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Functional Zoning Mode and Management Measures of Qianjiangyuan National Park based on Ecological Sensitivity Evaluation

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Abstract: Functional zoning is an important guarantee for regulating the land use intensity of national parks and maintaining the integrity and stability of natural ecosystem. In this paper, we tease out of the functional zoning models and methods based on the empirical analysis of the world national parks, and then take the Qianjiangyuan National Park (QNP) as an example, study the functional zoning method based on ecological sensitivity. Results show that, the goal of national park construction in the world is changing from enhancing national cohesion to displaying the national image, from the pure natural protection and recreation use to protection of the comprehensive function of natural ecosystem integrity protection, recreation, environmental education, etc. The establishment of QNP is to protect the natural ecosystem of sub-tropical lowland broad-leaved evergreen forest, also to meet the community development and recreational consume of large population in Eastern China. So this paper establishes an evaluation index system based on ecological sensitivity, combining ecosystem services, potential habitats of important species, and development opportunities. Based on the analysis result, the functional zoning of QNP can be divided into strict protection area, ecological conservation area, traditional using area and recreational area. In this way, it can make the functional partition reflect system controls thought in area difference and space layout, and take the corresponding management measures in different functional areas, to promote the sustainable evolution of the natural ecological system in national park.

Key words: ecological sensitivity; function zoning; Qianjiangyuan National Park (QNP)

1 Introduction

Zoning is an effective way to achieve regional planning and construction as well as standardized management. The designation of national parks is a conservation technique employed worldwide, and building national parks is an indispensable part of China's 13th five-year ecological civilization construction plan. In order to guarantee the sustainable development of national parks, managers usually introduce zoning according to the regional characteristics of the natural ecological system. This approach can control the use of natural resources and land utilization type, alleviate any conflict between different interest groups, and protect the integrity and biodiversity of the natural ecological systems. It thereby provides an institutional guarantee of conservation and recreational use of the parks (Wang, 2000; Liu 2001; Paul et al., 2005). The functional zoning of national parks requires a systematic design to ensure the conservation and sustainable use of natural ecosystems. This is important to enable the national park to protect representative national samples of natural wilderness landscapes and na-

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tive plants and animals in the ecosystem. The zoning supports various ecological and social service functions, including natural resources and biodiversity protection, as well as the enjoyment of natural landscapes, entertainment and recreation, scientific research and education, and community development (Dearden, 1993; Zhang and Li, 2006; Luo, 2013). In addition, a national park can provide a place in which to carry out scientific research, environmental education, and ecological recreation activities (Chen et al., 2014). A park's main goal is to protect the integrity of natural ecosystems, biodiversity, and beautiful landscapes to facilitate recreational activities and increase the community's quality of life.

Functional zoning controls are key measures in the governance of national parks. National park managers use functional zoning for land-use control and it is the main means of implementing part of the national park functions. Other studies have focused on the functional zoning management model and land ownership adjustments of parks in the USA, Canada, Japan, and other countries (Zhang and Bai, 2002; Nabokov and Loendorf, 2004; Wagner et al., 2006). Europe, the United States, and other developed countries have established their functional zoning systems based on their respective regional characteristics. Foster thought national parks could be divided into core reserve, visit buffer area, and intensive visit area. National park functions include key resource reserves, low use of wilderness areas, dispersing visit areas, intensive visit areas, and tourism service areas (Hong and Ran, 2005). McNamee (1993) stated that its functions included special protection belts, original habitat, natural environment belts, outdoor recreation belts, and park service belts. Since the 19th century, national park designation has received global attention, and research studies on functional zoning have also increased. Research in China has focused on the necessity of creating a national park system and the management systems for the parks, while the research related to functional zoning has concentrated on ecotourism functional zoning (Zhang et al., 2008; Zhang et al., 2015). When designing the functional zoning of national parks, most countries make appropriate adjustments to preserve the parks' main functions, according to the characteristics of regional natural resources and social-economic development. As national park creation in China is in its pilot phase, it is necessary to plan functional zoning modes in accordance with China's national conditions and local characteristics. The plans should consider regional ecological, economic, and social conditions, and the methods developed can guide the future evolution of Chinese natural ecological resources protection and national park creation.

