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Spatial Assessment and Management of Regional Ecosystem Services in the Yangtze River Delta Region

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Abstract

The Yangtze River Delta (YRD) metropolitan region is one of the most rapidly urbanized regions in China and has experienced a remarkable period of population growth (at an annual growth rate of 3.0%), and urbanization (at an annual growth rate of 9.2%). Rapid urbanization has dramatically changed land use/land cover patterns and ecosystems in the region, causing widespread environmental problems such as habitat fragmentation, aggravation of environmental pollution, decline in biodiversity and ecosystem degredation. These problems have restricted the sustainable development of socio-economic system of the Yangtze River Delta Region. Facing the challenges, the Yangtze River Delta Region is carrying out the practice of regional integration planning and cooperation in environmental governance, which urgently needs the guidance of relevant theories and methods. Some of the key environmental policy pilots have been carried on in this region, such as the Ecological Red Line Policy (Bai et al, 2016; Lü et al, 2013). This policy has one of the main objectives of protecting important eco-function areas i.e. ecosystem service hot spots, to deliver services such as water storage, clean drinking water, and carbon sequestration, and to maintain ecological safety to support economic and social development, which an important policy orientation of ecosystem services approach.

Ecosystem services are the contributions of ecosystem structure and function to human well-being, connecting natural and socio-economic systems. The ecosystem services approach is considered to be one of the important decision support tools for guiding and formulating environmental policies. Based on the theories and methods of ecosystem services, combined with local expert knowledge, remote sensing and GIS technologies, this dissertation aims is mainly to develop a comprehensive framework of ecosystem services assessment and decision support for rapid urbanization regions.

Based on this framework, the spatial characteristics, supply-demand relationship and flow direction of ecosystem services in the Yangtze River Delta Region are analysed and evaluated. Main results of this thesis are as follows:

(1) According to the characteristics of the regional ecosystems of the Yangtze River Delta Region, combined with local expert knowledge, the Burkhard's scoring and assessment method of ecosystem services was improved, and the score matrix between

twelve ecosystem types and twenty-three ecosystem services in the Yangtze River Delta Region was established.

(2) Based on DPSIR model, the characteristics of the social-ecological complex ecosystem and change of ecosystem services in the Yangtze River Delta Region were analysed. The main ecological and environmental problems were identified. Causes and main driving forces of decline in ecosystem services were revealed in the region.

(3) Based on ARCGIS platform, the status quo of ecosystem services in the Yangtze River Delta region was analysed and evaluated. The spatial differentiation characteristics and main impact factors of ecosystem services in the Yangtze River Delta region were clarified. The hot spots of total ecosystem services were aggregated in the southwest areas, while the cold spots were distributed in the middle and northeast areas of the region. The hot spots of supporting services and regulating services aggregately distributed in the southwest mountainous areas while hot spots of provisioning services mainly in the northeast plain, and high value of cultural services widespread in the waterbodies and southwest mountainous areas. The spatial heterogeneity is determined by biophysical features and land use types. Based on the assessment, six major ecosystem services functional zones were divided: (I) South Ecological Integrity Conservation Zone, (II) Southwest Mountainous and Hilly Forest Ecological Zone, (III) Northeast Plain Agriculture Ecological Zone, (IV) Middle Aquatic Ecological Conservation Zone, (V) Eastern Coastal Estuaries Ecological Zone, and (VI) Urban Development Area., and the corresponding management strategies on the basis of environmental problems and ecosystem services characteristics in each of the functional zones were put forward.

(4) Using regional spatial data in net primary productivity, the quality levels of forest and cropland were graded and the previous scores of ecosystem services in forest and cropland were calibrated. Then, the hot spots and clustering patches of forest and farmland ecosystem services were identified by ARCGIS tools. Finally, the forest ecosystem conservation areas (red line) and cropland ecosystem conservation areas (red line) in the Yangtze River Delta region were delineated.

(5) Based on the improved Burkhard's supply-demand budget of ecosystem services method, the budgets of three regulating services (erosion regulating service, flood

regulating service and water purification regulating service) of the sixteen core cities in the region were established, and the characteristics of surplus and deficit of three services of the cities in the region were analysed. Combing the budget with analysis of flow direction of ecosystem services, the potential provisioning cities and the benefiting cities of ecosystem services are identified. On the basis of the results, the potential model of regional inter-city environmental cooperation is proposed.

This dissertation not only improves the methods of ecosystem service assessment and decision support in rapidly urbanized regions, but also makes contributions to the guidance in delineation of ecological red line, regional environmental cooperation and sustainable development in the Yangtze River Delta Region.

Declaration

I hereby declare that the work presented in this thesis is entirely my original work, except explicit attribution is made. None of this thesis has been previously submitted for any other award.

Signature: Wenbo Cai

Publications

Cai, Wenbo, David Gibbs, Lang Zhang, Graham Ferrier, and Yongli Cai. "Identifying hotspots and management of critical ecosystem services in rapidly urbanizing Yangtze River Delta Region, China." *Journal of environmental management* 191 (2017): 258-267.

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Abbreviations

MEA	Millennium Ecosystem Assessment
CORINE	Co-ordinated Information on the Environment
GIS	Geographic Information System
DPSIR	Driver-pressure-state-impact-response

Chapter 1 Introduction

1.1. Background

With the continuous rise in global population, a simultaneous growth of urban areas is omnipresent (Haas & Ban, 2014). Urban populations are projected to reach nearly 60% of the human population by 2030; while urban areas will grow twice as fast as urban populations (Elmqvist et al, 2013). With the acceleration of global industrialisation, urbanisation is speeding up. Urbanisation refers to the process of changing the agricultural population into urban population. In 1900, only 10% of the world's population was made up of urban residents (UN, 2012; WHO, 2013; Worldbank, 2017). In 2008, global urban areas accounted for only 2.8% of the land area, but the urban population exceeded half of the global total - with Europe and the United States having urban population rates of 80%, Asia 50% and Latin America more than 90% (UN, 2012; WHO, 2013; Worldbank, 2017). By 2030, the world's urban population will reach 5 billion (UN, 2012; WHO, 2013; Worldbank, 2017). About 95% of the net increase of the global population will occur in cities in developing countries, yet the level of urbanisation in these countries will approach 80%, that is, the current level of those countries with the highest level of industrialization (UN, 2012; WHO, 2013; Worldbank, 2017). In addition, individual cities will grow to an unprecedented scale, and almost all emerging megacities (generally defined as cities with a population greater than 10 million) will appear in developing countries. Urban population growth is accompanied by economic growth and demographic changes, which will place greater demands on the provisioning of adjacent and remote ecosystems, especially in densely populated China and India (UN, 2012; WHO, 2013; Worldbank, 2017). Rapid urbanization has altered many ecosystems, generating ecological crisis such as habitat fragmentation, water shortages and pollution, air pollution, soil pollution, causing a decline in many ecosystem services in developing countries (Li et al, 2016a; Li et al, 2016b). The ecological crisis has become a great threat to global and regional sustainable development. In order to address the challenges resulting from rapid urbanization, it is urgent to identify and protect endangered ecosystems.

China is one of the developing countries with rapid urbanization. Over the past 40 years, China has experienced rapid urbanization and an immense growth in population as the consequence of economic and political reforms in 1978 (Haas & Ban, 2014). China has entered a period of accelerated development in the past 20 years. In the year 2011, the urban population finally exceeded the rural population (UN, 2012). It is expected that by 2030, the urbanisation level in China will reach 60% (UN, 2012). The ever-increasing number and scale of cities, and the resulting shift in the original landscape at different scales resulted in changes to the local biogeochemical cycles, leaving enormous challenges in mitigating biodiversity loss and maintaining ecosystem function and human well-being (Han et al, 2017; Li et al, 2016a; Qiu et al, 2015; Su et al, 2014; Su et al, 2012; Zhou et al, 2016b).

Facing the challenges, the State Council of the People's Republic of China put forward the national-level Ecological Red Line Policy in 2011 (Bai et al, 2016; Lü et al, 2013). This policy has one of the main objectives of protecting important eco-function areas i.e. ecosystem service hot spots, to deliver services such as water storage, clean drinking water, and carbon sequestration, and to maintain ecological safety to support economic and social development, which an important policy orientation of ecosystem services approach.

The Yangtze River Delta (YRD) Region is one of the most rapidly urbanized regions in China and has experienced a remarkable period of population growth (at an annual growth rate of 3.0%), and urbanization (at an annual growth rate of 9.2%) (Xu et al, 2014a). Rapid urbanization has dramatically changed land use/land cover patterns and ecosystems in the region, causing widespread ecological and environmental problems such as water shortages and decline in water quality, and serious air pollution (Zhang and Chen, 2011; Wang et al., 2012). These environmental problems have posed great threats to the regional eco-safety, adding new challenges to sustainable development in the region.At present, the provinces and cities in the Yangtze River Delta Region is carrying out the practice of provincial and prefecture-level environmental governance individually. However, decision makers just realized that ecological conservation and environmental pollution have obvious cross-administrative boundary characteristics, it is necessary to carry out integration of environmental planning and management in this region.

Due to the urgency and seriousness environmental problems and managerial problems in the Yangtze River Delta Region, and it is necessary to identify an approach connecting natural and socio-economic system, and promoting quick decision making in such an urbanising region.

1.2. An ecosystem services approach

Traditional environmental approaches only focus on natural system and ignore the demand of human society, which make the environmental decision always be imperfect (Burkhard et al, 2014; Burkhard et al, 2012; Fu & Li, 2007; Palomo et al, 2017; Xiao et al, 2016): For example, traditional natural reservations with singe-objective for conservation sometimes forbidden all of the agriculture activities. However, moderate agriculture in some of the areas sometimes improves the multifunctionality of farmland ecosystems and promoting harmony between human and nature (Burkhard et al, 2014; Burkhard et al, 2012; Fu & Li, 2007; Palomo et al, 2017; Xiao et al, 2016).

Ecosystem services are defined as the contributions of ecosystem structure and function to human well-being (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015). This implies that mankind is strongly dependent on well-functioning ecosystems and natural capital that are the basis for a constant flow of ecosystem services from nature to society (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015). Therefore, ecosystem services have the potential to become a major tool for environmental policy and decision making.

There is a growing concern in study of ecosystem services approach for decision support in environmental management (Fu & Li, 2007; Li et al, 2014; MEP, 2015; Rao et al, 2012; Zheng & Ouyang, 2014). Several methodologies and frameworks using ecosystem services to support environmental management and decision making have been discussed (Burkhard & Müller, 2008; Crossman et al, 2013; de Groot et al, 2010; Kroll et al, 2012). However, these researches failed to provide a complete and systematic framework from problems to management and cannot target to multiple ecosystem services management.

Among ecosystem service approaches, monetary approaches like cost-benefit analyses, contingent valuations or willingness-to-pay assessments are useful attempts (Farber et al., 2002) but their outcomes are often disappointing due to the economic focus and the lack of appropriate pricing methods, e.g. for non-marketed goods and services (Ludwig, 2000; Spangenberg and Settele, 2010). Burkhard et al's non-monetary matrix approach based on expert knowledge has several advantages which make potentials in assessment in an urbanising region: It can generate quick results for rapid decision making, provide an effective decision support tool in a data-poor region and design matrix linking spatial explicit land cover types to ecological integrity, ecosystem services supply and demand. However, this approach should be modified and adapted by the local classification system of land cover and land use system.

1.3. Research questions and objectives

Based on the background of the environmental challenges, e.g. habitat fragmentation, air and water pollutions, brought by rapid urbanization (section 1.1.), the practice of regional environmental polices, e.g. ecological red line policy, and the potential and problems of being a major tool for environmental policy and decision making of ecosystem services approach (section 1.2.), especially Burkhard et al matrix approach based on expert knowledge, the aims of the dissertation are to: Develop an ecosystem services approach framework on the scientific and rapid assessment and decision for an urbanising region in the research process; Modify the classification system of land cover and land use system and values in Burkhard's method into the context in Yangtze River Delta Region by local experts knowledge in the research methods; Make cross-administrative boundary ecosystem services assessment at regional scale, which is still rare in the research and practice in China and the Yangtze River Delta region; Make comprehensive research on functional regionalization, red line delineation and inter-city environmental cooperation by ecosystem services approach.

To achieve these, the author put forward the following research questions and objectives:

Objective 1: Develop a general framework guiding ecosystem services approach from problem to decision

Research questions:

What is the framework for ecosystem services approach from problem to decision?

Objective 2: Problems identification and driving forces for the decline of the ecosystem services in the Yangtze River Delta region

Research questions:

What are the pressures driving by urbanization and economic growth, the state of ecosystem and the stock of ecosystem services, and aims of environmental management responses for mitigating negative impact on ecosystem services in the Yangtze River Delta metropolitan region?

Objective 3: Comprehensive regionalization of multiple ecosystem services in the Yangtze River Delta Region

Research questions:

What is the spatial pattern of multiple ecosystem services in the Yangtze River Delta region?

How to make quick assessment of the capacities of multiple ecosystem services in a rapidly urbanising region?

Objective 4: Decision support for red line delineation by priority area identification of ecosystem services in the Yangtze River Delta Region

Research questions:

Where are the hot spots of ecosystem functions and services for cropland and forest in the Yangtze River Delta Region?

How to identify conservation priority area of ecosystem functions and services for main ecosystems at regional scale?

Objectives 5: Decision support for inter-city cooperation of water-related regulating services in the Yangtze River Delta Region

Research questions:

Which cities are potential service provisioning cities and service benefiting cities for water regulating services in the Yangtze River Delta Region?

How to define service provisioning cities and service benefiting cities in a metropolitan region?

1.4. Thesis structure

Following the instruction of environmental problems and ecosystem service approach in Chapter 1, Chapter 2 literature review will provide basic information on the progress of ecosystem services assessment and management, globally and in China, and explain why the author choose the approach.

Chapter 3 will introduce the socio-ecological context, major ecological and environmental problems and driving forces in the Yangtze River Delta metropolitan region (study area);

Chapter 4 Methodology will introduce the empirical approach, data sources, analysis methods, the main steps of ecosystem services spatial assessment and management framework for a rapidly urbanizing region and problems/critique.

Chapter 5 will identity the spatial pattern of multiple ecosystem services and management strategies for the comprehensive ecological function zone in the Yangtze River Delta metropolitan region.

Chapter 6 will optimize ecosystem services priority areas for red line delineation of cropland and forest in the Yangtze River Delta metropolitan region.

Chapter 7 will analyse the spatial pattern of ecosystem services supply and demand, establish the 16 core cities' ecosystem services supply-demand budget and identify specific spatial explicit and quantitative mismatches for selected ecosystem services in the Yangtze River Delta metropolitan region. It will identify ecosystem services provisioning cities and services benefiting cities by combining the ecosystem services supply-demand budget with flow analysis in the different watershed zones in the Yangtze River Delta metropolitan region.

Chapter 8 Conclusion will briefly summarize the main results, contributions and limitations of the research.

1.5. Core concepts

Ecosystems are the planet's life-support systems -for the human species and all other forms of life (Board, 2005; Bouma & van Beukering, 2015; MEA, 2003; 2005; Ostrom, 2009; Palomo et al, 2017).

Ecosystem usually refers to an ecological structure, function and evolutionary unit consisting of biological communities and their inorganic environments within a certain period and spatial area, and formed in certain patterns using functional flows (material flow, energy flow, species flow, information flow and value flow) (Bouma & van Beukering, 2015; Palomo et al, 2017).

Ostrom (2009) developed the general concept of an ecosystem in her textbooks based on the pattern of energy flow and metabolisms of ecosystems and some related ecosystem functions.

The ecosystem mainly emphasises the importance of substance exchanges between biological organisms and their non-biological environments, including the interactions among all animals and plants and their physical interactions in a given space (Ostrom, 2009).

An ecosystem is characterised by spatial structure, trophic structure, energy flow, material flow, information flow, growth and development and self-regulation (Ostrom, 2009). Like biological communities, ecosystems are also exclusive in temporal and spatial terms (Bouma & van Beukering, 2015; Ostrom, 2009; Palomo et al, 2017).

The boundary of an ecosystem is the boundary between the ecosystem and the outside world. It may be very clear or may be very vague and transitional (Bouma & van Beukering, 2015; Ostrom, 2009; Palomo et al, 2017).

The spatial scope of an ecosystem varies to a great degree, from a pool of water to an ocean (Bouma & van Beukering, 2015; Ostrom, 2009; Palomo et al, 2017).

Ecological integrity means the preservation against nonspecific ecological risks that are general disturbances of the self-organizing capacity of ecological systems (Burkhard et al, 2012).

Ecosystem services: contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Bouma & van Beukering, 2015; Burkhard et al, 2012; Palomo et al, 2017).

Ecosystem services are the benefits that people obtain from ecosystems, including food, natural fibers, a steady supply of clean water, regulation of pests and diseases, medicinal substances, recreation, and protection from natural hazards such as floods (Board, 2005; Bouma & van Beukering, 2015; MEA, 2003; 2005; Palomo et al, 2017).

It was as recently as the 1960s that the concept of ecosystem services was first proposed (Bouma & van Beukering, 2015; Palomo et al, 2017). This concept outlined the service function of the ecosystem and listed the "ecosystem service functions" of natural ecosystems, including pest control, insect pollination, climate regulation and material circulation (Bouma & van Beukering, 2015; Palomo et al, 2017). It was in fact not until 1981 that the term "ecosystem services" came into being, and this term first saw publication in scientific journals in 1983 (Bouma & van Beukering, 2015; Palomo et al, 2017).

After this point, however, the study of ecosystem services stagnated. Then with the publication of Nature's Services and the initial valuation of the global natural capital, and especially in the wake of the implementation of Costanza's ecosystem services assessment project (Costanza et al, 1997; Costanza et al, 1998), research on ecosystem services began to increase exponentially. As one can see by searching for "ecosystem services" on the Web of Science, there was only one relevant article published in the 1980s, but over 40,000 articles in 2018.

Supply of ecosystem services: the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period (Bouma & van Beukering, 2015; Burkhard et al, 2012; Palomo et al, 2017). Here, capacity refers to the generation of the actually used set of natural resources and services (Bouma & van Beukering, 2015; Burkhard et al, 2012; Palomo et al, 2017).

Thus, it is not similar to the potential supply of ecosystem services in a certain ecosystem, which would be the hypothetical maximum yield of selected optimized services (Bouma & van Beukering, 2015; Burkhard et al, 2012; Palomo et al, 2017).

Demand for ecosystem services: ecosystem goods and services currently consumed or used in a particular area over a given time period, not considering where ecosystem services actually are provided (Burkhard et al, 2014; Burkhard et al, 2012).

Ecosystem services hot spot often refers to areas where high amounts of one particular service are present (Cimon-Morin et al., 2013), but other studies have defined hot spots as areas where multiple ecosystem services overlap (e.g., Gos and Lavorel, 2012).

As their opposite, the '**ecosystem services cold spot**' refers to areas where low amounts of one particular service low are present or as areas with low richness of ecosystem services (Palomo et al, 2017).

Ecosystem service providing units: spatial units that are the source of an ecosystem service (Costanza, 2008; Fisher & Turner, 2008; Fisher et al, 2009; Syrbe & Walz, 2012).

Ecosystem service benefiting areas: the complement to ecosystem service providing units. Service benefiting areas may be far distant from relevant service providing units (Costanza, 2008; Fisher & Turner, 2008; Fisher et al, 2009; Syrbe & Walz, 2012).

Service providing unit - Service benefiting area spatial relations: spatial characteristics describing the relationships between the place of service production and where the benefits are realized (Costanza, 2008; Fisher & Turner, 2008; Fisher et al, 2009; Syrbe & Walz, 2012).

Payment for ecosystem services or ecological compensation is a kind of management policy design based on ecosystem services, in which economic means are taken as the main method to adjust the interesting relationship of related parties and payment for compensation is made to service providers by payers who enjoy the ecosystem service function, so as not to harm the benefits of the provider while achieving sustainable availability of ecosystem service functions (Bouma & van Beukering, 2015; Bremer et al, 2014a; Bremer et al, 2014b). Constructing a payment mechanism for ecosystem services is considered to be an efficient and advanced management method for ecosystem service functions as the mechanism will effectively improve the ecosystem services and relieve the conflicts between environmental protection and economic development (Bouma & van Beukering, 2015; Bremer et al, 2014a; Bremer et al, 2014b). Moreover, numerous studies show that the mechanism of payment for ecosystem services works more efficiently in protection than other strategies (Bouma & van Beukering, 2015; Bremer et al, 2014a; Bremer et al, 2014b).

Ecological red line means the minimum space to be strictly protected in order to enhance the ecological function and ensure the continuous supply of ecosystem goods and services, including the red line for the ecological function (the baseline of the ecological function guarantee), the red line for environmental quality (the bottom line of the environmental quality safety), and the red line for the utilization of the resources (the upper limit of the use of natural resources). This policy has three main objectives: (i) To protect important eco-function areas i.e. ecosystem service hot spots, to deliver services such as water storage, clean drinking water, and carbon sequestration, and to maintain ecological safety to support economic and social development at both a local and national scale; (ii) To protect ecologically fragile areas (eco-fragile hot spots); (iii) To protect habitats for important species (Bai et al, 2016; Lü et al, 2013). Together, these three objectives aim to build up ecological security network so that it can sustain economic development and living environments from national scale to regional scale (Bai et al, 2016; Lü et al, 2013).

Chapter 2 Literature review

2.1. Introduction

This chapter will review the research progress of the following aspects of ecosystem services approach: the basic knowledge, methods of ecosystem services assessment (classification and scoring), mapping ecosystem services and ecological red line policy in China. For using the particular approach in this thesis, justification of choosing Burkhard et al's classification and matrix-based methods of ecosystem services will be summarized in the section 2.3 (Ecosystem services assessment) 2.3.3 and section 2.3.5. Then, the research progress of mapping approaches of ecosystem services will be reviewed in the section 2.4 (Mapping ecosystem services) such as approaches for ecosystem service hot spot and cold spot in section 2.4.5, and mapping ecosystem services supply and demand in section 2.4.6. Finally, the research progress and practice of ecological red line policy in China will be reviewed in section 2.5.

After reviewing the research progress of approaches, the application environment for the choosing ecosystem service approach should be described in the next chapter. Therefore, the socio-ecological characters of the study area will be introduced in the next chapter.

2.2. The basic knowledge of ecosystem service approach

2.2.1. The relationships between ecosystem service and human wellbeing

According Figure 2.1, understanding the dynamic relationships between ecosystem service and human wellbeing under driving forces at different scales (from local scales to global scales) is vital to achieve sustainable regional development (Chapin et al, 2010). Human well-being is the extent to which human needs related to human subjective perception are satisfied (Board, 2005; MEA, 2003; 2005). It is a multi-dimensional concept that integrates human beings into nature, and so is a focus of research on ecosystem services management. According to the definition in the MEA, human well-being has five basic elements: the maintenance of the basic material needs for high-quality life, health, good social connection, security and freedom to make choices and take actions (Board, 2005; MEA, 2003; 2005).

In general, human well-being depends on a series of conditions such as nature, technology and social systems; yet among them, the continuous provisioning of ecosystems services is the most important (Board, 2005; MEA, 2003; 2005).Through the provisioning, supporting, regulating and cultural services, ecosystem services functions have directly acted on human well-being (Board, 2005; MEA, 2003; 2005). In turn, the condition of well-being changes the human consumption of natural resources in intensity, thus affecting ecosystem services (Board, 2005; MEA, 2003; 2005). Human well-being is the fundamental starting point for the study of ecosystem services (Board, 2005; MEA, 2003; 2005).

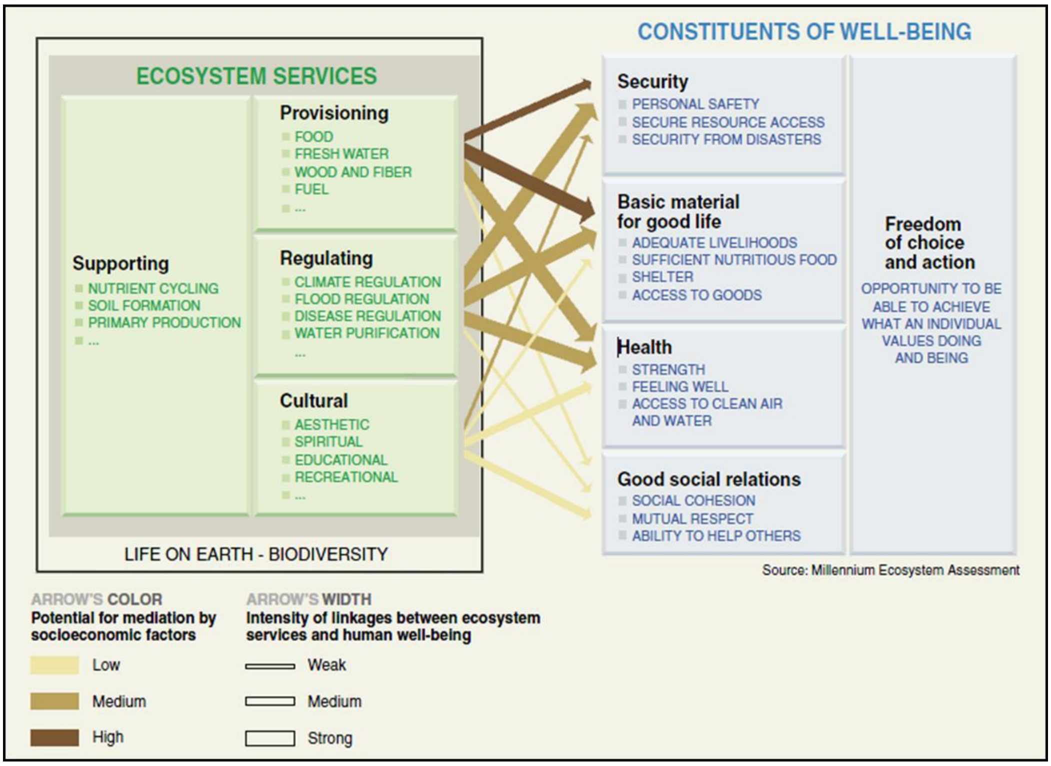

Figure 2.1 The Millennium Ecosystem Assessment (MEA) ecosystem services typology showing linkages between services and human wellbeing

(Source: MEA, 2005)

Research has focused on how to apply ecosystem services into resource utilization, ecosystem management, biodiversity conservation, regional sustainable development and poverty reduction (Board, 2005; MEA, 2003; 2005). Bryan et al (2010) established a new natural capital and ecosystem services framework by using multi-objectives decision making analysis to identify strategic prior targets in regional environmental management. Chapin et al (2010) considered the social-ecological relationship between human activities and ecosystem services as the basic orientation in ecosystem management. Mäler et al (2008) put forward the use of ecosystem service accounting as characterization of sustainable development.

2.2.2. Ecosystem services and environmental management framework

The assessing, mapping and managing ecosystem services were useful approaches to inform environmental management and planning (Burkhard et al., 2012; Burkhard et al., 2014; Wolf et al. 2015; Villamagna et al., 2013). For scientific ecosystem services management and decision making, various spatial environmental management models theories were integrated in promoting the spatial management of ecosystem services.

Several methodologies and frameworks using ecosystem services to support environmental management and decision making have been discussed (Burkhard & Müller, 2008; Crossman et al, 2013; de Groot et al, 2010; Kroll et al, 2012). Van Jaarsveld et al (2005) presented a practical application of ecosystem services mapping at the subcontinental scale for Africa. Troy & Wilson (2006) developed a decision framework or spatially explicit value transfer to estimate ecosystem services flow values and to map results for three case studies that represented a diversity of spatial scales and locations. Paetzold et al (2010) developed a framework for the assessment of ecosystem services. Kroll et al (2012) provided a method to quantify and map the ecosystem service supply at the regional scale for a rural-urban region in eastern Germany. Burkhard's framework made a great improvement. Burkhard's ecosystem services matrixes were useful in providing statistical and spatial information and illustrations (maps) in environmental planning and management (Burkhard et al, 2012). However, these researches failed to provide a complete and systematic framework from problems to management and cannot target to multiple ecosystem services management.

For environmental and managerial problems and driving forces identification, scientific analysis models such as DPSIR models has been introduced for assessment of ecosystem conditions and Impact on ecosystem services. The conceptual model DPSIR was proposed by the OECD in 1993, and has been developed by the European

Environment Agency (EEA, 1999; Gabrielsen & Bosch, 2003; Performance, 1993). Under this framework, Driving forces refer to socio-economic and socio-cultural forces driving human activities, which are underlying causes for environmental changes; Pressures are the stresses that human activities place on the environment, and are the direct factors that lead to environmental changes; State is the condition of the environment under the above pressures, for example, pollution level; Impacts are the influences on human health and socio-economic structures from the state; Responses refer to countermeasures taken and positive policies formulated by humans in the process of promoting sustainable development (Gabrielsen & Bosch, 2003). DPSIR is used to describe environmental issues and their relationship with relevant socio-economic fields. It features the function of laying out interactive relationships between various sub-systems of the environment, society and the economy, and evaluating the causality between these sub-systems (Gabrielsen & Bosch, 2003).

Of the 212 articles selected from Science Direct and Google Scholar, 10 of the papers closely related to ecosystem services research published since 2009 were used to demonstrate the detail application of DPSIR in detail. The most practical use of the DPSIR theoretical framework was applying it in the field of ecosystem management to analyze the influence on ecosystem services from changes in ecosystem process state driven by socio-economic activities. In some of the previous research, ecosystem services were included directly as a part of the DPSIR theoretical framework of "Driver - Pressure - State - Impact - Response".

Atkins et al (2011) incorporated ecosystem services into the impact part of the social ecosystem according to the relationship between ecosystem services and social welfare, and attempted to apply it in water resource management and marine biodiversity risk management of seaports in the UK. Cooper (2013) attempted to incorporate ecosystem services into the state part of the DPSIR theoretical framework, that is, changes in ecological environment impacting ecosystem services, and also analyzed cost and benefit for social well-being. This research has realized a certain degree of risk management. Kelble et al (2013) developed the EBM-DPSER (Ecosystem-Based Management Model) for evaluated both negative and positive impacts on ecosystem through ecosystem services and was applied to the Florida Keys and Dry Tortugas marine ecosystem management. Other research included ecosystem services indirectly in the 'impact' assessment in the DPSIR theoretical framework. Maxim et al (2009) looked atpair-wise interface aspects in analyzing the supply-demand relation between each sub-system of the DPSIR theoretical framework, analyzed the influence from ecosystem diversity changes on ecosystem services under external driving forces, and provided theoretical guidance for two European biodiversity risk management cases based on that method. Lozoya et al (2011) analyzed the relationship between coastal disasters and ecosystem services with the DPSIR theoretical framework. They identified and strengthened functioning methods and influences of each sub-system by building risk folders, which somewhat promoted the development of coastal ecosystem risk assessment and optimal management. Cook et al (2014) applied the Delphi method and impact matrix in the DPSIR theoretical framework to analyze changes across 11 state indexes of the ecological environment under 12 pressures from human activities in a marine ecosystem, and changes in the relevant 11 ecosystem services. This method adopted expert suggestions in risk management, and can promote exchanges on risk management to a certain degree.

2.2.3. Ecosystem services and policy making

The main purpose of study on the assessment of ecosystem services is to reveal the function mechanism of ecosystems in the operation of the human societal system and to better realise the coordinated development of human and nature (Bouma & van Beukering, 2015; Palomo et al, 2017). It follows, therefore, that it is necessary to adopt some policy measures to maintain the sustainability of ecosystem services (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014). However, due to the wide range of factors involved in ecosystem services and the comprehensive nature of such policies themselves, there is a lack of policy research on ecosystem services (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014).

Regarding the currently related researches, policy researches on ecosystem services can be divided into two levels: strategic frameworks and land-use-based measures (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014).

A national strategic framework of ecosystem services should be constructed, integrating the demand for ecosystem maintenance into the system design (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014). Folke et al (2005) believe that without a correct understanding of the functions of natural resources and ecosystems, the sustainable development of a society cannot be achieved; similarly, taking only the natural system as the decision-making basis will also hinder the implementation of policies. In order to solve the conflicts between nature and society as a whole, given that the ecosystem service problem is related to both systems, the author suggests to paying attention to the roles of these policies and systems. Only by integrating the demand of ecosystem maintenance into the system design, as well as establishing an ecological compensation mechanism and various forms of public payment systems, can human make the coordinated development of the ecosystem and the social economy possible (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014). The importance of information exchange between government decision-makers, environmental ecologists, planners and the general public should be stressed (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014).

At present, the quantification and maintenance of ecosystem service value, as well as how to communicate and popularise relevant information, are still the major problems faced by policy makers and urban environmental planners (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Sutherland et al, 2014).

Some limitations of ecosystem service value measurement, such as the spatiotemporal scale effect and the uncertainty of some parameters, limit its application in government decision-making (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Moore et al, 2017; Sutherland et al, 2014; Van Wensem et al, 2017).

In addition, due to the lack of awareness of the importance of ecosystem services among planning scholars and the public, and the excessive concern for land prices by the government departments involved in land use, the ecosystem function and value has not been given enough attention (Biggs et al, 2017; Burkhard et al, 2013; Gorg et al, 2016; La Notte et al, 2015; Maes et al, 2012a; Moore et al, 2017; Sutherland et al, 2014; Van Wensem et al, 2017). How to eliminate the cognitive gap among ecologists, decision makers and planners will be a major challenge for the application of ecosystem services value.

2.2.4. Ecosystem services and land use / land cover management

Figure 2.2 Conceptual framework linking ecosystem integrity, ecosystem services and human well-being as supply and demand sides in human–environmental systems.
(Source: Burkhard et al (2012))

As an important form of human activity, land use has a strong impact on ecosystem services (Cai et al, 2016; Gaglio et al, 2017; Gong et al, 2017a; Grafius et al, 2016; Keller et al, 2015; Metzger et al, 2006). Changes of land-use type affect the main ecological processes such as energy exchange, water cycle, soil erosion and accumulation, biogeochemical cycle and so on, thus changing the provision of ecosystem services. For example, the agricultural product supply service capacity of cultivated land is stronger, but its regulation, culture and support service capacities are weaker; the regulating and supporting service capacities of natural forest is stronger, but its product supply service capacity is weaker (Cai et al, 2016; Gaglio et al, 2017; Gong et al, 2017a; Grafius et al, 2016; Keller et al, 2015; Metzger et al, 2006).

Different land use patterns will produce corresponding ecological processes, which will have an impact on ecosystem services (Cai et al, 2016; Gaglio et al, 2017; Gong et al, 2017a; Grafius et al, 2016; Keller et al, 2015; Metzger et al, 2006). For example, Su et al (2012) pointed out that the landscape fragmentation caused by the expansion of artificial land type in the process of urbanisation would have a negative impact on ecosystem services. Generally speaking, the ecosystem services supply capacity of the natural ecosystem with less human interference is relatively weak, but its capacities of regulating and supporting services are relatively strong; In the cases with moderate human interference, the ecosystem service supply capacity is often relatively strong, while the regulating and supporting services capacities are relatively weak; when human interference is particularly strong, land degradation occurs, and the supply of various types of ecosystem services will be seriously threatened (Bai et al, 2018; Gaglio et al, 2017; Nordborg et al, 2017; Tolvanen & Aronson, 2016). Therefore, many studies are devoted to the improvement of regional ecosystem services from the perspective of land-use optimization (Fürst et al, 2014; Gong et al, 2017a; Kopperoinen et al, 2014; Li et al, 2017a; Nin et al, 2016; Nordborg et al, 2017; van Noordwijk et al, 2017; Wu et al, 2013).

