of ecology and environment of heritage sites with high temporal resolution, as well as breakthroughs in rapid recognition and accurate extraction of habitat change information of endangered species.
(3) Study on animal habitat suitability model and suitability mapping. Animal habitat is the place for animal survival and reproduction. The quality of habitat is very important for the continuation and reproduction of species. Habitat suitability is an important indicator to measure the quality of habitats. Habitat suitability mapping can provide the spatial distribution information of wildlife suitable habitats, thus providing decision-making basis for wildlife population management and conservation planning. Combined with ground survey and GPS tracking and positioning technology, and remote sensing on the ecological environment (vegetation-related animal food and living environment) to obtain information, data assimilation to build a more accurate habitat suitability model, habitat suitability mapping fine spatial change.
(4) Empirical and comparative study on the impact of global change on heritage sites. Select typical regions to conduct empirical and comparative research on the impact of global change on heritage sites. The research focuses on the process and mechanism of global change and the impact of human activities on heritage sites. This paper studies the natural effects (drought, floods, earthquakes, landslides, warming, etc.), as well as human activities (deforestation, planting, hunting, roads, etc.) to study the influence of rare creatures, revealing the different regional ecosystem safety pattern and the evolution trend of space and time, from different scales to know its landscape pattern change impact on biodiversity, ecosystem stability and the feedback function. The ecological status assessment method of rare and endangered animal habitat and the spatial correlation between the spatial pattern of various vegetation types and environmental factors such as vegetation ecology will be discussed.

1.2.2 *Space Observation Technique*

Before satellite observation is widely used, scientists mainly seek a global perspective through ground observation, which requires international cooperation and large-scale field investigation. Placing data points together requires interpolation and extrapolation to fill the gaps in data, especially those far away. In addition, large-scale sampling requires extensive logistics support and pre-planning to reduce frequent duplication of work. Since in the era before the emergence of artificial satellites, the change rate of many research parameters is faster than that of global map drawing, it is impossible to observe the complete dynamic characteristics of the Earth system. Even if the individual surface observation can be combined into a global picture, a lot of work needs to be done due to the coverage rate and density of the network and the lack of longitudinal resolution. Other geophysical and biological phenomena are less frequently sampled and are often used as part of a dynamic "snapshot" of Earth processes interacting.

The advent of artificial satellites triggered a transformation in Earth science, providing the world with the first complete global record of biological, physical, and chemical parameters (e.g., cloudiness, wind fields, ice cover). The synchronicity of observations with larger spatial coverage provided by artificial satellites is not available from ground-based measurements; the time series data provided by artificial satellites reveal large scale processes and features that have not been discovered by other methods. Thus, artificial satellites give scientists quantifiable global images and maps with a frequency and coverage unmatched by any ground-based observation technique.

At present, the space observation techniques commonly used in the space monitoring and evaluation of natural heritage sites include optical remote sensing technology, microwave remote sensing technology and LiDAR remote sensing technology.

1. **Optical remote sensing technology**

Optical Remote Sensing is a passive remote sensing technology that uses electromagnetic wave as the transmission medium and the working band of sensor is limited to the range of visible light (0.38–0.76 μm). It is the most commonly used working band in traditional aerial photogrammetry.

Since the color range of the photosensitive film is exactly in this wavelength range, optical remote sensing can obtain black-and-white panchromatic or color images with high ground resolution, thereby improving the performance of image interpretation and mapping. Optical remote sensing is mainly limited by the solar illumination conditions. Due to the successive emergence of infrared photography and multi-band remote sensing, visible light remote sensing has extended the working band to the near-infrared region (about 0.9 μm). The imaging mode has also developed from a single photographic imaging to a variety of ways including black-and-white photography, infrared photography, color photography, color infrared photography, multi-band photography and multi-band scanning, which greatly improves the detection ability of optical remote sensing. Low-medium resolution optical remote sensing technology mainly refers to the scientific research based on low-medium resolution (less than 5 m) optical remote sensing images. Medium and low resolution remote sensing images have the advantages of wide observation range, short observation period and strong data timeliness (Li 2008).

After the 21st century, with the rapid development of space technology, the development of remote sensing observation system has also appeared a new climax. Countries all over the world compete to research, develop and launch high-resolution remote sensing satellites. Since 1998, high-resolution remote sensing satellites have been on the stage of remote sensing application, and their resolution has been greatly improved compared with the previous remote sensing satellites. These high-resolution remote sensing satellites mainly include EarlyBird (3 m resolution) and QuickBird (1 m resolution) of Earth-Watch Company. SpaceImaging's IKONOS (1 m resolution); Orbital Sciences' OrbVIEW-1 (1, 2, 4 m resolution). In particular, the successful launch of the IKONOS satellite, the world's first to provide high-resolution satellite imagery at a resolution of more than 1 m, marks the establishment of a new, faster and more economical way to obtain the latest basic geographical information.