This paper analyzes the functional zoning method for Qianjiangyuan National Park (QNP), based on the ecological sensitivity evaluation, and then proposes a functional zoning method that conforms to the actual situation of regional development, which would be beneficial to the management and construction of China's national parks.

2 Methods

2.1 Study area

The QNP is located in the Baiji Mountains in the northeast of Kaihua County, Quzhou City, Zhejiang Province. It is adjacent to the Wuyuan County of Jiangxi Province and the Xiuning County of Anhui Province. The QNP contains two national natural protection areas, namely Gutian Mountain National Nature Reserve (81.07 km^2) and Qianjiangyuan National Forest Park (45 km^2), as well as an ecological corridor connecting them (mostly comprising ecological public welfare forests) with a total area of 252 km^2. The QNP's objectives are to protect the important representative habitats of the area. These include typical, primitive, large, low-altitude, subtropical evergreen broad-leaved forests, and their living creatures. The ecosystem and landscape are rare in China and the world. The QNP has an obvious hypsographic feature, with an average elevation of about 600−700 m. The highest point is Green Peak (1236 m) in Gutian Mountain. Its water system includes Qianjiangyuan river system and Suzhuang river system. The QNP's forest coverage rate is 81.70%, mainly concentrating on Qianjiangyuan National Forest Park and Gutian Mountain National Nature Reserve, and the two large areas of forest vegetation are above an altitude of 1000 m, where a lot of wild animals survive, including Elliot's pheasant (*Syrmaticus ellioti*) and clouded leopard (*Neofelis nebulosa*). Apart from these two protected forest areas, other areas are below an altitude of 1000 m. From north to south, there are four villages and towns, namely, Suzhuang, Changhong, Hetian, and Jixi, which include 19 administrative villages, 72 natural villages, and 9744 people. The goal of setting up QNP was to protect the ecological service function of Qianjiangyuan, and the natural ecological system in the central Asian tropical lowland broad-leaved evergreen forests.

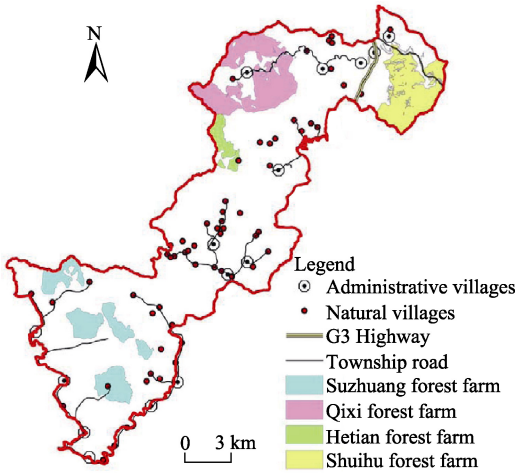

Fig. 1 Location of Qianjiangyuan National Park (QNP)

2.2 Data collection

The data selected in this paper mainly include：

(1) Data on land use. Based on the vector data of the Second National Land Survey of China, we classified the land use types and ownership to determine the area, utilization types, and spatial proximity of each plot.

(2) Data on settlements and population. We obtained these data as follows: the research team conducted field research in each township and administrative village in QNP, distributing the questionnaires on population data to all village committees, and collecting the numbers of administrative villages and natural villages, as well as the number of settlements and the distribution of major roads. Finally, these data were entered into the main database.

(3) Data on distribution of natural resources. Digital elevation model (DEM) data for the 30-meter resolution of the study area was downloaded from the Geospatial Metadata Website and later integrated into the database for elevation analysis.

(4) Data on the distribution of important species. These data were mainly based on the findings of the terrestrial mammal resources survey of Gutian Mountain and Qianjiangyuan conducted by the Institute of Botany, Chinese Academy of Sciences.

(5) NPP (Net primary productivity). This was obtained by using the natural vegetation NPP model.

