The Theory and Methodology of Ecological Security Design for Nature Reserves

自然保护区生态安全设计的理论与方法

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中国环境科学出版社

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前　言

自然保护区建设是生物多样性就地保护的主要措施，而自然保护区设计是自然保护区建设的关键性基础工作。国际上对自然保护区设计非常重视。20 世纪 70 年代，麦克阿瑟和威尔逊提出的保护区设计原则曾引起对保护区设计的广泛争论。联合国教科文组织“人与生物圈计划”(MAB)从全球角度强调保护区网络的重要性，并把保护区划分为核心区、缓冲区和过渡区。我国先后发布了《中国自然保护纲要》、《自然保护区条例》，提出了保护区选划的条件和功能分区的原则。但由于自然保护区设计不仅取决于生态系统和保护对象的生态学特性，还取决于土地利用和当地社会经济等因素，因此自然保护区设计无论在理论上还是在实践上都面临很多困难，至今尚无成熟的理论和方法。《生物多样性公约》第 8 条(b)款规定，“于必要时，制定准则据以选定、建立和管理保护区或需要采取特殊措施以保护生物多样性地区。”因此，自然保护区设计的理论与方法研究对于我国自然保护区建设事业的健康发展和履行有关

国际公约具有重要指导意义。

本书正是基于这种背景和实际需要，对自然保护区设计的理论与方法进行了探索性研究。本人在大量阅读国内外文献和分析前人研究成果的基础上，结合我国自然保护区实际，提出了自然保护区生态安全设计的概念和三个层次（网络、保护区和廊道），将地理信息系统、应用数学等现代技术与景观生态学等学科相融合，提出了不同层次自然保护区生态安全设计的原则和方法，包括自然保护区网络设计、自然保护区功能分区的具体原则和方法，并以丹顶鹤（*Grus japonensis*）为例，采用 GIS、迭代法和整数规划模型进行了保护区网络设计及生态安全设计。

本书基于本人的博士论文，受时间、资料和研究手段的限制，研究工作仍有许多方面有待完善，尚处于理论构建阶段，方法有待创新，提出的丹顶鹤保护区设计建议仅代表个人观点，有待实践中检验。鉴于自然保护区生态安全设计尚处于研究探索阶段，本研究也仅仅是一次探索，错误、不当之处在所难免，恳请读者批评指正。

作　者

2000 年 6 月于南京

摘　要

自然保护区建设是生物多样性就地保护的主要措施，而自然保护区设计是自然保护区建设的关键性基础工作。《生物多样性公约》第8条(b)款规定："于必要时，制定准则据以选定、建立和管理保护区或需要采取特殊措施以保护生物多样性地区。"为此，一些国际组织和生物多样性特别丰富的国家先后进行了大量的探索，但由于自然保护区设计需要考虑的因素太多，数据依赖性强，研究进展不大，至今尚无成熟的理论和方法。我国虽然先后发布了《中国自然保护纲要》、《自然保护区条例》，提出了保护区选划的条件和功能分区的原则，但所提出的条件和原则针对性、可操作性不强，难于应用于实际工作。本研究正是基于这种背景和实际需要，试图通过资料调研与野外调查相结合、理论研究与案例研究相结合的方法，建立自然保护区生态安全设计的理论与方法体系，并应用GIS技术、迭代法和整数规划等方法，研究丹顶鹤(*Grus japonensis*)自然保护区的生态安全设计。

本研究首先提出了自然保护区生态安全

设计的概念，认为安全概念应考虑非军事威胁和解决威胁的非军事手段，因为随着世界经济和环境交流与合作的不断发展，安全已不仅仅局限于军事和主权等领域，环境退化会削弱经济发展的潜力，影响人类社会的进步，导致社会的不稳定。生态安全指的是这么一种状态，一个群落的自然环境能满足群落持续生存的需求，而不损害自然环境的潜力。生态安全是社会安全和经济安全的基础，同时生态安全需要社会安全和经济安全来保障。自然保护区生态安全设计就是从区域生态系统高度，根据保护生态系统的完整性、代表性和生态过程的原则及一定的保护目标，提出一个区域内自然保护区网络、保护区功能区和廊道的合理布置，以有效地保护生物多样性和自然栖息地。它是一种集社会、经济、环境、生态于一体的协调设计战略。自然保护区生态安全设计专门针对生物资源类保护区，即我国目前保护区分类标准中的自然生态系统类和野生生物类保护区。

