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Spatial distribution characteristics and differentiated management strategies of China Nationally Important Agricultural Heritage Systems

GUO Xuan[1,2], MIN Qingwen[1,2,3], *JIAO Wenjun[1]

1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
2. University of Chinese Academy of Sciences, Beijing 100049, China;
3. Tourism College of Beijing Union University, Beijing 100101, China

Abstract: Climate change and rapid urbanization pose significant challenges to the conservation and management of agricultural heritage systems, including decline in agricultural land, loss of labor, and ecosystem degradation. Although existing studies have proposed general strategies with theoretical guidance and specific strategies for particular systems to promote the conservation of agricultural heritage systems, there remains a large knowledge gap in effective and differentiated management strategies at the regional level. This is especially so in China because of the clear regional differences in the natural and socioeconomic conditions of the widely distributed China Nationally Important Agricultural Heritage Systems (China-NIAHS). In this study, we integrated multi-source data and spatial analysis to reveal the distribution characteristics of existing China-NIAHS and proposed differentiated management strategies. Results show that there are four clustering distribution zones of China-NIAHS, i.e., the northwest clustering zone west of the Heihe-Tengchong Line (Zone I), the clustering belt with 'Northeast-Hebei-Shandong' as core (Zone II), the Yangtze River Delta clustering zone (Zone III), and the Hunan-Chongqing-Yunnan-Guizhou clustering zone (Zone IV). Different management strategies are proposed for the China-NIAHS in each clustering zone. Specifically, Zone I should focus on maintaining their ecological functions and services, while Zone II should aim for livelihood supply, sustainable resource use, and ecological protection. For Zone III, rapid urbanization could become a positive driving force for China-NIAHS conservation through sustainable tourism and reasonable urban zoning. Zone IV should emphasize the mutual support between characteristic product development and the brand effect of the China-NIAHS. These findings will help establish regional and targeted management strategies for China-NIAHS and provide a reference for the conservation of agricultural heritage systems in other countries.

Keywords: China Nationally Important Agricultural Heritage Systems (China-NIAHS); spatial distribution characteristics; differentiated management strategies; clustering zone; ecological functions and services; synergistic development with the socio-economy

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Author: Guo Xuan (1996–), PhD Candidate, E-mail: guoxuan6924@igsnrr.ac.cn
***Corresponding author:** Jiao Wenjun (1983–), Associate Professor, E-mail: jiaowj@igsnrr.ac.cn

1 Introduction

The world is experiencing massive urbanization that not only partially encroaches on agricultural land around cities (Chen, 2007; d'Amour *et al*., 2017; Huang *et al*., 2020; Gao *et al*., 2023) but also accelerates modern, intensive, and large-scale agricultural practices. However, these contemporary agricultural systems prioritize industrial inputs and profit maximization at the expense of extensive exposure to chemical fertilizers, pesticides, and hormones, leading to new global ecological issues (Pimentel *et al*., 1992; Van der Werf, 1996; Ikoyi *et al*., 2018; Zhang *et al*., 2018; Mustafa *et al*., 2019), including reduced biodiversity, increased greenhouse gas emissions, and destruction of agroecosystem structures. In this context, researchers have renewed their interest in traditional agroecosystems oriented towards green development and their application in environmental protection (Jiao *et al*., 2017). International organizations are also becoming aware of these issues and have launched a series of conservation initiatives. One was the initiative on the dynamic conservation and adaptive management of Globally Important Agricultural Heritage Systems (GIAHS), launched by the Food and Agriculture Organization (FAO) of the United Nations in 2002.

China is one of the first countries to respond to and actively participate in the GIAHS initiative (Min *et al*., 2009; Min *et al*., 2022). With the support of the Global Environment Facility (GEF) project (2009–2013), the concept of China Nationally Important Agricultural Heritage Systems (China-NIAHS) has been proposed. China-NIAHS are defined as "ingenious agricultural production systems created on the long-term coadaptation of a rural community/population with its environment and inherited to now". They are characterized not only by rich biodiversity, valuable knowledge of indigenous technology, and unique ecological landscapes, but also by outstanding cultural features, including traditional rural knowledge, folk regulations, beliefs, customs, singing and dancing, food, clothing culture, and architectural cultures, which exhibit multiple values in terms of the environment and ecology, economy and life, spirituality and cultural inheritance, science and education, demonstration and application (Mary Jane Dela *et al*., 2009; Min *et al*., 2016; Min *et al*., 2020; Jiao *et al*., 2021). In 2012, the Ministry of Agriculture and Rural Affairs of China (MARA) initiated an exploration and conservation program for the China-NIAHS. By 2022, China had identified 138 China-NIAHS in six batches distributed across 29 provincial-level regions.

The conservation and development of the China-NIAHS is of great significance to important global issues facing human it, including ensuring food security, coping with global climate change, conserving biodiversity (Ren *et al*., 2018), and inheriting traditional rural culture (Min *et al*., 2012). However, influenced by climate change, rapid urbanization, and industrial transformation, the conservation and development of China-NIAHS is facing multiple threats and challenges. Rapid expansion of urban land has led to a sharp decline in agricultural land, thus threatening the land base for the conservation and development of China-NIAHS (Bai *et al*., 2014). Compared with secondary and tertiary industries, traditional agriculture often yields lower profits, resulting in farmers switching to other industries to maintain their livelihoods (Jiao *et al*., 2016; Park *et al*., 2017). The loss of the labor force also limits the conservation and inheritance of traditional cultures. In addition, unsustainable development patterns have accelerated the destruction of ecological landscapes and environmental problems at some heritage sites (Tang *et al*., 2010; Yang *et al*., 2018).