Above all, based on the vector data of the Second National Land Survey of Kaihua County, this paper adopted the spatial analysis platform of ArcGIS10.0 to cut down the scope of QNP. Finally, the above data was loaded into the ArcGIS to build the basic database.

2.3 Data analysis

Functional zoning mainly involves combining spatial superposition with mathematical statistics (such as cluster analysis, principal component analysis, and factor analysis) (Wall, 1982; Kathirithamby, 2005). Based on the characteristics of natural ecosystem interference in QNP, as well as the sensitivity of the natural ecosystem and ecological pressures on the area (Fu et al., 2017), we designed a comprehensive zoning system by focusing on community and recreation. Meanwhile, considering the importance, systematicness, and availability of the indicators, we finally selected 12 of them for evaluation of the potential habitats, ecological sensitivity, and ecological pressure on important species together with the development opportunities in the study area (Table 1).

Firstly, as ecosystem service is the foundation for the establishment of national parks, we selected the three indicators of carbon sequestration, water conservation, and soil conservation for evaluation.

Secondly, some key nationally protected animals, such as white-necked pheasant, live in QNP, and their existence is an important indicator of the integrity of the regional ecosystem. Therefore, according to the importance of the wild species, 8 species and 3 taxa were screened for analysis. Meanwhile, buffer analysis on habitat was conducted to obtain the potential scope of protection for each species.

Thirdly, since ecological sensitivity reflects the ability of the ecosystem to adapt to human disturbance, and the more sensitive it is, the more vulnerable it is, ecologically sensitive areas are the areas where human activity must be restricted or prohibited. In this study, vegetation coverage, rivers and lakes, topography were chosen to conduct a comprehensive evaluation.

Fourthly, development opportunities reflect the potential of traditional life, recreation, and utilization, and can be expressed in terms of tourism resource density.

Fifthly, ecological sensitivity was calculated according to the natural regional characteristics of QNP, and three levels were created to determine the level of protection, namely, core protection, ecological conservation, and traditional utilization. Simultaneously, considering the community development of residential areas, utilization of ecological resources, and construction of service facilities, we identified the potential for the development of recreation to determine the recreation areas. Finally, the regulatory requirements and specific measures were designed in accordance with the need for protection and utilization.

Table 1 Evaluation index system on functional zoning of QNP

Category	Weight	Indicator	Weight
Ecosystem Services	0.15	Carbon sequestration	0.18
		Water conservation	0.51
		Soil conservation	0.31
Potential habitat of important species	0.30	Distribution of ungulates	0.47
		Distribution of birds	0.37
		Distribution of fish	0.16
Ecological sensitivity	0.20	Vegetation coverage	0.43
		Rivers and lakes	0.36
		Topography	0.21
Development opportunities	0.15	Population density	0.20
		Traffic network density	0.25
		Tourism resource density	0.55

Note: This index system refers to Fu et al. (2017).

3 Result

3.1 Regional characteristics analysis

The ecological characteristics of QNP were analyzed by establishing the evaluation index system of functional zoning. It was found that QNP is rich in vegetation types and includes typical forest vegetation types such as evergreen broad-leaved forests, temperate coniferous and broad-leaved mixed forests, temperate coniferous forests, and evergreen and deciduous broad-leaved mixed forests on mountains and in valleys. What is more, the spatial distribution of the eco-

system service of QNP is obvious, and the value of the ecosystem service is the highest in the Gutian Mountain Nature Reserve and the Qianjiangyuan National Forest Park (which are at each end of QNP), as they preserve the original subtropical low-altitude evergreen broad-leaved forest ecosystem, which is mainly located in the hillsides and foothills 165 to 1246 meters above sea level. In general, the forest coverage rate of QNP is 81.70%, and these forests play an important role in water conservation, soil and water conservation, biodiversity conservation, and air purification. However, in the middle connecting area, the capability of the ecosystem service has decreased significantly. In addition, the ecological corridor connecting the two ends has many secondary forests with a large number of settlements and transport infrastructures, and a certain level of tourism activities has been developed.