通过理论分析认为，异质种群理论、景观生态学理论和种群生存力分析理论是自然保护区生态安全设计的理论基础，并总结出如下主要结论：(1)景观异质性有利于物种的持续生存和生态系统的稳定，例如，一些物种在幼体和成体不同生活史阶段需要两种完全不同的栖息环境，还有不少物种随着季节变换或进行不同生命活动时，也需要不同类型的栖息环境；(2)物种的持续生存和生态系统的整体保护需建立自然保护区网络，因此目前以单个、孤立自然保护区为主的保护模式是远远不够的，应以生物等级系统的各个层次或节点作为保护对象，将节点连接成为一个整体的保护网络，提高保护区间的连接度；(3)景观生态安全格局和最小可存活种群是确定自然保护区生态安全阈值的依据。

通过国内外大量资料调研和理论分析，本研究建立了自然保护区生态安全设计的方法论，包括三个层次，首先从区域层次研究保护区网络的优化设计：其次，在网络的每个节点(保护区)，研究

保护区的功能分区、面积、形状；最后，研究网络与节点的连接（廊道）。其中，自然保护区网络设计是生态安全设计的基础，保护区功能分区是生态安全设计的保障，而廊道设计是生态安全设计的补充。自然保护区网络设计需遵循生态系统的地域完整性和生态过程完整性原则及生物多样性原则，主要方法有地理途径方法、计分法、迭代法和整数规划方法。一般把迭代法和整数规划方法作为互相补充的方法用于保护区网络的设计。当有详细的植被分布图时，也可以采用地理途径方法。自然保护区功能分区应遵循保护第一的原则、核心区与缓冲区的生态完整性原则和实验区的可持续性原则，应采用逆向设计的途径，首先进行核心区的设计，继而缓冲区，最后完成整个保护区的设计。核心区设计的主要方法有种群生存力分析方法、栖息地分布模型方法和阻力面分析方法。缓冲区设计的主要方法有等宽度法、层次分析法和阻力面分析方法。

到1999年底，我国虽然建立了33处以保护丹顶鹤及其栖息地为主要目的的自然保护区，总面积约309.9万 hm^2，但丹顶鹤面临严峻的生境安全问题，主要威胁包括：(1)大规模湿地围垦引起生境丧失；(2)水利工程建设使湿地失去水源；(3)环境污染造成丹顶鹤生境的破坏；(4)人类活动对丹顶鹤栖息的影响；(5)保护区缺乏系统规划，安全性低。针对以上生境安全问题，本研究以丹顶鹤及其栖息地作为试点案例，采用GIS技术、迭代法和整数规划等方法，先后进行了丹顶鹤保护区的网络优化设计，丹顶鹤繁殖地、迁徙停歇地和越冬地的生态安全设计。

在对丹顶鹤分布和生态习性进行资料调研的基础上，本研究提出了丹顶鹤保护区网络设计的指标，评价了丹顶鹤湿地的适宜性。根据高、中适宜性湿地面积70%和60%的保护目标，设计了基于迭代法和整数规划方法的保护区选择算法，获得了符合实际的保护区网络备选地点集，研究表明迭代法和整数规划方法是保

护区网络设计的可行方法。

在丹顶鹤保护区网络设计的基础上，本研究提出了丹顶鹤繁殖地、迁徙停歇地的生态安全设计，主要包括：(1)新建都鲁河自然保护区、乌拉盖沼泽地自然保护区、图门江国际保护区、天津汉沽沿海滩涂自然保护区、天津塘沽沿海滩涂鸟类自然保护区、天津北大港洼地芦苇沼泽自然保护区、山东日照海滩自然保护区；(2)扩建双台河口自然保护区、黄河三角州自然保护区；(3)在松嫩平原沿乌裕尔河、嫩江、霍林河和洮儿河建立“S型”保护走廊；(4)重新规划和调整三江平原的自然保护区，合并扎力河、富锦莲花泡、连山泡、兴隆芦苇、七星河、雁窝岛、长林岛7个自然保护区，合并洪河、八岔岛、三江3个自然保护区，分别建立大型国家级自然保护区，合并兴凯湖、虎口湿地和宝丰湿地3个自然保护区，建立一个大型国家级自然保护区；(5)沿渤海西海岸和山东黄海沿海，建立宽度为60 km的丹顶鹤迁徙走廊，北起双台河口自然保护区，经渤海西海岸连接黄河三角洲自然保护区，向南经山东日照连接盐城自然保护区。