To address these threats and challenges, studies have proposed theoretical guidance

through an integrated consideration of the relationships between China-NIAHS and the environment, agricultural landscape, biophysical characteristics, and social systems. For example, in terms of development modes, Zhang *et al*. (2021) proposed that effective conservation can be achieved through integrated industrial development based on local resource advantages, with an emphasis on policy coordination and stakeholder combinations. Sun *et al*. (2021) noted that although tourism is an effective means of dynamic conservation and adaptive management, sustainable tourism development strategies should be developed by combining global and local experiences. With regard to participating subjects, Xu *et al*. (2021) argued that residents in heritage sites should develop a correct perception of conservation and establish a close relationship through social participation and benefit-sharing, and Wu *et al*. (2022) suggested that an ecological compensation system should be introduced to resolve conflicts in benefit distribution, to compensate farmers for their investment costs and lost resource benefits, further stimulating their enthusiasm for heritage conservation. Specific management strategies for some China-NIAHS have been reported in other studies, including the Deqing Traditional Freshwater Pearl Culture and Utilization System in Zhejiang province (Yang *et al*., 2022), Shuangjiang Mengku Ancient Tea Garden and Tea Cultural System in Yunnan province (Yang *et al*., 2020), and Turfan Karez Agricultural System in Xinjiang autonomous region (Wang, 2018).

China-NIAHS are distributed across 29 provincial-level regions in China, with clear regional differences in their natural resources, socioeconomic development, and threats and challenges. This requires effective management strategies for the China-NIAHS at the regional level, while considering the diversity of conditions. Currently, neither general management strategies with theoretical guidance nor specific management strategies for a particular system can meet the conservation and management needs of China-NIAHS at a regional scale. Although the spatial distribution differences of GIAHS (Liu *et al*., 2020), different batches of China-NIAHS (Han, 2017), and China-NIAHS in specific regions or provinces (Han *et al*., 2018; Xu and Zhang, 2021) have been documented, there remains a large knowledge gap in the systematic analysis of their distribution characteristics and in-depth clarification of differentiated management strategies. Therefore, clarifying the spatial distribution characteristics of the China-NIAHS and proposing regionally differentiated management strategies are critical for the scientific and effective conservation of the China-NIAHS.

In this study, we integrated multi-source data (e.g., landforms, meteorological elements, agricultural zones, ecological function reserves, number of government documents, and socioeconomic factors) and applied spatial analysis methods (e.g., kernel density analysis and average nearest neighbor analysis) to reveal the spatial distribution characteristics of the China-NIAHS. We then propose differentiated management strategies for the China-NIAHS in different regions based on regional geographic and socioeconomic characteristics, as well as varied threats and challenges. We believe that this study will provide a scientific basis for understanding regional differences in the China-NIAHS and promote the effective conservation and sustainable development of the China-NIAHS.

2 Materials and methods

2.1 China-NIAHS dataset

Since the initiation of the exploration and conservation program in 2012, the MARA has

recognized 138 China-NIAHS in six batches across 160 counties, specifically 19 in 2013, 20 in 2014, 23 in 2015, 29 in 2017, 27 in 2020, and 20 in 2021 (Supplementary materials). These nationally recognized agricultural heritage systems constitute the focus of this study. To establish the China-NIAHS database, we first collected names and locations, and obtained their coordinates using the Baidu Map API coordinate picker (https://api.map.baidu.com/lbsapi/getpoint/index.html). Using ArcGIS10.2, each item of the China-NIAHS was then abstracted into spatial points, and its attribute information (e.g., the batch of recognition and whether it was a GIAHS) was counted (Xu *et al*., 2019).

The 138 items of the China-NIAHS are mainly distributed in 29 provincial-level regions, and there is no China-NIAHS in Shanghai municipality and Qinghai province (Figure 1). Overall, the China-NIAHS are mainly distributed in the southeast coastal, southwestern, and central regions of China, including Zhejiang (14 items), Yunnan, Sichuan, Jiangsu, Hunan (all with 8 items), Jiangxi and Shandong (both with 7 items) provinces. In comparison, Beijing and Tianjin municipalities, Ningxia and Xizang autonomous regions, and Hainan province have relatively less China-NIAHS.