As shown in Fig. 2, Gutian Mountain Nature Reserve supports greatest variety of wild animals in QNP, and also possesses important habitats for the priority protected animals of China such as Elliot's pheasant (*Syrmaticus ellioti*), hairy-fronted muntjac (*Muntiacus crinifrons*), clouded leopard (*Neofelis nebulosi*), and Sri Lankan leopard (*Panthera pardus*) with large species and population. As for the northern part of QNP, the waters are the habitat for important fish species. With regard to Gutian Mountain Nature Reserve and Qianjiangyuan National Forest Park, the national priority protected plants of Chinese yew (*Taxus chinensis*), together with the national secondary-level protected plants such as Henry's emmenopterys (*Emmenopterys henryi*), Chinese tulip tree *(Liriodendron chinense*), katsura tree (*Cercidiphyllum*), and the hardy rubber tree (*Eucommia ulmoides*) are concentrated in these two regions. However, few wild animals are found in the central area due to the effects of human activities.

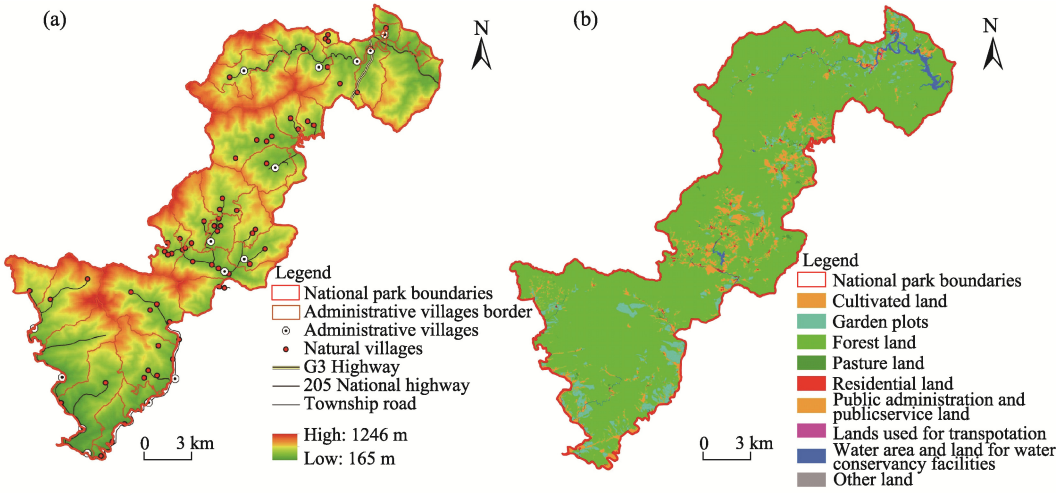

Fig. 2 Elevation (a) and land use structure (b) of QNP

3.2 Ecological sensitivity analysis

According to the ecological sensitivity analysis of QNP, the ecologically sensitive area is moderate in size and mainly concentrated in the Gutianshan and Qianjiangyuan areas (Fig. 3, Table 2). It accounts for 15.7% of the entire study area. The degree of ecological sensitivity of the QNP varies greatly, and it mainly shows medium sensitivity. This category is primarily concentrated in the primeval forest area around the Gutianshan Mountain and Qianjiangyuan Mountain and accounts for 60.92% of the total area. Second, the highly sensitive area, which is mostly secondary forest around the primeval forest area, accounts for 23.53%. The proportions of the mildly sensitive area and the slightly sensitive areas were 14.61% and 0.95% respectively and were mainly distributed in the middle zone. As for development opportunities, these are strictly limited for the Gutian Mountain and Qianjiangyuan areas, and the recreational potential here is small. However, in areas adjacent to the administrative villages of Taoyuan and Hetian, more tourism activities have developed, and there is space for recreational activities and traditional utilization.