本研究还采用GIS和阻力面分析方法，研究了盐城自然保护区的功能分区，提出了针对不同保护目标的核心区和缓冲区生态安全阈值。

总之，本研究采用资料调研与野外调查相结合、理论研究与案例研究相结合的方法，在国内首次建立了自然保护区生态安全设计的理论与方法体系，并应用GIS技术和迭代法、整数规划、阻力面分析等方法，研究了丹顶鹤自然保护区网络的优化设计，提出了在丹顶鹤繁殖地、迁徙停歇地新建扩建保护区、建立保护走廊和迁徙走廊、调整保护区规划等生态安全措施，研究了不同保护目标条件下盐城自然保护区核心区和缓冲区的生态安全阈值。

由于本研究工作量大、涉及面广、时间紧，研究工作还停留在理论构建和宏观水平，许多方面还有待完善，特别是自然保护生态

安全设计的指标、算法和阈值，还有待今后作进一步深入的研究。

关键词：自然保护区，生态安全，设计，异质种群理论，景观生态学，种群生存力分析，自然保护区网络，迭代法，整数规划方法，最小累积阻力模型，地理信息系统(GIS)，丹顶鹤，繁殖地，越冬地，迁徙停歇地，保护走廊，迁徙走廊。

Abstract

The construction of nature reserves is the main means of *in-situ* conservation of biodiversity, while nature reserve design is the key fundamental component of nature reserve construction. Article 8(b) of the Convention on Biological Diversity stipulates that each Contracting Party shall, as for as possible and as appropriate, develop, where necessary, guidelines for the selection, establishment and management of protected areas or areas where special measures need to be taken to conserve biological diversity. International organizations and "megadiversity" countries have paid much attention to nature reserve design. However, due to large number of factors need to be considered and heavy dependence on input data, little progress has been made. There exists no sophisticated theory and methodology. China has promulgated the National Programme of Nature Conservation and the Regulation on Nature Reserves in which conditions to select and principles to zone nature reserve were proposed. However, these conditions and principles are not applica-

ble. Based on these background and practical needs, this study attempts to establish the theory and methodology of ecological security design for nature reserves through literature analysis and field survey, as well as theoretical analysis and case study, and employs GIS, iterative method and integer linear programming to conduct ecological security design for nature reserves of Red-Growned Grane(*Grus japonensis*).

The concept of ecological security design for nature reserves was first presented in this study. The conception of security should include nonmilitary threats and non-military means of providing security, because with the development of world economy and environmental cooperation, security has not been comfined to military or state sovereignty, and environmental degradation often undercuts economic potential and human well-being, which in turn helps fuel social instability. Ecological security is defined as a condition where the natural environment of a community provides the needs for the persistence of the community without diminishing the potential of natural environment. Ecological security is the basis of social security and economic security. Meanwhile, social security and economic security are the guarantee of ecological security. Ecological security design for nature reserves is defined as the reasonable allocation of reserve network, zones of a reserve and corridors in a region, so as to effectively conserve biodiversity and natural habitats in line with the principle of conserving the integrity, representativeness and ecological process of ecosystems and conservation goals. It is a coordinative design strategy integrating social, economic, environmental and ecological aspects. Ecological security design for nature reserves is intended for biological resource reserves, i.e. the categories of natural ecosystem reserves and wildlife reserves under the national nature reserve classification standard of China.

Metapopulation theory, landscape ecology and population viability

analysis should be the theoretical basis of ecological security design for nature reserves, and the following conclusions were obtained:

(1) Landscape heterogeneity promotes the persistence of species and the stability of ecosystems. For instance, the infants and abults of a species need different habitats in different life periods, and many species need different types of habitats with the change of seasons or activities.

(2) The persistence of species and overall conservation of ecosystems needs the establishment of nature reserve network. The current conservation model based on a single and isolated nature reserve is not enough. Different levels or nodes in hierarchical biological system should be treated as conservation objects, and the nodes should be connected to a network, so as to increase the connectivity of nature reserves.

(3) Ecological security pattern and minimum viable population is the basis to determine the threshold of ecological security for nature reserves.

The methodology of ecological security design for nature reserves was established through literature and theoretical analysis. This methodology includes three levels: in the first level, a network of nature reserves in a region is designed; in the second level, zones, areas and shape of nodes (nature reserves) are determined; and in the third level, connections (corridors) between the network and nodes are designed. Network design of nature reserves is the basis of ecological security design, zoning of a nature reserve is the guarantee of ecological security design, and corridor design is the supplement to ecological security design. Network design of nature reserves should observe the principle of integrity of ecosystems and ecological process, and the principle of biodiversity. Its methods include geographic approach, scoring method, iterative method and integer linear programming. As mutually complementary methods, iterative method and

integer linear programming are generally used in network design of nature reserves. If there is detailed map of vegetation, geographic apporoach can also be employed. The zoning of a nature reserve should observe the principle of conservation first, the principle of ecological integrity of core zone and buffer zone, and the principle of sustainability of experimentation zone. A reverse design strategy should be employed, i.e. core zone is first designed, then the buffer zone, and finally the overall nature reserve. Methods of core zone design include population viability analysis, habitat distribution model, and resistance surface analysis. Methods of buffer zone design include equalwidth method, analytic hierarchy process, and resistance surface analysis.