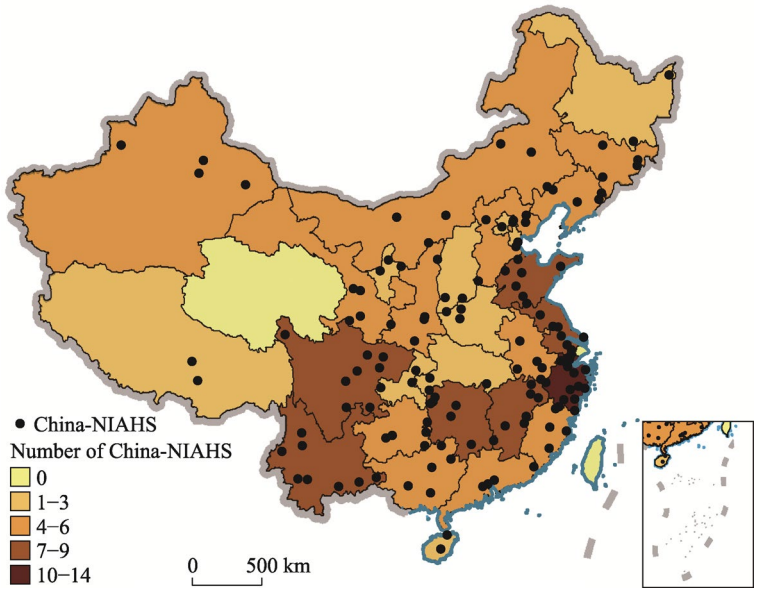

Figure 1 Provincial distribution of China-NIAHS

2.2 Geographic and socio-economic dataset

The China-NIAHS are the result of the combined effects of natural resources and social conditions. Landform and elevation have a constraining effect on the distribution of China-NIAHS at the regional level by affecting climatic and hydrological conditions. Regional meteorological conditions, particularly temperature and precipitation, which reflect water and heat resources, are key determinants of agricultural production. Population and economy are important factors on which the development of China-NIAHS depends. People are the main actors in the development, conservation, and inheritance of China-NIAHS, and the level of economic development largely determines social support and modern management. The distribution of ecologically functional reserves and agricultural zoning reflect the key

ecological functions and agricultural characteristics that are the core elements of the China-NIAHS. Government awareness toward China-NIAHS conservation varies among provinces, which affects the political and financial support for exploring China-NIAHS in different provinces. These factors are also objective laws and scientific bases that must be followed when formulating differentiated management strategies for China-NIAHS.

To reveal the spatial distribution characteristics of China-NIAHS, we selected a set of indicators, including landform, elevation (m), annual precipitation (mm), annual average temperature (℃), gross domestic product (GDP) (10,000 yuan/km^2), population density (people/km^2), ecological function reserve, agricultural zoning, and the number of government documents, to portray regional geographic and socio-economic characteristics. Elevation, ecologically functional reserves, national agricultural zoning, population density, GDP, and meteorological data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/). Landform data were obtained from the National Tibetan Plateau Data Center (http://data.tpdc.ac.cn). The number of government documents was extracted from a previous study, which counted the number of documents concerning the China-NIAHS issued by each province during the period 2009–2020 (Hua *et al*., 2023). To reflect the latest conditions, temperature, precipitation, population density, and GDP were characterized using data in the year of 2020, 2020, 2019, and 2019, respectively.

2.3 Methods of analyses

We employed average nearest neighbor analysis to clarify the spatial pattern of China-NIAHS at the national level through the nearest neighbor index and observed mean distance (Zeng *et al*., 2022). The calculation formula is as follows:

$$r_E = \frac{1}{2\sqrt{\frac{n}{A}}} \tag{1}$$

$$R = \frac{r}{r_E} \tag{2}$$

where n is the number of observation points; A is the area of the region; r_E is the expected mean distance, which is the average distance between neighbors in a hypothetical random distribution; r is the observed mean distance; and R is the nearest neighbor index, which is the ratio of the observed mean distance to the expected mean distance. If the index equals to 1 (R=1), the observation points show random distribution, and if the index is less than 1 (R <1), the pattern exhibits clustering, and if the index is greater than 1 (R>1), the trend is toward dispersion.

Kernel density analysis was applied to examine spatial clustering characteristics of China-NIAHS. It performs non-parametric estimation of the unknown density function, and its estimation results have higher continuity compared with the traditional point density (Zhou *et al*., 2020; Zhang *et al*., 2023). The calculation formula is as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \tag{3}$$

where $f(x)$ is the estimated value of the kernel density at the spatial position point x; h is the

bandwidth; n is the number of points within the bandwidth range; k is the kernel function; $x - x_i$ is the distance from the estimated point to x_i.

3 Spatial distribution characteristics of China-NIAHS

3.1 Geographic characteristics of China-NIAHS spatial distribution

The majority of China-NIAHS were in mountains with varying degrees of rolling (56 items), plains (52 items), and hills (20 items), accounting for 40.6%, 37.7%, and 14.5%, respectively, of the total. In contrast, few China-NIAHS were observed on the platform (10 items, 7.2%) (Figure 2b). Specifically, the number of China-NIAHS declined with increasing elevation (Figure 2a). The area with elevation interval of 0–400 m contained the majority of China-NIAHS (accounting for 57.97%), whereas slight upward trend in the number of China-NIAHS was observed at elevation interval of 800–900 m and 1000–1400 m. The China-NIAHS with the highest elevation are nomadic-type system, including the Dangxiong Alpine Nomadic System in Xizang autonomous region (4283 m) and the Shiqu Zhaxika Nomadic System in Sichuan province (4174 m). In contrast, the cultivation-type China-NIAHS, owing to the characteristics of the crops they grow, are more likely to be found in flat areas at lower elevations, including the Qidong Weitian Agrosystem in Jiangsu province (3 m) and Tai'an Wenyang Field Farming System in Shandong province (92 m).