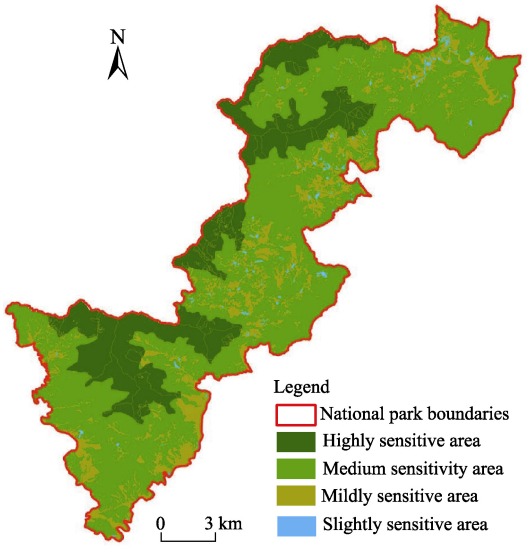

Fig. 3 Analysis results of ecological sensitivity of QNP

Table 2 Classification statistics of habitat sensitivity of QNP

Sensitivity level	Area (km^2)	Proportion (%)
Highly sensitive area	59.23	23.53
Medium sensitive area	153.36	60.92
Mildly sensitive area	36.77	14.61
Slightly sensitive area	2.39	0.95
Total	251.75	100.00

3.3 Functional zone identification

In general, the functional zoning of national parks should be based on the characteristics of the natural regional ecosystems, the distribution of community settlements, and the scenic spots. Moreover, the zoning needs to reflect the dominant functions and regional relations, coordinating and controlling the land use to promote the conservation and utilization of resources. As for QNP, it should not only protect the ecosystem of low-elevation evergreen broad-leaved forests in the subtropics, but also meet the needs of large-scale national recreation in the east, and create sustainable livelihoods for a large number of communities in the region, mainly focusing on three aspects: protection, recreation, and community development. According to our analysis of the international approach to the zoning of national parks, it would be appropriate to adopt the four-point method of functional zoning: the core protected area, the ecological conservation area, the traditional utilization area, and the recreational display area. To ensure the integrity of the core protected area, the surroundings should create an ecological buffer zone, separating the core area from community development and recreation utilization. The relationship between functional zoning and ecological sensitivity is illustrated below (Fig. 4). For an ecological geographical unit, the external pressure generated by human activities would have an impact and generate differentiation effects in the ecologically sensitive and non-sensitive regions. Due to the fragility of the systems, the eco-sensitive areas are prone to ecological degradation, while the non-sensitive areas can be adapted to a certain extent and can tolerate human activities. For the ecologically sensitive areas, protection and restoration should be strengthened while, for the non-sensitive areas with attractive landscapes, environmental education and recreation projects with the same development goals as national parks can be carried out appropriately. The areas with attractive landscapes can maintain the status quo and ensure the continuance of traditional production methods and lifestyles.

Figure 5 shows a model of functional zoning for QNP. This is based on the analysis of ecosystem characteristics and ecological sensitivity in different parts of the QNP, taking the protection of representative natural landscapes and habitats of important species as a precondition, and considering future community development and recreation utilization. The functional zone is divided into four parts. Firstly,