Over the next decade, the level of satellite resolution developed rapidly. Spatial resolution has reached sub-meter level, even comparable to low-altitude aerial photographs, which provides favorable conditions for the extraction of fine information. For example, the WorldView-1 satellite launched in 2007 can shoot 0.5 m resolution images of up to 500,000 km^2 every day. The WorldView-2 satellite launched in 2009 can provide 0.5 m panchromatic images and 1.8 m resolution multispectral images. The Pleiades-1 satellite launched by the SPOT family in 2011 has a resolution of 0.5 m and a width of 20 km $\times$ 20 km.

In the research of high-resolution remote sensing satellites, China has also made remarkable development. In order to ensure the autonomy of China's space information resources and promote the development of space information industry, China has incorporated the National Science and Technology Major Project of High Resolution Earth Observation System into the National Medium and Long Term Science and Technology Development Plan (2006–2020), becoming one of the 16 national major science and technology projects. Since the launch of the high-resolution special project in 2010, the first satellite GF-1 was successfully launched on April 26, 2013. GF-1 is equipped with two 2 m resolution panchromatic/8 m resolution multispectral cameras and four 16 m resolution multispectral wide-swath cameras. On August 19, 2014, GF-2 was successfully launched, which can query the resolution better than 1 m in the remote sensing market platform. At the same time, it has the characteristics of high radiation accuracy, high positioning accuracy and fast attitude maneuver ability, which marks that China's remote sensing satellite has entered the sub-meter "high-resolution era". Table 1.1 lists the current mainstream high-resolution satellite remote sensing and related technical parameters.

It can be seen that compared with traditional medium and low resolution remote sensing images, high-resolution satellite images have many advantages such as more obvious geometric structure of ground objects, clearer position and related layout of ground objects, finer texture and size information, and from two-dimensional

Table 1.1 Parameters of mainstream high-resolution satellite remote sensing technology in China and abroad

Satellite	Country	Launch time	PAN/m	Multispectral/m	Stereoscopic acquisition capability	Width/km	Spectral features	Positioning accuracy (CE90)	Acquisition capability/(ten thousand km^2/d)	Orbit height/km
IKONOS	U.S	1999.9	0.82	3.2	Yes	11.3	Panchromatic + 4 multispectral bands	9 m	Collection stopped	681
EROS-A1	Israel	2000.12	1.8	N/A	Yes	14	Panchromatic	–	–	520
QuickBird	U.S	2001.10	0.61	2.44	N/A	16.8	panchromatic + 4 multispectral bands	14 m	Collection stopped	482
SPOT5	France	2002.5	2.5/5	10	N/A	60	panchromatic + 4 multispectral bands	30 m	400	832
Cartosat-1 (IRS-P5)	India	2005.5	2.5	N/A	Yes	26	Panchromatic	–	–	618
ALOS	Japan	2006.1	2.5	10	Yes	70	Panchromatic + 4 multispectral bands	1 m (Control points available)	Collection stopped	691
EROS-B	Israel	2006.4	0.7	N/A	Yes	7	Panchromatic	–	–	520

(continued)

Table 1.1 (continued)

Satellite	Country	Launch time	PAN/m	Multispectral/m	Stereoscopic acquisition capability	Width/km	Spectral features	Positioning accuracy (CE90)	Acquisition capability/(ten thousand km^2/d)	Orbit height/km
KOMPSAT-2	Korea	2006.7	1	4	Yes	15	Panchromatic + 4 multispectral bands	<50.9 m	170	685
WorldView-1	U.S	2007.9	0.5	Inapplicability	Yes	17.7	Panchromatic	4 m	130	496
RapidEye	Germany	2008.8	N/A	5		77	5 multispectral bands	–	400	620
GeoEye-1	U.S	2008.9	0.41	1.65	Yes	15.2	panchromatic + 4 multispectral bands	3 m	35	681
WorldView-2	U.S	2009.10	0.46	1.85	Yes	16.4	Panchromatic + 8 multispectral bands	3.5 m	100	770
Pléiades (1A,1B)	France	2011.12	0.5	2	Yes	20	Panchromatic + 4 multispectral bands	3 m	100	695
ZY-1 02C	China	2011.12	2.36 /5	10	N/A	54	Panchromatic + 3 multispectral bands	–	140	780

(continued)

Table 1.1 (continued)

Satellite	Country	Launch time	PAN/m	Multispectral/m	Stereoscopic acquisition capability	Width/km	Spectral features	Positioning accuracy (CE90)	Acquisition capability/(ten thousand km^2/d)	Orbit height/km
ZY-3	China	2012.1	2.1	5.8	Yes	51	Panchromatic + 4 multispectral bands	No point of plane precision 10 m, height accuracy better than 5 m	140	505
KOMPSAT-3	Korea	2012.5	0.5	2.8	Yes	16	Panchromatic + 4 multispectral bands	<27.5 m	170	685
SPOT-6	France	2012.9	1.5	6	Yes	60	Panchromatic + 4 multispectral bands	10 m	300	695
GF-1	China	2013.4	2	8	N/A	60/800	Panchromatic + 4 multispectral bands	50 m	–	645
Deimos-2	Spain	2014.6	0.75	4	Yes	12	Panchromatic + 4 multispectral bands	100 m	20	620