Given China's country's population economy as well as the status quo and development trend of land-use and ecological environment development, in future land use, it is necessary to improve the capacity of regional ecosystem services by improving the assessment system of land planning and giving priority to the control of ecologically sensitive areas (Carrasco et al, 2016; Gong et al, 2017a; Li et al, 2017a; Nordborg et al, 2017; Tolvanen & Aronson, 2016). The assessment system of land planning should be improved and the application of ecosystem value assessment should be strengthened in related planning (Cai et al, 2016; Long et al, 2014; Wu et al, 2013; Xu et al, 2016). Regional land planning and control is an important measure of land use in China, but there is still a lack of attention given to the value of ecosystem services in current land use-planning, especially in urban land-use planning (Cai et al, 2016; Long et al, 2014; Wu et al, 2013; Xu et al, 2016). The protection of important ecosystems, such as green land and water, is often neglected due to too much attention being given to the economic benefits (Cai et al, 2016; Long et al, 2014; Wu et al, 2013; Xu et al, 2016). In addition, as part of the ongoing large-scale land remediation, a great number of pits and grasslands have been reclaimed for arable land, which is having a negative impact on the value of regional ecosystem services (Cai et al, 2016; Long et al, 2014; Wu et al, 2013; Xu et al, 2016).

Thus, in order to maintain the sustainable development of regional ecosystem, it is necessary to take the assessment of ecosystem service value as an important part of pre-assessment of planning effects and assessment of planning implementation, and establish a planning and assessment system that truly integrates society, economy, and ecological benefits. The main function area should be divided, and the trans-regional ecological compensation system should be carried out, bringing ecological compensation into the national economic system. Ecosystem services are indispensable products. The capacity of such services' supply and demand is not balanced among different regions. It is necessary to carry out functional zoning by spatial identification of regional ecosystem service capacity.

2.3. Ecosystem services assessment

2.3.1. Comparison of the classification systems of ecosystem services

Despite public interest in ecosystem services increasing rapidly, there remains some controversy over the concept of ecosystems services, especially when it comes to agreeing on a standard, precise definition (Costanza, 2008; Fisher & Kerry Turner, 2008; La Notte et al, 2017; Wallace, 2007). In Nature's Services, ecosystem services are defined as conditions and processes that maintain the development of natural ecosystems and their constituent species, and that enable human survival (Board, 2005; Costanza, 2008; Fisher & Kerry Turner, 2008; La Notte et al, 2017; MEA, 2003; 2005; Wallace, 2007). They sustain the biodiversity and the production of various ecosystem products (such as seafood, vegetation, wood, bio-fuels, natural fibres and many pharmaceutical and industrial products and other raw materials for production) (Board, 2005; Costanza, 2008; Fisher & Kerry Turner, 2008; La Notte et al, 2017; MEA, 2003; 2005; Wallace, 2007).

Table 2.1. showed the main development of the classification of ecosystem services. The MEA places greater emphasis on the status and role of humanity in the ecosystem (Board, 2005; MEA, 2003; 2005). Therefore, ecosystem services are defined as the various benefits humans receive from the ecosystem (Board, 2005; MEA, 2003; 2005). The narrative method of this definition makes it universal and appreciable and also provides a background for people to start discussions from.

Table 2.1 Comparison of the classification of ecosystem services

Costanza et al. (1997)	**MEA (2005)**	**Wallace (2007)**	**Burkhard et al. (2012)**	**CICES (2013)**
Gas regulation	PROVISIONING SERVICES	ADEQUATE RESOURCES	**PROVIONING SERVICES**	PROVIONING SERVICES
Climate regulation	Food	Food	Crops, livestock, fish	Nutrition
Disturban regulation	Fresh water	Oxygen	Fresh water	
Water regulation	Wood and fibre	Water (potable)	Wood and fibre	Materials
Water supply	Fuel	Energy	Fuel	Energy
Erosion control and sediment retention	…	Dispersal aids	…	
Soil formation				
Nutrient cycling	SUPPORTING SERVICES	BENIGN PHYSICAL AND CHEMICAL ENVIRONMENT	**ECOLOGICAL INTEGRITY**	REGULATION AND MAINTENANCE
Waste treatment	Nutrient cycling	Benign environmental regimes of:	Abiotic heterogeneity	Regulation of wastes
Pollination	Soil formation	Temperature	Biodiversity	Flow regulation
Biological control	Primary production	Moisture	Exergy Capture	Regulation of physical environment
Refugia (suitable space for living organisms)		Light	…	Regulation of biotic environment
Food production		Chemical		
	REGULATING SERVICES		**REGULATING SERVICES**	
	Climate regulation	PROTECTION FROM PREDATORS/DISEASE/PARASITES	Climate regulation	
	Flood regulation	Protection from predation	Flood regulation	
	Disease regulation	Protection from disease and parasites	Disease regulation	
	Water purification		Water purification	
	…		…	
	CULTURAL SERVICES	SOCIO-CULTRUAL FULFILMENT	**CULTURAL SERVICES**	CULTURAL SERVICES
	Aesthetic	Beneficial resources for:	Aesthetic	Symbolic
	Spiritual	Social activity	Spiritual	Intellectual and experiential
	Educational	Spiritual	Educational	
	Recreational	Recreation/leisure	Recreational	
	…	Meaningful occupation	…	
		Aesthetics		
		Cultural biological evolution		
		Genetic resources		
		Education		

The 2001-2005 Millennium Ecosystem Assessment (Board, 2005; MEA, 2003; 2005) greatly promoted the ecosystem service researches. The Millennium Ecosystem Assessment focused on the links between ecosystem services and human wellbeing and grouped ecosystem services into four major categories (Table 2.1):

Provisioning services consisting of the commodities that people use such as fibre, food, timber, and water; Regulating services that affect climate, disease, floods, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; Supporting services that assist in soil formation, photosynthesis, and nutrient cycling (Board, 2005; MEA, 2003; 2005). This has become the most widely used classification of the ecosystem services.

Wallace (2007) argued that ecosystem services were the goals set and the results expected by ecosystem management, and therefore, should be defined as per the structure and components of the ecosystem. Wallace's ecosystem services mainly include ecological resources such as food, water, timber, and cultural values, as well as other resources that are directly consumed by humans (Wallace, 2007). Wallace emphasised that the ecosystem process not be a system service but a production method of ecosystem services. It is through the intervention to ecosystem processes that ecosystem management obtains expected ecosystem services. From the perspective of building an environmental accounting and performance system and eventually establishing green GDP, Boyd & Banzhaf (2007) proposed that ecosystem services, though a proper unit in general to track to account for benefits to humans provided by nature, was still too broad a label. Therefore, the concept of "final ecosystem services" was proposed and defined as "a natural component that humans use or consume directly to create well-being."

The term "final" refers to the ultimate contribution of the ecosystem. Ecosystem services have also been defined as not the benefits that humans obtain from ecosystems, but the ecological components that provide benefits to humans. This definition includes two aspects:

(1) An ecosystem service is a phenomenon or a process; (2) Such a phenomenon or process should serve humans directly or indirectly. According to this concept, ecosystem services include the ecosystem structure, processes and functions that can be utilised directly or indirectly by humans, and so any ecosystem processes or functions useful to humans are defined as ecosystem services.

Fisher & Kerry Turner (2008) believed that the definition of ecosystem service given by the MEA would make it possible to repeatedly calculate the service value of the intermediate steps when assessing the ecosystem value, leading to confusion. Inspired by accounting systems in traditional economics, Fisher & Kerry Turner (2008) proposed a necessity to distinguish the immediate benefits and the ultimate benefits of ecosystem services. Moreover, only the benefits generated by the ultimate services can be accumulated. In this way, double counting is avoided. Further, the same service may be recorded as generating a variety of benefits (such as flood protection, drinking water and entertainment) which can be accumulated. Similarly, to conduct an economic analysis of the value of ecosystem services, Mäler et al (2008) classified provisioning services and cultural services in the MEA into the same category, the ultimate services, and combined supporting services and regulating services into one.

Costanza (2008) disagreed with the views of Wallace (2007) and Boyd & Banzhaf (2007) and argued instead that ecosystem services were not the final product of the ecosystem and that the final product was sustainable well-beings of humans. He considered intermediate services to also be ecological services, and that ecological processes and ecological services were not necessarily mutually exclusive in classifications and definitions. He further believed that Wallace's premise is flawed, and that the dissertation simplified the complexity of the actual reality, even though he agreed that the currently used classification system has its shortcomings. Wallace assumed that the world has a clear boundary, a fixed linear process but no feedback, and that there is the lack of the uncertainty in the means and objectives in clearly distinguishing ecosystem services and ecosystem process. People are always curious everything in this world and how they affect their welfare. The benefit concept used by Wallace is narrow in the prospective of economy. If they are limited to what people perceive and what they are willing to pay, for the general public most services may not be perceived, especially those that are public and non-excludable and will never enter into the private, exclusive market.

Although Fisher et al (2009) agreed with the view proposed by Boyd & Banzhaf (2007) that ecosystem services should be ecological entities, there existed the difference that they believed that regardless of the element of an ecosystem or an ecosystem process, all aspects of the ecosystem, as long as they serve to create well-being for humans either directly or indirectly, may be referred to as ecosystem services, that is, ecosystem services can be any aspect of the ecosystem that humans use directly or indirectly to create human well-being.

On the basis of the previous definition and classification of ecosystem services, Burkhard et al. (2012) considered ecological integrity as the base for the supply of regulating, provisioning and cultural ecosystem services, and regrouped ecosystem services into four categories based on the classification system in MEA: ecological integrity, regulating services, provisioning services and cultural services. Ecological integrity means the preservation against nonspecific ecological risks that are general disturbances of the self-organizing capacity of ecological systems (Burkhard et al., 2012). This self-organizing capacity is based on structures and processes in ecosystems, and appropriate indicators for their description have been defined and applied in several case studies (Burkhard et al., 2012).

In the meantime, the European Environment Agency (EEA) published the Common International Classification of Ecosystem Services (CICES). According to the classifications therein, ultimate ecosystem services are the contribution of ecosystems to human well-being; while ecosystem products and benefits are manufactured or extracted by humans from the ultimate ecosystem services. After the final output of the ecosystem is translated into products and experiences, such products and experiences are no longer functionally connected to the system from which they originated. It is proposed that the most fundamental characteristic of the output of ecosystem is its dependence on ecological processes, and non-biological output is not considered to be ecosystem services. However, the CICES includes non-biological factors such as mineral resources, wind power, solar energy and hydropower in its defined ecosystem services.

2.3.2. Justification of using Burkhard's classification system of ecosystem services

Due to the demand of assessment and decision-making, the discussion of ecosystem services classification system has never stopped with the emergence of the concept of ecosystem services. Before Burkhard et al (2012) proposed its classification system, the main widely-used and globally influential classification system included the systems proposed by Costanza et al (1997), MEA (2005), and Wallace (2007). These systems have their own advantages in assessment and valuation of ecosystem service supply and demand.

However, a consistent problem faced by these systems problem is how to make a clear distinction between ecosystem functions, services and benefits and to avoid accounting (de Groot et al.,2010; Haines-Young and Potschin, 2010; Burkhard et al., 2010). For several practical reasons, the commonly used four categories of supporting, provisioning, regulating and cultural services from the Millennium Ecosystem Assessment are not always appropriate (MEA, 2005; Seppelt et al., 2011, 2012; Wallace, 2007). Therefore, Boyd and Banzhaf (2007) introduced the term final ecosystem services which are components of nature directly enjoyed, consumed or used to yield human well-being.

However, the distinction between intermediate and final services is often observer-based and depending on rather subjective decisions. Therefore, the author follows a classification system which integrates the concept of ecological integrity as the base for the supply of regulating, provisioning and cultural ecosystem services (Müller and Burkhard, 2007). Ecological integrity means the preservation against nonspecific ecological risks that are general disturbances of the self-organizing capacity of ecological systems. This self-organizing capacity is based on structures and processes in ecosystems, and appropriate indicators for their description have been defined and applied in several case studies (Müller, 2005; Burkhard and Müller, 2008). The distinction of ecological integrity and the three main categories of ecosystem services (provisioning, regulating and cultural services) make a step to avoid double accounting between ecosystem functions and final ecosystem services.

2.3.3. Strength and weakness of monetary and non-monetary approach of ecosystem services assessment

1) Monetary approach

The existence and operation of various ecosystems provide different types of supporting functions and services for human life and production (Board, 2005; Bouma & van Beukering, 2015; MEA, 2005). According to the previous researchers' classification of ecosystem service value, there are two main types of ecosystem services: The first is the services that can be estimated by the value of goods and substitute goods. The second is the services that cannot be economically assessed through any entity, such as some regulating services. Although it is difficult to accurately assess the ecosystem service value in theory and practice, the economic assessment of regional ecosystem services through visualised money can help to understand the important role of ecosystem services in human survival and manifest the economic value of natural resources. In the previous studies, monetary approaches i.e. cost-benefit analysis, contingent valuations and willingness-to-pay methods has been applied in ecosystem services assessment for decision support in western countries (Farber et al, 2002). However, these methods did not has perfect results due to the economic focus and the lack of appropriate pricing methods, i.e. for non-marketed goods and services (Burkhard et al, 2012; Ludwig, 2000; Spangenberg & Settele, 2010).

The monetary approach of ecosystem services has been applied in environmental management decision support in China. On the national scale, Ouyang et al (1999) evaluated the total monetary value of China's terrestrial ecosystem services; Chen & Zhang (2000) calculated the total monetary value of ecosystem services based on the value coefficient of each type the main ecosystems in China. For the evaluation of the monetary values of ecosystem services, the early stage mainly focused on the forest (Jiang et al., 1999; Zhao et al., 2004) and the grassland ecosystem (Xie et al., 2001: Zhao et al., 2004), as well as on the farmland ecosystem (Sun et al., 2000) and the wetland ecosystem (Zhao et al, 2003). In recent years, it has begun to evaluate the ecosystem services in the ocean and sea-land interaction zones (Wang and Hexue, 2009; Zhang et al., 2013). At the regional scale, the evaluation of ecosystem service value has yielded fruitful results i.e. the total monetary value of ecosystem services of Qinghai-Tibet Plateau (Xie et al., 2003), the Inner Mongolia Plateau (Zhao et al., 2004) and the Southwestern Karst Region (Zhang et al., 2009).

2) Non-monetary approach

An ecosystem service can be regarded as a public product, in which the existence of a great deal of non-monetary assessment difficult (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Li et al, 2016b). In addition, economic assessments also depend on some basic assumptions, such as the ideal trading market environment, but in fact these assumptions are difficult to realise (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Li et al, 2016b).

Expert knowledge-based non-monetary ecosystem services assessment has been applied into the practice of decision support for ecosystem conservation globally (Burkhard et al, 2016; Kandziora et al, 2013; Settele et al, 2015). There was a clear demand for spatially explicit ecosystem service assessments from environmental management and planning (Daily & Matson, 2008) and several approaches mainly based on expert knowledge have been developed from regional scale to continental scale (Haines-Young et al, 2012; Maes et al, 2012a; Nedkov & Burkhard, 2012; Vihervaara et al, 2015). However, until now, a non-monetary ecosystem services assessment framework has not been developed (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Li et al, 2016b). There were still very few literature and case study of application by non-monetary approach in mapping and decision support for environmental management in China.

In the author's view, because the main purpose of ecosystem service value assessment is to strengthen the understanding of ecosystem services functions and provide a basis for the formulation of relevant policies, expert knowledge-based non-monetary assessment methods can not only achieve the above purposes, but also strengthen the relationship among ecologists, the general public and government officials taking part in the expert decision-making process, thus this method can play a certain role in the formulation and assessment of regional ecosystem policy.

2.4. Mapping ecosystem services

2.4.1. Ecosystem service mapping and decision making

Ecosystem service mapping is a process of quantifying--via several different ecosystem service assessment methods--the comprehensive characteristics of ecosystem services, such as their composition, quantity, spatial distribution and interrelationship, on a specific spatiotemporal scale, as well as the situational changing characteristics under the influence of various natural and social factors, in accordance with decision-making requirements (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015).

Its ultimate goal is to aid decision making, to provide a quantitative and visual expression of the comprehensive characteristics of ecosystem services in the study area and a detailed description of temporal and spatial changes, including display forms such as static display and dynamic simulation, for the decision-makers, stakeholders, beneficiaries and other relevant parties involved in the decision-making process (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015).

It includes not only the integrated characteristics of ecosystem services in the current study area, but also the predicted changes to the integrated characteristics of ecosystem services under the possible future decision-making and impact scenarios (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015). This enables the decision-makers to make use of these possible change scenarios, weigh the pros and cons, and finally make a sustainable natural resource utilisation decision meeting the regional needs.

The mapping of ecosystem services plays a key role in promoting the integration of ecosystem service assessment into the maintenance of the ecological environment, the planning and formulation of environmental policies and so on (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015). Ecosystem service mapping refers to the process of effectively planning the spatial pattern of ecosystem services at different spatial and temporal scales by using a reasonable mapping program as per the ultimate management objectives, and performing scenario-specific simulation and forecasting of ecosystem services under the influence of different social and natural drivers (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015).

The mapping provides decision-makers with concretely identifiable, intuitive and visual information that includes the integrated features of the current ecosystem services and the simulated comprehensive features under different scenarios in the future; furthermore, it describes relevant information regarding dynamic temporal and spatial changes, provides assistance to decision-makers in weighing advantages and disadvantages, and formulates optimal strategies for promoting the sustainable development of humans, society and the environment (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Willemen et al, 2015).

2.4.2. Ecosystem services mapping process

It is necessary for researchers to make a detailed mapping analysis of the variety, change, quantity, distribution, relationship of the supply and demand of the local ecosystem services as well as the changes of the integrated characteristics under different decision-making scenarios (Bouma & van Beukering, 2015; Palomo et al, 2017). The mapping of ecosystem services mainly occurs in an early stage of decision-making process, that is, the initial stage of comprehensive assessment of ecosystem services (Bouma & van Beukering, 2015; Palomo et al, 2017). First, researchers should collect data on the natural-social characteristics of the decision-making area, including meteorological and climatic data, location and terrain data, remote sensing data, geographical data, land use and statistical data, by the initial decision-making needs (Bouma & van Beukering, 2015; Palomo et al, 2017). Because the choice of methods for quantitative mapping analysis of ecosystem services depends primarily on the availability of data in the study area, researchers need to conduct a comprehensive analysis of the data that can be collected (Bouma & van Beukering, 2015; Palomo et al, 2017). Thus, the mapping model of ecosystem services has been established, which accords with the actual situation of the region and the demands of decision-making. The model method of ecosystem service mapping is the most important core content in the process of ecosystem service mapping. The reliability of mapping results is determined by the choice or establishment of the ecosystem service mapping model. Finally, after the mapping model for the ecosystem services is determined, the researchers provide the final analysis map of ecosystem services to the participants in different decision-making stages through cartographic generalization (Bouma & van Beukering, 2015; Palomo et al, 2017). Then the decision makers can weigh the pros and cons.

In the end, effective and beneficial decision-making planning will be worked out. Of course, in the process of establishing the model, the actual investigation data, such as field survey data, questionnaire interview data and observation experimental data are also needed to verify the reliability of the analysis results of the model. It makes the prediction results of the final model analysis accurate and reliable, to assist decision-making in the most real sense.

2.4.3. Ecosystem services mapping and Geographic Information System (GIS)

GIS has many powerful functions, such as data collection, information integration, spatial modelling and visualisation, and it can comprehensively represent the spatial heterogeneity of the regional ecosystem (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). At present, GIS is mainly used in the study of ecosystem services, including spatial data management, data visualisation, spatial modelling and so on, on the regional scale (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017).

Generic and reliable data are critical for studying the supply of ecosystem services and their influencing factors. Because of the heterogeneity of ecosystem structure and function, the ecosystem service supply varies greatly at different times and spaces, which needs a large amount of spatial data to aid in analysis and simulation (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). At the same time, with the accumulation of remote sensing data and ground survey data, a powerful spatial database management platform is also needed for the massive data of ecosystem services research and management (Bouma & van Beukering, 2015; Large & Gilvear, 2015; Li et al, 2014; Palomo et al, 2017).

In this context, GIS is widely used in the field of ecosystem service data management. The spatial database based on GIS can not only manage a great deal of spatial data, but also analyse the spatial and temporal patterns and driving forces of ecosystem services (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). It can also stimulate land use, land coverage change, climate change and the impact of social and economic factors on ecosystem service supply (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). GIS is an excellent visual expression tool. Both original data and calculated results can be expressed and presented in the form of images. Because the spatial data is heterogeneous, this kind of visualisation expression which is closely related to the spatial location is particularly important. The supply, flow, and consumption of ecosystem services, as well as the value distribution, hot spot identification and so on, all rely on the GIS platform description (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). In addition, the ecosystem service mapping practice must be completed through the GIS software platform. One of the powerful functions of GIS is the modelling and analysis of spatial data, so it is widely used in ecosystem service simulation and weighing research. GIS is often used to model the mechanism of ecosystem services and the relationship between natural phenomena and human activities, in order to understand the relationships within a single ecosystem service or between multiple ecosystem services, as well as the complex relationship between the ecosystem and human beings (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). At the same time, many researchers use GIS to analyse the temporal and spatial distribution of ecosystem services on different scales. Based on the analysis of the spatial and temporal pattern of services, the researchers can identify the supply areas of single or compound ecosystem services, and compare the distribution differences among multiple ecosystem services, so that the ecosystem services can be better managed (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017).

Recently, several research studies have applied GIS analysis in assessment of ecological factors which contributed in an assessment of ecosystem service supply (Brown & Fagerholm, 2015; Swetnam et al, 2011). Except for mapping ecosystem service supply, the demand of mapping distribution of ecosystem service consumption was gradually recognized (Burkhard et al, 2014; Burkhard et al, 2012; Palomo et al, 2017). Extensive ecosystem service assessments are also based on GIS. Scientists have been trying to find a consistent and comparable way to quantify ecosystem services (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). Typically, a series of indicators and metrics are used to quantify the supply (production) and demand (consumption) of ecosystem services on different spatial and temporal scales (Bouma & van Beukering, 2015; Li et al, 2014; Palomo et al, 2017). In this process, the application of GIS can help analyse the spatial structure of the supply and demand indicators of ecosystem services. When used in combination with other judgment criteria, the supply area, consumption area and connection area of ecosystem services can be identified.

Using GIS technology can solve the problem of spatial heterogeneity of ecosystem services to some extent, and help decision makers to better evaluate and manage ecosystem services in a regional context (Bouma & van Beukering, 2015; Palomo et al, 2017). Although GIS is often unable to model and evaluate ecosystem services on its own, it is an excellent platform when integrated with other tools and resources. Many pieces of specialised ecosystem service software can be run as modules or plug-ins on the GIS platform, thus expanding the scope of GIS functions and applications.

2.4.4. Scale effect in mapping ecosystem services

The scale refers to the space or time unit used in carrying out various observations, or the spatial range or the time frame of a certain event (Burkhard et al, 2014; Fu et al, 2011; Glaser & Glaeser, 2014; Scholes et al, 2013).

The observation scale is defined based on the measurement system used by humans (Burkhard et al, 2014; Fu et al, 2011; Scholes et al, 2013). The observation scale has three components: range (or duration), resolution and granularity (Burkhard et al, 2014; Fu et al, 2011; Scholes et al, 2013).

The range refers to the total range or duration included when in observing a phenomenon; the resolution refers to the interval or the distance between two observations; and the granularity refers to the range or duration included in a single observation (Burkhard et al, 2014; Fu et al, 2011; Scholes et al, 2013).

The formation of ecosystem services depend on the structure and process of the ecosystem on certain spatial and temporal scales, and they only demonstrate their dominant role and effect on specific temporal and spatial scales (Burkhard et al, 2014; Fu et al, 2011; Scholes et al, 2013). Ecosystem services at different scales are of different importance to stakeholders at different administrative scales (Burkhard et al, 2014; Scholes et al, 2013).

One of the challenges of ecosystem management is the mismatch between the development and the implementation of policies (Burkhard et al, 2014; Fu et al, 2011; Fu et al, 2013b; Scholes et al, 2013). Because ecosystem services depend on natural and social processes of different spatiotemporal scales, there is a scale effect on both the supply and demand of ecosystem services (Burkhard et al, 2014; Palomo et al, 2017; Scholes et al, 2013). The scale-matching in the process of mapping ecosystem services is not only to technically match the resolution of multi-source data, but also to carefully identify and select the key ecosystem service types that are consistent with the scale range of the decision-making planning to enable the mapping results to be effective (Burkhard et al, 2014; Fu et al, 2011; Fu et al, 2013b; Palomo et al, 2017; Scholes et al, 2013).

The stresses of ecosystem services vary with the change of spatial scale. On a larger spatial scale, regulating services should be valued, while on a smaller spatial scale, the provision of ecosystem services should be paid more attention (Burkhard et al, 2014; Fu et al, 2011; Glaser & Glaeser, 2014; Scholes et al, 2013). For example, flood control and disaster reduction as well as agricultural products mainly serve the local scale, while biodiversity and climate regulation are more considered on the national or global scale (Burkhard et al, 2014; Fu et al, 2011; Glaser & Glaeser, 2014; Scholes et al, 2013). On the temporal scale, the blind pursuit of immediate benefits will damage the long-term sustainable supply capacity of ecosystem services, so in the process of mapping ecosystem services, full consideration should be given to the impact of current decision-making objectives on a range of ecosystem services in the long term (Burkhard et al, 2014; Palomo et al, 2017; Scholes et al, 2013).

2.4.5. Mapping ecosystem services hot spot and cold spot

The hot spot and cold spot mentioned in the geography are high value and low value in terms of the eigenvalue distribution of a geological matter, such as abundance centres of biodiversity distribution (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). For ecosystem services, areas with higher diversity of service types, high value physical area or value quantities of a service, or areas with high capacity of service provision are the hot spots of the service, and others are labelled cold spots (Cimon-Morin et al, 2013; Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016).

In the research on ecosystem services, identifying hot spot areas of service supply and demand and representing them on the map will visually reflect the supply source and key utilization area of ecosystem services, and will provide an important basis for ecosystem service division and management (Karimi et al, 2015; Li et al, 2017c;

Schroter et al, 2017; Xiao et al, 2016).

GIS provides convenient tools for exploring the hot and cold spot areas of ecosystem services within a region (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). Applying GIS for identifying ecosystem service hot spot areas needs to define assessment unit, eigenvalue and threshold value of ecosystem services (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016).

(i) Assessment units are the minimum assessment units for measuring ecosystem services, which generally has three types (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016).

The first type is pixel or grid dimension, i.e. using single pixel or a set of several pixels on remote-sensing images as the minimum assessment units. The second type is ecosystem dimension, i.e. using a certain ecosystem boundary as the basis for partitioning assessment units, such as drainage basins and land covers. The third type is administration dimension, i.e. using administrative borders as the boundaries of assessment units, which is the type most frequently used for policy analysis.

(ii) Eigenvalues are indexes for determining strength or type diversity of ecosystem services, which can be type abundance, grade and physical or value quantity of the service (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). For example, net primary productivity can be used to represent carbon sequestration service strength or determine relative strength grade of ecosystem services based on expert grading results.

(iii) Two methods are widely applied for determining threshold values. One of the methods is to set a proportion value, for example to set the first 10% of the assessment units with leading capacity of the service as hot spot areas and the later 10% assessment units as cold spot areas (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). With this method, the hot and the cold spot areas can be easily identified for analysis. However, this method lacks corresponding explanations about internal mechanisms, and different areas are difficult to compare.

Another method is to choose a physical quantity as the threshold (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). The service provision indexes larger than that value are called hot spot areas. Unlike the previously outlined method, this features a certain scientific basis, but the value-setting often requires the comparison and judgement of a large amount of similar research results. After defining assessment unit, eigenvalue and threshold value of ecosystem services, researchers can identify the hot and the cold spot areas of ecosystem services in the research region with the GIS analysis tools (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016).

In addition, when the research objects are various ecosystem services, we may overlay the hot spot areas of each ecosystem service to explore the hot spot areas of multiple services, or organize different ecosystem services in the same dimensions by homogeneity integration method and then set the threshold value for seeking the hot spot areas (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). The GIS platform provides hot spot analysis tools based on statistical indexes, which can directly reflect clusters of high value (hot spot) and low value (cold spot) areas in the space by calculating Z scores between patches of land (Karimi et al, 2015; Li et al, 2017c; Schroter et al, 2017; Xiao et al, 2016). The higher Z score indicates more significant clustering of hot spot areas.

The term ‘ecosystem services hot spot’ is increasingly used for the purpose of informing spatial prioritization of ecosystem services (Cimon-Morin et al, 2013). Despite this growing use of the term, an ecosystem services hot spot is not clearly defined in the literature yet (Schroter & Remme, 2016). The term ecosystem services hot spot often refers to areas where high amounts of one particular service are present (Cimon-Morin et al, 2013), but other studies have defined hot spots as areas where multiple ecosystem services overlap (Gos & Lavorel, 2012).

To facilitate financial incentives for the responsible management of land and habitat, assessments and mapping of ecosystem services provide quantitative information to initiate sustainable ecosystem management (Robinson et al, 2013). Alessa et al (2008) reported that output from hot spot mapping were dependent on the assumptions underlying the methodology. Mola-Yudego & Gritten (2010) used GIS-based hot spot analysis to study forest management conflict clusters based on the number of reported conflicts. Other studies have identified areas for conservation efforts, as well as mapping ecosystem services such as water supply, soil quality, and carbon in South

Africa (Timilsina et al, 2013). Such assessments help identify which services are declining because of urbanization. Researches on the identification and mapping of ‘hot spots’ are relatively recent and little formal guidance in the current literature (Karimi et al, 2015).

2.4.6. Mapping ecosystem services supply and demand

First of all, the spatial expression of the supply of ecosystem services is dominant among current research projects. Scholars have conducted a large number of analyses on different types of ecosystem services at different spatial scales, most of which have focused on the regional and national scales, while most of the mapping done is targeted at the regulating services (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Palomo et al, 2017; Stürck et al, 2014).

3) Mapping ecosystem services supply

Ecosystem service supply refers to the ability of an ecosystem to produce a series of ecosystem products and services that can be utilised by human beings on a specific spatial and temporal scale, which can be measured through the value or produced goods (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Palomo et al, 2017).

It differs from the potential largest ecosystem service supply, but refers to the products and services that can be directly utilised by human beings to meet their needs (Burkhard et al, 2014; Burkhard et al, 2010; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Palomo et al, 2017).

The main influencing factors include direct environmental resources and services, as well as human activities and decision-making, such as government decision-making and technological progress (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Palomo et al, 2017). Scholars, by studying and analysing the characteristics of the supply of one or more types of local, regional, continental and global ecosystem services on various spatial scales, have provided a wealth of practical cases for the mapping of ecosystem service supply (Burkhard et al, 2014; Burkhard et al, 2012; Martínez-Harms & Balvanera, 2012; Palomo et al, 2017).

Based on the statistical analysis of relevant literature on mapping of ecosystem service supply, Martínez-Harms & Balvanera (2012) found that current research on mapping of ecosystem service supply mostly focuses on regional and national scales, among which the regulation service is the most studied service type. Rather than relying on original data from actual surveys and experiments, scholars often use secondary data, such as remote sensing data as well as land-use and socioeconomic data, for mapping analysis of ecosystem service supply (Burkhard et al, 2014; Burkhard et al, 2012; Large & Gilvear, 2015; Martínez-Harms & Balvanera, 2012; Palomo et al, 2017).

4) Mapping ecosystem services demand

Ecosystem service demand refers to the sum of ecosystem products and services used or consumed by people in a specific research area on a certain time scale, which is affected by factors such as government policies, population changes, economic levels, marketing, and cultural regulations (Burkhard et al, 2012; Nedkov & Burkhard, 2012; Stürck et al, 2014; Tao et al, 2018; Verhagen et al, 2017; Villamagna et al, 2013; Wolff et al, 2015). At present, the research on mapping of ecosystem service supply is the mainstream, while the spatial pattern mapping of ecosystem service demand is receiving increasing amounts of attention.

The mapping of ecosystem service demand involves identifying the demand for ecosystem service products from beneficiaries who use ecosystem products and services (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017). It is described by the distribution of demand, the amount of demand and the location of the beneficiaries. For example, by extracting the amount and composition of consumption, from remote sensing images or geographical data, as the substitute indicators for attributes of human consumption of ecosystem services (such as population distribution, settlement size, location), researchers can analyse the consumption related to population, settlements, infrastructure, and so on (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017). The mapping of ecosystem service demand is mostly combined with the mapping of ecosystem service supply (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017).

Through the superposition of the mapping results of the supply and demand of the ecosystem services in the study area, one or more forms of regional ecosystem service supply-demand balance will be generated (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017). For example, Kroll et al (2012) comprehensively analysed the supply and demand characteristics of energy, water supply and food ecosystem services in Germany's Leipzig-Halle region by integrating social statistical information such as population distribution, consumption amount, and consumption composition, and environmental variables such as climate change, river, transport, and land-use change. By integrating the vegetation coverage data and hydrological model, Nedkov & Burkhard (2012) have analysed through mapping the spatial characteristics of supply and demand of hydrological regulation service in Bulgaria. (Nedkov & Burkhard, 2012) made use of the land cover data of CORINE, combined with the different characteristics of supply and demand capacity of each classification system put forward in previous literature, and finally got the supply and demand capacity table of various kinds of land in CORINE by scoring, providing a good reference for the study of spatial visualisation and scale transformation of ecosystem service mapping.

In addition to the mapping for the supply of ecosystem services, the mapping for the demand of ecosystem services has also become a hot research topic recently (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Stürck et al, 2014). Four different types of demand have been defined: reducing risk, preference and value, directly useable demand, and consumption of goods and services (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017). There are specific methods associated with each different type of demand (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017). Recent studies also found that the operability of the ecosystem service demand assessment in policy-making and planning and management requires a compatible understanding and definition of the ecosystem service demand and their driving factors and temporal dynamics (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017; Stürck et al, 2014). Most researchers superimposed the results of the sub-graphs of ecosystem service supply and demand to combine the two in their analysis, so as to build a supply and demand equilibrium diagram of a single or multiple ecosystem services in the studied area (Burkhard et al, 2014; Burkhard et al, 2012; Nedkov & Burkhard, 2012; Palomo et al, 2017).

2.4.7. The advantage of the Burkhard's ecosystem services supply-demand mapping approach

In the early stage, the assessing, mapping of ecosystem services were focused on the monetary value of ecosystem services supply, but ignored the non-market value and the demand side (Burkhard et al, 2014; Burkhard et al, 2012; Palomo et al, 2017). Previous studies assessed ecosystem services from the view of monetary value approach (Costanza et al, 1997; Costanza et al, 1998) and focused on the assessment and mapping of supply of ecosystem services (Egoh et al, 2008; Mensah et al, 2017; Yaneva, 2016). The direct comparison of ecosystem service supply and demand in spatially explicit maps was rather rare in spite of the wide agreement about the importance of including the demand side into ecosystem service assessments (Burkhard et al, 2014; Burkhard et al, 2012; Palomo et al, 2017). In the current stage, the non-monetary value assessment was also considered in the ecosystem services assessment (Burkhard et al, 2014; Burkhard et al, 2012). The both of the supply and demand of ecosystem services, and their spatial relations were being explored at specific scales in the mapping and managing process (Burkhard et al, 2014; Burkhard et al, 2012).