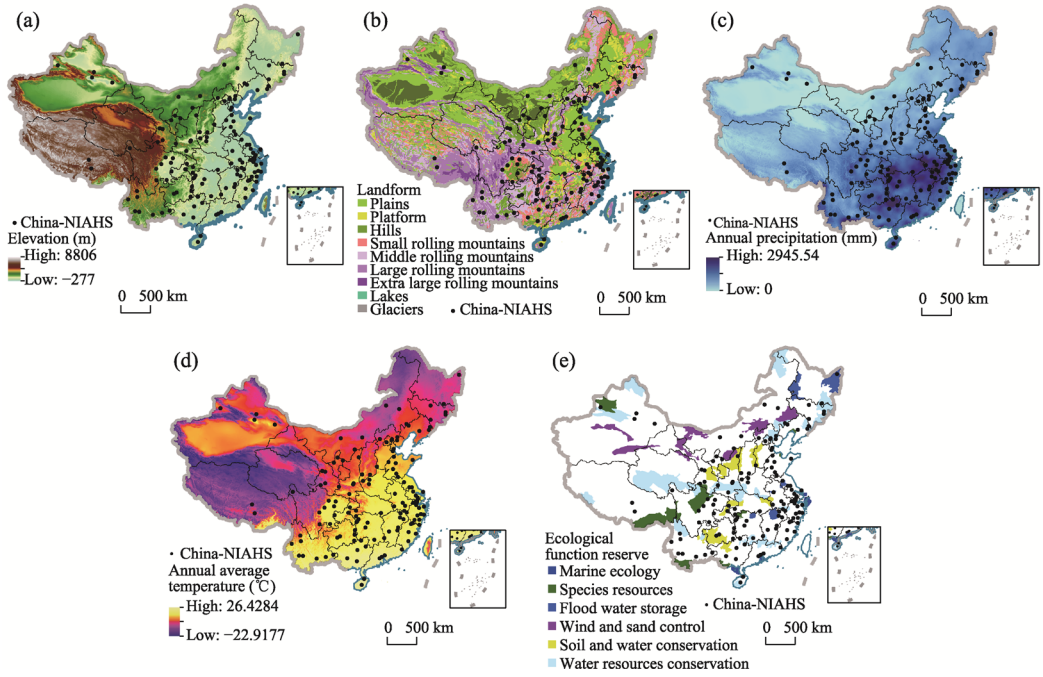

Figure 2 Geographic characteristics of China-NIAHS: elevation (a), landform (b), annual precipitation (c), annual average temperature (d), ecological function reserve (e)

Generally, China-NIAHS are distributed in relatively humid and warm regions with annual precipitation of 400–800 mm (32 items, accounting for 23.2%) and 1000–1700 mm (50 items, accounting for 36.2%), and the annual average temperature of 8–20℃ (107 items,

accounting for 77.5%), which are also the main areas of human activities (Figures 2c, 2d, and 3). Areas with annual precipitation of 400–800 mm are dominated by cultivation-type China-NIAHS, including the Urban Agricultural Heritage-Xuanhua Grape Garden and Shexian Dryland Terraces System in Hebei province. Tea, terrace, and composite types of China-NIAHS are frequently observed in humid areas with annual precipitation of 1000–1700 mm, including the Anxi Tieguanyin Tea Culture System in Fujian province, Honghe Hani Terrace System in Yunnan province, Congjiang Dong's Rice-Fish-Duck System in Guizhou province, and the Qingtian Rice-Fish Culture System in Zhejiang province. Few China-NIAHS occur in areas with annual average temperature below 8℃ or above 20℃.

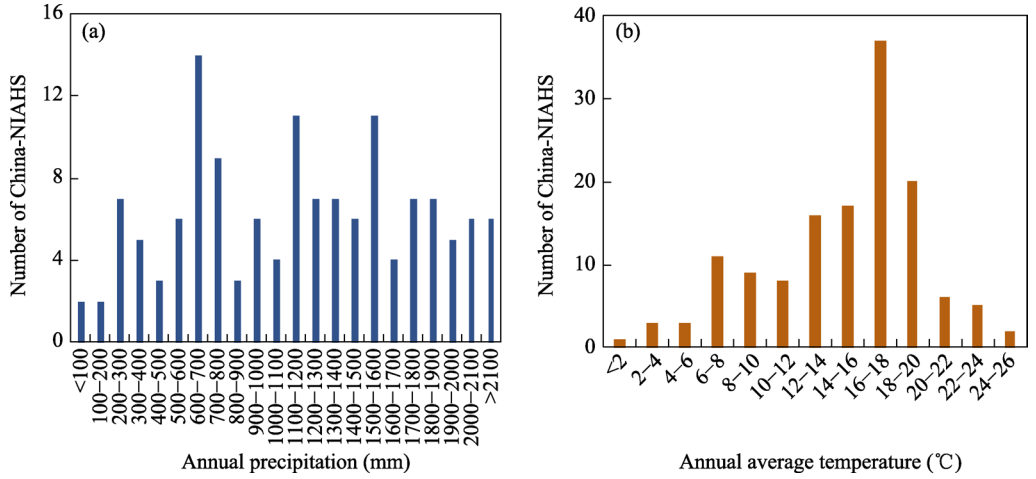

Figure 3 Number of China-NIAHS according to annual precipitation (a) and annual average temperature (b)

Almost 20% of the China-NIAHS were distributed across five ecological function reserves, with the largest number in the water resource conservation function reserve (14 items), followed by the soil and water conservation function reserve and the species resource conservation function reserve (both with 5 items), the marine ecological function reserve (2 items), and the flood water storage reserve (1 item) (Figure 2e). The Changbai Mountains, Beijing-Tianjin region, and Qinling Mountains areas are the main water conservation function reserves where China-NIAHS are distributed, with cultivation as the main type, including the Ning'an Xiangshui Rice Culture System in Heilongjiang province, Kuancheng Traditional Chestnut Cultivation System in Hebei province, and Fengxian Dahongpao Pepper Cultivation System in Shaanxi province. The Loess Plateau, Taihang Mountains, Three Gorges Reservoir Area, and Dabie Mountains are core areas where the China-NIAHS exert soil and water conservation function, mainly supported by the Shexian Dryland Terraces System in Hebei province and the Jiaxian Traditional Chinese Date Gardens in Shaanxi province. Additionally, Diebu Zhagana Agriculture-Forest-Animal Husbandry Compound System in Gansu province and Ili Chabuchar Buha Agricultural System in Xinjiang autonomous region are the main providers of species resource functions. However, few China-NIAHS have been found in marine ecological function reserve and flood water storage reserve.