By the end of 1999, there exist 33 nature reserves intended for the conservation of Red-Crowned Crane, totalling 3.099 million hm^2. However, the habitats of Red-Crowned Crane are facing severe security problems, mainly covering the following aspects: (1) the conversion of wetlands into farmlands results in habitat losses; (2) the construction of irrigation engineering causes wetlands to lose water sources; (3) environmental pollution damages the habitats of Red-Crowned Crane; (4) human activities disturb the behaviour of Red-Crowned Crane; and (5) nature reserves lack systematic planning and security. According to above-mentioned habitat security problems, Red-Growned Crane and its habitats were selected as case study. The network design of reserves and the ecological security design of breeding, migrating and wintering areas of Red-Crowned Crane were conducted with GIS techniques, iterative methods and integer linear programming.

Indices of reserve network design of Red-Growned Crane were presented and the suitability of wetlands for the species was assessed after analysis of literatures concerning the distribution and ecology of Red-

Growned Grane. According to the conservation golas of 70% and 60% areas of high suitable wetlands and moderate suitable wetlands, two reserve selection algorithms, i.e, an iterative algorithm and an integer linear programming, were designed, and two sets of reserve sites were selected accordingly, which shows that the iterative method and integer linear programming are feasible methods for reserve selection the the configuration of reserve network.

On the basis of reserve network design of Red-Growned Crane, this study conducted ecological security design for breeding, migrating and wintering areas of the species as follows:

(1) Setting up the Duluhe River Nature Reserve, the Wulagai Wetland Nature Reserve, the Tumen River International Reserve, the Hangu Coastal Wetland Nature Reserve (Tianjin), the Tanggu Coastal Wetland Bird Nature Reserve (Tianjin), the Beidagang Reed Weland Nature Reserve(Tianjin), and the Rizhao Wetland Nature Reserve(Shandong);

(2) Enlarging the shuangtai Estuary Nature Reserve and the Yellow River Delta Nature Reserve;

(3) Establishing "S Type" conservation corridor along Wuyuer River, Nen River, Huolin River and Taoer River in Songnen Plain;

(4) Adjusting nature reserves in Sanjiang Plain, merging 7 nature reserves of Raolihe, Fujin Lianhuapao, Lianshanpao, Xinglong Reed, Qixinghe, Yanwodao, and Changlindao to a large national nature reserve, merging 3 nature reserves of Honghe, Bachadao and Sanjiang to a large national nature reserve, and amalgamatiog Xingkaihu, Hukou Wetland, and Baofeng Wetland Nature Reserves to a large national nature reserve;

(5) Eseablishing a migrating corridor with the width of 60 km for Red-Crowned Crane along the western coast of Bohai Sea and the coast of Yellow Sea in Shandong Province which starts from the Shuangtai Estuary

Nature Reserve, connects the Yellow River Delta Nature Reserve along the western coast of Bohai Sea, moves southward to Rizhao, Shandong, and finally connects with Yangcheng Nature Reserve.

The zoning of Yangcheng Nature Reserve was also studied using GIS techniques and resistance surface analysis, and the ecological security threshold of core zone and buffer zone was determined according to different conservation goals.

In a word, this study estabished a system of theories and methods of ecological security design for nature reserves for the first time in China through literature analysis and field survey as well as theoretical analysis and case study. GIS techniques, iterative method, integer linear programming and resistance surface analysis were employed to study reserve network design of Red-Crowned Crane, in which ecological security measures, such as setting up new reserves, enlarging reserves, establishing conservation and migrating corridors, and adjusting reserve planning, were presented for breeding, migrating and wintering areas of Red-Crowned Crane, and the ecological security threshold of core zone and buffer zone of Yangcheng Nature Reserve was determined according to different conservation goals.

This study still remains in the stage of theory construction and macroscopic reserch because of large amount of reserch work, complex impact factors, and limited time. There exists many areas that deserves further study, especially the index, algorithm, and threshold of ecological security design for nature reserves.

Key Words: Nature reserve, ecological security, design, metapopulation theory, landscape ecology, population viability analysis, nature reserve network, iterative method, integer linear programming, minimum cumula-

tive resistance model, GIS, Red – Crowned Crane, breeding area, wintering area, migrating area, conservation corridor, migrating corridor.