Using existing assessment results and survey data of various ecosystem services as their decision criteria, Burkhard et al (2012) divided the ecosystem services of the study area into 29 indicators. Then, the capacity and demand of ecosystem services corresponding to different land-use types of the study area were obtained using the expert knowledge-based method, and the demand-supply matrix of ecosystem services was established. The status of the supply-demand balance of regional ecosystem services was spatially visualised. A remarkable feature of this method is that the quantitative assessment of ecosystem services is supported by a series of correlative criteria and the help of an expert knowledge-based decision-making system: The general process is as follows: first, analyse the land-use status in the region; and then construct the classification system of the regional ecosystem services and determine the quantitative indicators; on the basis of the classification system, formulate the assessment scale of ecosystem services corresponding to land-use type; transfer the assessment scale and the decision criterion information to the experts for decision-making; and then adjust it according to the results of the expert judgment and the weight system; and at this point, the assessment results of ecosystem services for all kinds of land use types can be obtained.

Burkhard et al (2012) proposed the land-cover-based matrix model to assess and map ecosystem services supply-demand budget to identify ecosystem services mismatch and promote ecosystem conservation planning through expert knowledge. Comparing with other studies, the Benjamin Burkhard's ecosystem services Mapping Approach had three advantages:

1) Burkhard's ecosystem services matrix was directly correlated with the land cover types. This was convenient for spatial environmental management decision making support.

2) Burkhard's ecosystem services supply-demand matrix connected the demand side with the supply side of the ecosystem services research, when other studies mainly focused on the supply of ecosystem services.

3) Burkhard's ecosystem services matrix was suitable to apply expert knowledge in data-rare region's research. Then, further steps of methods for assessing and mapping the ecosystem services supply and demand had been made to identify ecosystem services mismatch (Arbieu et al, 2017; Baró et al, 2015; Burkhard et al, 2014; Burkhard et al, 2012).

However, the applicability of each method depended on different ecosystem services, data availability and research purposes. For the management of regional ecosystem services, the author suggested to assessing and mapping both the surplus and deficit of the ecosystem services in the entire region as well as the surplus and deficit of ecosystem services in each administrative unit (such as a city) in the region, so as to facilitate the cooperation among administrative units in the region. Relevant researches in this area are still relatively rare.

2.5. Ecological red line policy in China

2.5.1. The concept and meaning of ecological red line policy

China has put forward the ecological red line policy to deal with negative impacts of urbanization and economic growth recently. These police were still in a pilot stage in the Yangtze River Delta metropolitan region.

The concept of an "ecological red line" was put forward for the first time by *State Council's Opinions on Strengthening Key Environmental Protection Work* in October 2011(Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). Subsequently, the water conservancy, marine and forestry departments put forward corresponding "red lines", emphasizing rigid restrictions on various ecological protection areas (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). In 2013, the Decision of the *Central Committee of the Communist Party of China on Several Major Issues of Comprehensively Deepening the Reform* extended the scope of the application of the ecological red line to the areas of environmental quality and resource utilization (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). On this basis, in January 2015, the Ministry of Environmental Protection issued the '*Technical guide for delineation of national ecological protection red line ecological function baseline*', and defined the intension and extension of the "ecological red line", including the red line for the ecological function (the baseline of the ecological function guarantee), the red line for environmental quality (the bottom line of the environmental quality safety), and the red line for the utilization of the resources (the upper limit of the use of natural resources) (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013).

At present, definitions of the need for ecological red line are not uniform. Some domestic experts and scholars have also interpreted the ecological red line differently:

In order to maintain the ecological security and sustainable development of the country or the region, *Rao et al (2012)* believed that the ecological red line was based on the protection demand of the integrity and connectivity of the ecosystem, and the special protection area should be enforced, and the minimum comprehensive ecological risk standard system was set up.

Zheng & Ouyang (2014) and others defined that delineation of the ecological red line as the delineation of the minimum space to be strictly protected in order to enhance the ecological function and ensure the continuous supply of ecosystem goods and services. *Fu & Li (2007)* put forward that the ecological red line was an important area of ecosystem service function or a fragile ecological environment. On this basis, *Gao (2014)* also defines the ecological red line as a land space that must be strictly protected in areas such as important ecological functional zoning, ecological environment sensitive areas and fragile areas.

According to the characteristics of the ecological environment and need for ecological protection in China, the ecological red line can be defined as the delineated area that requires special protection to maintain national or regional ecological security and sustainable development according to the protection needs of ecosystem integrity and connectivity (Bai et al, 2016; Lü et al, 2013). Biodiversity, natural relics, and cultural heritage are the main areas of protection in traditional conservation areas. Meanwhile, ecological red lines are delineated as important ecological functional areas and ecologically fragile areas/sensitive areas (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). In addition to biodiversity conservation, other ecological functions, such as freshwater and product supply, soil conservation, wind prevention, sand fixation, water purification, climate regulation, and water conservation, also need to be considered for the delineation of ecological red lines (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). In this sense, the ecological red line has a wider meaning. The functional importance of ecology and vulnerability of the assessment object do not depend merely on the ecological attributes of the assessment object itself. They depend on the type and severity of environmental issues and the urgency of the demand for ecosystem services in the delineated area (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013). Therefore, the importance of ecological functions and ecological vulnerability/sensitivity should be assessed in conjunction with the ecological environment of the target area.

Also, the ecological and functional importance of the assessment object depends not only on its ecological attributes but also on its spatial position in the landscape or area where it is located and its role in maintaining the security pattern of the said landscape or area. Since the purpose of delineating and managing ecological red lines is to maintain national or regional ecological security and protect the integrity and continuity of ecosystems, spatial background factors at the regional level and the role of assessment object in the regional security pattern need to be considered (Bai et al, 2016; Gong et al, 2017b; Guo et al, 2018; Li et al, 2017b; Lü et al, 2013).

2.5.2. The method of ecological red line delineation

The delineation of the ecological red line should be based on the existing natural ecological environment conditions, taking the integrity of the ecosystem, the consistency of the ecosystem service function and the continuity of the ecological space as the core (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). On the basis of the assessment of the current situation of the regional ecological environment, the structure and work of the regional ecosystem are analysed. The delineation should focus on the assessment of the importance of ecosystem services, identify the primary ecological functions of different regions, and put forward the classification system of ecological red line (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010).

Ecological environment assessment

The assessment of ecological environment is the basic work of delineation of the ecological red line (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010). The regulating services and GIS techniques are used to analyze and study the natural and geographical conditions, the ecological environment and the characteristics of the ecosystem in different regions, so as to clarify the spatial differentiation and distribution patterns of ecosystem types in different regions (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

1) Assessment of ecosystem services

In view of the typical ecosystem in the region, the ecosystem services such as climate regulation, water conservation, flood regulation, environmental purification, nutrient retention, biodiversity conservation and scientific research culture are evaluated respectively (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). In combination with the development and utilization of natural resources and the analysis of land use planning, the ecosystem services are comprehensively evaluated in the region (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010).

2) Ecosystem management

Ecological red line is a new concept put forward by China in recent years, and also a material change in environmental protection. This is consistent with the international emphasis on changing from single factor management to multi factor and comprehensive system management. Delineation and protection of ecological red line is an important step in achieving ecosystem management (Asah et al, 2014; Bastos et al, 2016; Fu et al, 2004; Li et al, 2014; Muhweezi et al, 2007; Yu et al, 2002).

The ecosystem management is based on the understanding of the composition, structure and function of the ecosystem, and regards human economic activity and cultural diversity as an important ecological process, which is integrated into a certain time and space (Asah et al, 2014; Bastos et al, 2016; Li et al, 2014; Muhweezi et al, 2007). Ecosystem management is about formulating adaptive management strategies to restore or maintain the integrity and sustainability of ecosystems based on a thorough understanding of the composition, structure, and functional processes of ecosystems (Asah et al, 2014; Bastos et al, 2016; Fu et al, 2004; Muhweezi et al, 2007; Yu et al, 2002). Protecting biodiversity, protecting key ecological processes, and maintaining ecosystem integrity are the main goals of ecosystem management (Asah et al, 2014; Bastos et al, 2016; Fu et al, 2004; Muhweezi et al, 2007; Yu et al, 2002).

Moreover, ecosystem management is integrated management. Its management boundary is the natural boundary of the ecosystem instead of the administrative boundary. Depending on the impact scope of ecological processes, the management boundary is the basis for ecosystem management (Fu et al, 2004; Li et al, 2014; Yu et al, 2002). On land, basin boundary is often used to define ecological management boundary, while middle stream and upstream basin boundaries are often used to determine coastal zone management boundaries in integrated coastal zone management (Fu et al, 2004; Li et al, 2014; Yu et al, 2002).

In addition, ecosystem management emphasizes public participation, with clear and operational management objectives (Fu et al, 2004; Li et al, 2014; Yu et al, 2002).

Various ecological, social, and economic goals are comprehensively considered and defined on the basis of mediating conflicts between stakeholders. Furthermore, ecosystem management considers human beings as an organic part of the ecosystem, and the impact of human activities on ecosystems is the basis of ecosystem management (Fu et al, 2004; Yu et al, 2002). The objects of ecosystem management are ecological systems on the surface, but they are essentially human activities. Owing to the uncertainty, complexity, and time lag of ecosystems, man has limited understanding of the main driving forces, behavior and responses of ecosystems (Fu et al, 2004; Li et al, 2014; Yu et al, 2002).

The scale of ecosystem management is to restore or maintain the integrity and sustainability of ecosystems (Fu et al, 2004; Li et al, 2014; Yu et al, 2002). The purpose of delineation of the ecological red line is to emphasize the protection of the structure, process, function and service of the ecosystem, and pay more attention to maintaining the balance of the ecosystem and promoting the supply of ecosystem goods (Fu et al, 2004; Li et al, 2014; Yu et al, 2002).

The goal and key of ecosystem management is to realize the sustainable and harmonious development between people and nature (Fu et al, 2004; Li et al, 2014; Yu et al, 2002). In essence, it is to maintain the balance of the system and realize the coordinated development of the system of human, society and nature. In order to strengthen the management of the ecosystem system and maintain the sustainability of the ecosystem service function, the key and control measures of the ecological red line area protection are put forward respectively (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010).

The protection of the ecological red line is in the absolute sense of protection. The red line of resources and environment in China is the ecological cropland function zone and the ecological water function zone (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010). Taking the ecological cropland function zone as an example, China's arable land has 180 million hm^2 in arable red line, which is an insurmountable bottom line, and the red line on this quantity is related to national food security (Bai et al, 2016; Liu et al, 2013; Lü et al, 2013; MEP, 2015; PRC, 2010).

3) Landscape/regional planning

At landscape and regional scales, the spatial distribution pattern of ecosystems significantly influences the structural functions and service value of ecosystems (Burkhard et al, 2010; Burkhard et al, 2012). The concept of ‘think globally, plan regionally, and act locally’, as the guiding idea of land use planning, emphasizes the importance of spatial context for landscape and regional ecological planning (Forman, 2014; Lin et al, 2016; MEP, 2015). This concept gives consideration to the impact of landscape and regional ecological planning on the surroundings and the region. Whether an area is ecologically important depends on not only its natural, social, and economic attributes, but also on its value in protecting the integrity and connectivity of ecosystems in the local region (Forman, 2014; Lin et al, 2016; MEP, 2015).

The spatial pattern determines the functions of a landscape/region while ecological functions in turn influence spatial pattern (Forman, 2014; Lin et al, 2016; MEP, 2015). Protecting broad river corridors, reducing fragmentation of natural landscapes, increasing the connectivity of landscapes, and protecting large natural patches comprise the guiding ideology for the development of ecological security pattern (Forman, 2014; Lin et al, 2016; MEP, 2015). The basis for delineating ecological red lines is not only the ecological importance and vulnerability/sensitivity of the assessed unit at the ecosystem level. More importantly, its basis rests on its ecological importance to the regional and landscape security patterns (Forman, 2014; Lin et al, 2016; MEP, 2015).

Ecological function orientation

The focus of ecological red line protection is its dominant ecological function. Therefore, before delineation of the ecological red line, the primary ecological functions should be determined according to the structure, functional characteristics and importance assessment of the ecosystem services, which lays the foundation for the classification and protection of the ecological red line area (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

2.5.3. The basis and composition of the ecological red line policy

1) Major functional zones

The "development" referred to when we discuss the optimised, key, restricted and prohibited development during principal function regionalisation specifically refers to large-scale intensive industrial and urban development (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). 'Restricted development' specifically refers to the restriction of large-scale intensive industrial and urban development, rather than the restriction of all development. In the major production areas of agricultural products, in addition to restricting large-scale intensive industrial and urban development, agricultural development should also be encouraged (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

In key ecological function areas, in addition to restricting large-scale intensive industrial and urban development, the development of energy and mineral resources should also be allowed to a certain extent (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). To label some regions as having restricted development refers not to an area where all development is restricted, but to an area in which the agricultural productivity and ecological productivity is protected, in order to realise scientific development.

The concept of appropriate development depends on to natural conditions: different parts of a territory can have different natural conditions (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). Large-scale intensive industrial and urban development is not a good fit those regions of very high elevation, complex landforms, a harsh climate or other kinds of fragile ecology and critical ecological functions. Similarly, some regions even cannot bear intensive development of agriculture and animal husbandry, otherwise their ecosystems will be damaged, and they will have impaired ecological product supply capacity. Therefore, the decision makers should respect and comply with the local natural context in order to determine different development needs and suitability according to the differing natural qualities of the territory.

Another concept underlying is that of dividing principal functions: A certain part of a territory features multiple functions, among which there must be a principal function

(Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). Divided according to aspects of product provision, the principal function may be the provision of industrial products and services, or the provision of agricultural products, or the provision of ecological products (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

In regions which are related to overall ecological safety, the principal function should be the provision of ecological products, and the provision of agricultural products, services and industrial products should be regarded as subordinate functions; otherwise the productivity of ecological products may be impaired. For example, the principal function of grassland is to provide ecological products. If it is overgrazed, it may be degraded or become desert.

In regions with outstanding agricultural development conditions, the principal function should be the provision of agricultural products, otherwise occupying extensive areas of farmland may damage the productivity of agricultural products. Therefore, territories should be divided according to their different principal functions, based on which the principal development targets and the major development tasks will then be determined.

The concept of development is also subject to the bearing capacity of resources and environment: Different parts of the territory have different principal functions and thus, different population agglomeration types and economic scales (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). It is difficult for ecological function areas and the major production areas of agricultural products to bear much of a consumer population because they are not suitable for or should not carry out large-scale intensive industrial and urban development. During the course of industrialisation and urbanisation, some portion of the population will certainly be transferred to urbanised areas with more job opportunities. Meanwhile, the over-agglomeration of population and economy as well as unreasonable industrial structures also brings about unbearable pressure on resources, environment, transportation, etc. Hence, the bearable population and economic size and proper industrial structures must be determined according to the “weak point” factors of the resources and environment.

Another concept is controlling development intensity: A great proportion of China's territory is not suitable for industrial and urban development (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). Although areas such as plains and other parts of the territory with good natural conditions are suitable for industrial and urban development, those parts are more suitable for agricultural development, which takes priority. In order to guarantee agricultural supply security, they cannot be excessively occupied for the purpose of industrialisation and urbanisation.

Consequently, the remaining territory suitable for industrialisation and urbanisation is no longer sufficient. Even in urbanised areas, necessary farmland and green ecological space must be maintained to meet the local demands for agricultural and ecological products to a certain extent. Hence, areas of various principal functions must be developed to a moderate degree, at an appropriate level of development intensity.

Another consideration is the concept of adjusting spatial structure: The spatial structure is the reflection of different kinds of space, including urban, agricultural and ecological space in the development of the territory, and is the spatial carrier of economic and social structures (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). Changes to the spatial structure determine the economic development modes and resource allocation efficiency to some extent. In overall terms, the total area of built-up urban area, designated town areas, independent industrial and mining areas, rural residential areas and various development zones is rather vast, but the spatial structure is not reasonable and the spatial utilisation is not very efficient. Therefore, the adjustment of spatial structure must be included into the content of the economic structure adjustment, and the root of territory development should be transformed from focus on land occupation to the adjustment and optimisation of spatial structure and the improvement of spatial utilisation efficiency.

A key issue of the play is the concept for providing ecological products: Human demands include both those for agricultural, industrial and service products and those for ecological products including fresh air, clean water resources and a pleasant climate (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). When taking these demands into account, these natural factors can also be understood as kinds of natural products. The process of protecting and expanding the natural capability of providing ecological products is also a process of value creation. The activities involved in protecting the ecological environment and providing ecological products are also part of development.

In general, China’s capability of providing industrial products keeps rapidly increasing while its capability of providing ecological products is weakening (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). With the improvement of people’s living standards, the demands for ecological products are increasingly high. Therefore, the provision of ecological products must be regarded as an important component of development, and the improvement of ecological productivity must be a priority for territory development.

Based on the above definitions and concepts of development, China’s territory will be divided into the following major function zones in this plan: Categorized by their development modes, the major function zones are divided into optimised, key, restricted and prohibited development areas; by development content, they are urbanised areas, major production areas of agricultural products and key ecological function areas; by levels, they are national and provincial level areas (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

The optimised, key, restricted and prohibited development areas are divided based on the bearing capacity of resources and environment, current development intensity and future development potential of different regions, and whether they are suitable for and how they will carry out large-scale intensive industrial and urban development.

The urbanised areas, major production areas of agricultural products and key ecological function areas are divided by the major types of products provided (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). The urbanised areas are those with the principal function of providing industrial and service products, although they also provide agricultural and ecological products. The major production areas of agricultural products are those with principal functions of providing agricultural products and also subsidiary humans of providing ecological, service and some industrial products. The key ecological function areas are those with the principal function of providing ecological products, with certain agricultural, service and industrial products as subsidiary.

The optimised development areas are those with a more developed economy, denser population, more intensive development and more serious problems in resources and environment, so they should be optimised in terms of industrial and urban development. The key development areas are those with a certain economic foundation, strong bearing capacity in resources and environmental terms, great development potential, appropriate population aggregation and good economic conditions, so they should the key areas of industrial and urban development (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). The optimised and key development areas both belong to urbanised areas with basically similar development content and differing in development intensity and modes.

The restricted development areas are classified into two types (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007) : One is the major production area of agricultural products, that is, the areas with more farmland and better agricultural development conditions. Although they are also suitable for industrial and urban development, in view of the demand for guaranteeing the safety of national agricultural products and the sustainable development of Chinese people, it must be regarded as the priority of the development to strengthen comprehensive agricultural productivity. Thus, such areas should be restricted from carrying out large-scale intensive industrial and urban development. The other type is the key ecological function area, that is, the areas with a fragile ecosystem or important ecological functions and low bearing capacity in resource and environmental terms without the conditions for large-scale intensive industrial and urban development, where it should be regarded as the priority to enhance the productivity of ecological products (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). Thus, such areas should be restricted from carrying out large-scale intensive industrial and urban development.

The prohibited development areas are legally set natural and cultural resource protection areas of different levels and types, and other key ecological function areas prohibited from industrial and urban development and requiring special protection (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). The national level prohibited development areas include national level natural protection areas, world cultural and natural heritages, national level scenic areas, national forest parks and national geological parks. The provincial level prohibited development areas include natural and cultural resource protection areas, important water origins of different types and of provincial and lower levels, and other prohibited development areas determined by the provincial people's government based on the region's specific demands. Various major function zones are of similarly important status within the national economic and social development, only differing in development modes, protection content, development priorities and focus of national support (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). The urbanised areas are mainly supported in terms of population aggregation and economy; the major production areas of agricultural products are mainly supported to strengthen their comprehensive agricultural productivity; the key ecological function areas are mainly supported to protect and repair their ecological environment.

The following significant relationships should be handled well in order to promote and form the major function zones:

(i) The relationship between the principal functions and other functions (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007):

The principal function does not mean the sole function. To determine the principal function of a region, its principal development targets, and the major development tasks is not to exclude other functions from the region.

As urbanised areas, the optimised and key development regions have the principal function of providing industrial and service products and aggregating population and economy, but also have secondary functions including protecting the basic farmland and other agricultural space within the region, protecting ecological space like forests, grassland, water surface and wetland, and providing certain amount of agricultural and ecological products.

As major production areas of agricultural products and key ecological function areas, the restricted development areas have the principal function of providing agricultural and ecological products and guaranteeing the national agricultural supply safety and ecosystem stability, but they are also allowed to develop energy and mineral resources properly, to develop those industries without impact on the principal function positioning and that are bearable for the local resources and environment, and to carry out necessary urban construction. The prohibited development areas should be protected compulsively in compliance with all relevant laws. The government provides public services and strengthens social administration for various major function zones in order to properly fulfil its responsibilities.

(ii) The relationship between the major function zones and agricultural development (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007):

To treat the major production areas of agricultural products as restricted regions prevented from large-scale intensive industrial and urban development is to practically protect that kind of farmland with outstanding agricultural conditions to enable it integrate various resources to develop modern agriculture and keep improving its comprehensive agricultural productivity.

Meanwhile, this approach will also integrate more national policies for strengthening and favouring the agriculture into that kind of regions so as to ensure continuous increase in rural workers' income and constant improvement in the rural quality of life. Besides, by developing proper non-agricultural industries in counties by means of centralised layout and point-to-point development, problems including the excessive occupation of farmland resulting from excessively decentralised industrial development can be prevented.

(iii) The relationship between the major function zones and the overall strategy of regional development (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007):

To promote and form the major function zones is to properly implement the overall strategy of regional development, to deepen and specify regional policies and to support coordinated regional development more vigorously. Setting the Circum-Bohai Sea, the Yangtze River Delta and the Pearl River Delta as optimised development regions was done to strengthen these kinds of regions with dense populations, highly intensive development and resource and environment overload, in order to usher in the transformation of economic development modes as well as the promotion of industrial transfer, and thus to allow more development space for the central and western regions.

To set some of the areas in the central and western regions with stronger bearing capacity of resources and environment and outstanding population aggregation and economic conditions is to guide production factors to integrate in such areas to promote industrialisation and urbanisation and hasten economic development. To set some areas in the western regions without the conditions for large-scale intensive industrial and urban development as key ecological function areas restricted from development is to better protect the ecological productivity of those kinds of areas, to concentrate and implement more national policies in favour of ecological environment protection and livelihood improvement in those kinds of areas and to improve the local public services and living conditions as quickly as possible.

(iv) The relationship between the government and the market (Fan et al, 2012; He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007):

The division of the major function zones is determined based on natural and economic rules, on the comprehensive assessment of bearing capacity of resources and environment and through sufficient communication and coordination between different departments and different regions. In order to promote the formation of the major function zones, the relationship between the government and the market must be handled properly, by exerting the government's role of scientific guidance and more giving play to the basic role of the market in resource allocation.

The government's major responsibility for promoting and forming the major function zones is to specify the positioning of the principal functions and accordingly allocate public resources, enact laws, regulations and regional policies, comprehensively apply various methods to guide the main market players to develop in order according to the positioning of relevant regional principal functions so as to promote overall, coordinated and sustainable development of the economy and society. The formation of the principal function positioning in the optimised and key development areas mainly relies on the market mechanisms properly playing their roles. In comparison, the government mainly guides the production factors to integrate into those kinds of areas by releasing plans and formulating policies. To form the positioning of the principal functions in the restricted and prohibited development areas, the development activities in breach of the principal function positioning must be restrained by enacting laws and regulations and planning systems, and the local people's government and the main market players should be guided by setting compensation mechanisms to enable them to consciously promote the principal function construction.

2) Ecological functional zoning

Ecological functional zoning is the process of dividing different ecological functional zones by consolidating their similarities and dissimilarities and fully considering the unique ecological environment characteristics and ecological problems of the region (Bai et al, 2016; Lü et al, 2013; MEP, 2015; PRC, 2010). It identifies the structural and functional differences of the ecosystem. It is mainly about realizing spatial segregation on the basis of ecological environment sensitivity and importance of ecological services (Bai et al, 2016; Lü et al, 2013; MEP, 2015; PRC, 2010).

The regions are more or less homogeneous and yet different from other regions. Ecological zoning is about applying ecological principles and methods to divide ecological environment into regional units (Bai et al, 2016; Lü et al, 2013; MEP, 2015; PRC, 2010). An ecological zone integrates ecosystem with the region; ecology with geography. In classifying and dividing ecosystem complexes, full consideration is given to the characteristics of ecosystems and the environmental factors that drive ecosystem changes, resulting in functionally similar ecosystem combinations called 'ecological zones' (Bai et al, 2016; Lü et al, 2013; MEP, 2015; PRC, 2010). They are comprehensive results of multidisciplinary knowledge.

An ecological zone is an area that occupies a specific position on the surface of the earth. It is a basic model that helps understand the complexity of an area. It is unique in terms of physical environment and human use. It makes full use of the ecological zone framework system and moves from single land resource management to the management of the entire ecosystem to actualize ecological monitoring, biological conservation, and sustainable development of resources and environment (Bai et al, 2016; Lü et al, 2013; MEP, 2015; PRC, 2010).

At present, the most influential ecological zoning frameworks in the world are from the United States, represented by the Omernik's ecological zoning system developed by the U.S. Environmental Protection Agency (Omernik, 1987), the Bailey (1989) ecological zoning system developed by the U.S. Forestry Service, and the World Wide

Fund's ecological zoning framework for the North America. The discussions on ecological zoning have been hot since the United States published its first ecological map in 1987. It is complicated to consider the value of ecosystems and environmental resources from economic and political perspectives. In 2004, Omernik improved, elaborated, and synthesized a more detailed four-level space unit based on the 1987 ecological zoning program (Omernik, 1987). The new version reflected the differences and similarities between ecosystems and discussed the development process of mapping zones.

Three main characteristics:

1) It is based on the structure, function, and composition of an ecosystem, with less consideration to human factors, while ecological zones are divided on a certain scale, with emphasis on scale and degree.

2) Its research focus is on the interconnection of natural systems and the impact of human activities on ecosystems is downplayed, while the structure of ecological zone is defined by the concept of potential natural ecosystem.

3) Its purpose is to manage and protect resources and environment. It regards biodiversity as the core of an ecosystem, and zones with typical habitat characteristics and rich biodiversity are valued in the zoning process.

Study on the method of ecological functional zoning

Affected by regional differences in environmental elements and human interference of varying degrees, the structures and functions of ecosystems are somewhat different and complex (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010). Such differences in quantitative and relative importance are irrelevant to regional size or scale. This means that researchers cannot absolutely understand ecosystems; researchers can only try to understand them through maps, models, and classifications. Multi-level zoning must be adopted to faithfully reflect regional differences in ecological environmental characteristics, ecological environmental sensitivity, and importance of ecological service functions in ecological functional zoning, thereby enabling it to truly guide environmental protection in light of local conditions (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010).

Ecological functional zoning is a multi-level classification system. It can either divide areas with similar differentiation laws into different levels from top to bottom, or combine small geospatial units with identical properties into groups of higher levels using a bottom-up approach (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010). The zoning method needs to grasp the overall characteristics of the area from a macroscopic perspective. The grouping can be realized through computer or GIS software, which is a simplified method. So far, no evidence has proven the absolute advantage of any method, and perhaps the combination of the two can yield results that are more satisfactory (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010).

Hargrove & Hoffman (1999) proposed a quantitative research method for multivariate spatial clustering analysis. They believed that this quantitative method was reproducible and could be applied to any other areas quickly once the technique and approach were mastered (Hargrove & Hoffman, 1999). This process is implemented by statistically analysing (principal component analysis, cluster analysis, etc.) the digital map formed by environmental factors (soil, temperature, etc.) (Hargrove & Hoffman, 1999). However, this quantitative method has a defect. Its research objects include all players in an area and the zoning results are limited by data quality and availability. At the same time, the zoning method based on GIS and statistical analysis and assumptions based on the dominant factors for scale zoning are not objective (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010). The use of a qualitative method does not reduce the rigor and effectiveness of zoning results. Therefore, in conducting a spatial analysis of ecological functional zoning, adding human subjective judgments based on actual conditions, perfecting ecological functional zoning, and improving the ecological function zoning index system will more accurately reflect the reality in results.

Furthermore, computer technology, mapping technology, remote sensing, and geographic information system technology have been rapidly developed and applied to ecological functional zoning since the 1990s, thereby providing important tools for data collection, analysis, and zoning (Bai et al, 2016; Guo et al, 2018; Large & Gilvear, 2015; Lü et al, 2013; MEP, 2015; PRC, 2010). They play an important role in increasing the accuracy of delineation in ecological zones, the quality of map products, and the efficiency of data management. However, traditional geographic analysis, synthesis, and zoning techniques are poorly used. This is not to say that modern geospatial information technology and computer analysis technique should not be used in the zoning process. It is only advised that the application potential of advanced computer technology and quantitative methods in ecological functional zoning deserves in-depth study and it is need to explore comprehensive integrated methods that include the intelligence of expert individuals and groups, philosophy analysis, and model application (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010).

Although ecological functional zoning has been practiced for many years and its results have been widely used in resource management assessment and protection, no universally applicable theoretical basis and framework has been developed so far (Bai et al, 2016; Guo et al, 2018; Lü et al, 2013; MEP, 2015; PRC, 2010). The author believes the following:

1) The research results of ecological functional zoning mainly focus on two aspects: theoretical research on the principles and methods of ecological functional zoning; and empirical research on regional ecological functional zoning, mainly various types of administrative regions. However, there is still a lack of theoretical and technical research on water ecological functional zoning in river basins. Therefore, it is necessary to conduct more research in this regard.

2) Ecological functional zoning is meant for one or more specific purposes. However, it has been applied far beyond the original purpose and its results are closely related to urban planning, overall land use planning, and ecological red line delineation. Studying the application of ecological functional zoning to understand what kind of zoning is needed now or in the future, who applies it, and how to customize zoning can help us improve the zoning process.

3) Users ought to formulate policies or management decisions having significant economic and social influences after the rationality of an ecological functional zoning program has been examined. Therefore, it is necessary to provide additional education for users or potential users. The zoning results should be used for ecosystem management and conservation planning in an efficient way.

3) Ecological cropland management and ecosystem services

According to the Regulations on the Protection of Basic Farmland, amended in 1998, 'Basic farmland refers to specially protected arable land that may not be occupied (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). Such an area is demarcated per the agricultural demands of the population and the national economy with due considerations to the overall land-use planning.' The regulations also stipulate, 'Protected areas of basic farmland refer to any areas delimited in accordance with the overall land use planning and legal procedures aimed at protecting basic farmland'(Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). During this period, basic farmland can be understood as high-quality arable land with a certain number of protection indexes, which may not be occupied once demarcated. As the protection of basic farmland became a pressing issue, the Decision of the Central Committee of the Communist Party of China on Several Major Issues in Promoting Rural Reform and Development made on the Third Plenary Session of the 17th CPC Central Committee proposed a clear method of demarcating the new ecological cropland function zone. Meanwhile, the New Revised Overall Land Use Planning (2006-2020) calls for scientific demarcation of 'ecological cropland area' and comprehensive enhancement of 'ecological cropland area' protection (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). It also lays equal emphasis on 'ecological cropland area protection and construction, quantity and quality, and production functions and ecological functions'.

Problems in delineation of the ecological cropland function zone (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013):

The qualifications for an arable land to become the ecological cropland area are ambiguous, and there are no scientific, quantitative standards. At present, the policy considers over 80% of arable land as basic farmland, without specifying its conditions and characteristics (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). The concept is ambiguous, and the qualifications for being delineated as basic farmland are unclear. Consequently, counties and districts with a faster rate of economic development demarcate little basic farmland while those that develop slowly fully reach the standard of basic farmland protection. The relationship between development and land use has been lopsided.

(1) Delineation of ecological cropland area focuses on administrative implementation and lacks an assessment system

Delineation of ecological cropland area is considered as a policy operation that is performed by townships in line with the targets set by superiors according to national regulations. Currently, there is a lack of a scientific assessment system for ecological cropland area demarcation (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). Meanwhile, the traditional assessment system of arable land tends to focus on farmland quality, and the assessment of basic farmland demarcation is done by "taking or borrowing from" other assessment methods.

(2) No arable land is reserved for economic construction, while demarcated ecological cropland area runs into conflict or is poorly coordinated with social development.

With basic farmland as the "high tension line", local governments of some areas exploit all, and not just traditionally partial farmlands, to meet the land needs of economic development (Dong et al, 2011; Liu et al, 2014b; Qian et al, 2013). This violates the main purpose of national regulations and policies. The governments neglect the need for coordination between ecological cropland area and socioeconomic development and demarcate basic farmland blindly, thereby destabilizing basic farmland.

(3) Ecosystem services provision of ecological cropland area are poorly understood and underestimated.

Demarcation of ecological cropland area is normally centred on its production function while ignoring its multiple ecosystem services. A city lacking basic farmland loses its "green heart" and the essential quantum of "green belts". Moreover, the absence of basic farmland between cities can unshackle the land use for urban development. It can distance cities from each other and lead to a continuous and disorderly expansion of cities, leading to the creation of "road cities". Meanwhile, basic farmland demarcation also neglects the need for protecting farmers' survival and employment. When farmers lose their basic farmland, they are likely to be deprived of job, land, and social security. Social stability will then be seriously affected.

2.5.4. The delineation of ecological red line

In 2001, the Ministry of Environmental Protection and the Chinese Academy of Sciences had compiled the first draft of the *National Ecological Function Zoning Regulations* on the basis of the work of regionalization of ecological functional zoning and the status of the national ecological environment in Gansu province (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

In May 2007, the national ecological function zoning was formed. In July 31, 2008, the state formally promulgated and implemented the national ecological functional zoning. Among them, the country was divided into 216 ecological functional zones, including 148 ecological functional zones with ecological regulation function (78% of the territory area), 46 ecological functional zones (21% of the territory area), and 22 residents protection function zones (1% of the territory area) (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). The policy implications of ecological functional zoning mentioned was fundamental to the establishment of the ecological red line, which had a guiding role for the construction of regional ecological system.

1) Regional ecological function zones' delineation in China

According to the national requirements and deployment of the national ecological functional zoning, Jiangsu Province completed the ecological functional zoning work in August 2004, and divided the province into 3 ecological zones, 7 ecological subregions and 33 ecological functional zones (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007).

In February 2009, the regional planning of important ecological function protection areas of Jiangsu Province was promulgated and implemented, and initially the construction of ecological space management and control pattern. Since then, Sichuan, Fujian, Shanxi and other provinces had also promulgated and implemented the ecological functional zoning of the corresponding regions, which laid the theoretical and practical basis for the delineation of other province and region's ecological control lines and ecological red lines (He et al, 2018; Liao et al, 2013; Lü et al, 2013; Xinzhang et al, 2007). In 2005, Guangdong Province promulgated and implemented *the Plan for Environmental Protection of the Pearl River Delta (2004 - 2020)* and delineated the regulation area of "*the regulation of the red line, the promotion of the green line and* *the construction of the blue line*".

In the same year, under the pressure of urban construction land expansion and the rapid decrease of urban natural ecological space, the Shenzhen municipal government promulgated and implemented *the Regulations on the Management of Basic Ecological Control Line of Shenzhen*, established the management system of basic ecological control line, and promulgated and implemented "*the Implementation of the Management of the Basic Ecological Control Line in Shenzhen*" in 2007. Shenzhen had become the pioneer and benchmarking of the national ecological control line. It had a foundation for the delineation of the ecological control lines in other areas and even the country. It was a great leap in the work of delineation the ecological function zone in the zoning.