3.2 Socio-economic characteristics of China-NIAHS spatial distribution

Overall, the number of China-NIAHS exhibits a logarithmically decreasing shape along with population density and area-averaged GDP. Almost three-quarters of the China-NIAHS are distributed in areas with a population density of 0–600 persons/km^2 and an area-averaged GDP of 0–20 million yuan/km² (Figures 4a, 4b, and 5). They are mostly located in rural

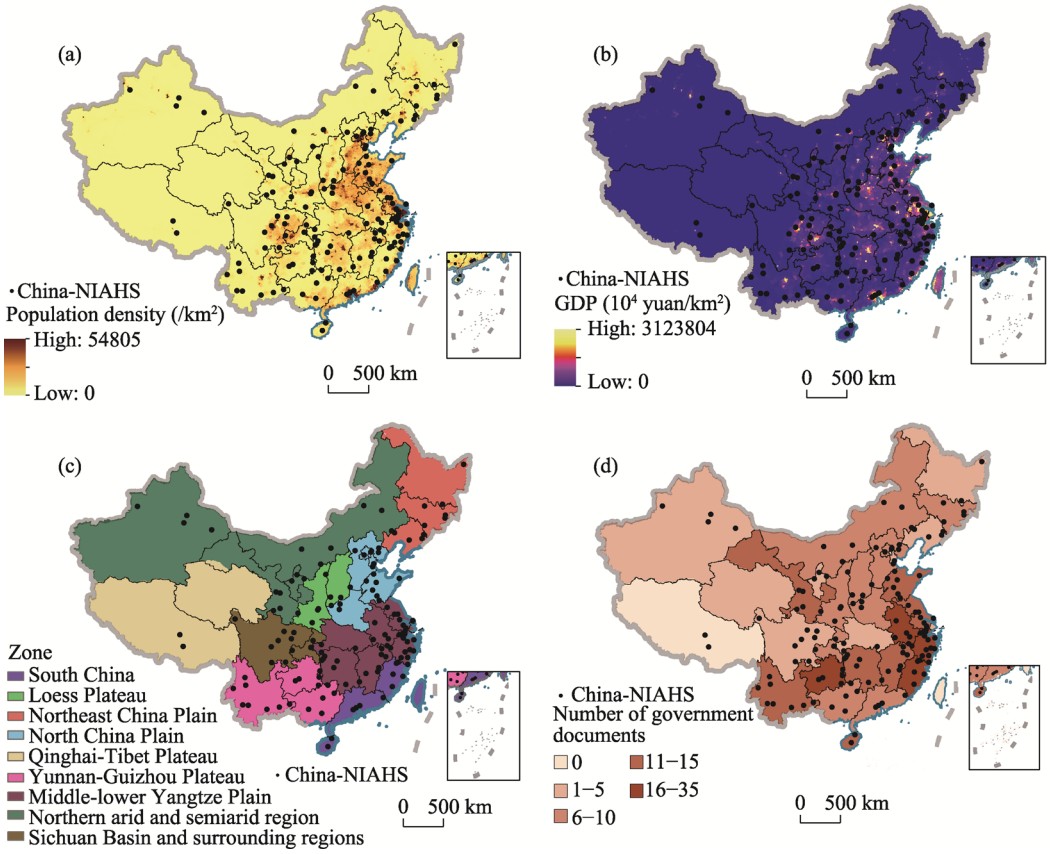

Figure 4 Socio-economic characteristics of China-NIAHS: population density (a), GDP (b), agricultural zones (c), and number of government document (d)

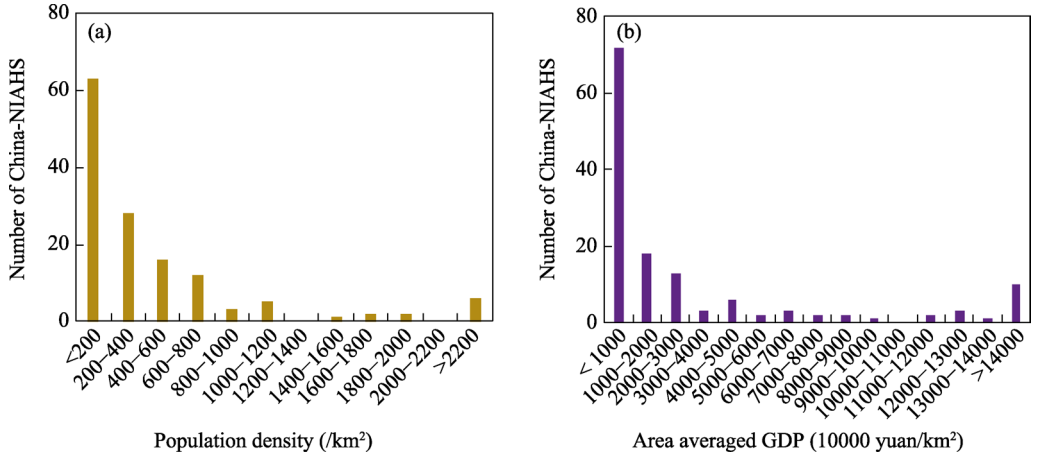

Figure 5 Number of China-NIAHS according to population density (a) and area averaged GDP (b)

areas farther away from developed cities, less affected by urbanization and modernization, making it easier to conserve traditional agricultural techniques and production methods in their original and natural state. In general, areas with lower population density and area-averaged GDP are mostly distributed with the nomadic-type of China-NIAHS, which is related to the high altitude and arid and semi-arid environments, including Shiqu Zhaxika Nomadic System in Sichuan province and the Arukorqin Grassland Nomadic System in Inner Mongolia autonomous region. Densely-populated and economically-developed regions are generally occupied by the cultivation-type of China-NIAHS, which require more labor to support agricultural production activities and provide livelihood support for the local people, such as Xinghua Duotian Traditional Agrosystem in Jiangsu province and the Fuzhou Jasmine and Tea Culture System in Fujian province.