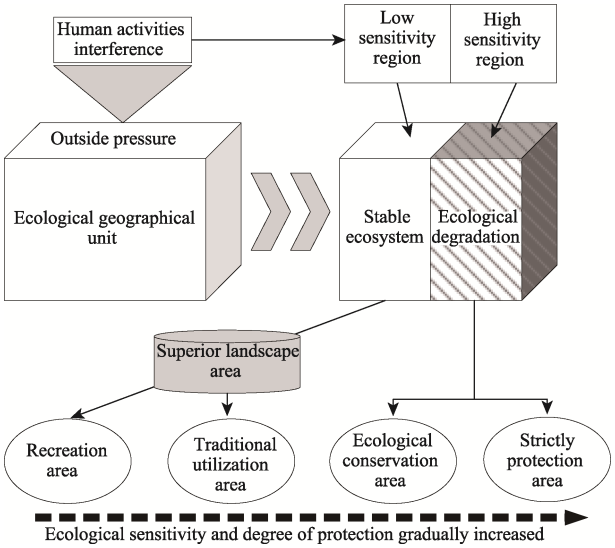

Fig. 4 The relationship between functional zoning and ecological sensitivity

the strictly protected zone covers 81.32 km^2 and accounts for 32.3% of the total QNP area. It preserves the original subtropical low-altitude evergreen broad-leaved forest ecosystem and provides suitable habitat for important organisms, a key function of ecosystem service. Secondly, the ecological conservation area, which has an area of 88.54 km^2 and accounts for 35.17% of the total area, contains an important and fragile primary-secondary forest ecosystem, including relatively large patches of native habitat or areas that have been damaged and require natural recovery. Generally speaking, this area is the ecological barrier and buffer zone for the strictly protected area. Thirdly, the traditional utilization area is 70.49 km^2, accounting for 28.0% of the total QNP, and it is mainly distributed in the eastern area of Changhong and Qiuxi. There are many economic forests in this area, and the ecosystem's ecological service capacity is relatively strong. Therefore, this area is suitable for traditional community production and management activities and traditional forest harvesting and breeding. Finally, the recreation area covers 11.39 km^2 and accounts for 4.53% of the total area. With a large number of tourist resources and good access, this is the area close to where the settlements such as Gutian Village, Qixi, Changhong, and Tianfan are concentrated. In this area, it would be appropriate to facilitate activities such as sightseeing and recreation, science education, and franchising that display the natural and cultural- ecological landscapes of QNP.

4 Discussion

(1) Index system establishment and partition modes have regional characters in relation to functional zoning of national parks, which is the adaptive selection to cope with ecological regional management under the administrative system of the state or region. The diversity of national parks in different countries is reflected in the following aspects:

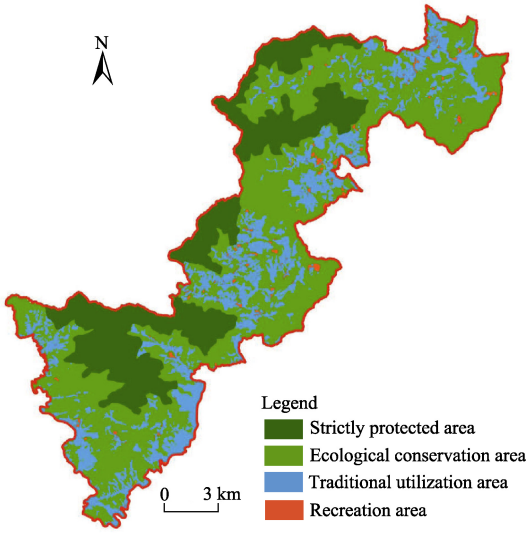

Fig. 5 Functional zone map based on ecological sensitivity evaluation results of QNP

different natural geographical features, social economy and protected objects, and different requirements for functional zoning. However, in general, it is based on the three-circle structure proposed by the United Nations Educational Scientific and Cultural Organization. The tension between human activities and land determines the proportion placed in each functional area. At present, most national parks in the world are divided into 3−5 functional areas, namely ecological protection area, special landscape area, historical and cultural area, recreation area, and general control area. From the viewpoint of protection and utilization, they can be divided into strictly protected areas, important protected areas, restrictive utilization areas, and utilization areas. The degree of protection is gradually reduced, and the degree of utilization is gradually increased. Normally, the percentage of original forest habitat to maintain the sustainability of species and ecological processes is at least 50%−70%. As for China, it is confronted with a two-way tension between population development and land use. While protecting the natural ecological space in national parks, community development must be considered, and recreational activities should be developed in moderation to meet the needs of national life and leisure. However, functional zoning of national parks needs to prioritize maintenance of the natural ecological process. When this ecologically sensitive core area has been identified, then land for community use and tourism can be allocated. Therefore, this paper identifies four functional areas of the QNP according to the ecological sensitivity evaluation model: the core area, ecological conservation area, recreational environment, and traditional utilization area. Meanwhile, it is necessary to implement conservation or utilization activities in the different functional areas according to the dominant features to ensure the sustainable development of natural ecosystems in the future.