With the efforts of the state to promote the demarcation of the ecological red line, the work of delineating the ecological red line has also entered a period of vigorous development. In 2013, Jiangsu Province formally promulgated and implemented '*Jiangsu Province Ecological Red Line Regional Protection Plan*', Wuhan city also promulgated the 'Wuhan Urban Development Zone 1:2000 basic ecological control line planning'. In the same year, Hebei Province, Gansu Province, Yangzhou City, and so on in the form of policy documents required to open the ecological red line. In 2014, China formally promulgated and implemented the '*National Ecological Protection Red Line of Ecological Function Baseline Delineation Technical Guide (Trial)*', not only for the national ecological function of the red line provides technical support, but also indicates that the red line delineation of ecological protection has entered the whole stage of national advancement.

2) Delineation and functional division of regional ecological red lines in the Yangtze River Delta metropolitan region

In 2011, the State Council's Opinions on Strengthening Key Environmental Protection Work and the National 12th Five-Year Plan for Environmental Protection required "designing environmental functional zones and drawing ecological red lines in ecological functional zones and ecologically sensitive and fragile zones on land and at sea" (Bai et al, 2016; Lü et al, 2013). Also, the document called for "developing different environmental goals, policies, and standards for different regions". The introduction of the ecological red line is a breakthrough in the process of ecological and environmental protection in China. It is an important measure for implementing comprehensive ecosystem management and strengthening ecological protection and management in the country. It will be very effective in maintaining national and regional ecological security and safeguarding the sustainable development capacity of China.

By the national arrangements, the provinces and cities in the YRD metropolitan region are embarking on the delineation of ecological red lines and ecological functional zones. For example, Jiangsu Province has completed the delineation of provincial ecological red lines, while Nanjing has completed the work at the municipal scale. Due to different understandings and definitions of ecological red lines, the delineation results may vary even though the delineated zones are in the same province. Moreover, Zhejiang Province has completed functional ecological zoning. For two identical zones, there can be two division versions. Now that the results are not even unified within a province, there may be greater differences when more provinces are involved and convergence can be more difficult. Therefore, it is imperative to have unified zoning at the regional scale.

2.5.5. Problems in ecological red line delineation

In the author's view, there are still some problems in the construction and implementation of the system of ecological red line system. These problems have hindered the development of the system and the security function, which are mainly manifested in the following aspects.

There is a lack of transboundary regional coordination mechanism

In some areas, the ecological red line is delineated, and some areas are delineated in accordance with the guidelines of the guide, and lack exploration and local characteristics in the actual implementation. At the same time, the lack of coordination policy among the corresponding regions will definitely affect the implementation effect of the ecological red line system.

Ecological functional zoning requires detailed geo-ecological spatial data.

With the available incomplete data of the Yangtze River Delta metropolitan region, the credibility of ecological red lines and ecological functional zones that have been delineated is doubtful. Based on incomplete regional database of the Yangtze River Delta metropolitan region, the local governments only have made initial attempts in ecological functional zoning (Bai et al, 2016; Lü et al, 2013). The results serve as reference only and need to be refined in the future. Although some work has been done on the delineation of ecological red lines, the delineation methods are mostly simple and extensive. Mainly borrowed from other methods, they simply define important functional areas, nature reserves, scenic spots, and historical sites as the basis for delineating ecological red lines. However, due to the arbitrariness and subjectivity of existing nature reserves and important ecological function areas, and the fact that space-time scale may change over time, it is not appropriate to simply borrow other methods using a simpleton approach.

2.6. Summary

Ecosystem services are defined as the contributions of ecosystem structure and function to human well-being. This implies that mankind is strongly dependent on well-functioning ecosystems and natural capital that are the basis for a constant flow of ecosystem services from nature to society. Therefore, ecosystem services have the potential to become a major tool for environmental policy and decision making. Comparing with other approaches, Burkhard et al's matrix-based ecosystem service approach combines GIS (geographical information system) and spreadsheets analysis of LULC input data to produce maps of ecosystem services supply and/or demand. It combines GIS LULC layers and scored values for the provision of ecosystem services to provide ecosystem services provision maps across a study area. By using standardised values, ecosystem services provision may be compared between regions or, by using locally targeted ecosystem services values, more locally appropriate values can be generated. The process can be undertaken with stakeholders to allow maps of both ecosystem services supply and demand to be mapped. Burkhard et al's Matrix-based approach is suitable for rapid spatial decision-support in the Yangtze River Delta Region for the following reasons:

Generate quick results for rapid decision making: The ecological and environmental problems in the Yangtze River Delta are urgent. Rapid urbanization is causing rapid damage to the ecosystem of the Yangtze River Delta, resulting in the rapid loss of ecosystem services. Taking advantage of expert knowledge, Burkhard et al's approach can generate quick spatial results and is conducive to the rapid environmental policymaking in the region. With a minimum of resources, maps for decision support can be obtained, with known reliability and high credibility.

Provide an effective decision support tool in a data-poor region: The database of the ecological, economic and social systems in the Yangtze River Delta is not perfect enough to meet the needs of decision-making and evaluation of scientific systems. Engaging expert knowledge to provide estimates of ecosystem services supply, locations or contexts where a given dataset is not providing quantitative information, Burkhard et al's approach is suitable for rapid decision-making in such a data-poor region. This is a highly effective way of filling in missing data to obtain a dataset which allows the creation of a map.

Design matrix linking spatial explicit land cover types to ecological integrity, ecosystem services supply and demand: Burkhard's matrix direct comparison of ecosystem services supply and demand in spatial explicit maps, which is rare in spite of the wide agreement about the importance of including the demand side into ecosystem services assessment. In the early stage, the assessing, mapping of ecosystem services were focused on the monetary value of ecosystem services supply, but ignored the non-market value and the demand side (Burkhard et al, 2014; Burkhard et al, 2012; Palomo et al, 2017). Previous studies assessed ecosystem services from the view of monetary value approach (Costanza et al, 1997; Costanza et al, 1998) and focused on the assessment and mapping of supply of ecosystem services (Egoh et al, 2008; Mensah et al, 2017; Yaneva, 2016). The direct comparison of ecosystem service supply and demand in spatially explicit maps was rather rare in spite of the wide agreement about the importance of including the demand side into ecosystem service assessments (Burkhard et al, 2014; Burkhard et al, 2012; Palomo et al, 2017). This matrix-based approach can be applied with very limited technical expertise. However, the more the matrix values rely on expert knowledge rather than quantification with primary data, the more they are open to the critique of over-simplification and subjectivity, particularly when compared to primary data or more detailed modelling approaches.

As an interdisciplinary approach, multiple spatial environmental theories were integrated in the spatial assessment and management of ecosystem services. For environmental and managerial problems and driving forces identification, scientific analysis models such as DPSIR models has been introduced for assessment of ecosystem conditions and Impact on ecosystem services. In the author's view, the Yangtze River Delta metropolitan region's ecological red line management conformed to the frameworks of ecosystem management. The decision makers might make proper responses according to the impact of the state on the ecosystem and the origin of the state (driving forces and pressures) to realize the goals of ecosystem completeness and connectivity of ecological red-line division and management. The DPSIR model, which is comprehensive, systematic, integral and flexible, places a great deal of importance on the relationship between economic operation and its environmental impact. It can unveil the causality between environment and economy, and effectively integrate resources, development, environment and human health. The above characteristics make DSPIR an important tool for ecological red-line division and management. For managing the spatial distribution and spatial relations of ecosystem services, environmental management theories and methods such as ecological function zoning and landscape planning were also being explored and applied. After reviewing the research progress of approaches, the application environment for the choosing ecosystem service approach should be described in the next chapter. Therefore, the socio-ecological characters of the study area will be introduced in the next chapter.

Chapter 3 Socio-ecological context and driver-pressure-state-impact-response analysis of the Yangtze River Delta metropolitan region

3.1. Introduction

The Yangtze River Delta metropolitan region is located in a strategic position which plays a key role in regional urbanization and economic development in China (Haas & Ban, 2014; Han et al, 2017; Li et al, 2016a; Tian et al, 2011). The estuary of the Yangtze River, which is called the "Gold Coast" or "Golden Waterway (for shipping)," is located in this region (Tian et al, 2011; Wei et al, 2015; Zhang, 2010). It is both an ecologically fragile and economically developing zone. The Yangtze River Delta Urban Agglomerations are mainly distributed in the coastal areas in Shanghai, south Jiangsu and north Zhejiang. They are the economic driving force in this region, and as a result also have a high demand for ecosystem services. As a result, they have both pros and cons. The ecosystem in Shanghai and in cities in Jiangsu Province cannot satisfy their high demand themselves, due to the rapid development of the Yangtze River Delta metropolitan region. In addition, ecosystem service values in Shanghai and Jiangsu have significantly decreased in the recent years. For example, the total ecosystem services value of Shanghai decreased from 4718.1 to 3263.6 million RMB Yuan from 1994 to 2006 due to urbanization (Su, et al. 2014).

In addition, regional environmental problems which cannot be solved only by Shanghai, Jiangsu and Zhejiang, such as the Taihu Lake Watershed Water Pollution problems, need cross-provincial management (Jiao et al., 2014). If Shanghai, cities in Jiangsu Province and cities in Zhejiang Province only focused on their own development planning and are unable to establish cooperation mechanisms related to ecosystem services for the whole region, it will finally not only have a negative impact on the entire regional ecosystem, but also destroy sustainable development in the Yangtze River Delta Region. It is therefore urgent to establish environmental planning and cooperation for the whole region through an ecosystem services approach.

In addressing these issues, this chapter introduces the regional scope in section 3.2, the socio-ecological context of the ‘Yangtze River Delta metropolitan region in section 3.3, and the driver-pressure-state-impact-response (DPSIR) analysis in section 3.4. In this way it establishes the scientific basis of the author’s ecosystem services assessment and management framework application results contained in the next three chapters.

The research objective of this chapter is problem identification through analysis of causes for the decline of the ecosystem services in the Yangtze River Delta region.

The research questions addressed in this chapter are:

What are the pressures driven by urbanization and economic growth, the state of the ecosystem and the stock of ecosystem services, and aims of environmental management responses for mitigating negative impact on ecosystem services in the Yangtze River Delta metropolitan region?

3.2. Study Area

3.2.1. Physical geography of the Yangtze River Delta

The region’s boundary encloses New Tongyang Canal in the north, Hangzhou Bay in the south, and the hills in Ningzhen in the west. The entire area is bowl-shaped and tilts toward the Taihu Lake. Therefore, it is also known as the Taihu Lake Basin (Ai et al, 2015; Zhang et al, 2017b). This region is widely recognized in physical geography studies and is often referred to by Chinese scholars and government agencies as a “Small Delta”.

Over the past few thousand years, the Yangtze River Delta was formed because of the eastward movement of the entrance based on the depression in Taihu Lake. Conditions for organism growth and distribution of ecosystems emerged in the gradually formed terrestrial ecosystem because of the varying times of formation. They also influence the layout of economic activities.

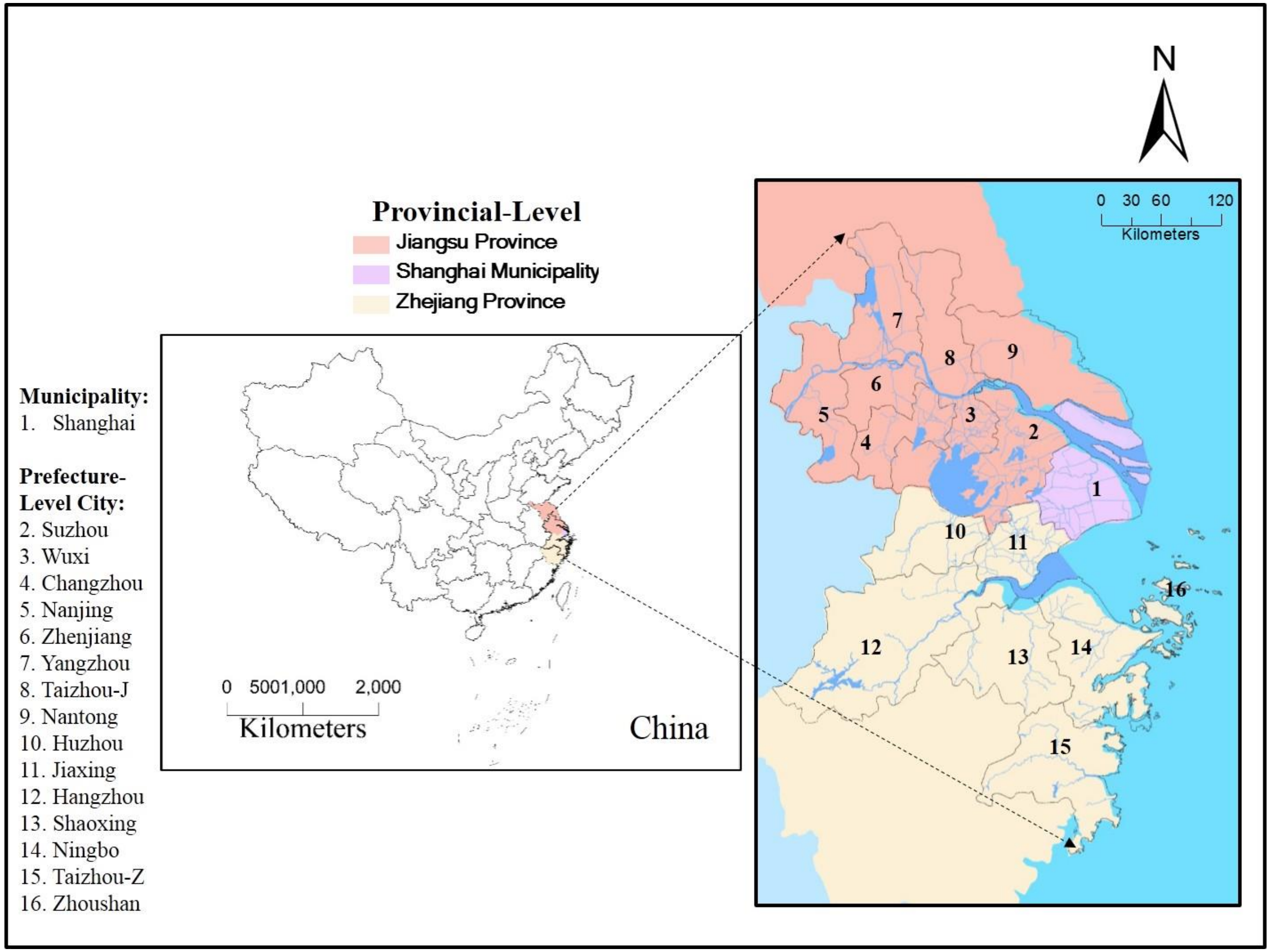

Figure 3.1 Map for the location, and sixteen core cities of the Yangtze River Delta metropolitan region, china

3.2.2. Economic geography of the Yangtze River Delta

In 1992, there were 14 prefecture-level cities in the Yangtze River Delta metropolitan region. By 2003, Taizhou (originally subordinate to Yangzhou and later a specifically designated city), as well as 16 prefecture-level cities, covered a total area of 109,600 km^2 in the region. They include eight prefecture-level cities along the Yangtze River in Jiangsu Province: Nantong, Wuxi, Changzhou, Taizhou, Yangzhou, Nanjing, Zhenjiang, and Suzhou; and seven prefecture-level cities in northern Zhejiang: Hangzhou, Jiaxing, Huzhou, Ningbo, Shaoxing, Zhoushan, Taizhou and Shanghai (Haas & Ban, 2014; Wei et al, 2015).

This scope not only covers the boundaries in physical geography, but also encompasses the economic relationship between regional cities (Fig.4.1). This spatial delineation is widely adopted by scholars and government agencies. For example, the Regional Plan for the Yangtze River Delta metropolitan region, formulated by the National Development and Reform Commission, and the Urban Group Planning for Yangtze River Delta, organised by the Ministry of Housing and Urban-Rural Development, also adopt this definition.

3.3. Socio-ecological context of the Yangtze River Delta metropolitan region

3.3.1. Climate

The Yangtze River Delta metropolitan region is located in China’s biggest estuarine delta alluvial plain of the subtropical monsoon climate zone, which has warm, humid weather and abundant rainfall (Fu et al, 2013a; Zhou et al, 2016a). It had four distinct seasons, and the temperatures of winter and summer differ significantly:

It is rich in water, heat and light conditions. The wind direction is from southeast to northwest in spring and summer, while it is from northwest to southeast in autumn and winter; The range of average annual temperatures is 15℃ ~ 16℃, in the coldest month is 2℃ ~ 4℃ and the 27℃ ~ 28℃ in the hottest month. The range of the accumulated temperature above 10 is 4750℃ ~5200℃. The growth period of vegetation is 225 to 250 days; The annual rainfall is l000 ~ 1400 mm, while the frost-free period is 230 to 250 days, so the seasonal distribution is uniform (Fu et al, 2013a; Zhou et al, 2016a).

3.3.2. Landform

There is large spatial heterogeneity in the terrain features of this region (Fig.3.2). Plains cover the main body of the north of the region, while the mountainous areas predominate in the south of the region.

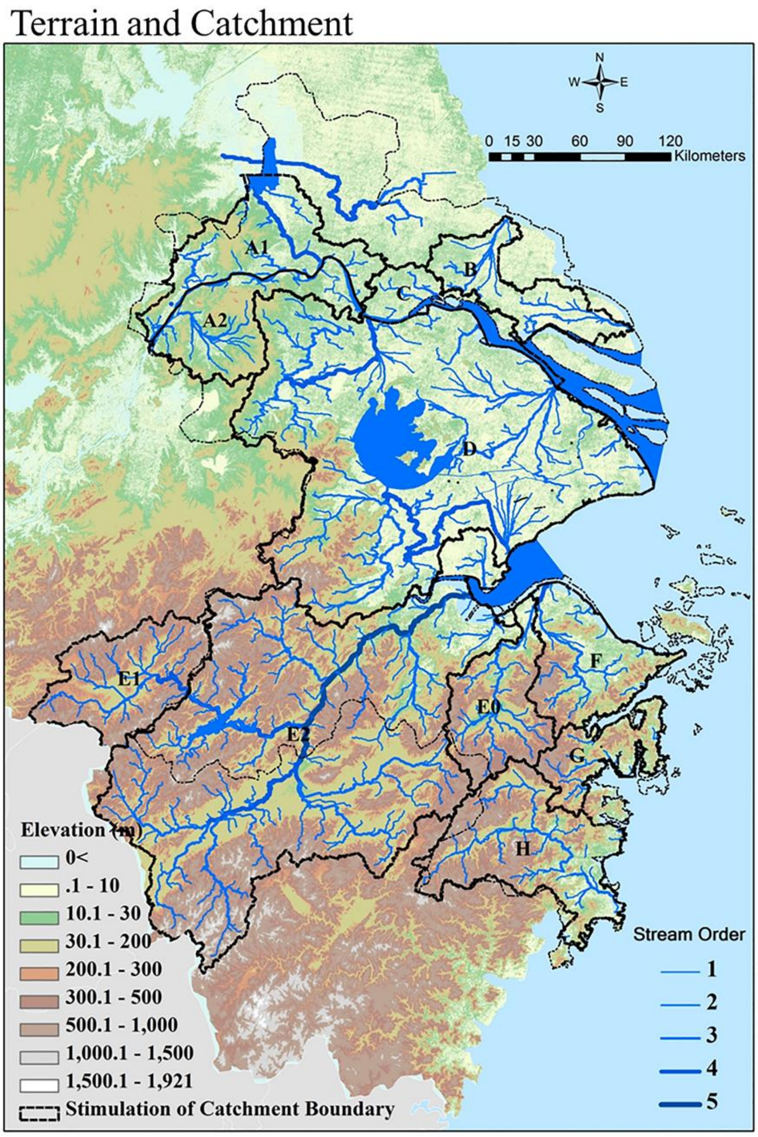

Figure 3.2 Map of the terrain of the Yangtze River Delta metropolitan region

The terrain of the region is high in the west and low in the east, and high in the south and low in the north. The plain areas are mainly distributed to the north of the Yangtze River and the Taihu Lake Basin, and in the north of the Zhejiang Province. The elevation of the plain areas is below 10 metres. The hilly areas are mainly distributed in the west of the Yangtze River and the Taihu Lake Basin. The elevation of the hilly areas is between 10-30 metres. The mountainous areas are mainly distributed to the north of the Yangtze River and the Taihu Lake Basin, and to the south of Zhejiang Province. The elevation of the lower mountainous areas in the north of the Yangtze River and the Taihu Lake Basin is mainly between 30-300 metres, while the elevation of the highest mountainous areas in the south of the Zhejiang Province was mainly between 300-2000 metres.

The mountains and hills in the west and south of the Yangtze River Delta region occupy about one-third of the entire region. The mountains are small, such as Tianmu Mountain, Mogan Mountain, and mountains in Ningzhen and Yili. They are home to natural and artificial forests. Meanwhile, most parts of the north central area are low-lying. They are an important part of the middle and lower reaches of the Yangtze River. They are traditional production bases of grain, cotton, and food oil. In contrast, the central area teems with urban agglomerations.

3.3.3. Ecosystem

The region's complex geographical environment has accommodated a variety of ecosystems: aquatic ecosystems (including salty and freshwater ecosystems, such as oceans, lakes, and rivers), wetland ecosystems (including wetland ecosystems, such as coastal, riverfront, and lakeside), and terrestrial ecosystems (including forests, shrubs, grasslands, farmland, and urban ecosystems) (Fu et al, 2013a; RPYRDR, 2010). These ecosystems provide various ecosystem services, such as food production; fresh water supply; habitat; climate, drought and flood mediation; pollution control; soil and water conservation; and recreation and entertainment.

Forest Ecosystems

Forest ecosystems are mainly distributed in the mountainous areas situated in the southwest of the Yangtze River Delta. Hillocks and low mountains are sparsely distributed in the central and western regions, accounting for more than one-third (33.6%) of the entire area (Fu et al, 2013a; RPYRDR, 2010). Known as the "Lungs of the Earth", forests cover all the functions of an ecosystem. They are the most important type of ecosystem in the region. Most of the forest areas of the region are secondary forests, restored to varying degrees, in addition to natural or semi-artificial timber forests. In recent years, bamboo forests, for economic forestry, have been expanded in large areas in Zhejiang Province. They have greatly threatened the natural restoration of zonal communities.

Wetland Ecosystems

Known as the 'Kidneys of the Earth', wetlands are a transition between land and aquatic ecosystems. There are three major categories of wetlands in the region: coastal wetlands, shoal and island wetlands, and low-lying lake wetlands (Fu et al, 2013a). Coastal wetlands are mainly distributed on the banks of the Yangtze and Qiantang rivers and along the coasts. They fall midway in the routes of migratory birds in Asia and the Pacific, and are home to more than 150 species of birds, of which 17 are included in the national protection list; They also house 81 species of macrobenthos and 332 kinds of fish, of which 19 are included in the catalogue of national key protected wild animals (RPYRDR, 2010; Zhou et al, 2016a).

Meanwhile, shoal and island wetlands are mid-channel bars formed from siltation (Huang et al, 2010; Zhang et al, 2012): They have low and flat terrain, and predominantly host moss and reed communities. Low-lying lake wetlands are the most prevalent in this region. They are mainly distributed on the north side of the Taihu Lake, and in the Suzhou-Wuxi-Changzhou River Network, and the water network in the north of Shaoxing. These wetlands are dotted with large and small lakes with lush aquatic plants and hygrophilous vegetation divided into communities of moss, reed, cattail, and wild rice shoots. Moreover, emergent aquatic plants include lotus, arrowhead, etc., while floating plants include communities of ridge, water chestnut, water lettuce, water hyacinth, and alternanthera philoxeroides (Huang et al, 2010; Zhang et al, 2012). The latter two species proliferate in eutrophic waters and result in invasion hazards that affect water quality and navigation.

Cropland Ecosystems

The plain areas in the Yangtze River Delta have been developed as high-yield croplands suitable for crop growth, except some particularly low-lying areas (Fu et al, 2013a; RPYRDR, 2010; Zhou et al, 2016a). Also, flood-prone areas are developed into paddy fields, while areas unfavourable to irrigation are developed into rainfed cropland (Fu et al, 2013a; Zhou et al, 2016a). The main crops in these areas are rice, wheat, cotton, and rapeseed. Unique field patterns have taken shape in some areas. There are three harvests a year in the south and two in the north. Following the country's reform and opening-up and the development of township enterprises and expansion of cities, cropland has been extensively occupied. The rampant use of pesticides, chemical fertilisers, and sewage irrigation has led to increasingly polluted farmland soil and imbalance in cropland ecosystems. Agricultural water loss and soil erosion are important surface sources of water pollution in the region.

River and Lake Ecosystems

There are numerous lakes in the Yangtze River Delta region. They cluster around the Taihu Lake in the central area, with Gaoyou Lake being the northern centre. Also, there are some small lakes in the south, while there is a large-scale artificial lake named Qiandao Lake in the west (Fu et al, 2013a; RPYRDR, 2010; Zhou et al, 2016a). There are dense river networks in the Yangtze River Delta (Huang et al, 2010; RPYRDR, 2010; Zhang et al, 2012). The Yangtze River is the most important transit river in the region. It not only forms a large-scale delta, but also provides a special habitat at the Yangtze River estuary for aquatic species. Moreover, it is the largest stopover station for migratory birds in the West Pacific coast. In particular, it provides abundant water resources for industrial and agricultural production and urban development of the region (Huang et al, 2010; Zhang et al, 2012).Qiantang River is the second largest river in the region. Because of its special estuary form, a phenomenal tide view is shown every year, attracting many tourists from China and abroad. However, most of the rivers and lakes have been seriously polluted, and water ecosystems have been seriously degraded due to the high levels of economic and urban development and inadequate protection of the region (Huang et al, 2010; Zhang et al, 2012).

Urban Ecosystems

Owing to the geographical advantages of the Yangtze River Delta and great opportunities brought by the country's reform and opening-up, cities in the region have developed by leaps and bounds (Huang et al, 2010; RPYRDR, 2010; Zhang et al, 2012). The region has become the sixth largest urban agglomeration in the world, with Shanghai at the centre and supported by mega-cities such as Nanjing, Hangzhou, and Suzhou. However, from an ecological perspective, these cities have various disadvantages, such as large size, high population density, low forest coverage, low per capita green space, and serious atmospheric and water pollution, which have made them uninhabitable or ecologically unhealthy. All in all, the human living environment in this region needs to be improved.

3.3.4. Water System

The water systems in the Yangtze River Delta metropolitan region consist of the Gaoyou Lake system in the north, the Taihu Lake system in the south, the Qiantang River system, and the water system of Southeastern Zhejiang. Taihu Lake and Qiandao Lake are located at the south of the Yangtze River (Fig.3.3).

There are two main rivers in the Yangtze River Delta region: the east section of the Yangtze River and the Qiantang River. Rivers and streams account for 1.38% of the total land area. The east section of the Yangtze River flows across the Taihu Lake Basin in the middle of the Yangtze River Delta region and then flows into the sea through the Yangtze River Delta estuary. The Yangtze River Estuary accounts for 0.79% of the total land area. The Qiantang River flows from the west of the Zhejiang Province to the Hangzhou Bay in the northeast of the Zhejiang Province.

There are three main lakes in the Yangtze River Delta region: Taihu Lake, Qiandao Lake, Gaoyou Lake. The lakes account for 3.01% of the total area, while other smaller water bodies account for 2.34% of the total. Taihu Lake and Qiandao Lake are located at the south of the Yangtze River. Taihu Lake is located in the middle of the region (south of Jiangsu Province), while the Qiandao Lake is located in the Qiantang River Basin, southwest of the region (west of the Zhejiang Province). Gaoyou Lake is located at the north of the Yangtze River.

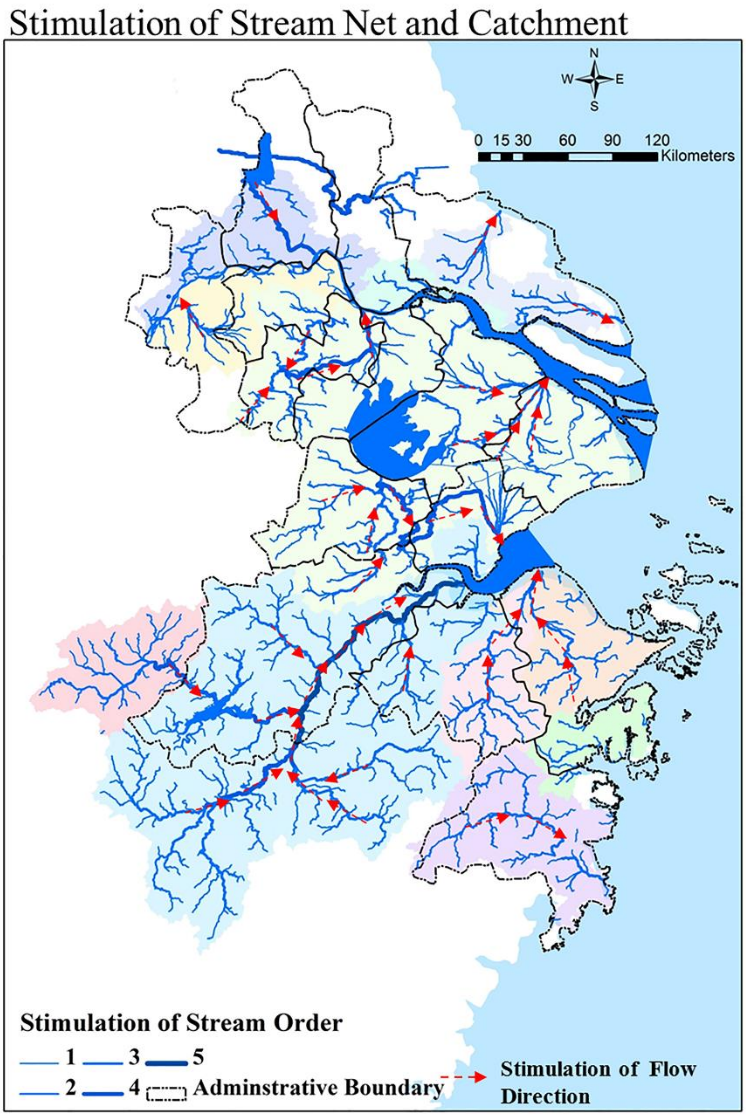

Figure 3.3 Water system in the Yangtze River Delta metropolitan region

The Yangtze River and Qiantang River pass through the middle of the region and have an important impact on the regional ecological environment. In particular, distinct climatic conditions and varying socioeconomic characteristics have shaped the area south of the Yangtze River. In an exception to the fact that the Taihu Lake Basin and the small water systems in Southeastern Zhejiang are fully included in the region, the Yangtze River and Qiantang River are parts of downstream and midstream areas that bring together incoming water from upstream provinces. The number of water resources and the quality of water environment is easily affected by the upstream area.The water system in the Taihu Lake basin is a grille-shaped river network that was formed under complex conditions. Reflow is often found in the downstream area because of tidal effects. The low-lying land and the slow water flow further prevent the diffusion of pollutants. Major rivers and lakes in the region cover provincial-level administrative regions, leading to prominent conflicts in the water environment between upstream and downstream and environmental conflicts across administrative regions.

3.3.5. Sixteen cities

Shanghai Municipality (Cai et al, 2015; Fu & Pan, 2016; Shira et al, 2012): (Fig.3.1. City No. 6): Shanghai Municipality is located where the Yangtze River converges with the Huangpu River before flowing into the sea. As part of the alluvial plain of the Yangtze River Delta, it covers a total area of 6,340 km^2, and is densely covered by rivers, lakes and ponds. It has abundant water resources but lacks mineral resources and naturally-occurring animals and plants. Vegetation is mostly crops and artificially cultivated green trees.

Zhejiang Province (Cai et al, 2015; Fu & Pan, 2016; Shira et al, 2012):

Hangzhou (Fig.3.1. City No. 12): Located in the north of Zhejiang Province, Hangzhou is a city downstream of the Qiantang River, covering a total area of 16,596 km^2. The landforms within its surrounding region are mainly hills and some plains, with numerous rivers and lakes and abundant natural resources. Its forest coverage rate in 2014 reached 65%, but there are fewer animal and plant resources.

Ningbo (Fig.3.1. City No. 14): Ningbo is located in the east of Zhejiang Province, covering a total area of 9,816 km^2. Its landforms are mainly plains, and also some hills and basins. With many rivers, it is one of the eight river systems in Zhejiang Province, and there are islands of various sizes in its waters. The vegetation distribution is very different from east to west. There are abundant resources of wild animals and plants.

Huzhou (Fig.3.1. City No. 10): Located in the north of Zhejiang Province, Huzhou covers a total area of 5,818 km^2, with landforms descending from the southwest to the northeast. There are mostly mountains and hills in the west and plains in the east. The region is densely covered by a network of rivers.

Shaoxing (Fig.3.1. City No. 13): Located in the centre and north of Zhejiang Province, Shaoxing covers a total area of 8,279 km^2. It features various landforms descending from southwest to northeast. There are mountains in the west, centre and east, and plains in the north. There are numerous rivers and lakes and abundant resources of animals and plants.

Taizhou-Z (Fig.3.1. City No. 15): Located in the centre of Zhejiang Province, Taizhou covers a total area of 9,411 km^2. Its landforms mainly include mountains and hills as well as some plains. There are many islands scattered all over in the coastal waters. There are also many rivers and abundant resources of animals and plants, but insufficient fresh water resources.

Zhoushan (Fig.3.1. City No. 16): Located in the northeast of Zhejiang Province, Zhoushan Islands covers an inland area of 1,440.12 km^2, and is the largest base of marine products in China. There are mountains in its surrounding region. It has an underdeveloped inland surface river system, but very abundant marine and mineral resources.

Jiangsu Province (Cai et al, 2015; Fu & Pan, 2016; Shira et al, 2012):

Nanjing (Fig.3.1. City No. 5): As a downstream city of the Yangtze River located in the southwest of Jiangsu Province, Nanjing covers a total area of 6,597 km^2, mainly consisting of hills and downland. Its water area accounts for over 11% of the total area with the Yangtze River running across its city as well as many rivers and lakes. Its underground water source is rich and of outstanding quality. With various varieties of plants, the built-up area features 13.7 m^2 per capita of greenery.

Changzhou (Fig.3.1. City No. 4): Changzhou is located on the southern bank of the lower reaches of the Yangtze River and on the Taihu Lake basin plain in the south of Jiangsu Province. It covers a total area of 4,385 km^2, with abundant resources of animals and plants. Its hilly and mountainous area abounds in forest products, ranking the second in terms of bamboo yield in Jiangsu Province.

Nantong (Fig.3.1. City No. 9): Nantong is an alluvial plain surrounded by water, located in the lower reaches of the Yangtze River and in the southeast of Jiangsu Province. It covers a total area of 8,544 km^2, with very rich aquatic resources. It also boasts abundant energy and mineral resources, and produces many agricultural crops such as rice, cotton and oil materials, but it has few wild animal and plant resources.

Suzhou (Fig.3.1. City No. 2): Located in the lower reaches of the Yangtze River and the south of Jiangsu Province, Suzhou covers a total area of 8,488 km^2. Its landforms mainly include plains, accounting for over 55% of its total area, and also a few low mountains and hills. It is densely covered by rivers and lakes, with intertwining watercourses.

Taizhou-J (Fig.3.1. City No. 8): Located in the centre of Jiangsu Province, Taizhou covers a total area of 5,797 km^2, mainly consisting of alluvial plains, and densely covered by rivers and lakes. It is a national key production, processing and export base for rice, cotton and vegetables.