The distribution of China-NIAHS in agricultural zones showed high spatial heterogeneity. Figure 4c shows that the Middle-lower Yangtze Plain has the most China-NIAHS (44 items, accounting for approximately 31.9%), followed by the North China Plain (19 items), the Yunnan-Guizhou Plateau (17 items), and the Northern Arid and Semi-Arid regions (17 items). Additionally, the South China, the Sichuan Basin and surrounding regions, the Northeast China Plain, and the Loess Plateau have relatively few China-NIAHS, accounting for 8%, 8%, 7.2%, and 5%, respectively. There are only two China-NIAHS on the Qinghai-Tibet Plateau: the Dangxiong Alpine Nomadic System and the Naidong Highland Barley Planting System in Xizang autonomous region (Figure 4c).

There are relatively more government documents supporting the China-NIAHS issued by Zhejiang, Anhui, Fujian, and Guizhou provinces, with 35, 31, 27, and 20 documents, respectively (Figure 4d). In Jiangsu, Jiangxi, Shandong, Hunan, Hainan, Gansu, and Yunnan provinces, the number of supporting government documents was between 12–15. The local governments of Tianjin, Hubei, Xinjiang, Shanghai, Qinghai, and Xizang issued fewer documents regarding the China-NIAHS. There was a positive correlation between the number of China-NIAHS and government documents, indicating the attitude of government development strategies and the cognitive level of local leaders towards China-NIAHS conservation.

3.3 Clustering characteristics of China-NIAHS spatial distribution

Spatially, China-NIAHS cluster significantly, with the neighbor index of 0.7 (p<0.01). Specifically, China-NIAHS are more clustered in the southeastern coastal areas but less in the northwestern inland and the clustering pattern can be characterized as ‘one belt’ and ‘three zones’. They are the clustering belt with ‘Northeast-Hebei-Shandong’ as the core (Zone II), the northwestern distribution zone west of the Heihe-Tengchong Line (Zone I), the Yangtze River Delta clustering zone (Zone III), and the Hunan-Chongqing-Yunnan-Guizhou clustering zone (Zone IV) (Figure 6).

Zone I, comprising Inner Mongolia and the Qinghai-Tibet Plateau, is a typical ecologically fragile region with high sensitivity to global climate change. The inland location makes it difficult for moist airflow from the ocean to penetrate deeply, resulting in annual precipitation of below 400 mm. The socioeconomic development of Zone I is relatively slow, with a lower population density and GDP than the other zones. Local government policy support for China-NIAHS needs to be improved. Owing to its high elevation (mostly above 1000 m),

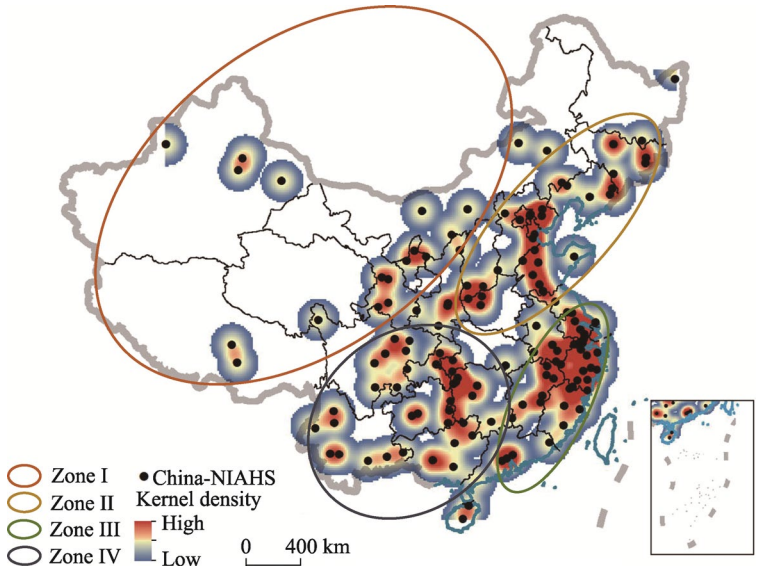

Figure 6 Spatial clustering characteristics of China-NIAHS

agriculture is dominated by husbandry, compound farming, and oasis farming.

Zone II mainly contains the middle and lower reaches of the Yellow River, the Liaodong Peninsula, and the Beijing-Tianjin-Hebei region. Relying on ideal natural conditions such as plains and hills as the main landforms and annual precipitation ranging from 400 to 800 mm with warm conditions, Zone II has become the main grain-producing area in China. Population density and area-averaged GDP of Zone II is relatively high, however the level of government document support for China-NIAHS is relatively low in some provinces, such as Liaoning and Heilongjiang. Agriculture is dominated by the cultivation with a rich variety of crops, and livelihood supply is an extremely important function of the agroecosystems in this region.

Zone III is in a developed region along the southeast coast, mainly including the Yangtze River Delta and the Pearl River Delta. Influenced by the subtropical monsoon climate, the annual precipitation in Zone III is approximately 1500 mm. Accompanied by favorable plain landforms, rice cultivation and dyke-pond agriculture have become the main agricultural types in Zone III. This region attaches higher importance to the China-NIAHS, as indicated by the issuing of more supporting government documents than for the other zones. Although socioeconomic development in Zone III is more advanced than in the other zones, problems such as insufficient agricultural land and a relative shortage of rural labor are gradually becoming apparent.