(2) From the aspect of regional differences, QNP is located in Eastern China, which is a “small scale region”. The proposed national park functional zoning method is based on ecological sensitivity, taking into account the natural resources and environmental elements to identify the different functional areas. It differs from previous methods, such as the analytic hierarchy process and the artificial judgment method based on ecological integrity and the biodiversity and ecological carrying capacity, which can better optimize the management of the ecological environment. The article is based on ecological sensitivity evaluation and identification of four functional areas of QNP, the proportion of the different areas is 3:3:3:1, which is practical in terms of maintaining ecosystem integrity and meeting recreational needs. However, QNP is different from China’s national parks in western regions, which possess different natural resources, land area, and population size. However, whether the functional zoning method is appropriate to the national parks in Qinghai-Tibet Plateau or the Sanjiangyuan region, needs further discussion.

(3) The essence of national park control is classified hierarchical management, and the target of functional zoning is to determine the protection goals of different levels on the basis of balanced and sustainable use. The aim is to support control decisions, ensure the subsequent land ownership adjustment, space layout, partition management, and community relocation compensation, and to maximize the effectiveness of the national park. In addition, the function partition management is important for the regional planning, construction, and management of the technical method (Paul et al., 2005; Warwick, 2009). It combines the natural ecosystem protection with functional zoning settings and provides an institutional guarantee to control land use to protect the natural ecological system integrity and biodiversity. This could ease the conflicts between different users or interest groups in relation to the protection and recreational use of natural resources. Therefore, national park management and control should meet diversified functional requirements, and cannot unilaterally emphasize protection or utilization, both of which will have adverse effects on the natural ecosystem and/or regional development. Reasonable controls of national parks should focus on the reference intensity of different functional areas of ecological sensitivity, and make a reasonable division between scientific research, education, tourism, and other activities. In this way, it can ensure a good match between human activity intensity and land-use intensity, and ensure that the national parks can achieve sustainable evolution within their carrying capacity.

5 Conclusions

This paper establishes an evaluation index system based on ecological sensitivity, combining ecosystem services, potential habitats of important species, and development opportunities of QNP and identifies different levels of sensitivity. It found that ecologically sensitive regions have cross-sectional differences in space and can be divided into four grades,

namely highly sensitive area, medium sensitive area, mildly sensitive area, and slightly sensitive area; their percentages were 23.53%, 60.92%, 14.61%, and 0.95%, respectively. Based on the classification of ecological sensitivity, functional zoning can be implemented. Highly sensitive areas can be defined as core protection areas, and mildly sensitive and low-sensitive areas can act as traditional community use areas and recreation areas.

The key point of this paper is to propose that conservation or utilization activities should be set up according to the dominant characteristics of different functional areas to ensure the sustainable development of the natural ecosystem in the future. National park management should meet diversified functional requirements, and cannot unilaterally emphasize protection or utilization, both of which can have adverse effects on the natural ecosystem and/or regional development. Zoning in the national park should focus on the reference intensity of different functional areas of ecological sensitivity, and then allocate a reasonable space for scientific research, education, tourism, and other activities. These can ensure a good balance between human activity intensity and land-use intensity, and ensure that the national park can achieve sustainable evolution within its carrying capacity.

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基于生态敏感性评价的钱江源国家公园功能分区研究

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摘　要： 功能分区是调节国家公园土地利用强度、维护自然生态系统完整性和稳定性的重要制度保障。本文以钱江源国家公园为例，基于生态敏感性的功能分区方法，研究发现世界各国国家公园建设的目标正从纯粹的自然保护和游憩利用向保护自然生态系统完整性、游憩、环境教育等综合功能转变，大多数国家公园功能分区采用同心圆环的布局模式。钱江源国家公园生态敏感性表现出较大的规模差异性，中等以上敏感区域占 84.45%，主要集中在古田山和钱江源源头地区的森林地区；轻度敏感区和极轻度敏感区分别占 14.61% 和 0.95%，呈碎片化分布在中间区域。结合生态敏感性程度、重要物种潜在生境和社区发展与休闲游憩等需求，可以将钱江源国家公园划分为严格保护区、生态保护区、传统利用区和游憩娱乐区，以达到对不同类型功能区域的差异化调控和管理，促进钱江源国家公园自然生态保护和资源利用的可持续发展。

关键词： 生态敏感性；功能分区；钱江源国家公园