Wuxi (Fig.3.1. City No. 3): Located in the southeast of Jiangsu Province, Wuxi covers a total area of 4,628 km^2. Its landforms mainly include plains, and also a few low mountains. With an intertwining network of rivers, it boasts rich water resources. The total amount of herbaceous plant variety accounts for 78% of the national total, but its animal resources are less outstanding.

Yangzhou (Fig.3.1. City No. 7): Located on the eastern bank of the lower reaches of the Yangtze River and in the centre of Jiangsu Province, Yangzhou covers a total area of 6,634 km^2. There are mostly hills in the north and plains in the east. It boasts many rivers and lakes.

Zhenjiang (Fig.3.1. City No. 6): Located in the lower reaches of the Yangtze River and the south of Jiangsu Province, Zhenjiang covers a total area of 3,843 km^2. Its landforms mainly include hills, accounting for over 50% of the area. There are over 60 rivers across the city, most of which are artificial canals. It abounds in plant resources, but has few animal resources, with the exception of fish.

3.3.6. Economy

The urban area in the Yangtze River Delta metropolitan region features the most developed economy and the highest urban agglomeration level in China. As one of the regions with the most vigorous economic development in China, the Yangtze River Delta metropolitan region is regarded as a vital engine for China's economic development (Xu et al, 2014b; Zhou et al, 2016a). It is the most economically developed region in China.

The three administrative provinces differ in characteristics of land utilization: Shanghai Municipality has rapidly expanded its land allocated for construction purposes, to about 35.47% of its total area; Jiangsu Province has a large farmland area, taking up 65.51%; and Zhejiang Province boasts a larger area of woodland, covering 64.35% of its total area (2010). The national GDP in the "two provinces and one municipality" region surpassed 8.6 trillion yuan in 2010 (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). The "two provinces and one municipality" region has created 20% of the national GDP with 2% of the national territory, and boasts an annual growth rate far higher than the national average. As the economic centre of the "two provinces and one municipality" region, Shanghai boasted a GDP of over 2 trillion yuan in 2012, the highest in all of China (Shira et al, 2012; SSYB; Zhou et al, 2016a). Led by Shanghai, the two provinces of Jiangsu and Zhejiang also made excellent economic development achievements (JSYB; Shira et al, 2012; Zhou et al, 2016a; ZSYB). In 2012, the total GDP of the sixteen core cities in the "two provinces and one municipality" region approached 9 trillion yuan, indicating a sound economic foundation and a rapid pace of development (Zhou et al, 2016a).

In relation to total GDP, the leading location in 2012 of the Yangtze River Delta metropolitan region economic development is Shanghai, followed by Suzhou, Hangzhou, Wuxi, Nanjing, Ningbo, Nantong, Changzhou, Shaoxing, Yangzhou, Taizhou, Jiaxing, Taizhou, Zhenjiang, Huzhou, Zhoushan; From the point of view of GDP growth from 2011 to 2012, the largest GDP growth rate is in Zhenjiang (12.8%), followed by Taizhou (12.5%), Nantong (11.8%), Nanjing (11.7%), Yangzhou (11.7), Changzhou (11.5 %), Zhoushan (10.2%), Suzhou (10.1%), Wuxi (10.1%), Shaoxing (9.7%), Huzhou (9.7%), Hangzhou (9%), Jiaxing (8.7%), Ningbo (7.8%) Taizhou (7.5%), Shanghai (7.5%) (JSYB; Shira et al, 2012; SSYB;

Zhou et al, 2016a; ZSYB). The average annual growth rate of GDP of the sixteen cities was 10.1%, higher than the national average of 7.8% (Shira et al, 2012) .

3.3.7. Population

In 2011, the "two provinces and one municipality" region recorded a permanent resident population of 157 million people, accounting for 11.65% of the total national population. The permanent resident populations in Shanghai, Jiangsu and Zhejiang are 23,474,600, 78,988,000 and 54,630,000 people respectively (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB).

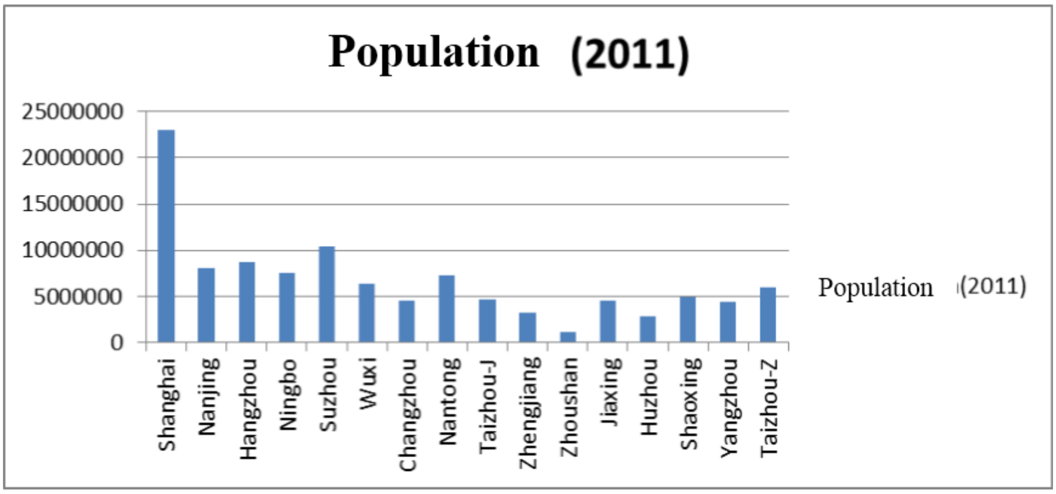

Figure 3.4 Population of sixteen cities in the Yangtze River Delta Region.

(Data Source: Jiangsu Province Year Book, Shanghai Municipality Year Book, Zhejiang Province Year Book, 2011)

The population of the Yangtze River Delta metropolitan region was 7.85% of China's total resident population in 2010 (Shira et al, 2012; Wu, 2017; Zhou et al, 2016a). At the end of 2011, the Yangtze River Delta region had a total population of about 86.3 million, and the city area had a total population of about 43.9 million (Shira et al, 2012; Wu, 2017). In 2011, the largest population was in Shanghai (23,019,148), followed by Suzhou (10,465,994), Hangzhou (8,700,400), Nanjing (8,001,680) (Fig.4.4). The population density is higher in the north and lower in the south with a single obvious centre (Shira et al, 2012; Wu, 2017; Zhou et al, 2016a). Although the Yangtze River Delta metropolitan region has high great population density, on the whole, its inner population density differs significantly from area to area:

The population density in the Yangtze River Delta metropolitan region shows an overall characteristic of being higher in the north and lower in the south, that is, Shanghai had the highest population density, and the eight cities in Jiangsu Province have a higher population density than the six cities in Zhejiang Province. Regarding cities, Shanghai was always the most densely populated city(Shira et al, 2012; Wu, 2017). As shown in the 2010 census data, Shanghai had a population density as high as 3,614 people/km^2, next to which were the cities of Suzhou, Wuxi, Nanjing, Jiaxing, Changzhou with over 1,000 people/km^2 each. The population density in the other ten cities ranged from 500 to 1,000 people/km^2 (JSYB; SSYB; Wu, 2017; ZSYB). This population density distribution demonstrates that the population density reduces significantly as the distance from the central city Shanghai increases and that the population density features a single centre in Shanghai.

3.3.8. Land cover

There is a large spatial heterogeneity in the distribution of land use/cover of this region (Fig.3.5):

Table 3.1 Land cover/use in the Yangtze River Delta metropolitan region (2010)

Land Cover	**Area (km^2)**	**%**
Arable land	57881.27	49.82
Forest	26943.11	23.19
Grassland	2863.56	2.46
Shrubland	159.8	0.14
Inland marshes	25.01	0.02
Salt marshes	941.76	0.81
Streams and lakes	10335.98	8.9
Shallow sea wetlands	394.91	0.34
Estuaries	3610.15	3.11
Bareland	0.85	0
Rural residential land	6363.57	5.48
Urban land	6651.26	5.73
Total	116171.23	

Firstly, forests are continuously and densely distributed in the south of the region and cover most areas of the Zhejiang Province. Also, they have a more scattered distribution in the middle and north of the region. In total, forest accounts for 23.19%

of the total area according to the author's calculations (Table 3.1). Secondly, there is a spatial difference in the distribution of arable land. Arable land is densely distributed in the middle and north of the region and covers most of the Jiangsu Province and Shanghai Municipality. It has a more patchy distribution in Zhejiang Province. Arable land in total accounts for 49.82% of the total area according to the author's calculations (Table 3.1). Thirdly, streams and lakes are relatively clustered in the middle of the region and have a belt pattern in the north and south of the region. Streams and lakes accounted for 8.90% of the total area (Table 3.1)

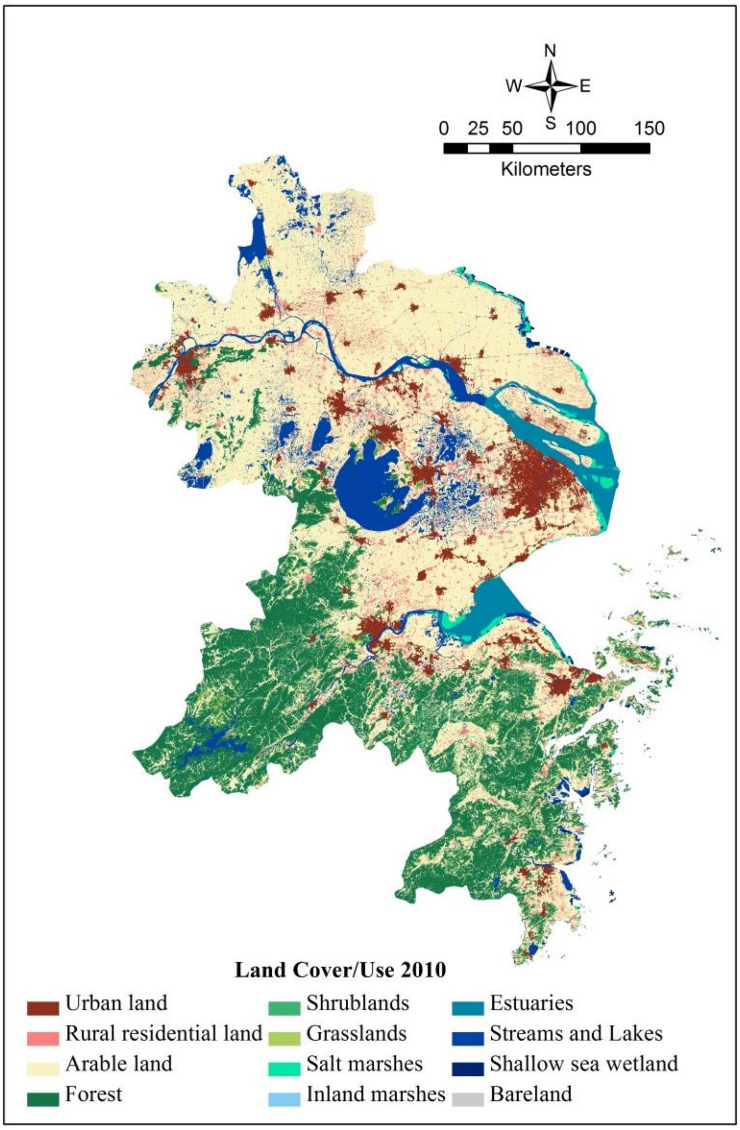

Figure 3.5 Land cover/use in the Yangtze River Delta metropolitan region (2010)

Finally, urban land and rural residential land have a patchy pattern in the region and are relatively clustered in the middle of the region. Urban land accounts for 5.73%

of the total area, while rural residential land accounts for 5.48% of the total area (Table 3.1).

3.4. Driver-pressure-state-impact-response analysis

3.4.1. Driving forces

As the Yangtze River Delta region witnesses rapid economic development, the most directly visible impact from rapid urbanization, industrialization and population growth on ecosystem is the change in land utilization (Haas & Ban, 2014; Li et al, 2016a; Li et al, 2016b; Liu et al, 2014a; Tian et al, 2011; Xu et al, 2014a). According to data from statistical yearbooks (JSYB; SSYB; ZSYB), rapid urbanization has resulted in sharply increased use of land for construction and sharply reduced farmland area around the Yangtze River Delta. This industrial structure adjustment, especially an increase in the aquaculture area year by year, has resulted in reduction of some farmland and increase of the water area. These changes in land utilization in the Yangtze River Delta region directly influence the ecosystem service value of various ecotypes.

From 1980 to 2005, the main reason for the reduced ecosystem service value in the Yangtze River Delta was the reduction of farmland and wetland areas, while between 2005 and 2010, the decline in ecosystem service value was due to the reduction in grassland (77.66%), wetland (71.04%), farmland (24.41%) and woodland (5.94%) areas (Liu et al, 2014a; Zhou et al, 2016a). The intensified urban expansion caused by rapid economic development itself results in reduced woodland, grassland and farmland areas, and additionally in lower ecosystem service values. In terms of different ecosystem service functions, the ecosystem service function of water conservation in the Yangtze River Delta has tended to improve over the past few decades, mainly because in 1980 - 2010, the increased water area and denser man-made ditches linked various ecosystems and enhanced the mobility of information, material and energy flows between patches of land (Li et al, 2016b; Liu et al, 2014a; Tian et al, 2011; Xu et al, 2014a). This ultimately contributed to the improving ecosystem service of water conservation and the increasing ecosystem service value.

With the Yangtze River Delta metropolitan region suffering from a sharply reduced farmland area, the remaing area experienced large agricultural investment, especially the usage of chemical fertilizers and pesticides, resulting in agricultural non-point source pollution (Haas & Ban, 2014; Li et al, 2016b; Liu et al, 2014a; Zhou et al, 2016a). The rapid development in the Yangtze River Delta, particularly the booming of township enterprises, has resulted in a large amount of industrial wastewater discharge (Haas & Ban, 2014; Liu et al, 2014a; Tian et al, 2011; Zhou et al, 2016a). Moreover, population growth has created more domestic sewage (Haas & Ban, 2014; Liu et al, 2014a; Tian et al, 2011; Zhou et al, 2016a). All these lead to the polluted water environment in the Yangtze River Delta metropolitan region. Therefore, water conservation has become the main ecosystem service function in that region. In addition, the domestic and industrial waste and heavy metals in the soil make waste treatment and soil formation and protection major ecosystem service issues in the Yangtze River Delta metropolitan region.

Urban growth

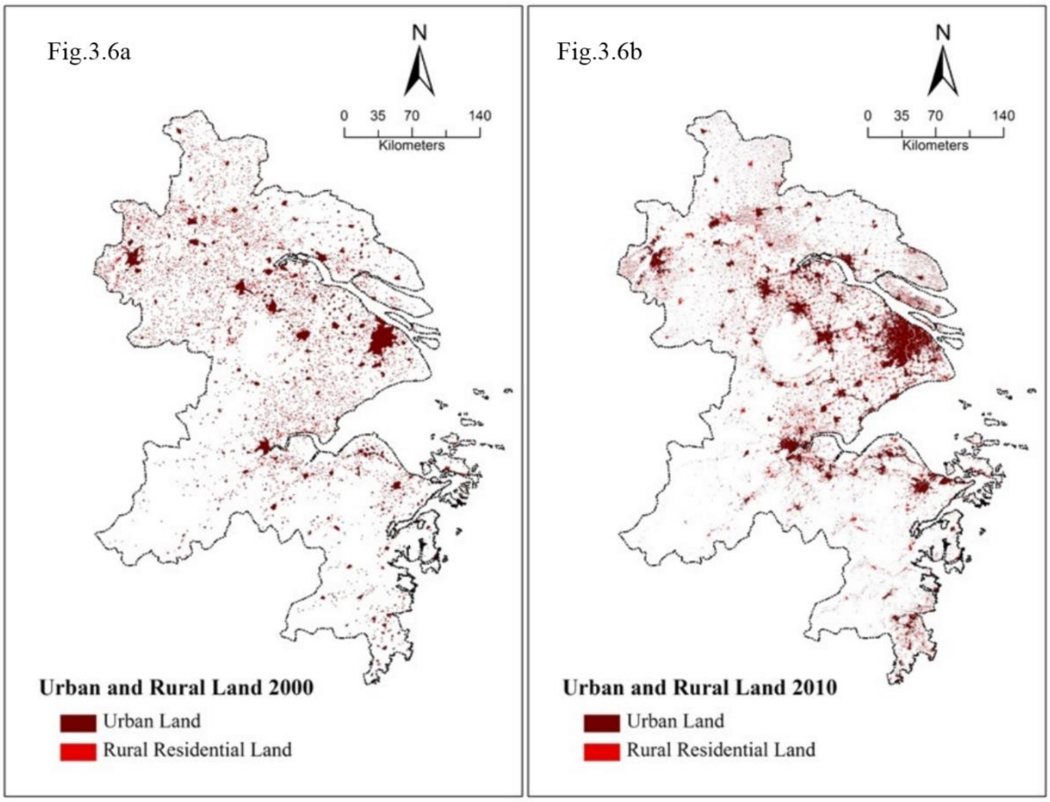

Figure 3.6 Urban growth in the Yangtze River Delta metropolitan region 2000-2010

According to the author's statistics in GIS attribute table by using land use and land cover data of year 2000 and 2010 provided in Table 4.1 in Chapter 4 and map (Table 3.2 and Fig 3.6), the area of the urban land increased from 3667.60 km^2 to 6651.26 km^2 in 2000-2010 (Growth Rate: 81.35%). During the same period, the rural residential land increased from 4767.72 km^2 to 3663.57 km^2 (Growth Rate: 33.47%). The expansion of urban land and rural residential land occurred mainly around major cities i.e. Shanghai. This rapid urban growth was one of the main drivers generating land cover change in the Yangtze River Delta metropolitan region.

Increasingly consolidated capacity of population aggregation

The population in most cities of the Yangtze River Delta urban agglomeration is growing increasingly larger, because economic development has attracted a great amount of migrants, the urban development has transferred the agricultural population within the region into non-agricultural population, and the rural population keeps flowing into the cities (Shira et al, 2012; Wu, 2017). The highly agglomerated population generates acute social and economic activities, applies too much pressure on the ecological environment in the regions and may also pose certain threats for social stability (Shira et al, 2012; Wu, 2017).

Over the ten years between 2000 and 2010, the population proportions in Shanghai Municipality and Nanjing, Wuxi, Suzhou, Hangzhou, Ningbo both increased by over 2%, compared with other cities in the Yangtze River metropolitan region, which were down by 1.11% and 4.46% (JSYB; Shira et al, 2012; SSYB; Wu, 2017; ZSYB). Shanghai Municipality had a population proportion increase from 18.77% in 2000 to 21.39% in 2010, up 2.62% with an average annual growth rate of as high as 3.44% (Shira et al, 2012; SSYB; Wu, 2017). The total population increased by 6.61 million people, with a growth rate as high as 40.3% (JSYB; Shira et al, 2012; SSYB; Wu, 2017; ZSYB).

Nanjing, Wuxi, Suzhou, Hangzhou, Ningbo had a population proportion increase from 35.28% in 2000 to 38.23% in 2010, up 2.95% and 10.30 million people (JSYB; Shira et al, 2012; Wu, 2017; ZSYB). It recorded the greatest proportion and population growth, with growth rate second to the core circle. Changzhou, Zhenjiang, Jiaxing, Huzhou, Shaoxing, Zhoushan had a population proportion decrease from 20.74% in 2000 to 19.64% in 2010, down 1.11% (JSYB; Shira et al, 2012; Wu, 2017; ZSYB). Its average annual growth rate was only 1.54%, lower than the overall rate in the Yangtze River Delta metropolitan region (Shira et al, 2012; Wu, 2017).

However, the population still increased in the decade, by 2,998,900 people, amounting to 16.54% (Shira et al, 2012; Wu, 2017). Nantong, Yangzhou, Taizhou (Jiangsu Province) and Taizhou (Zhejiang Province) had a population proportional decrease from 25.21% in 2000 to 20.75% in 2010, down 4.46% (JSYB; Shira et al, 2012; Wu, 2017; ZSYB). In the decade, the population only increased by 299,200 people (Shira et al, 2012; Wu, 2017). Its population growth and rate were the lowest among all the cities, and its average annual growth rate was only 0.13% (Shira et al, 2012; Wu, 2017).

Population growth

As one of the most densely populated regions in China, the Yangtze River Delta metropolitan region has therefore recorded vigorous population growth since 2000, with a notable aggregation effect (Shira et al, 2012; Wu, 2017).

In the decade from 2000 to 2010, the total population in the Yangtze River Delta metropolitan region soared from 87.43 million to 107.63 million people, recording a growth of 20,206,800 people at a total rate of 23.11% and an average annual growth rate of 2.1% according to Table 3.2 and Fig 3.7 (JSYB; Shira et al, 2012; SSYB; Wu, 2017; ZSYB). Such growth and rates are much higher than those of the total national population over the same period (5.84% and 0.57% nationally) (Shira et al, 2012; Wu, 2017).

The proportion of the total national population increased from 6.38% in 2000 to 8.5% in 2010 (Shira et al, 2012; Wu, 2017). Since the natural growth rates in each city in the Yangtze River Delta metropolitan region were generally kept at a very low level, the population growth there was mainly mechanical population growth, i.e. immigration from other provinces and cities in China, which indicates the "pulling force" in population due to powerful economic growth in the Yangtze River Delta metropolitan region (Shira et al, 2012; Wu, 2017).

Table 3.2 Population Growth in the Yangtze River Region 2000-2010 (Wu, 2017)

City	2000 (million)	2010 (million)	2010-2000	Growth Rate %
Shanghai	16.4077	23.0192	661.15	2.62
Nanjing	6.1212	8.0047	188.35	0.44
Wuxi	5.0866	6.3726	128.6	0.1
Changzhou	3.7763	4.592	81.57	-0.05
Suzhou	6.7922	10.466	367.38	1.95
Nantong	7.5129	7.2828	-23.01	-1.83
Yangzhou	4.5886	4.4598	-12.88	-1.11
Zhenjiang	2.8449	3.1134	26.85	-0.36
Taizhou-J	4.7858	4.6186	-16.72	-1.18
Hangzhou	6.8787	8.7	182.13	0.22
Ningbo	5.9634	7.606	164.26	0.25
Jiaxing	3.583	4.502	91.9	0.08
Huzhou	2.6256	2.894	26.84	-0.31
Shaoxing	4.3042	4.912	60.78	-0.36
Zhoushan	1.0015	1.121	11.95	-0.1
Taizhou-Z	5.1537	5.969	81.53	-0.35

Over the ten years between 2000 and 2010, the population proportions in Shanghai Municipality and Nanjing, Wuxi, Suzhou, Hangzhou, and Ningbo increased by over 2%, compared with other cities in the Yangtze River metropolitan region, which were down by 1.11% and 4.46% (JSYB; Shira et al, 2012; SSYB; Wu, 2017; ZSYB). Shanghai Municipality had a population proportion increase from 18.77% in 2000 to 21.39% in 2010, up 2.62% with an average annual growth rate of as high as 3.44% (Shira et al, 2012; SSYB; Wu, 2017). The total population increased by 6.61 million people, a growth rate of as high as 40.3% (Shira et al, 2012; SSYB; Wu, 2017). It had the fastest growth among the sixteen cities. Nanjing, Wuxi, Suzhou, Hangzhou, Ningbo had a population proportion increase from 35.28% in 2000 to 38.23% in 2010, up 2.95% and 10.30 million people(JSYB; Shira et al, 2012; Wu, 2017; ZSYB).

It recorded the greatest proportion and population growth, with a growth rate second to the Shanghai Municipality. Changzhou, Zhenjiang, Jiaxing, Huzhou, Shaoxing, and Zhoushan had a population proportion decrease from 20.74% in 2000 to 19.64% in 2010, down 1.11%. Its average annual growth rate was only 1.54%, lower than the overall rate in the Yangtze River Delta metropolitan region

(JSYB; Shira et al, 2012; Wu, 2017; ZSYB). However, the population still increased in the decade, by 2,998,900 people, an increase of 16.54%.

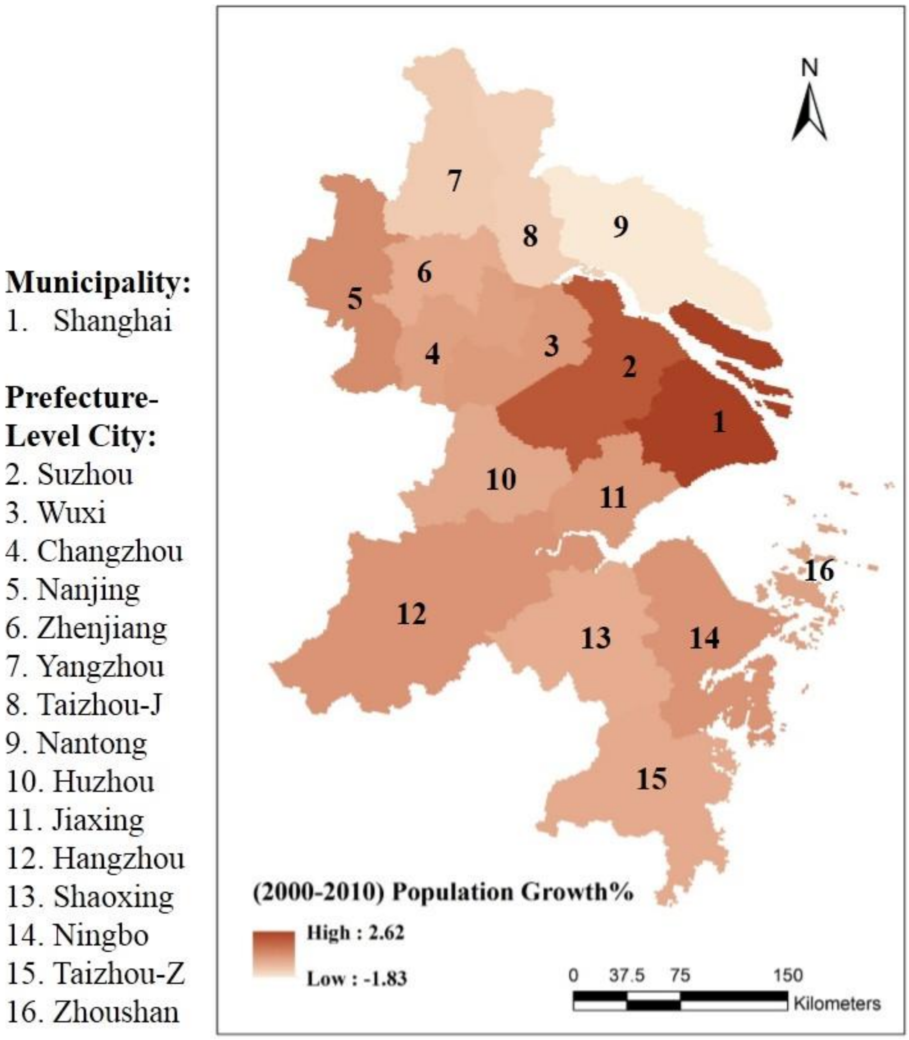

Figure 3.7 Population Growth in the Yangtze River Region 2000-2010

(Data source: Wu, 2017)

Nantong, Yangzhou, Taizhou (Jiangsu Province) and Taizhou (Zhejiang Province) had a population proportion decrease from 25.21% in 2000 to 20.75% in 2010, down 4.46% (JSYB; Shira et al, 2012; Wu, 2017; ZSYB). In the decade, the population increased by only 299,200 people (JSYB; Shira et al, 2012; Wu, 2017; ZSYB). The population growth and rate of these cities were the lowest among all the cities, and its average annual growth rate was only 0.13% (JSYB; Shira et al, 2012; Wu, 2017; ZSYB).

Change of population density

Municipality:
1. Shanghai

Prefecture-Level City:
2. Suzhou
3. Wuxi
4. Changzhou
5. Nanjing
6. Zhenjiang
7. Yangzhou
8. Taizhou-J
9. Nantong
10. Huzhou
11. Jiaxing
12. Hangzhou
13. Shaoxing
14. Ningbo
15. Taizhou-Z
16. Zhoushan

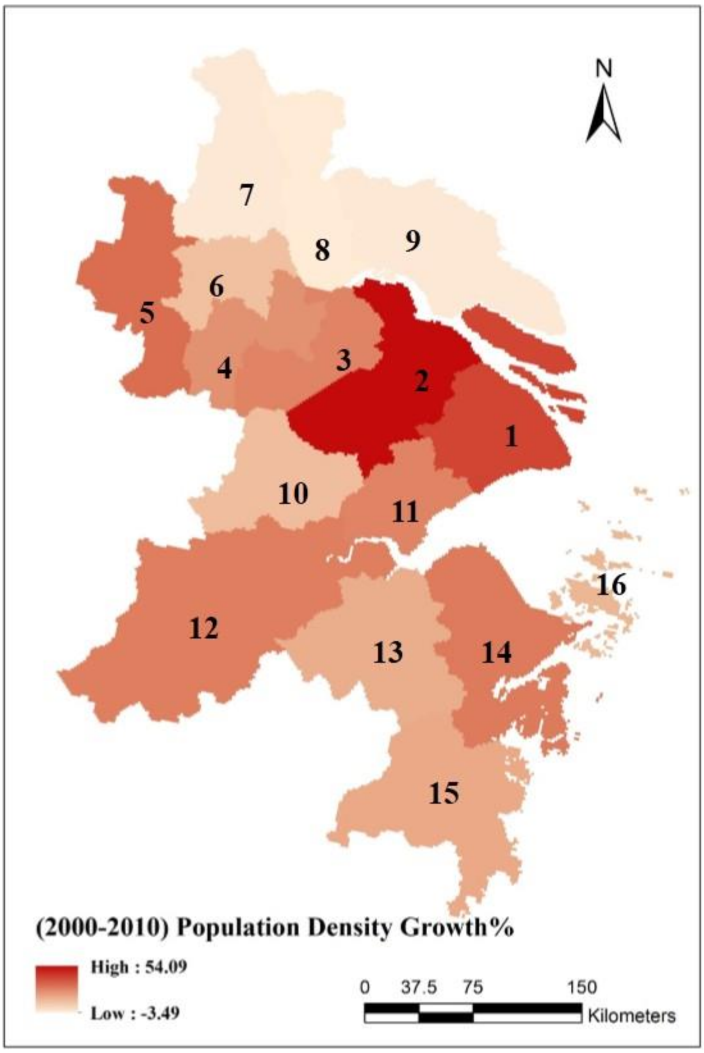

Figure 3.8 Population Density Growth in the Yangtze River Region 2000-2010

(Data source: Wu, 2017)

The population density has grown significantly (Fig 3.8/Table 3.3) . Regarding cities, in 2000 - 2010, most of the sixteen cities witnessed increased population density (Shira et al, 2012; Wu, 2017), although the population density in Nantong, Yangzhou and Taizhou became lower due to their decreased total population (Shira et al, 2012; Wu, 2017). Among other cities, Shanghai had the greatest growth in population density, of nearly 1,000 people/km^2; Suzhou came second with population density increased by nearly 600 people/km^2; The population density growth of other cities with greatly increased total population also ranged from 100 to 300 people/km^2.

Table 3.3 Population Density in the Yangtze River Region 2000-2010 (after Wu, 2017)

City	2000 (people/km^2)	2010 (people/km^2)	Growth Rate %
Shanghai	2219.14	3113.34	40.30
Nanjing	912.67	1193.50	30.77
Wuxi	1110.83	1391.67	25.28
Changzhou	873.65	1062.36	21.60
Suzhou	848.08	1306.79	54.09
Nantong	859.81	833.48	-3.06
Yangzhou	693.51	674.04	-2.81
Zhenjiang	800.01	875.52	9.44
Taizhou-J	837.57	808.31	-3.49
Hangzhou	402.38	508.92	26.48
Ningbo	655.37	835.89	27.54
Jiaxing	888.11	1115.90	25.65
Huzhou	447.61	493.37	10.22
Shaoxing	520.17	593.62	14.12
Zhoushan	683.49	765.04	11.93
Taizhou-Z	538.78	624.01	15.82

In 2000, only Shanghai, Suzhou and Wuxi had a population density of over 1,000, whereas by 2010, there were several regions with a population density of over 1,000, including Shanghai, Suzhou, Wuxi, Changzhou, Nanjing and Jiaxing (JSYB; Shira et al, 2012; SSYB; Wu, 2017; ZSYB).

Economic growth

In recent years, the Yangtze River metropolitan region has witnessed tremendous growth in its public sectors, including industrial and agricultural sectors, besides making major shifts vis-à-vis urban-rural development. In 2014, the Yangtze River Delta metropolitan region accomplished gross regional production of 10.60 trillion CNY, a breakthrough in gross output of industrial enterprises above designated size to over 19 trillion CNY, fixed-asset investment of over 5 trillion CNY, total retail sales of consumer goods exceeding 3.95 trillion CNY, and total volume of foreign trade at USD 1.29 trillion; The annual gross regional production dropped by 0.7% compared with 2013; The fixed-asset investment increased by 13.4%, down 3.3% from 2013; The total retail sales of consumer goods rose by 11.3%, down 0.9% from 2013; The disbursement of foreign capital reduced by 3.5%, down 8.1% from

2013; The general public budget revenue increased by 9.9%, down 0.7% from 2013 (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB) .

In 2009, primary industry in the Yangtze River Delta metropolitan region recorded value added of 353.876 billion CNY, i.e. 7.0% higher calculated by the then-prices, and had gross output of 597.257 billion CNY, i.e. 5.69% higher calculated by the then-prices (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). In terms of areal distribution, the gross output of primary industry in Shanghai Municipality reached 28.315 billion CNY, taking up 4.74% of the gross output of primary industry in the Yangtze River Delta metropolitan region; the amount in Jiangsu Province was 381.602 billion CNY, accounting for 63.89% of the total in the Yangtze River Delta metropolitan region; and the amount in Zhejiang Province was 187.340, constuting 31.37% of the total number in the Yangtze River Delta metropolitan region (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB).

In 2009, the industrial added value in the Yangtze River Delta metropolitan region reached 3,239.19 billion CNY, composing 23.95% of China's industrial added value; the gross output of secondary industry was 3,626.088 billion CNY, up 5.16% over the previous year (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). In 2009, the added value of the construction industry in the Yangtze River Delta metropolitan region reached 408.474 billion CNY, amounting to 18.24% of the total added value of China's construction industry (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). In terms of areal distribution, the construction industry in Shanghai Municipality recorded added value of 59.303 billion CNY, accounting for 14.52% of the added value of the construction industry in the Yangtze River Delta metropolitan region, and 2.65% nation-wide; the amount in Jiangsu Province was 210.143 billion CNY, accounting for 51.45% of the added value of the construction industry in the Yangtze River Delta metropolitan region, and 9.38% nation-wide; the amount in Zhejiang Province was 139.028 billion CNY, taking up 34.04% of the added value of the construction industry in the Yangtze River Delta metropolitan region, and 6.21% nation-wide (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB).

In 2009, the residents' income and consumption levels saw stable improvement in the Yangtze River Delta metropolitan region. The PDI (Personal Disposable

Income) of urban residents in the Yangtze River Delta metropolitan region in 2009 was 24,667 CNY, up 4,973.2 CNY over 2008, and their consumer spending reached 16,609 CNY, up 1,097.8 over the previous year (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). In 2009, the per-capita net income of rural residents in the Yangtze River Delta metropolitan region was 10,112 CNY, up 778.7 CNY over 2008, and their living expenditure reached 7,661 CNY, up 489.9 over the previous year (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB). The average annual pay of employees was 38,711 in 2009, up 3,606 CNY over the previous year (JSYB; Shira et al, 2012; SSYB; Zhou et al, 2016a; ZSYB).