Zone IV is located in southwest China and includes the Sichuan Basin and the Yunnan-Guizhou Plateau. Hilly landforms and high altitudes severely limit crop cultivation in this zone. However, suitable thermal conditions and abundant precipitation, with an annual precipitation of approximately 1000–1600 mm, provide favorable conditions for the production of specialty crops, such as tea, Chinese herbs, and flowers. The government's strong emphasis on China-NIAHS is responsible for the large number of China-NIAHS in this region.

4 Differentiated management strategies for China-NIAHS

4.1 Management strategies focusing on maintaining ecosystem functions

Previous studies have indicated that the ecosystems in Zone I are sensitive to global climate and environmental changes, and are susceptible to degradation by external disturbances, with a relatively weak self-healing capacity (Yu *et al*., 2017; Yin *et al*., 2022; Wang *et al*., 2023). Zone I also belongs to the agricultural zone of the Qinghai-Tibet Plateau and the northern arid and semi-arid region, where agricultural activities, mainly nomadic pastoralism, may exert pressure on the local ecological environment. In addition, due to the limited carrying capacity or poor management, the China-NIAHS in Zone I are vulnerable to severe destructive disturbances (Min *et al*., 2022), which may cause grassland degradation, land desertification, biodiversity reduction, and soil erosion. Consequently, adaptive conservation and management strategies for China-NIAHS in Zone I should focus on maintaining the stability of their structures and functions and enhancing their biodiversity.

Measures such as the construction of composite agricultural systems and pasture rotation modes play a vital role in maintaining the stable and efficient functions of China-NIAHS in Zone I, especially in mitigating grassland degradation and improving ecosystem productivity. For example, the Diebu Zhagana Agriculture-Forestry-Animal Husbandry Compound System, located in the Minshan-Qionglai Mountain species resource reserve, is an example where livestock pressure in alpine meadows has been eased through rational winter and summer grazing. In addition, crop rotation patterns of barley, potato, and broad bean not only reduce the incidence of single crops but also effectively maintain soil fertility.

Science-based landscape structures formed during long-term land use optimization constitute, another important aspect of management strategies for the China-NIAHS in Zone I, show more obvious effects in addressing extreme global climate change and environmental issues, such as soil erosion. The Jiaxian Traditional Chinese Date Gardens in Shaanxi province provide a good example. The local people introduced sour dates to the sparsely vegetated Loess Plateau along the Yellow River, which not only enhanced the stability of the ecosystem, but also improved sand fixation and soil and water conservation, as date trees have well-developed horizontal roots which extend in all directions.

Although multiple industrial integration paths, including characteristic product development and tourism, have been reported as useful ideas for the development of China-NIAHS in other regions, the conservation of ecological functions and services should always be prioritized in the adaptive management of China-NIAHS in Zone I. Government support for China-NIAHS in this region should be improved and should play a positive role in the conservation and management of China-NIAHS, including ecological protection, industrial development, and management policies.

4.2 Management strategies to maintain livelihoods in major grain producing areas

Zone II contains important major grain-producing regions of China, namely the North China Plain and the Northeast China Plain, where food supply has been considered as the vital function and service of the China-NIAHS. However, there remain some general problems in agricultural production, such as small scale and low yield (Min *et al*., 2020), and market demand-driven fertilizer and pesticide applications result in more pronounced ecological

pressures (Jiao *et al*., 2021). Therefore, to realize a win-win of economy and ecology, the multidimensional goals of 'livelihood supply, sustainable resource use, and ecological conservation' should be emphasized among the management strategies for the China-NIAHS in Zone II.

Specifically, agricultural production can be improved without reducing soil quality and ecosystem services with the help of the sustainable recycling mode, the combination of planting and breeding, mixed farming and intercropping. These modes reconstruct the composite ecosystem of 'human-land-food-animal-fertilizer' (Min *et al*., 2022), and also improve the material and energy cycle and utilization efficiency. China-NIAHS are inherently Nature-based Solutions (NbS), as they integrate valuable knowledge of indigenous technology and modern concepts to improve resource efficiency and reduce ecological pollution (Min *et al*., 2022), thus providing ecological conservation value while safeguarding local economic development. Local governments in Zone II, especially in the Liaoning and Heilongjiang provinces, should strengthen policy support for the conservation of China- NIAHS and popularize the conservation experience of China-NIAHS, to promote the sustainable development of local traditional agricultural production.

For example, Tai'an Wenyang Field Farming System in Shandong province adopts the intercropping pattern of 'wheat-corn', 'wheat-peanut', and 'corn-fruit' to improve grain production by extending the growing season of crops. In the 'agro-pastoral cycle' model, the manure of dairy cattle can be used to fertilize fields, and crop straw can meet the feed needs of dairy cattle, thus realizing the reuse of waste resources and enhancing soil fertility while maintaining biodiversity. In addition, locals have shifted from pursuing yield through water and fertilizer to adopting multiple efficient measures, such as micro-spraying water and fertilizer integration, multi-prevention by one spray, to minimize the application of chemical fertilizers and pesticides. These efforts have promoted the green, high-quality, and efficient development of grain production.