(continued)

Table 1.1 (continued)

Satellite	Country	Launch time	PAN/m	Multispectral/m	Stereoscopic acquisition capability	Width/km	Spectral features	Positioning accuracy (CE90)	Acquisition capability/(ten thousand km^2/d)	Orbit height/km
SPOT-7	France	2014.6	1.5	6	Yes	60	panchromatic + 4 multispectral bands	10 m	300	695
WorldView-3	U.S	2014.8	0.31	1.24	Yes	13.1	Panchromatic + 8 multispectral bands + 8 short-wave infrared bands + CAVIS	3.5 m	68	617
GF-2	China	2014.8	0.8	4	N/A	45 (Two camera combinations)	Panchromatic + 4 multispectral bands	20-35 m	–	631
KOMPSAT-3A	Korea	2015.3	0.4	2.2	Yes	13	Panchromatic + 4 multispectral bands + mid-wave infrared	<27.5 m	170	528

(continued)

Table 1.1 (continued)

Satellite	Country	Launch time	PAN/m	Multispectral/m	Stereoscopic acquisition capability	Width/km	Spectral features	Positioning accuracy (CE90)	Acquisition capability/(ten thousand km^2/d)	Orbit height/km
GF-3	China	2016.8	Band (1/3/5/10/25) Scan (50/100) Wave mode (10) Global (500) Extended Incident Angle (25°)			Bunching (10 × 10) Band (25/30, 50/100/150) Scanning (300/500) Wave mode (5 × 5) Global (650) diffusion Incidence Angle (≥80°)	C-band multipolarization SAR	Uncontrolled better than 230 m (incident angle) 20°–50°, 3σ)	–	755
GF-4	China	2015.12	≤50	≤50, IR ≤ 400	N/A	400	Panchromatic + 4 multispectral bands + infrared	–	57,600	36,000
WorldView-4	U.S	2016.11	0.31	1.24	Yes	13.1	Panchromatic + 4 multispectral bands	<4 m	68	617

Note -Indicates that related parameters are not found information to three-dimensional information. Therefore, it is playing an increasingly important role in space observation of natural heritage sites and animal habitats.

2. **Microwave remote sensing technology**

Microwave remote sensing is a technology that uses sensors to receive microwave signals emitted or reflected from ground objects, so as to extract the required information and analyze or identify ground objects (Shu 2000). Microwave refers to the electromagnetic wave with a wavelength from 1 to 1000 mm, which can be divided into millimeter wave, centimeter wave, decimeter wave and meter wave. Microwave signal contains abundant surface information, and different surface and ground object types have completely different scattering characteristics. According to the given observation parameters, many differences of ground object, such as geometry, strike, texture, surface roughness, water content and topography, can be identified.

Characteristics of the microwave determine the advantages of microwave remote sensing has the following several aspects: one is the day, all-weather work ability. The most fundamental difference between microwave and visible light is that it does not rely on the sun as the source of irradiation, even in the night can also detect the information of the ground target. The wavelength of microwave is significantly larger than that of visible and infrared light, which can penetrate clouds and rain and is not affected by climatic conditions (Ulaby et al. 1981). Second, it has a certain surface penetration ability. The penetration depth is closely related to wavelength and object type. Long wave has strong penetration, while short wave scatters more and has weak penetration. Third, it can obtain some different information from visible light and infrared. The information obtained by visible light and microwave is a complementary relationship, the former is to obtain the resonant characteristics of surface molecules, the latter is to obtain the geometric and dielectric properties of surface or volume. Microwave is extremely sensitive to ground objects in specific directions, such as roads, waterways, pipelines, walls and canyons. In some areas where there are no obvious surface features or vegetation, the ability of microwave to penetrate the surface and detect dielectric properties makes it the only telemetry tool. Active microwave system can also record the phase information of electromagnetic wave, which can be used for geoid measurement and high-precision monitoring of surface deformation. It plays an important role in three-dimensional display and disaster monitoring of natural heritage sites.

The parameters related to imaging of radar system include: (i) Resolution, the resolution of radar is different in azimuth and range, azimuth refers to the direction parallel to the flight direction, range refers to the direction perpendicular to the flight direction, the range determined by azimuth resolution and range resolution is called resolution cell; (ii) Wavelength. There are mainly six microwave bands for synthetic aperture radar (SAR) sensors, and the wavelengths from short to long are K, X, C, S, L and P. Generally, the spatial resolution of the short-wave system is high, but the requirement for energy is also high. In addition, wavelength also affects the penetration ability and surface roughness of radar waves. The longer the wavelength is, the stronger the penetration ability is, and the smoother the surface of ground