3.4.2. Pressure

This economic development also consumed a large amount of resources and triggered severe environmental problems. Since the Yangtze River Delta has very limited natural resources, with few forests and not much grassland, the rapid economic development resulted in a sharp reduction of resource reserves within just a few years (Haas & Ban, 2014; Han et al, 2017; Li et al, 2016a; Liu et al, 2014a; Xu et al, 2014a). Meanwhile, the Yangtze River Delta metropolitan region lacks energy and mineral products, so a substantial amount of consumption mostly relies on imports (Zhou et al, 2016a).

The Yangtze River Delta has become a new ecologically fragile zone in China, where various pollution problems are seen, including air and water pollution. The industrial production and the higher living demands aggravate the burning of fossil fuels, which causes air pollution (Zhou et al, 2016a). For example, although the air quality of Shanghai Municipality in 2010 was better than that in 2005, it still falls far below the WTO standard (Zhou et al, 2016a). Although the Yangtze River Delta has a high yield of water, the quality is poor due to severe eutrophication of rivers and lakes and serious groundwater pollution. For instance, the Wuxi basin of the Taihu Lake suffered greatly from a massive outbreak of blue-green algae in 2007, which also impacted on the urban tap water supply (Huang et al, 2010; Zhang et al, 2012). The increasing urban expansion occupied much farmland and replaced it with hard roads. The urban development also fragmented the ecological environment, causing a loss of biodiversity in the urban ecosystem.

Change of land cover/use

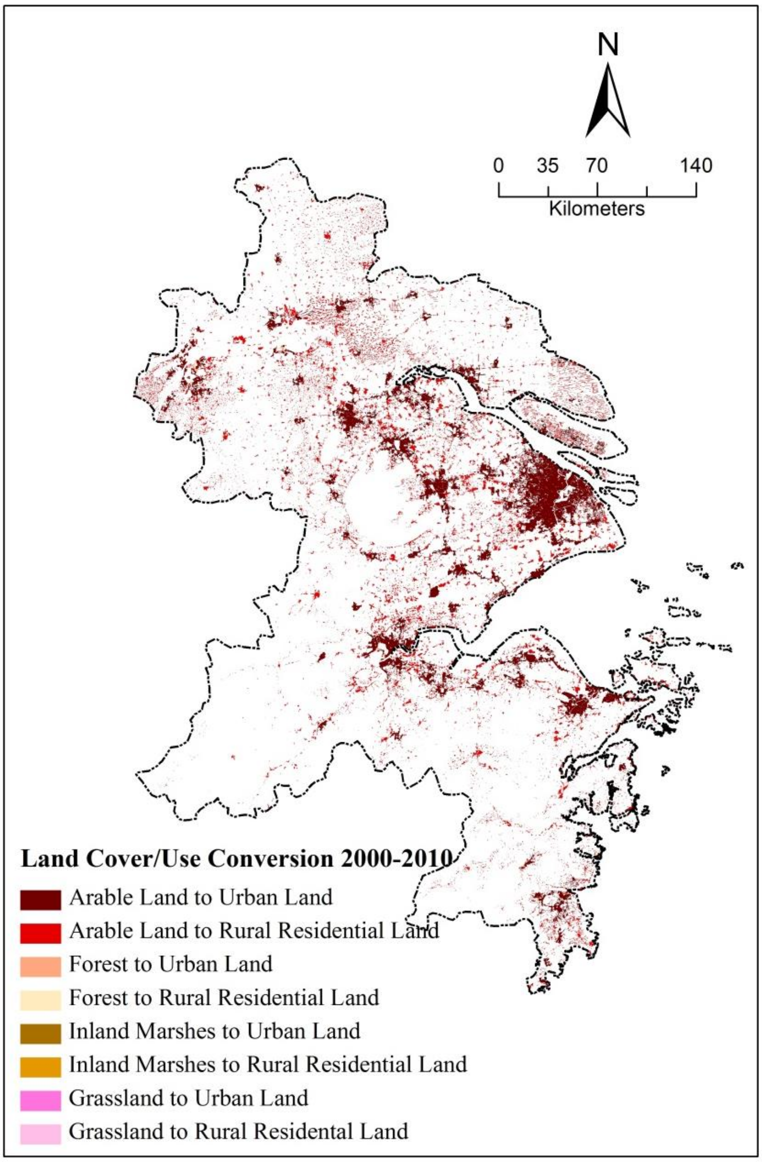

Figure 3.9 Land cover/use conversion in the Yangtze River region 2000-2010

According to the Fig. 3.9 and Table 3.4, the area of urban land and residential land increased significantly from 2000 to 2010, by 81.35% (2983.67 km^2) and 33.47% (1595.86 km^2) respectively. At the same time, arable land, forest, grassland, and inland marsh decreased by -8.09% (5091.52 km^2), -1.03% (-280.3 km^2), -4.22% (-126.03 km^2), and -18.62% (5.72 km^2).

Most of these types of land cover were converted into urban land or rural residential land. The area of streams and lakes increased by 6.77% (655.67 km^2), with the increase in artificial ponds in the entire region, in the local experts' view.

Table 3.4 Change of land cover/use in the Yangtze River metropolitan region 2000-2010

Category	2000 Area(km^2)	2010 Area(km^2)	2010-2000 Area(km^2)	Growth Rate %
Urban Land	3667.60	6651.26	2983.67	81.35
Rural Residential Land	4767.72	6363.57	1595.86	33.47
Arable Land	62972.79	57881.27	-5091.52	-8.09
Grasslands	2989.59	2863.56	-126.03	-4.22
Shrublands	157.49	159.80	2.31	1.47
Forest	27223.43	26943.11	-280.32	-1.03
Inland marshes	30.73	25.01	-5.72	-18.62
Salt marshes	879.96	941.76	61.80	7.02
Streams and Lakes	9680.31	10335.98	655.67	6.77
Estuaries	3610.15	3610.15	0.00	0.00
Shallow Sea Wetlands	394.91	394.91	0.00	0.00
Bareland	0.91	0.85	-0.06	-6.93
(Sum)	116375.59	116170.39	-205.19	-0.18

Based on the author's interviews with local experts, the Yangtze River Delta metropolitan region's ecosystems went through a stage of serious degradation from 2000 to 2010. This stage can be divided into two sub-stages:

Firstly, land and forests were allocated to households at the beginning of the reform and opening-up, and the deforestation of the original collective forests by farmers in the mountainous areas led to further reduction in the forest area. Also, township enterprises developed rapidly in plains and near shallow lakes as a result of which water pollution was universal due to the lack of environmental infrastructure, direct discharge of sewage, and excessive fish farming in net cages.

Secondly, the Yangtze River Delta region entered a period of rapid development in the 1990s, along with noticeably quicker urbanisation, rapid infrastructural construction, and increasing level of globalisation. Farmers in the western mountains no longer lived mainly on tree cutting and farming. At the same time, natural vegetation recovered at a quicker pace, and the forest coverage was increased. However, as economic forests (especially bamboo forests) developed more quickly, planting bamboo at the expense of trees became a new problem. Natural vegetation and biodiversity were under threat once again. Meanwhile, due to urbanization, disorderly urban sprawl, and construction of infrastructural networks, natural ecological space, including arable land, was rapidly reduced, while water space kept shrinking in the river network of the eastern plain. Due to the over-expansion of urban population and discharge of industrial and domestic wastewater, rivers, especially estuaries and coastal waters, suffered exacerbated eutrophication. Aquatic biodiversity was threatened, and ecosystems were seriously degraded. Moreover, the emergence of new types of compound pollution brought about by various new industries worsened soil pollution and put grain and food safety at greater risk.'

Major ecological and environmental problems

Land resources problem

The available cropland and ecological lands are shrinking because of rapid urbanisation and industrialisation. In Shanghai, agricultural acreage slumped from 323,200 hm^2 in 1990 to 202,300 hm^2 in 2009 when the city launched a development programme in Pudong (Cai et al, 2016; Zhou et al, 2016a). During the same period, the cropland per capita decreased from 773 m^2 to 553 m^2 (Cai et al, 2016; Zhou et al, 2016a). This reflects decreasing agricultural acreage in the delta. Moreover, the cropland per capita in the Yangtze River Delta is 0.04 hm^2, only half of the national average and a fifth of the world average (Cai et al, 2016; Zhou et al, 2016a). Nonetheless, the region has an utilised land area treble the national average.

Furthermore, besides a high load rate in the cropland, deteriorating land quality is also a big problem. As the country relies less on agriculture and promotes high-efficiency agriculture, the Yangtze River Delta metropolitan region has brought into use a large number of chemical fertilisers and pesticides. The level of application on average exceeds 450 kg/hectare, well past the safety cap of 225 kg/hectare in the developed countries (Fu et al, 2008; Wang et al, 2003). Meanwhile, untreated pollutants are massively discharged in urban and rural areas. These persistent organic pollutants and toxic heavy metals have accumulated, posing serious harm to the quality of land and agricultural products. Moreover, the wetlands have been seriously damaged. More than 20,000 hectares of wetland disappear every year, while the wetland ecosystem is declining (Cui et al, 2015). Also, the land reserve in the region is also insufficient. The unexploited land area accounts for only 16% of the region's total land area, nearly half of the national average (Cai et al, 2016; Zhou et al, 2016a). The land area in reserve accounts for 5.6% of the region's total land area, lower than the national average of 7.9% (Cai et al, 2016; Zhou et al, 2016a).

Water resources problem

Water is the lifeline of Yangtze River Delta for realising sustainable development. However, the region has been plagued with an ever-worsening water crisis, which is characterised by scarce water resources, increasing water demand, and water pollution caused by untreated industrial pollutants (Huang et al, 2010; Wang et al, 2003; Zhang et al, 2012). The total water resources in the region are 1.7 times the national average, but most of this comes from other regions. Moreover, uneven distribution of water networks, unreasonable structure of water consumption, and a low water use rate have made the available surface water per capita less than a third of the national average (CSYRE; Haas & Ban, 2014; Huang et al, 2010; Ren et al, 2003; Wang et al, 2003; Zhang et al, 2012). Meanwhile, to utilise trans-boundary water, the region has to build projects, such as pump stations, which means greater difficulty in water utilisation.

Furthermore, industrial water consumption in the Yangtze River Delta metropolitan region is high. In 2010, the Yangtze River Delta metropolitan region consumed 89,147 million m^3 of water, 73.1% of which was used in industrial activities (CSYRE; Huang et al, 2010; Zhang et al, 2012). Despite a large proportion, the industrial reuse rate was only 53.34% – far lower than the national average of 74.2%

(Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). At the same time, the region's thermal power industry is a heavy consumer of water. For example, the thermal power industry in Shanghai consumed 73.34% of the city's water supply (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). However, water in the thermal power industry is mainly used once for cooling and is hardly recycled. This is to blame for a low water reuse rate (Haas & Ban, 2014; Ren et al, 2003; Wang et al, 2003). Meanwhile, the domestic water utilisation rate also needs to improve. Without environmental awareness of the water crisis, most residents will directly discharge water rather than recycling it after the first usage (Haas & Ban, 2014; Ren et al, 2003; Wang et al, 2003). With the expanding scale of industry and growth in the urban population, water demand in the delta will go up.

Besides scarce water resources and poor water utilisation, the region has witnessed increasing sewage discharge. Given water pollution, that far exceeds the environmental capacity and poor wastewater treatment, the region finds it difficult to improve the water environment, which is a direct cause of quality-induced water shortage (Ren et al, 2003; Wang et al, 2003). In 2012, the total amount of wastewater in Shanghai (including cities and towns) hit 2,301 million m^3, including 1,647 million m^3 of domestic wastewater and 654 million m^3 of industrial wastewater (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). The sewage treatment rate was 78.9% (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). In total, the rivers in Shanghai measure 719.8 km, 28.7% of which exceed Grade III and the remaining are inferior (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). Moreover, the total amount of sewage discharge in Jiangsu reached 6,175 million tons in 2012 (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). The rivers in the province measure, as a whole 18,623 km, and those meeting Grade IV-V measure 13,222 km, a proportion of 71.0% (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a).

Meanwhile, the total amount of sewage discharge in Zhejiang accounted for 45.83% (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). The rivers in the province measure 3,322.6 km, of which 1,769.5 km of rivers meet Grade I-III standards, a proportion of 53.5%. Of nearly 20 major lakes in the delta, three quarters are in obvious eutrophication, and the safety of potable water sources is also at serious risk (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). In 2012, 85.27% of drinking water sources in Shanghai met water quality standards, a sharp decline from 96.85% in 2008 (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a).

Air pollution problems

Air pollution has come to the fore as a hot topic of discussion. Since the winter seasons of 2010, some persistent haze-fog events have occurred in the Yangtze River Delta metropolitan region, with $PM_{2.5}$ severely exceeding the safe limit (Gu et al, 2011; Wang et al, 2012; Zhou et al, 2016a). $PM_{2.5}$ refers to atmospheric particulate matter (PM) that has a diameter of fewer than 2.5 micrometres. It remains suspended in the air and can travel extremely long distances, hazardously influencing human health and ambient air quality. In fact, air pollution in the Yangtze River Delta metropolitan region is worsening with each passing day (Gu et al, 2011; Wang et al, 2012; Zhou et al, 2016a). In addition to $PM_{2.5,}$ which draws much attention, massive emissions of Sulphur dioxide (SO_2) is another major contributor to air pollution.

The flat terrain precludes the possibility of hydroelectricity and nuclear electricity generation has recently begun. To satisfy the growing demand for energy, building more thermal power plants has been seen as the only option. Large quantities of coal and petroleum are burnt. In particular, countless coal-fired units are not equipped with desulfurization, and SO_2 is discharged into the air without limitation, resulting in frequent acid rains in the region (Gu et al, 2011; Wang et al, 2012; Zhou et al, 2016a). At the same time, this trend is also a result of growing energy consumption and a predominantly coal-based industrial structure in the Yangtze River Delta metropolitan region. In 2012, coal consumption accounted for 58.7% of all energy consumption in the Yangtze River Delta metropolitan region (Gu et al, 2011; Wang et al, 2012; Zhou et al, 2016a). Meanwhile, in view of China's general energy utilisation structure, coal firing will still be a big part of the energy consumption structure of the Yangtze River Delta metropolitan region (Gu et al, 2011; Wang et al, 2012; Zhou et al, 2016a). As industrialisation progresses and industry expands in scale, the demand for coal fired power will keep growing in the

Yangtze River Delta metropolitan region. Gu et al (2011) and Wang et al (2012) pointed out that Shanghai's industrial waste gas emissions increased to 10709×108 Nm^3 in 2009, compared to 7799×108 Nm^3 in 2003, an average annual growth of 6.2%. During the same period, Jiangsu saw an even higher average annual growth of 14.6%, while its industrial waste gas emissions expanded from 14633×108 Nm^3 to 27432×108 Nm^3 (Gu et al, 2011; Wang et al, 2012). Meanwhile, Zhejiang has similar average annual growth of 13.78%, while its industrial waste gas emissions grew by 68.9% from 2003 to 2008; Double-digit average annual growth in waste gas emissions has seriously damaged the atmospheric environment of the Yangtze River Delta metropolitan region (Gu et al, 2011; Wang et al, 2012).

Rapid reduction in arable land

The area of arable land has decreased significantly, and land supply bottlenecks have become increasingly imminent because of urban expansion, development of industrial parks, and infrastructural construction for transportation. According to statistical analysis of remote sensing interpretation, the percentage of farmland in the Yangtze River Delta region rose from 44.46% in 1980 to 60.38% in 2000 before dropping sharply to 40.86% in 2014 (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a).

However, according to the statistics of other authors, there were 3.496 million hectares of arable land in the entire region in 1990 (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a). By 2000, only 3.012 million hectares of farmland were protected (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a). Within ten years, the reduction in arable land was equivalent to 14.8% of the original area (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a). This is an alarming rate of farmland loss.

Changes in the arable area of four major cities in the Yangtze River Delta region vary (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). Shanghai and Suzhou are experiencing a rapid reduction in arable land, which reflects rapid urbanisation trends in both cities (Dong et al, 2011). Meanwhile, Wuxi and Hangzhou, especially Hangzhou, show a slower rate of reduction, which suggests that the arable land-use in these two cities takes on a slower pace as compared to the other two cities (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a).

At present, the per capita arable land area in the Yangtze River Delta metropolitan region is only 0.6mu, which is equivalent to 50% of the national average, while the intensity of arable land loss is 6.7 times the national average (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). Meanwhile, the per capita arable land areas of 14 counties (cities) in Jiangsu are below the warning line of 0.8mu (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). This means that there are insufficient reserves of arable land. At the same time, the land utilisation rate of Shanghai has exceeded 85.8% (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). Moreover, the per capita arable land area in Zhejiang Province was 0.49mu in 2000 (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). It is expected to drop to 0.39mu in 2020 (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). According to the mid- and long-term development goals of the urban master plan of Shanghai, there is a great shortage of land resources for urban construction, and the already scarce arable land will inevitably be occupied (Cai et al, 2015; Dong et al, 2011; Zhou et al, 2016a). The sharp decline in arable land has aggravated the chasm between supply and demand of food, besides considerably damaging local ecosystems.

Constant reduction in natural ecological space

According to the author's local expert interviews, due to the relatively rich tidal flat resources in the Yangtze River Delta metropolitan region, reclamation of tidal flat resources has been an important channel for relieving land shortages and increasing reserves of land resources in coastal (bay) areas of the Yangtze River Delta for a long time. There is a long history of land reclamation from seas and lakes in the region. For example, Shanghai has been engaged in reclamation of tidal flats since the founding of the People's Republic of China. In the 1960s and 1970s, many large-scale reclamation projects were carried out. After the reform and opening-up, the scale of reclamation showed an upward trend, although no large-scale projects were carried out (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). Moreover, due to a reduction in arable land, reclamation of tidal flat resources has increased in various parts of the Yangtze River Delta metropolitan region (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a).

In recent years, Shanghai, Jiangsu and Zhejiang have increased their efforts to develop land reclamation. The rapid construction of new coastal cities and the consequent reclamation of tidal flats have led to a substantial reduction in the area of natural wetlands, which greatly affects the state of protection of wetland ecology and biodiversity (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). In this regard, as much as 17.8% of natural wetlands have been directly converted to construction land, while 66.4% have been converted into agricultural land (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a). At the same time, 15.8% of coastal wetlands that were converted into agricultural land have subsequently been turned into construction land (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a).

These results show that the process of rapid urbanization in the Yangtze River Delta has led to a higher proportion of construction land in natural wetland resources than that of coastal wetlands that have been converted into agricultural land. Furthermore, the estuaries of Chongming Island and Qiantang River in Hangzhou have experienced the most intense land-use changes in coastal wetlands. The analysis of coastline impact changes in land-use shows that the most dramatic land-use changes in the Yangtze River Delta metropolitan region appear at 1km from the coastline from 1990 to 2000, mainly towards the shore (Han et al, 2017; Li et al, 2016a; Xu et al, 2014a). Given the development needs in the next 20 years, even if the existing 2m-elevation tidal flats are all reclaimed to supplement the urban construction land, it will not be able to make up for the shortfall (Cai et al, 2015; Fu et al, 2013a; Zhou et al, 2016a). This region has the most abundant biodiversity in the Yangtze River Delta metropolitan region. All reclamation will run into conflict with the ecological protection of wetlands and even violate the regulations of nature reserve management (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). Ecological damage will ensue, and the loss will outweigh the gain.

3.4.3. State

State of ecosystem

The ecosystem is the material basis and environmental condition for the survival of human beings. It provides many important service functions for social and economic systems. However, in recent decades, rapid industrialization, urban expansion, irrational city layouts, and inappropriate land-use methods in the Yangtze River Delta metropolitan region have deteriorated natural ecosystems, besides seriously degrading their structures and functions (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Wang et al, 2015; Xu et al, 2014a).

According to respondents to interviews for this thesis, ecosystems have been seriously overloaded. Ecological problems have become more and more obvious, affecting the sustainability of socioeconomic development in the region. With a rise in urban agglomerations in the Yangtze River Delta metropolitan region, it is imperative to study the problems arising from the process of urban integration and come up with countermeasures.

Forests are the ecosystems that best resist interference. However, forests not only experience a reduction in area because of direct occupation of humans, urbanisation, industrialisation, and the construction of transportation networks, but also the resulting acid rain has also begun to damage forest trees (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). Among all natural disasters, forest fires are the biggest killer, followed by droughts and biological invasions (including diseases and pests). In the Yangtze River Delta region, global warming is conducive to the growth of forest trees (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). However, it may also induce droughts and increased pests and diseases, to have an adverse effect on forests.

Wetlands in this region are most sensitive to human activities. Urbanization, industrialization, large-scale basin engineering, and dense transportation networks not only break the integrity of regional wetlands and water ecosystems but also shrink their areas (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). Also, pollution caused by human activities and changes in hydrodynamic conditions are highly detrimental to wetland and water ecosystems.

Farmland is a very fragile artificial ecosystem. Natural and biological disasters, such as floods, droughts, diseases, and pests can have adverse effects on crop growth. Urbanization, industrialization, and transportation network construction occupy a large amount of arable land in the region (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). At the same time, pollution and the accumulation of various forms of pollutants in crops and vegetables pose a serious threat to food safety.

Habitat fragmentation

The damage to ecosystems is fundamental and irreversible. Substantial expansion of urban areas keeps squeezing natural space, while population explosion threatens biological resources. Also, the discharge of wastewater causes changes in aquatic habitats and disappearance of suitable species. At the regional level, an increase in urban population and land-use contribute to the fragmentation of ecological land-use (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). However, the degree of such fragmentation varies with differences in the characteristics of ecological land-use and agricultural cultivation, deforestation, and traffic routes. Judging from the situation in each city, the concentration of urban land is closely related to the degree of fragmentation of ecological land (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). The level of urbanisation is the driving force for urban land growth. The disturbance to urbanised ecological land is reflected in the transition between urban land and ecological land. The larger the scale of urban land, the greater shall be its perimeter, and the contact with ecological land will increase. However, scattered urban land uses require a larger perimeter than aggregated urban land-uses of the same area (Cai et al, 2015; CSYRE). In other words, it is a geometric problem about the comparison of the perimeter of a “large patch” and the sum of the perimeters of “many small patches”. Many small scattered patches together form a perimeter that is significantly larger than fewer large patches of the same area. Therefore, they have greater impact on the fragmentation of ecological land.

The number and distribution of nature reserves in the Yangtze River Delta (at international, provincial, regional, and county levels) also reflect fragmentation in regional habitats (Cai et al, 2015; CSYRE). Nature reserves are concentrated in the southwestern mountainous regions (in Zhejiang Province) of the Yangtze River Delta region (Cai et al, 2015; CSYRE). Relatively primitive or well-recovered vegetation types are reserved in different parts of these areas that are inaccessible and are not conducive to urban and agricultural development. These areas are currently protected as reserves. However, agricultural production was developed early in the wet plains in the northeastern part, and there is a high level of urbanization (Cai et al, 2015; CSYRE). Rare natural ecosystems can be preserved. Except for some local areas, such as the Chongming Islands and other coastal areas, a small amount of low-lying mountains in the southern part of Jiangsu, where vegetation has been well restored, are also protected areas (Cai et al, 2015; CSYRE). Small in number and size, these protected areas are isolated habitats among urbanised areas and are confronted with difficulties in biodiversity protection.

Reduced biodiversity

The reduction in biodiversity in the Yangtze River Delta region is mainly reflected in the reduction in zonal vegetation areas and rare species; a high degree of artificial plantations; simplified food chain networks; sharp reduction in aquatic species in lakes, estuaries and near-shore waters; and a decrease in the species and yields of fish that can be caught (Gu et al, 2011; Han et al, 2017; Hou et al, 2014; Li et al, 2016a; Xu et al, 2014a). At the same time, invasive species have become a serious threat in the region. Species like Canada goldenrod, water hyacinth, and Spartina alterniflora have occupied terrestrial communities, beaches, and waters, causing serious damage and economic losses.

As an example, according to the analysis of species density in nine communities of three types in Suzhou, herbaceous communities (farmland, farmland weeds, and mountain herbs) have the smallest species richness index. The species richness indexes are 3.76, 3.74, and 4.06 for artificial forest communities (artificial fruit forests, bamboo forests, and artificial coniferous forests, respectively) and 3.20, 3.33, and 3.62 for natural forest communities (secondary shrub, broadleaved deciduous forests, and evergreen broadleaved forests, respectively) (Cai et al, 2015; CSYRE). In natural forest communities, the species richness index increases from secondary shrubs to deciduous forests and evergreen forests. Due to the fringe effect of artificial forestland, artificial forest communities have higher species richness than natural forest communities. As far as the impact on amphibians is concerned, analysis of historical data analysis has revealed that the Shannon-Winner Biodiversity Index of amphibians in Suzhou was 2.25 in the 1980s and 1990s (Cai et al, 2015; CSYRE). However, a 2007 survey shows that it had dropped to 2.10, which echoes the change in habitat fragmentation index of 0.285 and the current value of 0.340 (Cai et al, 2015; CSYRE).

For another example, the Yangtze River Estuary is faced with a multitude of problems, such as water pollution, habitat fragmentation, habitat loss or monotony, species reduction, reduced biodiversity, simplification of community structure, serious decline in fishery resources, and functional loss of fishing grounds (Cai et al, 2015; CSYRE). There were 97 species of phytoplankton in the Yangtze River estuary in the early 1990s; Later on, the number dropped to about 63 in the late 1990s and further to 51 in the early 21st century; The number of species in the 1990s decreased by 47% as compared to the number in the early 1980s. Moreover, in the early 1980s, there were 105 species of zooplankton, while in the early 1990s, there were only 76 species, down by 27.6%; In the late 1990s, there were only 20 species left. Several surveys conducted in the early 21st century indicated that the average number of zooplankton species was 25, which was down by 67% from the level in the early 1990s (Cai et al, 2015; CSYRE). Furthermore, in the diluted waters of the Yangtze River, there were 81 species in the early 1980s. The number dropped to an average of 33 in the late 1990s. Within 20 years, the number of zooplankton species decreased by 59% (Cai et al, 2015; CSYRE).

State of the stock of ecological integrity

According to the author's statistics in GIS attribute table by using land use and land cover data of year 2010 provided in Table 4.1, and formula in 4.3.2 4) for calculation of the supply of the ecological integrity in 2010 in the Yangtze River Delta metropolitan region (Table 3.5), reveal the following results: The total score of the supply of ecological integrity in the Yangtze River Delta metropolitan region in 2010 was 218. The total scores of ecological integrity in forest and grassland were higher than those for other land cover types (32 and 30 respectively). This means that the ecosystems in these two types of land cover had the highest supply capacity in ecological integrity.

Table 3.5 The state of the stock of ecological integrity in the Yangtze River Delta metropolitan region

Category	Area(km^2)	% of Area	Score of Ecological Integrity	(Score*km^2)	%
Urban Land	6651.26	5.73	0	0.00	0.00
Rural Residential Land	6363.57	5.48	7	44545.01	1.74
Arable Land	57881.27	49.82	21	1215506.70	47.61
Grasslands	2863.56	2.46	30	85906.89	3.36
Shrublands	159.80	0.14	21	3355.89	0.13
Forest	26943.11	23.19	32	862179.60	33.77
Inland marshes	25.01	0.02	25	625.18	0.02
Salt marshes	941.76	0.81	23	21660.48	0.85
Streams and Lakes	10335.98	8.90	23	237727.49	9.31
Estuaries	3610.15	3.11	21	75813.11	2.97
Shallow Sea Wetlands	394.91	0.34	15	5923.71	0.23
Bareland	0.85	0.00	6	5.07	0.00
(Sum)	116170.39	100.00	218	2553244.05	100.00

Note: The amount of ecological integrity (‘Score*Area’) is used to estimate the total stock of ecological integrity for a metropolitan region. The unit of the amount of ecological integrity is ‘score×km^2’.

$$S = \sum (S_i \times A_i)$$

where S (Supply) is the stock of capacities of different land cover classes to support ecological integrity, Si (score) is the score of capacities of different land cover classes to support ecosystem integrity, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to support ecological integrity.

In contrast, the total scores of ecosystem services in urban land, bareland and rural residential land were lower than for other land cover types. This means that the urban ecosystems and sparsely vegetated areas had the lowest supply capacity for ecological integrity. The total stock of the supply of the ecological integrity in the Yangtze River Delta metropolitan region was 2553244.05 score*km^2 in 2010.The total stocks of the arable land, forest and streams and lakes were 47.61%, 33.77%, 9.31% respectively. This means that these three types of land cover were the main contributors to the total stock of the supply of ecological integrity (90.69% of the total stock).

These three types of land cover also had the largest proportion in the total area of the region (arable land, 49.82%; forest, 23.19%; streams and lakes, 8.90%). Compared with the proportion of stock in 2000, the proportions of forest and streams and lakes increased by 0.84% and 0.89% respectively, while the proportion of arable land decreased by 2.38%. In contrast, urban land, rural residential land and bareland made the lowest contribution to the total stock of the supply of ecological integrity. There was no stock of supply of ecological integrity in the urban land and bareland, while the stock in the rural residential land was only 1.74% of the total stock of ecological integrity (Table 3.5).

State of the stock of biodiversity

According to the author's statistics in GIS attribute table by using land use and land cover data of year 2010 provided in Table 4.1, and formula in 4.3.2 4) for calculation of the supply of the biodiversity in 2010 in the Yangtze River Delta metropolitan region in Table 3.6, the main sources of the stock in supply of biodiversity were forest (134715.56 km^2), arable land (115762.54 km^2), and streams and lakes (41343.91 km^2). These three sources accounted for 41.12%, 35.33% and 12.62% respectively.

Compared with the proportion of stock in 2000, the proportion of the forest and streams and lakes increased by 0.54% and 1.08% respectively, while the proportion of arable land decreased by 2.21%.

Table 3.6 The state of the stock in supply of biodiversity in the Yangtze River Delta metropolitan region

Category	Area(km^2)	% of Area	Biodiversity	(Score*km^2)	%
Urban Land	6651.26	5.73	0.00	0.00	0.00
Rural Residential Land	6363.57	5.48	1.00	6363.57	1.94
Arable Land	57881.27	49.82	2.00	115762.54	35.33
Grasslands	2863.56	2.46	5.00	14317.81	4.37
Shrublands	159.80	0.14	4.00	639.22	0.20
Forest	26943.11	23.19	5.00	134715.56	41.12
Inland marshes	25.01	0.02	2.00	50.01	0.02
Salt marshes	941.76	0.81	3.00	2825.28	0.86
Streams and Lakes	10335.98	8.90	4.00	41343.91	12.62
Estuaries	3610.15	3.11	3.00	10830.44	3.31
Shallow Sea Wetlands	394.91	0.34	2.00	789.83	0.24
Bareland	0.85	0.00	3.00	2.54	0.00
(Sum)	116170.39	100.00	34.00	327640.72	100.00

Note: The amount of biodiversity ('Score*Area') is used to estimate the total stock of biodiversity for a metropolitan region. The unit of the amount of biodiversity is 'score×km^2'.

$$S = \sum (S_i \times A_i)$$

where S (Supply) is the stock of capacities of different land cover classes to support biodiversity, Si (score) is the score of capacities of different land cover classes to support biodiversity, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to support biodiversity.

State of the final ecosystem services

According to the author's statistics in GIS attribute table by using land use and land cover data of year 2010 provided in Table 3.1, and the formula in chapter 4 (4.3.2, 4)) for calculation of the supply of supply of final services (the sum of regulating services, provisioning services and cultural services) in 2010 of the Yangtze River Delta metropolitan region (Table 3.7), the following results can be observed:

The total score of the supply of final services in the Yangtze River Delta metropolitan region in 2010 was 231. The total score of final services in forest areas was much higher than in other land cover types (49). This means than forest had the highest supply capacity in the total provision of regulating services, provisioning services and cultural services. In contrast, urban and rural residential land had the lowest score in the total supply capacity of the three integrated final services. According to Table 3.7, the total stock of the supply of the final ecosystem services in the Yangtze River Delta metropolitan region in 2010 was 2696993.11 score*km^2. Forest, arable land and streams and lakes were the main sources of the total stock of the supply in the final services (92.49% of the total stock).

Unlike the ranking of total stock in supply of ecological integrity, forest made the largest contribution to the total final ecosystem services (48.95%), while arable land made the second largest contribution (34.34%) and streams and lakes made the third contribution (9.20%). Compared with the proportion of stock in 2000, the proportion of forest and streams and lakes increased by 0.92% and 0.83% respectively, while the proportion of arable land decreased by 1.94%. In contrast, urban land, rural residential land and bareland made the lowest contribution to the total stock of the supply in final ecosystem services. There was no stock in supply of ecological integrity in urban land and bareland, while the stock in rural residential land was only 0.24% of the total stock of final ecosystem services. According to the following Table 3.8, Comparing the total score of the supply of regulating services, provisioning services and cultural services, the score of regulating services (130) was much larger than those of provisioning services (48) and cultural services (46).

Table 3.7 The state of the stock of total supply of final ecosystem services (total stock of the regulating services, provisioning services and cultural services) in the Yangtze River Delta metropolitan region

Category	**Area(km^2)**	**% of Area**	**Total Score of Final Services**	**(Score*km^2)**	**%**
Urban Land	6651.26	5.73	0	0.00	0.00
Rural Residential Land	6363.57	5.48	1	6363.57	0.24
Arable Land	57881.27	49.82	16	926100.34	34.34
Grasslands	2863.56	2.46	26	74452.63	2.76
Shrublands	159.80	0.14	24	3835.30	0.14
Forest	26943.11	23.19	49	1320212.52	48.95
Inland marshes	25.01	0.02	16	400.12	0.01
Salt marshes	941.76	0.81	13	12242.88	0.45
Streams and Lakes	10335.98	8.90	24	248063.46	9.20
Estuaries	3610.15	3.11	26	93863.85	3.48
Shallow Sea Wetlands	394.91	0.34	29	11452.51	0.42
Bareland	0.85	0.00	7	5.92	0.00
(Sum)	116170.39	100.00	231	2696993.11	100.00

Note: The amount of ecosystem services supply ('Score*Area') is used to estimate the total stock of ecosystem services for a metropolitan region. The unit of the amount of ecosystem services is 'score×km^2'. $S = \sum (Si \times Ai)$:

where S (Supply) is the stock of capacities of different land cover classes to provide ecosystem services, Si (score) is the score of capacities of different land cover classes to provide ecosystem services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide ecosystem services.

Forest had the highest total score in the supply of regulating services (39) and cultural services (10), while arable land, estuaries and shallow sea wetlands had the highest total score in the supply of provisioning services (10). Comparing total stock of the supply of regulating services, provisioning services and cultural services (Table 4.6), the total stock of forest was much higher than those of other types of land cover in regulating services and cultural services (69.61% of total regulating services, 57.69% of total cultural services), while arable land was the largest source in the stock of provisioning services (80.53%), and the second largest source in the stock of regulating services (49.82%). Streams and lakes were the second largest source in provisioning services (11.50%) and cultural services (19.85%), and the third largest source in regulating services (4.79%).