4.3 Management strategies for synergistic development with the socio-economy

The distribution of China-NIAHS is correlated with the level of economy and population aggregation, with Zone III (the developed southeastern coastal area) being one of the core distribution regions. However, rapid urbanization and industrial development pose significant challenges for the adaptive conservation of China-NIAHS in this zone. Specifically, the land base for China-NIAHS is threatened due to the encroachment of cropland by built-up land expansion (Bai *et al*., 2014), and the labor base is challenged by the shortage of farmers, who mostly transfer to other industries. These conditions directly affect the conservation and development of China-NIAHS (Jiao *et al*., 2016; Park *et al*., 2017). Eliminating the negative impact of rapid urbanization on China-NIAHS, and then transforming urbanization into a positive driving force as part of dynamic conservation efforts in Zone III.

Integration of multiple industries based on brand advantages and resource endowment of China-NIAHS has been a useful approach that not only improves farmers' quality of life but also partly alleviates loss of the labor force (Zhang *et al*., 2019). Additionally, sustainable tourism plays a crucial role in conservation and development of China-NIAHS by satisfying tourists' leisure needs, promoting economic progress, and expanding the cultural value of China-NIAHS. Qingtian actively promotes industrial transformation according to the tour-

ism resources of the Qingtian Rice-fish Culture System, resulting in a higher proportion of agriculture and service industries. This makes Qingtian a relatively developed region, with distinctive agriculture and a prosperous tertiary industry (Sun *et al*., 2006).

China has also gradually established a five-pronged multi-participation mechanism for governments, enterprises, scientists, social organizations, and farmers, among which farmers are important creators and inheritors of China-NIAHS. Therefore, farmers' interests should be prioritized to form cooperative relationships with shared interests (Min *et al*., 2022). Finally, prioritizing the role of China-NIAHS in ecological conservation is an effective way to manage China-NIAHS in developed regions, by preventing the encroachment of built-up land on agricultural land through reasonable and functional urban zoning.

4.4 Management strategies focused on the development of specialty agricultural products

Zone IV encompasses the agricultural zone of the Yunnan-Guizhou Plateau and the Sichuan Basin, with rugged terrain, rolling mountains, and limited conditions for traditional crop cultivation. Conservation of the China-NIAHS in Zone IV should focus on developing high-quality, unique products. Although the China-NIAHS in Zone IV includes different types such as cultivation, tea, terrace, compounds, and breeding, there are essentially unique agricultural products in each China-NIAHS. Supported by existing government policy, the development of characteristic agricultural products and the brand effect is a beneficial management strategy for the China-NIAHS.

Development of the China-NIAHS brand accelerates the development of characteristic local agricultural products and an improved ecological environment provides the foundation for healthy, organic, and sustainable agricultural products. At the same time, economic progress and the increasing demand for healthier foods have driven the market for high-quality products. Accompanied by the brand effect of China-NIAHS, characteristic product development has been employed to continuously and dynamically conserve China-NIAHS. For example, the Congjiang Dong's Rice Fish Duck System in Guizhou province uses a model of 'planting a season of rice, releasing a group of fish, and raising a group of ducks'. They have cultivated and selected the characteristic rice "Congjiang Xianghenuo", which has been included in the protection of geographical indications.

The promotion of characteristic or distinctive products will also help enhance social recognition of the China-NIAHS, which will positively impact on farmers' incomes, the farmland environment, and maintenance of traditional agricultural technology and culture, thus effectively conserving the China-NIAHS. For example, the Wanzhou Red Orange Cultivation System in Chongqing municipality has promoted the characteristic brand of ancient red orange planting area, which has driven the industry from planting and cultivation to deep processing. Brand development also helps farmers to increase their income and keeps the Wanzhou Red Orange Cultivation System 'alive'.

Finally, it should not be ignored that rural culture and thought are the important part of China-NIAHS, and also the important ideas for conservation and management of China-NIAHS and their natural and social environment, especially in Zone IV where ethnic minorities are concentrated. For example, in the Congjiang Dong's Rice-Fish-Duck System of Guizhou province, the Dong ethnic group apply the traditional self-management method to

protect forests (Liu *et al*., 2011); and in the Honghe Hani Rice Terrace System of Yunnan province, the beliefs and worships, traditional customs, and festivals of the local people enable the traditional agricultural production methods to be passed on and contribute to the long-term stability of the local society (Yang *et al*., 2017; Zhang *et al*., 2017). Similarly, "LONG forest" belief of the Dai ethnic minority is positive for the conservation of China-NIAHS and related natural resources (Mo *et al*., 2013).

5 Conclusions

Using multi-source data and spatial analysis methods, we clarified the spatial distribution pattern of the existing China-NIAHS, their geographical and socioeconomic characteristics, and various threats and challenges. The results show that China-NIAHS are mainly distributed in areas of major human activities, with landforms of mountains and plains, semi-humid and humid conditions, a suitable thermal environment, medium population density, and medium area-averaged GDP. Distribution of the China-NIAHS were clustered into four zones, and management strategies were proposed for each zone. Specifically, the management strategies for China-NIAHS in ecologically fragile areas (Zone I) should focus on maintaining their ecological functions and services, whereas those in major grain-producing areas (Zone II) should emphasize livelihood supply and its relationship with sustainable resource use and ecological protection. The management strategies for China-NIAHS in developed areas along the southeast coast (Zone III) should aim to transform rapid urbanization into a positive driving force through sustainable tourism, ensuring benefits to farmers' incomes and reasonable urban zoning. The management strategies for China-NIAHS in southwest China (Zone IV) should emphasize the mutual benefits between the development of distinctive, characteristic products and the brand effect of China-NIAHS. This study contributes to a comprehensive understanding of the distribution characteristics of China-NIAHS, helps to establish effective conservation and management strategies for China-NIAHS at the regional scale, and provides a reference for other countries to conserve and manage agricultural heritage sites.

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