(Table 3.8) Note: The amount of ecosystem services supply ('Score*Area') is used to estimate the total stock of ecosystem services for a metropolitan region. The unit of the amount of ecosystem services is 'score×km^2'. $S = \sum (S_i \times A_i)$: where S (Supply) is the stock of capacities of different land cover classes to provide regulating services, provisioning services or cultural services, Si (score) is the score of capacities of different land cover classes to provide regulating services, provisioning services or cultural services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide regulating services, provisioning services or cultural services.

Table 3.8 The state of the stock of the regulating services, provisioning services and cultural services in the Yangtze River Delta metropolitan region. RS: regulating services; PS: provisioning services; CS: cultural services

Category	Area(km^2)	% of Area	Score of RS	(Score*km^2)	%	Score of PS	(Score*km^2)	%	Score of CS	(Score*km^2)	%
Urban Land	6651.26	5.73	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Rural Residential Land	6363.57	5.48	0	0.00	0.00	1	6363.57	0.89	0	0.00	0.00
Arable Land	57881.27	49.82	5	289406.36	19.17	10	578812.71	80.53	1	57881.27	12.35
Grasslands	2863.56	2.46	17	48680.57	3.22	3	8590.69	1.20	6	17181.38	3.67
Shrublands	159.80	0.14	18	2876.47	0.19	2	319.61	0.04	4	639.22	0.14
Forest	26943.11	23.19	39	1050781.39	69.61	0	0.00	0.00	10	269431.13	57.49
Inland marshes	25.01	0.02	14	350.10	0.02	2	50.01	0.01	0	0.00	0.00
Salt marshes	941.76	0.81	8	7534.08	0.50	2	1883.52	0.26	3	2825.28	0.60
Streams and Lakes	10335.98	8.90	7	72351.84	4.79	8	82687.82	11.50	9	93023.80	19.85
Estuaries	3610.15	3.11	9	32491.33	2.15	10	36101.48	5.02	7	25271.04	5.39
Shallow Sea Wetlands	394.91	0.34	13	5133.89	0.34	10	3949.14	0.55	6	2369.49	0.51
Bareland	0.85	0.00	3	2.54	0.00	0	0.00	0.00	4	3.38	0.00
(Sum)	116170.39	100.00	130	1509608.57	100.00	48	718758.56	100.00	46	468625.98	100.00

3.4.4. Impact

Decline in ecosystem services non-monetary values

Table 3.9 The stock in supply of ecological integrity 2000-2010

Category	2000 (Score*km^2)	2010 (Score*km^2)	2010-2000 (Score*km^2)	Growth Rate %
Urban Land	0.00	0.00	0.00	0.00
Rural Residential Land	33374.01	44545.01	11171.00	33.47
Arable Land	1322428.62	1215506.70	-106921.92	-8.09
Grasslands	89687.69	85906.89	-3780.80	-4.22
Shrublands	3307.33	3355.89	48.56	1.47
Forest	871149.81	862179.60	-8970.20	-1.03
Inland marshes	768.25	625.18	-143.07	-18.62
Salt marshes	20238.99	21660.48	1421.49	7.02
Streams and Lakes	222647.13	237727.49	15080.35	6.77
Estuaries	75813.15	75813.11	-0.04	-0.00
Shallow Sea Wetlands	5923.71	5923.71	0.00	0.00
Bareland	5.45	5.07	-0.38	-6.93
(Sum)	2645344.13	2553249.12	-92095.01	-3.48

Note: Growth rate = [2010 (Score*km^2) – 2000 (Score*km^2)]/ 2000 (Score*km^2)

Note: The amount of ecological integrity ('Score*Area') is used to estimate the total stock of ecological integrity for a metropolitan region. The unit of the amount of ecological integrity is 'score×km^2'. $S = \sum \ (S_i \times A_i)$:

where S (Supply) is the stock of capacities of different land cover classes to support ecological integrity, Si (score) is the score of capacities of different land cover classes to support ecological integrity, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to support ecological integrity.

Impact on the decline of the total stock of the supply of ecosystem services

Comparing the stock of the supply of the ecological integrity in 2010 with the stock of ecological integrity in the baseline year (2000) of the Yangtze River Delta metropolitan region, there has been a dramatic decline in the stock of supply (Table 4.7):

The total stock of the supply of ecological integrity decreased by 92095.01 score*km^2 from 2000 to 2010 (Table 3.9). The total negative growth rate was 3.48% from 2000 to 2010. The top three causes of the loss of the amount of the total stock of ecological integrity were the decline of the stock in arable lands (-106921.92 score*km^2), forest (-8970.20 score*km^2), and grasslands (-3780.80 score*km^2). At the same time, the two highest decline rates were in the stock of inland marshes (-18.62%) and arable land (-8.09%). The stock of ecological integrity in rural residential land increased by 33.47% (11171.00 score* km^2) with the expansion of rural land.

Table 3.10 The stock in supply of the biodiversity 2000-2010

Category	**2000 (Score*km^2)**	**2010 (Score*km^2)**	**2010-2000 (Score*km^2)**	**Growth Rate %**
Urban Land	0.00	0.00	0.00	0.00
Rural Residential Land	4767.72	6363.57	1595.86	33.47
Arable Land	125945.58	115762.54	-10183.04	-8.09
Grasslands	14947.95	14317.81	-630.13	-4.22
Shrublands	629.97	639.22	9.25	1.47
Forest	136117.16	134715.56	-1401.59	-1.03
Inland marshes	61.46	50.01	-11.45	-18.62
Salt marshes	2639.87	2825.28	185.41	7.02
Streams and Lakes	38721.24	41343.91	2622.67	6.77
Estuaries	10830.45	10830.44	-0.01	-0.00
Shallow Sea Wetlands	789.83	789.83	0.00	0.00
Bareland	2.73	2.54	-0.19	-6.93
(Sum)	335453.94	327640.72	-7813.22	-2.33

Note: Growth rate = [2010 (Score*km^2) – 2000 (Score*km^2)]/ 2000 (Score*km^2)

The amount of biodiversity (‘Score*Area’) is used to estimate the total stock of biodiversity for a metropolitan region. The unit of the amount of biodiversity is ‘score×km^2’. $S = \sum (S_i \times A_i)$:

where S (Supply) is the stock of capacities of different land cover classes to support biodiversity, Si (score) is the score of capacities of different land cover classes to support biodiversity, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to support biodiversity.

Table 3.11 The stock in supply of the total final ecosystem services (sum of regulating services, provisioning services and cultural services) 2000-2010

Category	**2000 (Score*km^2)**	**2010 (Score*km^2)**	**2010-2000 (Score*km^2)**	**Growth Rate %**
Urban Land	0.00	0.00	0.00	0.00
Rural Residential Land	4767.72	6363.57	1595.86	33.47
Arable Land	1007564.66	926100.34	-81464.32	-8.09
Grasslands	77729.33	74452.63	-3276.70	-4.22
Shrublands	3779.80	3835.30	55.49	1.47
Forest	1333948.14	1320212.52	-13735.63	-1.03
Inland marshes	491.68	400.12	-91.57	-18.62
Salt marshes	11439.43	12242.88	803.45	7.02
Streams and Lakes	232327.44	248063.46	15736.02	6.77
Estuaries	93863.90	93863.85	-0.05	-0.00
Shallow Sea Wetlands	11452.51	11452.51	0.01	0.00
Bareland	6.36	5.92	-0.44	-6.93
(Sum)	2777370.97	2696993.11	-80377.86	-2.89

Note: Growth rate = [2010 (Score*km^2) – 2000 (Score*km^2)]/ 2000 (Score*km^2)

The amount of ecosystem services (‘Score*Area’) is used to estimate the total stock of ecosystem services for a metropolitan region. The unit of the amount of ecosystem services is ‘score×km^2’. $S = \sum (S_i \times A_i)$: where S (Supply) is the stock of capacities of different land cover classes to provide ecosystem services, Si (score) is the score of capacities of different land cover classes to provide ecosystem services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide ecosystem services.

The author and local experts paid attention to the decline of the total stock of biodiversity (Table 3.10). The total stock of biodiversity decreased by 7813.22 score*km^2 from 2000 to 2010. The total negative growth rate was 2.33% from 2000 to 2010. The three main elements of the loss of the amount of the total stock of biodiversity were similar to those for the total stock of ecological integrity: the decline of the stock in arable land (-10183.04 score*km^2), forest (-1401.59 score*km^2), and grassland (-630.13 score*km^2). At the same time, the two highest decline rates were also in the stock of inland marshes and arable land. The stock of biodiversity in rural residential land increased from 4767.72 score*km^2 to 6363.57 score*km^2 with the expansion of rural land (Fig.3.10). According to the following Table 3.10, the total stock of the supply of total final services decreased by -80377.86 score*km^2 from 2000 to 2010. The negative growth rate was 2.89% from 2000 to 2010. The three greatest declines in the total stock of total final ecosystem services were again in arable land (-81464.32 score*km^2), forest (-13735.63 score*km^2), and grassland (-3276.70 score*km^2). The two highest decline rates were again in the stock of inland marshes and arable land.

Comparing the decline in the total stock of regulating services from 2000 to 2010 (Table 3.12), provisioning services and cultural services, the most significant reduction was in the stock of provisioning services (-44335.31 score*km^2). The two greatest decline rates in the three integrated ecosystem services were also in the stock of inland marshes and arable land. Among the twelve types of land cover, arable land (-50915.20 score*km^2) and grassland (--378.08 score*km^2) were the main sources in the decline of the stock of provisioning services. According to Table 3.12, the decline of the total stock of regulating services was less than the provisioning services (-33487.09 score*km^2). The three greatest declines in the stock of provisioning services were arable land (-25457.60 score*km^2), forest (-10932.44 score*km^2) and grasslands (-2142.46% score*km^2). According to Table 4.10, the decline of the total stock of cultural services was -2555.46 score*km^2. Among the twelve types of land cover, the top three in decline of the stock of cultural services were the same as for the stock of regulating services (arable land, -5091.52 score*km^2, forest, -2803.19 score*km^2; grassland, -756.16 score*km^2).

Table 3.12 The stock in supply of the regulating services, provisioning services and cultural services 2000-2010

Category	**RS (2010-2000) Score*km^2**	**RS (Growth Rate %)**	**PS (2010-2000) Score*km^2**	**PS (Growth Rate %)**	**CS (2010-2000) Score*km^2**	**CS (Growth Rate %)**	**TFS (2010-2000) Score*km^2**	**TFS (Growth Rate %)**
Urban Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rural Residential Land	0.00	0.00	1595.86	33.47	0.00	0.00	1595.86	33.47
Arable Land	-25457.60	-8.09	-50915.20	-8.09	-5091.52	-8.09	-81464.32	-8.09
Grasslands	-2142.46	-4.22	-378.08	-4.22	-756.16	-4.22	-3276.70	-4.22
Shrublands	41.62	1.47	4.62	1.47	9.25	1.47	55.49	1.47
Forest	-10932.44	-1.03	0.00	0.00	-2803.19	-1.03	-13735.63	-1.03
Inland marshes	-80.12	-18.62	-11.45	-18.62	0.00	0.00	-91.57	-18.62
Salt marshes	494.43	7.02	123.61	7.02	185.41	7.02	803.45	7.02
Streams and Lakes	4589.67	6.77	5245.34	6.77	5901.01	6.77	15736.02	6.77
Estuaries	-0.02	-0.00	-0.02	-0.00	-0.01	-0.00	-0.05	-0.00
Shallow Sea Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Bareland	-0.19	-6.93	0.00	0.00	-0.25	-6.93	-0.44	-6.93
(Sum)	-33487.09	-0.18	-44335.31	-5.81	-2555.46	-0.54	-80377.86	-4.04

Note: RS: regulating services; PS: provisioning services; CS: cultural services; TFS: Total final ecosystem services; Growth rate = [2010 (Score*km^2) – 2000 (Score*km^2)]/ 2000 (Score*km^2)

The amount of ecosystem services supply (‘Score*Area’) is used to estimate the total stock of ecosystem services for a metropolitan region. The unit of the amount of ecosystem services is ‘score×km^2’. $S = \sum \ (S_i \times A_i)$:

where S (Supply) is the stock of capacities of different land cover classes to provide regulating services, provisioning services or cultural services, Si (score) is the score of capacities of different land cover classes to provide regulating services, provisioning services or cultural services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide regulating services, provisioning services or cultural services.

Decline in ecosystem services monetary values

At the regional level, Haas & Ban (2014) detected a loss in ecosystem service value from 100.8 million CNY to 92.5 million CNY in the Yangtze River Delta metropolitan region from 1990 to 2010. They detected that rapid urbanization at the cost of cropland yielded low ecosystem service values and the increase of aquaculture also contributed to the ecosystem services value. Xu et al (2014b) also found an overall decline of the stock of ecosystem services (Natural Capital) by 10.4% (or 8.44 billion CNY) in the Yangtze River metropolitan region from 2000 to 2010. At the prefecture-city level, the stock of ecosystem services of fifteen out of the sixteen core cities decreased dramatically which was highly correlated with rapid urbanization, population growth and industrialization. They argued that land use/cover change and deteriorating water quality are dominant factors causing the depletion of the overall stock of ecosystem services, although the decline of ecosystem services was somewhat offset by increased crop productivity and environmental policies. At prefecture-city level, Li et al (2016a) studied the impacts of urbanization on food supply service, carbon sequestration service, soil water storage service, air pollution removal service, habitat suitability, and recreation potential service) in Nanjing city of Jiangsu Province. They found that the rapid urbanization and industrialization in developing urban areas and rural residential areas led to the decline of food supply service, carbon sequestration service, soil water storage service, and habitat suitability service.

3.4.5. Responses

As a result, in this region, developed areas with more urban areas undergo serious environmental problems, whereas developing areas with more rural areas undergo economic development problems. If Shanghai, Jiangsu and Zhejiang only focus on their own development planning and are unable to establish cooperation mechanisms related to ecosystem services, it will not only have a negative impact on the ecosystem in the whole region, but also destroy prospects for sustainable development in the Yangtze River Delta metropolitan region. If developed areas with ecosystem service deficits can provide economic support to developing areas, and developing areas with ecosystem service surplus can provide ecosystem services to meet developed areas' demand, the situation in this region will improve.

1) Environmental policy aims from the 2009-2020 Regional Plan for the Yangtze River Delta metropolitan region (RPYRDR, 2010)

Resource utilisation and protection of ecological environment aims has been put forward in the Regional Plan for Yangtze River Delta metropolitan region. Against the backdrop of the aforementioned situation, a series of measures under ecological red line policy are in order: making tough rules for cropland land protection, realizing economic and intensive use of land, intensifying efforts for protecting the environment, materializing ecological construction, strengthening ecosystem functions and services and building an environment-friendly society for an overall improvement in the region's sustainable development.

Reasonable use of land resources (RPYRDR, 2010):

First of all, there is a need to safeguard arable land. Protection of basic farmland, one of China's fundamental state policies, should be executed firmly to protect basic farmland, particularly arable land and to improve its quality. In addition, a higher level of reclamation, land development, and consolidation should be achieved, along with the development of high-standard ecological cropland function zone. The reserve of basic farmland in the core regions should be no less than 3,330,000 hectares, with the permanent population being self-sufficient in terms of food. Moreover, the idea is to safeguard and protect land for ecological purposes. Protective limitations should be set for ecological priority areas and other regions with ecological importance. Strict protection should be ensured for regions including nature reserves, forest parks, key water source sites for centralised drinking water supply, key water function zones, mountains in Southern Zhejiang, and hilly mountains in Jiangsu and Zhejiang's Huzhou and Jiaxing. In addition, land use intensity should be put under strict control for peripheral areas of key water sources, both sides of water channels, main streams of Yangtze River and Qiantang River, important ecological patches among cities, the mountains in Western Zhejiang, and areas in Jiangsu and Zhejiang's Huzhou and Jiaxing. At the same time, new nature reserves and special protected areas should be established in an organised way to improve ecological and environmental quality in the region. Woodlands and grasslands should also be better protected from illegal occupation.

Furthermore, land resource allocation should be optimised. Differentiated land policies should be applied based on the overall framework, along with comprehensive planning of arable land, and optimisation of land use pattern. At the same time, the land use structure should be optimised, and greater efforts should be made for land consolidation and reclamation for higher land yield. Meanwhile, incremental expansion of urban construction land ought to be under strict control in large cities, such as Shanghai. Sufficient space should be provided for natural ecology, and an appropriate amount of construction land should be approved to boost the ordered clustering and development of cities and industries.

In addition, ecological protection should be prioritised for the lakeside function zone, i.e. Taihu Lake Basin, and effective measures should be adopted for controlling land use and intensity of land development. Moreover, the proportion of ecological farmland under protection should be raised modestly in other regions, and encroachments on arable land for construction should be controlled below a certain scale. Through scientific land planning, mud flat and low hills should be developed in a reasonable and orderly manner to increase the size of both arable and construction lands.

Ecological construction and environmental protection (RPYRDR, 2010):

The source sites of drinking water should be protected in a better way. Efforts should be focused on protecting the water quality of source sites for a centralised drinking water supply. Water function zones should be established for the mainstream of Yangtze River, Yangtze River Estuary, Taihu Lake water network, main and branch streams of Qiantang River, and small- and medium-sized lakes and reservoirs for inter-city environmental cooperation.

In addition, the level-to-level administration system should be improved for protected source sites of drinking water, and specific protection scope, requirements and comprehensive control and treatment plans should be developed. At the same time, stricter water pollution control and water quality protection should be realised in the protected source sites of water channels such as Taihu Lake-to-Northern Zhejiang water diversion and diversion to Eastern Zhejiang in the Yangtze River Delta metropolitan region. Development and construction activities along these protected function zones should be placed under strict regulation, and stringent standards should be set for discharging effluent sewage. Moreover, a mechanism for protecting the sources of drinking water should be established and optimised, securing win-win for all rivers and downstream and upstream regions. At the same time, underground water resources should be better protected by limiting excessive exploitation of underground water, and preventing and treating ground subsidence and saltwater intrusion. Improved water quality and sufficient water supply should be guaranteed at water source sites with serious pollution and insufficient water supply, and their water quality should be made to qualify certain standards.

1) Proposed environmental management responses based on ecosystem services assessment

To address the decline of ecosystem services and support the ecological function zone delineation in the Yangtze River Delta Metropolitan Region, the following responses are proposed in order to incorporate ecosystem services assessment into regional environmental management:

In chapter 5, the author will identify and manage ecosystem services hot spots and cold spots for promoting major function zones under the ecological red line policy for the Yangtze River Delta metropolitan region.

In chapter 6, the author will delineate conservation priority areas for promoting provincial ecological cropland and forest function zones under the ecological red line policy by ecosystem services supply.

In chapter 7, the author will establish ecosystem services supply-demand budget considering spatial relations for promoting inter-city cooperation at watershed scale for promoting inter-city environmental cooperation in the ecological water function zone under the ecological red line policy for the Yangtze River Delta metropolitan region.

3.5. Conclusion

The Yangtze River Delta metropolitan region is one of the fastest growing regions in China. In recent years, it has witnessed tremendous growth in its public sectors, including industrial and agricultural sectors, besides making substantial changes vis-à-vis urban-rural development. At the same time, pressures caused by urbanisation and economic growth, such as change of land cover/use, land resource problems, water pollution problems and air pollution problems, have been on the rise, leading to high disturbance in the state of some of the regional ecosystems, along with negative impacts such as a sharp degradation in the regional ecosystems, reduction of ecological space and loss in biodiversity. It is urgent to make rapid conservation-development decisions and apply an approach, such as an ecosystem service approach, that can not only mitigate the negative impacts driven by rapid urbanization, but also conserve benefits from ecosystem to the socio-economic system. Moreover, new national environmental policies such as the ecological red line policy, basic farmland policy and the watershed payment for ecosystem services mechanism all emphasise the need for an ecosystem services approach. However, as a theoretical approach, an ecosystem services approach sometimes experiences a gap between the science and policy implementation. The demand for a scientific and easy-to-apply ecosystem services approach framework will be in high demand in such a rapid urbanization region as the Yangtze River Delta metropolitan region. The next chapter will introduce the methods and general steps of the author research framework.

Chapter 4 Methodology

4.1. Introduction

The principal aim of this research is to reveal the role of the particular ecosystem service approach in a metropolitan region's environmental management and planning.

In order to make Burkhard's matrix-based approach adapted to the Yangze River Delta Region. The author corresponded local Land Use and Land Cover (LULC) system in the Yangtze River Delta Region to CORINE LULC system which was used in Burkhard's method. Then, the author applied local expert knowledge in confirming and adjusting Burkhard's original scores of the capacities of different land cover classes to support ecological integrity and to supply twenty-three ecosystem services for the Yangtze River Delta Region. The score matrix between twelve ecosystem types and twenty-three ecosystem services for the region was established for comprehensive function zone delineation Next, the author used net primary productivity to further adjust the capacities of ecosystem functions and services directly of two main terrestrial ecosystems for particular red line delineation. Also, based on the supply-demand budget of ecosystem services, the budgets of three regulating services (erosion regulating service, flood regulating service and water purification regulating service) of the sixteen core cities in the region were established, and the characteristics of service provision city (surplus city) and deficit (city) of three services of the cities in the region were analysed.

This chapter provides the rationale and detailed descriptions of the methods the author used to achieve the research objectives.

The author demonstrates how the methodological approaches relate to the author's theoretical questions and objectives.

First, the research methods area briefly introduced the research method in section 4.2. Then, the details of the research methods and process for meeting the research objectives are explained respectively in section 4.3 (Fig.4.1):

Section 4.3.2, Driver-pressure-state-impact-response analysis for the decline of total ecosystem services for meeting the research objective 2 (Fig. 4.3): problems identification analysis of causes for the decline of the ecosystem services in the Yangtze River Delta metropolitan region.

Section 4.3.3, Identifying and managing ecosystem services hot spot and cold spot for meeting the research objective 3 (Fig. 4.4): promoting major function zones under the ecological red line policy by ecosystem services hot spot and cold spot management for the Yangtze River Delta metropolitan region.

Section 4.3.4, Conservation priority area decision support for meeting the research objective 4 (Fig. 4.5): promoting provincial ecological cropland and forest function zones under the ecological red line policy by ecosystem services supply.

Section 4.3.5, Ecosystem services supply-demand budget considering spatial relations for promoting inter-city cooperation at watershed scale for meeting the research objective 5 (Fig. 4.6): promoting inter-city environmental cooperation in the ecological water function zone under the ecological red line policy by ecosystem services supply-demand budget for the Yangtze River Delta metropolitan region.

Finally, the author discusses the problems and critiques of the research methods process in section 3.4.

4.2. Research methods

As this thesis focuses on a specific region, the Yangtze River Delta metropolitan region, the collection and sorting past research findings account for a large part of this research. This research included theoretical research results on ecosystem services in China, and case studies of society and the ecological environment in the Yangtze River Delta metropolitan region.

4.2.1. Establishment of assessment database of ecosystem services

The assessment database of ecosystem services is composed of data and information divided into five parts (Table 4.1). They are as follows: GIS database, regional development planning database, remote sensing database, socioeconomic database and the supplementary survey data and materials.The regional development planning database collects data related to regional development planning. The remote sensing database is a collection of all kinds of data obtained by remote sensing, and also includes some aerial and satellite images. The socioeconomic database contains socio-economic data on population, settlements, industries and environment. Supplementary survey database is designed primarily for data and information derived from surveys conducted for specialised research work.

Through the integration of the above databases, a comprehensive and systematic ecosystem services assessment database can be established, which can be used for not only analysing spatiotemporal state but also evaluating by statistical data. The database was prepared from regional resources reports of provincial and prefecture-level cities in the study area, along with local environmental reports and development and planning reports (Table 4.1). Moreover, this thesis incorporates literature published domestically in the past years, as well as some monographs and statistical yearbooks of relevant cities. Some physical maps and satellite photos have also been obtained. In general, information collected on the Yangtze River Delta metropolitan region includes both graphics and textual data.

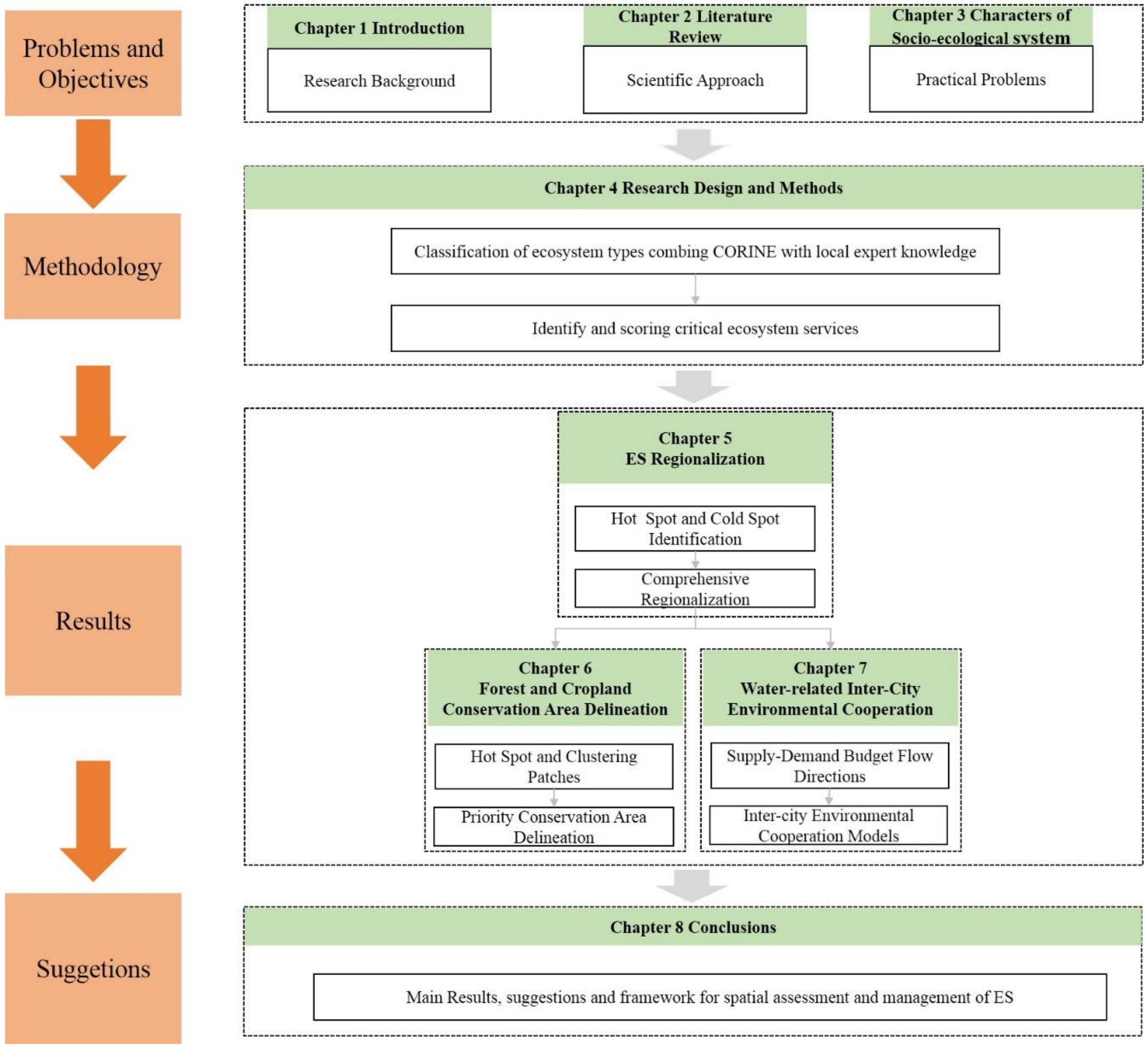

Figure 4.1 The flow chart of research

Table 4.1 Database

Data	Time	Resolution	Type	Accuracy	Source
Land cover/use (cropland and forest)	2015	30	Spatial data: Raster	Overall classification accuracy: 86.63%	Chinese Academy of Sciences Geography Science And Resource Institute(http://www.resdc.cn/DataList.aspx)
Land cover/use	2000/ 2010	30	Spatial data: Raster	Overall classification accuracy: 85.58%	GlobeLand30, 2000/2010. National Geomatics Centre of China. http://www.globeland30.org/GLC30Download/download.aspx.
The Digital Elevation Model (DEM)	/	30	Spatial data: Raster	Overall classification accuracy: 85.56%	Geospatial Data Cloud (http://www.gscloud.cn/).
Annual Maximum Value Product of Net Primary Productivity (NPP)	2015	500	Spatial data: Raster	Overall classification accuracy: 85.83%	Chinese Academy of Sciences Geography Science And Resource Institute(http://www.resdc.cn/DataList.aspx)
Population density	2010	500	Spatial data: Raster	Overall classification accuracy: 85.11%	Chinese Academy of Sciences Geography Science And Resource Institute(http://www.resdc.cn/DataList.aspx)
GDP per kilometre square	2010	500	Spatial data: Raster	Overall classification accuracy: 85.53%	Chinese Academy of Sciences Geography Science And Resource Institute(http://www.resdc.cn/DataList.aspx)
Land use classification system	2010	/	Document	/	Chinese Academy of Sciences Geography Science And Resource Institute(http://www.resdc.cn/DataList.aspx)
Ecosystem services supply and demand/supply capacities	2010/ 2015	/	Document	/	Local Expert interviews
Environmental reports	2015	/	Document	/	Local academic institutions and governments

4.2.2. Local experts interview

In the case of the Yangtze River Delta metropolitan region, among fifteen experts, five from government bodies (one from Shanghai, two from Jiangsu Province, two from Zhejiang Province), four from East China Normal University, one from Nanjing University, one from Nanjing Institution of Chinese Academy of Sciences, one from Jiangsu University, two from an environmental institution employed by government in Zhejiang Province) were interviewed (see Table 4.2) and asked to score each regional ecosystem services supply and demand for the Yangtze River Delta metropolitan region. The C-1 leader eco-policy advisor scientist gave the author great help in contact with the local academic experts and officers.

Table 4.2 Local expert interview

Region	No.	Role	Expertise
China	C-1	Leader Eco-Policy Advisor Scientist	National and Regional Ecological Conservation Policy
Shanghai	S-1	Leader Scientist of Shanghai	Landscape Ecology and Ecological Planning
	S-2	Scientist	Urbanization and Economic Development
	S-3	Scientist	Urbanization and Environmental Problems
	S-4	Scientist	Ecological Tourism
	S-5	Public Officer	Greening Administration
Jiangsu	J-1	Leader Scientist of Jiangsu	Ecology and Agriculture
	J-2	Scientist	Water Resource Management
	J-3	Scientist	Primary Farmland Management
	J-4	Public Officer	Land Management Administration
	J-5	Public Officer	Water Resource Administration
Zhejiang	Z-1	Leader Scientist of Zhejiang	Forest and Water Resource Conservation
	Z-2	Scientist	Ecological Forestry Conservation
	Z-3	Scientist	Water Resource and Eco-compensation
	Z-4	Public Officer	Forestry Administration
	Z-5	Public Officer	Water Resource Administration

All experts were familiar with the environmental issues in the Yangtze River Delta metropolitan region. All experts were familiar with the environmental issues in the Yangtze River Delta metropolitan region.

4.2.3. Field survey

During preliminary preparation and thesis writing, the author examined typical ecosystem in Yangtze River Delta metropolitan region (i.e. forests, wetlands, rivers, lakes, farmlands, cities) and proved a part of previous research findings. In addition to the typical ecosystem, the author used satellite photos and ground investigation to analyse regional differentiation and draw draft figures of ecosystem services zoning and planning.

4.2.4. Document analysis

Through the socio-ecological context analysis by academic reports and government documents review, driving forces between the environmental problems related to urbanisation and the decline of ecosystem services caused by deterioration of ecosystems were understood, and the objectives of management and priority conservation of critical ecosystems and their services in a region were defined.

4.2.5. Ecological planning

The method of macro-ecology investigation and analysis has been utilised to identify the ecosystem services. Moreover, methods of local experts' interviews have been used to test the supply and demand of ecosystem services, while ecological zoning theories have been adopted to divide Yangtze River Delta metropolitan region into different ecosystem services zones. Based on the analysis of current ecological services supply and demand occupancy of the Yangtze River Delta metropolitan region, the theory and method of ecological planning have been utilised to plan and develop the region's ecological environment via one or two functional documents.

4.3. Research framework[1]

4.3.1. Identification of major environmental problems and definition of conservation objectives

The author conducted survey to identify the regional ecosystem types in Shanghai Municipality, Nanjing, Zhenjiang, Yangzhou in Jiangsu Province, and Hangzhou, Ningbo, Shaoxing in Zhejiang Province in November, December and January, 2015. Moreover,

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[1] The author published some of the research process in Cai, W., Gibbs, D., Zhang, L., Ferrier, G. & Cai, Y. (2017) Identifying hotspots and management of critical ecosystem services in rapidly urbanizing Yangtze River Delta Region, China. *J Environ Manage*, 191, 258-267.

Shanghai’s local experts continued their survey in Shanghai Municipality, Jiangsu Province and Zhejiang Province in the summer and autumn in 2015. Combining analysis of regional professional materials at different spatial scales, i.e. environmental assessment reports, land cover/ land use, with fieldwork and local experts’ consultation, major regional environmental problems were defined.

4.3.2. Classification of ecosystem types combining CORINE with local expert knowledge

For the Yangtze River Delta metropolitan region, a raster land cover dataset was used in this study available from the National Geomatics Center of China (NGCC) and can be transferred and digitised in GIS format (Table 4.1). The images utilised for GlobeLand30-2000/2010 classification are multispectral images with 30 m resolution, including the TM5 and ETM + of America Land Resources Satellite (Landsat) and the multispectral images of China Environmental Disaster Alleviation Satellite (HJ-1) for the years of 2000 and 2010 (Table 4.1). According to Table 4.3, the CORINE (Co-ordinated Information on the Environment) data series was established by the European Community (EC) as a means of compiling geospatial environmental information in a standardised and comparable manner across the European continent. Although the CORINE focuses on the European continent, it provides a useful reference for land cover classification of other continents.

To address the difference in land cover in different regions, the author used local land cover or ecosystem classifications provided by the local government in the Yangtze River Delta metropolitan region and local expert knowledge to adjust the names and types of land cover or ecosystems of the CORINE classification (Table 3.3). The local classification system of land use/cover included twelve aggregated classes: (1) Urban land, (2) Rural residential land, (3) Arable land, (4) Forest, (5) Shrublands, (6) Grasslands, (7) Bareland, (8) Inland marshes, (9) Salt marshes, (10) Streams and lakes, (11) Estuaries, (12) Shallow sea wetland (Table 3.3).

Table 4.3 The classification system of land use/land cover and ecosystem types of Yangtze River Delta metropolitan region

CORINE Land cover	Yangtze River Delta Region Land cover	Ecosystem types
Continuous urban fabric	Urban land	Urban
Discontinuous urban fabric	Rural residential land	
Non-irrigated arable land	Arable land	Cropland
Permanently irrigated arable land		
Broad-leaved forest	Forest	Woodland and forest
Coniferous forest		
Mixed forest		
Transitional woodland shrub	Shrubland	
Natural grassland	Grassland	Grassland
Bare rock	Bareland	Sparsely vegetated areas
Inland marshes	Inland marshes	Wetlands
Salt marshes	Salt marshes	
Estuaries	Estuaries	Marine inlets and transitional waters
Intertidal flats/Sea	Shallow sea wetlands	
Water courses	Streams and Lakes	Rivers and lakes

4.3.3. Identifying and scoring critical ecosystem services

Twenty-three ecosystem services that derived respectively from ecological integrity, regulating services, provisioning services and cultural services were classified based on Millennium-Ecosystem Assessment and the classification of ecosystem services in Burkhard et al. (2012) and were scored by Burkhard's method. The matrix linking twenty-three ecosystem services (on the x-axis) to twelve different land cover types (on the y-axis) was constructed in this research (Table 4.4). Local expert knowledge was used to adjust the scores of the ecosystem services in Yangtze River Delta metropolitan region.

Table 4.4 List of ecological integrity and ecosystem service (after Burkhard et al., 2012; Burkhard et al., 2009)

Ecological integrity	**Definition**
Abiotic heterogeneity	The provision of suitable habitats for different species, for functional groups of species and for processes is essential for the functioning of ecosystems.
Biodiversity	The presence or absence of selected species, (functional)groups of species, biotic habitat components or species composition.
Biotic water flows	Referring to the water cycling affected by plant processes in the system.
Metabolic efficiency	Referring to the amount of energy necessary to maintain a specific biomass, also serving as a stress indicator for the system.
Exergy Capture (Radiation)	The capability of ecosystems to enhance the input of usable energy. Exergy is derived from thermodynamics and measures the energy fraction that can be transformed into mechanical work. In ecosystems, the captured exergy is used to build up biomass (e.g. by primary production) and structures.
Reduction of Nutrient loss	Referring to the irreversible output of elements from the system, the nutrient budget and matter flows.
Storage capacity (SOM)	Is referring to the nutrient, energy and water budgets of the system and the capacity of the system to store them when available and to release them when needed.
Regulating services	
Local climate regulation	Changes in land cover can locally affect temperature, wind, radiation and precipitation.
Global climate regulation	Ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.
Flood protection	Natural elements dampening extreme flood events
Groundwater recharge	The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
Air Quality Regulation	The capacity of ecosystems to remove toxic and other elements from the atmosphere.
Erosion Regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.
Nutrient regulation	The capacity of ecosystems to carry out (re)cycling of, e.g. N, P or others.
Water purification	Ecosystems have the capacity to purify water but can also be a source of impurities in fresh water.
Pollination	Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators. Wind and bees are in charge of the reproduction of a lot of culture plants.
Provisioning services	
Crops	Cultivation of edible plants.
Livestock	Keeping of edible animals.
Capture Fisheries	Catch of commercially interesting fish species, which are accessible for fishermen.
Aquaculture	Animals kept in terrestrial or marine aquaculture.
Freshwater	Presence of freshwater.
Cultural services	
Recreation & Aesthetic Values	Refers specifically to landscape and visual qualities of the resp. case study area (scenery, scenic beauty). The benefit is the sense of beauty people get from looking at the landscape and related recreational benefits.
Intrinsic Value of Biodiversity	The value of nature and species themselves, beyond economic or human benefits.

Local experts modified the ecosystem services classification system adapted to local context. Based on environmental problems solving and conservation objectives in the study area, local experts choose most of the ecosystem services (twenty-three) from the classification of

Burkhard et al's ecosystem services classification system for the assessment in the Yangtze River Delta Region. For instance, they did not assess some of the provisioning services such as Timber and Wood fuel of forest ecosystem, because most of the mountainous forest ecosystems in this region has been announced for conservation and forbidden for cutting down by local governments, especially mountainous forest ecosystems with large area and high-quality in Zhejiang Province. For another, also they know some of the water bodies have potentials of wild food provisioning, e.g. Qiandao Lake, they did not include this service in the assessment because most of such lakes and rivers has been considered as freshwater sources and restricted hunting.

According to Table 4.4, the classification system of ecosystem services grouped ecosystem services into four major categories: provisioning services (PS) consisting of the commodities that people use such as fibre, food, timber, and water; regulating services (RS) affecting climate, disease, floods, waste, and water quality; cultural services (CS) providing recreational, aesthetic, and spiritual benefits; and ecological integrity: EI assisting in soil formation, photosynthesis, and nutrient cycling (Burkhard et al, 2012; MEA, 2005).

According to the following Table 4.5 shows the process that how the three team of local experts work from each of the table (Table 4.7, Table 4.8, and Table 4.9) to the final score table (Table 4.10).

For scoring critical ecosystem services, the Burkhard's method was used to construct an ecosystem services matrix combining land cover information in the assessment of the state of ecosystems and their capacities to supply ecosystem services based on Millennium Ecosystem Assessment and the classification of ecosystem services in Burkhard et al (2012). Thirdly, the score of each critical ecosystem service was adjusted by using local expert knowledge. The local experts familiar with the environment of a study area were selected and be invited to score the ecosystem services of the study area.

They first had explained to the definition and classification of ecosystem services and were provided with Burkhard's original supply scores table and the relevant explanation (Burkhard et al, 2012) . Then, the final scores of critical ecosystem services were discussed together and determined by all experts. The 'medium' score of the capacity of the three teams (Shanghai team, Jiangsu team and Zhejiang team) of each of the land cover to support specific ecological integrity and ecosystem service was used for scoring as introduced process in Table 4.5.

Table 4.5 Process of local experts scoring matrix table

Shanghai	**Ecosystem service $_1$**	**Ecosystem service $_n$**
Land cover $_1$	Score$_1$ (Shanghai)=Median [Expert S1, Expert S2, Expert S3, Expert S4, Expert S5]	X
Land cover $_2$	Score$_2$ (Shanghai)= Median[Expert S1, Expert S2, Expert S3, Expert S4, Expert S5]	X
……	……	X
Land cover $_M$	Score$_M$ (Shanghai)=Median[Expert S1, Expert S2, Expert S3, Expert S4, Expert S5]	X

Jiangsu	**Ecosystem service $_1$**	**Ecosystem service $_n$**
Land cover $_1$	Score$_1$ (Jiangsu) =Median [Expert J1, Expert J2, Expert J3, Expert J4, Expert J5]	X
Land cover $_2$	Score$_2$ (Jiangsu) = Median[Expert J1, Expert J2, Expert J3, Expert J4, Expert J5]	X
……	……	X
Land cover $_M$	Score$_M$ (Jiangsu) = Median[Expert J1, Expert J2, Expert J3, Expert J4, Expert J5]	X

Zhejiang	**Ecosystem service $_1$**	**Ecosystem service $_n$**
Land cover $_1$	Score$_1$ (Zhejiang) = Median[Expert Z1, Expert Z2, Expert Z3, Expert Z4, Expert Z5]	X
Land cover $_2$	Score$_2$ (Zhejiang) = Median[Expert Z1, ExpertZ 2, Expert Z3, Expert Z4, Expert Z5]	X
……	……	X
Land cover $_M$	Score$_M$ (Zhejiang) = Median[Expert Z1, Expert Z2, Expert Z3, Expert Z4, Expert Z5]	X

Final Table	**Ecosystem service $_1$**	**Ecosystem service $_n$**
Land cover $_1$	Median [Score1 (Shanghai), Score1 (Jiangsu), Score1 (Zhejiang)]	X
Land cover $_2$	Median [Score2 (Shanghai), Score2 (Jiangsu), Score2 (Zhejiang)]	X
……	……	X
Land cover $_M$	Median [Score$_M$ (Shanghai), Score$_M$ (Jiangsu), Score$_M$ (Zhejiang)]	X

The following table (Table 4.6) is an example of the scoring process. Use the scoring process of the arable land for crops provisioning service as an example, the scoring process was started from left to right:

In the first step, five local experts in each team (Shanghai team, Jiangsu team or Zhejiang team) gave their own scores.

In the next step, the ‘median’ score of the five local experts in each team were selected (Table 4.6: Left) and formed the team process table (Table 4.7 or Table 4.8 or Table 4.9).

In the final step, the ‘median’ score of the three teams were selected and then formed the final score table (Table 4.10).

In the example showed in the following table (Table 4.6), the score of the capacity of arable land for crops provisioning service is ‘4’ in Shanghai team score table, ‘5’in ‘Jiangsu team’ score table and ‘5’ in Zhejiang team score table. The ‘median’ score of them is ‘5’. Therefore, the ‘5’ was selected as the final score of the capacity of arable land for crops provisioning services in the final score table for the Yangtze River Delta metropolitan region. Similar expert elucidation can be seen in the methodology of Burkhard et al (2015).

Table 4.6 Example of local experts scoring matrix table (from Shanghai team, Jiangsu team and Zhejiang team to final table)

Score Expert S1: 4
Score Expert S2: 3
Score Expert S3: 4
Score Expert S4: 4
Score Expert S5: 5

Median

Shanghai team (Table 3.7)	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater
Urban Land		0	0	0	0	0
Rural residential land		1	0	0	0	0
Arable land		**4**	**4**	0	0	0

Score Expert J1: 5
Score Expert J2: 5
Score Expert J3: 5
Score Expert J4: 4
Score Expert J5: 5

Median

Jiangsu team (Table 3.8)	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater
Urban Land		0	0	0	0	0
Rural residential land		1	0	0	0	0
Arable land		**5**	**5**	0	0	0

Final Score Table	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture
Urban Land		0	0	0	0
Rural residential land		1	0	0	0
Arable land		**5**	**5**	0	0

Median

Score Expert J1: 5
Score Expert J2: 4
Score Expert J3: 5
Score Expert J4: 5
Score Expert J5: 5

Median

Zhejiang team (Table 3.9)	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater
Urban Land		0	0	0	0	0
Rural residential land			0	0	0	0
Arable land		**5**	**5**	0	0	0

Table 4.7 Process score table of the Shanghai team for assessment of ecosystem services capacities

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation&Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		4	4	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		4	3	3	2	4	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right): The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

In the first round of local experts' interview, the author interviewed five local experts together (Table 4.2: S1-S5; Table 4.7: Shanghai team) in the East China Normal University.

According to the author's interview and scoring table of Shanghai team (Table 4.7), the local experts in Shanghai reduced the capacities of ecosystem services supply in these two types of ecosystems in the Yangtze River metropolitan region'.

The Shanghai team confirmed most of Burkhard's original score table for ecosystem services supply and demand, but gave a lower score for the ecosystem services supply capacities in local climate regulation service, global climate regulation service and air quality regulation service of forest, and crop provisioning service and livestock provisioning service of arable land (Table 4.7).

Local experts in Shanghai team considered that 'the fragmentation of forest and cropland in cities like Shanghai reduced the capacities of ecosystem services which they can provide.'

Table 4.8 Process score table of the Jiangsu team for assessment of ecosystem services capacities

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation&Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		5	5	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		5	4	3	2	5	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right). The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

In the second round of local experts' interview, the author interviewed the five local experts (Table 4.2: J1-J5; Table 4.8: Jiangsu team) in Nanjing University and Chinese Academy of Sciences in Jiangsu Province.

In the first step, the author contacted the leader advisor C-1 in a regional environmental government in Nanjing and the leader scientist of Jiangsu team J1 with help of the leader scientist S-1 of the Shanghai team. In the second step, the author and the S-1 scientist went to Nanjing together to meet the leader scientist C-1for collecting environmental polices aims and cooperation with other officers in the local governments in Jiangsu Province and Zhejiang Province.

With the help of the C-1 scientist, the author the scientist S-1 met the Jiangsu team in Nanjing. In the third step, the author introduced the scoring process to the five local experts which was successfully used by the Shanghai team. Finally, by using the author's process design, the author collected the scoring results and their views of five local experts in Nanjing University, Chinese Academy of Sciences and local government in Jiangsu Province.

According to Table 4.7 and Table 4.8, different from the Shanghai team, the five local experts in Jiangsu team give higher scores of the capacities of provisioning services in arable land and some higher scores of regulating services, such as global climate regulation service and air quality regulation service of forest. Local experts in Jiangsu team believed that 'although habitat fragmentation existed in some of the cropland ecosystem, there were still large area of high-quality cropland in the Yangtze River Delta metropolitan region (especially in Jiangsu Province) which had high capacities in crop provisioning service and livestock provisioning service' (Table 4.8).

Table 4.9 Process score table of the Zhejiang team for assessment of ecosystem services capacities

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation&Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		5	5	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		5	5	3	3	5	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right). The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

In the third round of local experts' interview, the author interviewed the five local experts (Table 4.2: J1-J5; Table 4.9: Zhejiang team) in Hangzhou in Zhejiang Province.

In the first step, the author went to Hangzhou with the leader scientist S-1 of Shanghai's team and introduced the scoring process to the leader scientist Z-1 in a government employed institution.

In the second step, the author contacted the leader advisor C-1 to cooperate with officers in forestry and watershed department in Hangzhou in the Xin'an river watershed.

In the third step, by using the author's process design as for Shanghai team, the author collected the scoring results and their views of five local experts in Zhejiang team.

Comparing with the scoring tables of other two teams (Table 4.7 and Table 4.8), the five local experts in Zhejiang team gave higher scores of the capacities of regulating services of forest land (Table 4.9).

Local experts in the Zhejiang team believed that 'large area and clustering forest in the Yangtze River Delta metropolitan region, especially in Zhejiang Province had high capacities in most of the regulating services' (Table 4.9).

Table 4.10 Final score table for assessment matrix illustrating the capacities of main land cover classes to support ecological integrity to supply ecosystem services and statistic indicators

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation & Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land	**0**	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0
Rural residential land	**7**	1	1	1	1	1	1	1	**0**	0	0	0	0	0	0	0	0	0	**1**	1	0	0	0	0	**0**	0	0
Arable land	**21**	3	2	5	2	5	1	3	**5**	3	1	1	0	0	0	0	0	0	**10**	5	5	0	0	0	**1**	1	0
Grasslands	**30**	3	5	4	4	4	5	5	**17**	2	3	1	1	0	5	5	0	0	**3**	0	3	0	0	0	**6**	3	3
Shrublands	**21**	3	4	2	3	3	4	2	**18**	1	0	0	0	0	5	5	5	2	**2**	0	2	0	0	0	**4**	2	2
Forest	**32**	3	5	5	4	5	5	5	**39**	5	4	3	2	5	5	5	5	5	**0**	0	0	0	0	0	**10**	5	5
Inland marshes	**25**	3	2	4	4	4	3	5	**14**	2	2	4	2	0	0	4	0	0	**2**	0	2	0	0	0	**0**	0	0
Salt marshes	**23**	2	3	4	3	3	3	5	**8**	1	0	5	0	0	0	2	0	0	**2**	0	2	0	0	0	**3**	3	0
Streams and Lakes	**23**	4	4	0	4	4	3	4	**7**	2	1	1	2	0	0	1	0	0	**8**	0	0	3	0	5	**9**	5	4
Estuaries	**21**	3	3	0	5	5	3	2	**9**	0	0	3	0	0	0	3	3	0	**10**	0	0	5	5	0	**7**	4	3
Shallow sea wetlands	**15**	2	2	0	3	3	4	1	**13**	3	5	0	0	0	0	5	0	0	**10**	0	0	5	5	0	**6**	4	2
Bareland	**6**	3	3	0	0	0	0	0	**3**	0	0	1	1	0	0	0	1	0	**0**	0	0	0	0	0	**4**	4	0
Standard Deviation	**10**								**11**										**4**						**4**		
Average	**19**								**11**										**4**						**4**		
Range	**32**								**39**										**10**						**10**		

Note (Table 4.10): Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right) and statistic indicators: The mean, standard deviation, range (column at the bottom left side). The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009).

After the separated interview process, the author kept in touch and discussed with the three leading experts of the Shanghai team, the Jiangsu team and the Zhejiang team about the three processing score tables (Table 4.7, Table 4.8 and Table 4.9).

In the last step, the three team leaders (S-1, J-1, Z-1) met together in the East China Normal University in Shanghai and exchanged their ideas face to face for discussing the score tables.

The three team leaders (S-1, J-1, Z-1) compared their individual tables and combined the scores together.

They chose the ‘medium’ score of the three team’ of each of the capacity of main land cover class to support each of the ecosystem service and then finally made an agreement with the results of the final score table (Table 4.10) for assessment matrix illustrating the capacities of main land cover classes to support ecological integrity and to supply ecosystem services for the Yangtze River Delta metropolitan region.

4.3.4. Driver-pressure-state-impact-response analysis for the decline of total ecosystem services

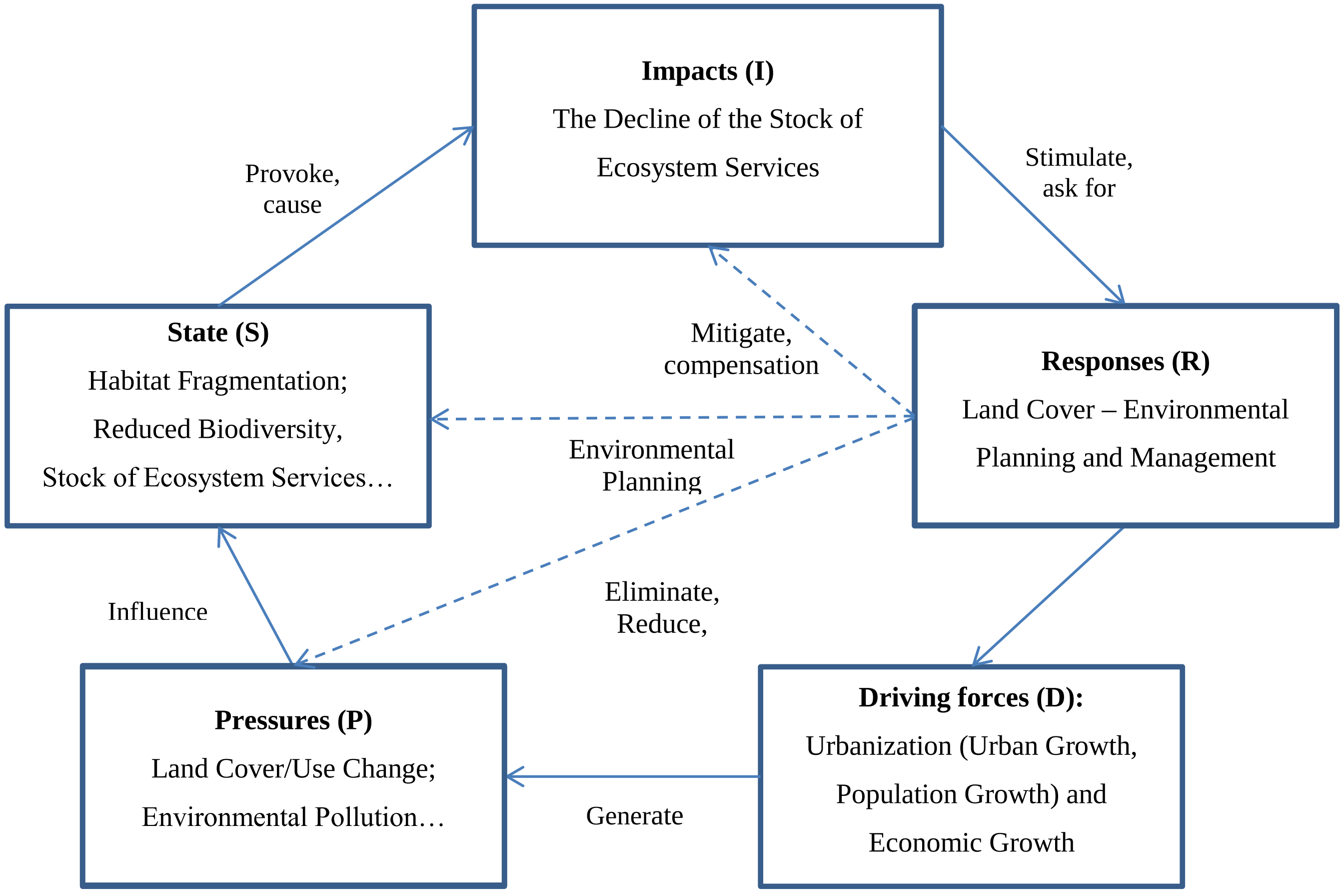

Figure 4.2 Driver-pressure-state-impact-response analysis for identification of environmental problems and management

The purpose of this section (Fig. 4.2) of the thesis was aims to identify the reason for the decline of total ecosystem services in the Yangtze River Delta metropolitan region (in chapter 3).

1) Driving forces (urban growth, population growth and economic development)

The urban growth, population growth and economic growth are considered as the main driving forces of the decline of the stock of ecosystem services in a metropolitan region (Han et al, 2017; Li et al, 2016a; Xu et al, 2014a). Land cover/use data can be used to simulate the expansion of the urban and rural residential land in a metropolitan region (Han et al, 2017; Li et al, 2016a; Xu et al, 2014a).

In the case study, the author used land use data of 2000 and 2010 to map and analyse the urban expansion in the Yangtze River Delta metropolitan region (Table 4.1). The literature review was used to analyse population growth and economic development.

In the case study, the author used the population and economic statistics in literature and statistics books to reveal the trend of population growth and economic development of the Yangtze River Delta metropolitan region from 2000 to 2010.

2) Pressures (land cover/use change, environmental problems)

Land cover/use change and environmental problems can be generated by urban and population growth and economic development (Han et al, 2017; Li et al, 2016a; Xu et al, 2014a).

In the case study, changes in the area of the land cover/use of twelve land cover types in the Yangtze River Delta Region metropolitan region were detected by using land use data for 2000 and 2010 (Table 4.1). The growth rates of area were calculated to detect the significant change in the main land cover types. Then, the author revealed the main environmental problems driven by urbanization and economic development in the Yangtze River Delta metropolitan region by using literature review and local environmental reports (Table 4.1).

3) State (current state of regional ecosystems and the stock of ecosystem services)

The current state of the ecosystem (i.e. ecological integrity) and the stock of the ecosystem services influenced by land cover change and environmental pollutions can be revealed by land cover data statistics i.e. spatial distribution, document review and literature review.

In the case study, the author revealed the current spatial distribution of the ecosystem, the problems in the ecological integrity of ecosystems (reduced biodiversity, habitat fragmentation) by literature review, local experts' opinions and reviewing environmental reports review (Table 4.1).

Moreover, the author calculated the non-monetary value of the stock of ecosystem services of the Yangtze River Delta metropolitan region in 2010 by using land cover data and local expert's scores of ecosystem services capacities.

The amount and proportion of total non-monetary value of ecological integrity, the final ecosystem services (the sum of the regulating services, provisioning services and cultural services) and the regulating services, provisioning services and cultural services were calculated for the Yangtze River Delta metropolitan region in 2010. These results revealed the current stock of the total amount of ecosystem services for the Yangtze River Delta metropolitan region in 2010.

4) Impact (decline of the ecosystem services)

The decline of non-monetary value and monetary value can be detected by assessed the loss of the stocks of ecosystem services in land covers in a metropolitan region.

In the case study, the author defined the amount of the non-monetary value of ecosystem services in each type of the land cover by the 'score of ecosystem services capacities by local experts' times the 'area of the land cover'.

The amount of ecological integrity or ecosystem services supply ('Score*Area') is used to estimate the total stock of ecosystem services for a metropolitan region. The unit of the amount of ecosystem services is 'score×km^2'.

$$S = \sum \ (Si \times Ai) \quad (1)$$

where S (Supply) is the stock of capacities of different land cover classes to support ecological integrity or provide ecosystem services, Si (score) is the score of capacities of different land cover classes to support ecological integrity or provide ecosystem services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to support ecological integrity or provide ecosystem services.

In order to detect decline or increase in the non-monetary value of the ecosystem services in the Yangtze River Delta metropolitan region, the author calculated and compared the amount of non-monetary value of ecosystem services by using land use data of 2000 and 2010 for the Yangtze River Delta metropolitan region.

The author identified the main sources of decline of the total non-monetary value of ecosystem services by comparing the change of the stock in ecological integrity, the change in the final ecosystem services (the sum of the regulating services, provisioning services and cultural services) and the regulating services, provisioning services and cultural services for the Yangtze River Delta metropolitan region from 2000 to 2010.

In the meantime, the decline of the monetary value of ecosystem services from 2000 to 2010 was detected from author Chinese scholars though literatures review.

5) Response (national and regional environmental management and planning policy)

In order to mitigate negative impact on the stock of the ecosystem services driven by urbanization and economic growth, national and regional environmental management and planning policy should be reviewed.

The aim of the analysis to put forward the rules of regional environmental management and planning polices and the intentions of policy makers towards the author's response approaches for the conservation of total stock and specific stock of ecosystem services in the Chapter 5, Chapter 6, and Chapter 7.

4.3.5. Identifying and managing ecosystem services hot spot and cold spot (chapter 5)

1) Defining and mapping hot spot and cold spot of critical ecosystem services

The critical ecosystem services hot spot and cold spot formulation were designed as follow:

If, Vmax<=5, H=Vmax, C = Vmin;

If, Vmax>5, H> $\bar{X}+\delta$, C < $\bar{X}-\delta$;

H: hot spot; C: cold spot;

Vmax: the maximum of ecosystem services scores;

Vmin: the minimum of ecosystem services scores;

Range: the maximum of ecosystem services scores - the minimum of ecosystem services scores (Range = Vmax-Vmin);

Average $\bar{X}$: the mean of ecosystem services values; the mean stands for the score of the average-level capacity of each of the three integrated services: RS, PS and CS;

STDEV (δ): the standard deviation of ecosystem services scores. (STDEV = $\sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}$).

From the data distribution, the highest levels of the twenty-three individual ecosystem services were all rated 5, but the maximum levels of the four integrated ecosystem services were all above 5. For each of the individual ecosystem services, the score of 5 represented the maximum level of a very high relevant capacity which has been defined in Burkhard's score matrix.

However, for the four integrated ecosystem services, the range and the fluctuation of the scores of the four integrated ecosystem services are different from each other. Thus the same score cannot be used as the threshold to define the hot spot. For this reason, the mean and the standard deviation were used to define the scores of hot spots and cold spots.

The mean of the four integrated ecosystem services represented the score of the average capacity of services, which is provided by relevant ecosystems. The standard deviation represented the fluctuation of the score of capacities for each of the integrated ecosystem services.

To compare the average levels in each of the four integrated ecosystem services and define how much the scores of capacities deviate from the average level, both mean and the standard deviation are applied. If the score is higher than the mean plus the standard deviation of ecosystem services values, the area with such a score has a highly relevant capacity of ecosystem service or is a hot spot.

In contrast, if the score is lower than the mean minus the standard deviation of ecosystem services values, the area with such a score has a low relevant capacity of ecosystem service, or is a the cold spot.

2) Regionalization of critical ecosystem services

The first step is to map hotspot areas where multiple chosen critical ecosystem services overlap by GIS, and the chosen ecosystem services for overlapping should to be determined by the priority conservation objectives defined above.

Then, critical ecosystems services zones are delineated by synthesizing same kinds of critical ecosystem services, land use and physical features.

Finally, the ecosystem services zones are characterized with major environmental problems, related ecosystems and their critical services, their social driving forces correlated with urbanization, and management strategies.

4.3.6. Conservation priority area decision support (chapter 6)

The shapefile land cover dataset with the further classification of cropland and forest of Jiangsu Province, Zhejiang Province and Shanghai Municipality used in the case study was acquired from the Chinese Academic of Sciences Geography Science and Resource Institute (http://www.resdc.cn/DataList.aspx) (Table 4.1).

In this dataset, the arable land in the Yangtze River metropolitan region was further classified into rainfed cropland and paddy fields according to China's general land cover classification system (http://www.resdc.cn/DataList.aspx):

Rainfed Croplands refer to non-irrigated arable land: cereals, legumes, fodder crops, root crops and fallow land. It includes flower and tree (nurseries) cultivation and vegetables, whether open field, under plastic or glass (includes market gardening); Paddy fields refer to permanently irrigated land: croplands irrigated permanently and periodically, using a permanent infrastructure (irrigation channels, drainage network) and land developed for rice cultivation. The author used further classification of arable land and forest to identify ecosystem function hotpot areas for more accurate decision support.

1) Importance classification of ecological function zone by net primary productivity

The net primary productivity has been successfully applied as a general proxy for intermediate ecosystem services (Costanza et al, 1998; Costanza et al, 2007). The author used the net primary productivity as a for ecosystem functions in order to optimise expert-scoring hot spot identification supporting conservation prioritisation of cropland or forest. The annual average net primary productivity raster data (500 m resolution) of 2015 was by modified VPM model from the Dataset Center of Institution of Geographic Science and Natural Resources Research, the Chinese Academic of Sciences Geography Science, Beijing, China (Table 4.1).In the following Table 4.11, the author used local expert's knowledge to confirm the threshold intervals of net primary productivity according to the statistical distribution of values. The importance of ecological function were further classified into five-level zones according to the demand for ecological red line delineation. This step is to identify the different importance of the ecological function within a single ecosystem.

Table 4.11 The five-level zone of net primary productivity for cropland and forest ecological function zone delineation

	Net primary productivity	Importance of ecosystem function
Paddy fields		
	(1200>=) g C/m3	Very High Importance
	(900-1200) g C/m3	High Importance
	(600-900) g C/m3	Medium Importance
	(300-600) g C/m3	Low Importance
	(0-300) g C/m3	Very Low Importance
Rainfed croplands		
	(1200>=) g C/m3	Very High Importance
	(1000-1200) g C/m3	High Importance
	(800-1000) g C/m3	Medium Importance
	(600-800) g C/m3	Low Importance
	(0-600) g C/m3	Very Low Importance
Forest		
	(700>=) g C/m3	Very High Importance
	(600-700) g C/m3	High Importance
	(500-600) g C/m3	Medium Importance
	(400-500) g C/m3	Low Importance
	(0-400) g C/m3	Very Low Importance

2) Identification of large and spatial clustering habitats

The raster calculator tool in ArcGIS was applied to spatially overlap the different zones. Hot spot analysis (Getis-Ord Gi*) was used for the area of the patches:

The Hot Spot Analysis (Getis-Ord Gi*) tool in ArcGIS identifies statistically significant spatial clusters of high values (hot spot) and low values (cold spot):

A high z-score and small p-value for a feature indicate a spatial clustering of high values. A low negative z-score and small p-value indicate a spatial clustering of low values.

The higher (or lower) the z-score, the more intense the clustering. A z-score near zero indicates no apparent spatial clustering.

The author applied the Hot spot analysis (Getis-Ord Gi*) tool to identify patches of the highly spatial clustering with a large area of habitats:

If z-score >2.58, $p< 0.01$, it means that there is 99 % confidence for spatial clustering of large-area patches;

If z-score >1.96, $p< 0.05$, it means that there is 95 % confidence for spatial clustering of large-area patches;

If z-score >1.65, $p< 0.10$, it means that there is 90 % confidence for spatial clustering of large-area patches.

3) Conservation priority area decision support

The assessment and mapping of net primary productivity and spatial clustering habitat can provide options for ecological function zone delineation decision support. Moreover, the decision making on the priority area setting should comprehensively take into consideration the suggestions of local experts and the demand of decision-makers. In the author's case study in chapter 6, to meet the demand for the delineation of the ecological forest function zone and the ecological cropland function zone of Jiangsu Province, Zhejiang Province and Shanghai Municipality.

4.3.7. Ecosystem services supply-demand budget considering spatial relations for promoting inter-city cooperation at watershed scale (chapter 7)

1) Identifying relevant ecosystem services for specific environmental problems and cooperation

The first sub-step is to analyse the features, driving forces and problems of the socio-ecological system in the study area based on a database of both natural systems (i.e. local ecosystem, catchment and terrain) and socio-economic systems (i.e. population).

In the case study area, many studies and reports have shown that rapid urbanization has caused not only severe pollution of water and soil (Tian et al, 2011; Wang et al, 2003), but also high occurrence of flood hazards (Zhang et al, 2008) in the Yangtze River Delta metropolitan region.

The next step is to choose relevant ecosystem services by considering both environmental problems (i.e. air and water pollution) and relevant environmental cooperation mechanisms (i.e. water purification mechanisms) in the study area. Thus, the author chose four regulating ecosystem services relevant to particular environmental cooperation mechanisms by according to them, i.e. flood protection, soil erosion regulation and the water purification as examples in the study. According to the prior definitions (Burkhard et al, 2010), flooding Protection refers to the capacity of natural elements to dampen extreme flood events; erosion regulation refers to the role that vegetation coverage plays in soil retention and prevention of landslides; water purification refers to the capacity that ecosystems have to purify water.

2) Establishing ecosystem services supply-demand budget matrix

This step is to combine the socio-ecological database with the local expert knowledge in order to score both the supply and demand of the chosen ecosystem services and establish a supply-demand budget matrix based on Burkhard's approach

(Burkhard et al, 2012). The raster land cover dataset used in this study is available from the National Geomatics Center of China (NGCC) and can be transferred and digitised in GIS format (Table 4.1). The land cover and ecosystem types of this case are identified by combining local expert knowledge in the Yangtze River Delta metropolitan region with the CORINE land cover system. The population statistics and original data on population density were from the Chinese Academy of Sciences Geography Science and Resource Institute, Chinese Academy of Sciences, China (http://www.resdc.cn/DataList.aspx). The Digital Elevation Model (DEM) with 30 m resolution was from the Geospatial Data Cloud (http://www.gscloud.cn/).

Scoring for supply and demand of each ecosystem service was based on Burkhard's method (Burkhard et al., 2009; Burkhard et al., 2012; Burkhard et al., 2014).

First, the local experts firstly were given the explanation of the definition and classification of ecosystem services, and were provided with Burkhard's original supply and demand scores table and the relevant explanation; Then, each expert adjusted the original score of each ecosystem services based on his own expertise, with reference to the recommended indicators in Nedkov & Burkhard (2012) and Burkhard et al (2014), i.e. regional NDVI and ecosystem types for supply of ecosystem services, regional air and water quality level, population density distribution and flood hazard for demand of ecosystem services.

The median score for special ecosystem services given by the local experts was the final scores of the special ecosystem services according to the same process in section 4.3.1, 3).

The author developed a ecosystem services supply-demand budget matrix for the Yangtze River Delta metropolitan region (Table 4.12). The ecosystem services supply-demand budget scale ranges from −5 to -1 = demand exceeds supply = undersupply; via 0 = demand = supply = balance; 1 to 5 = supply exceeds the demand = oversupply.

Table 4.12 The supply, demand and budget score matrix of the four ecosystem services for land cover types in the Yangtze River Delta metropolitan region: after (Burkhard et al, 2012)

Land cover	FP			ER			WP		
	S	D	B	S	D	B	S	D	B
Urban Land	0	4	-4	0	1	-1	0	1	-1
Rural Residential Land	0	5	-5	0	1	-1	0	2	-2
Arable land	1	2	-1	0	2	-2	0	5	-5
Forest	3	0	3	5	0	5	5	0	5
Shrublands	0	0	0	4	0	-4	4	0	4
Grasslands	1	0	1	5	0	5	4	0	4
Bareland	4	0	4	0	0	0	0	0	0
Inland marshes	5	0	5	0	0	0	0	0	0
Salt marshes	1	0	1	0	0	0	0	0	0
Streams and Lakes	1	0	1	0	0	0	1	0	1
Estuaries	3	0	3	0	0	0	2	0	2
Shallow Sea Wetlands	0	0	0	0	0	0	0	0	0

Notation: FP-Flood Protection, ER-Erosion Regulation, WP-Water Purification; S-Supply, D-Demand, B-Budget.Scale from 0 / 1 / 2 / 3 / 4 / 5 / = no / low/ relatively low/ medium/ high/ very high/ relevant capacity or demand

3) Calculating the amount of cities' ecosystem services supply-demand budget

This step is to calculate and compare the amount of ecosystem services Supply, Demand and Budget for cities in the study area based on the score and area of each land use/cover.

The amount of ecosystem services supply, demand and budget ('Score*Area') is used to estimate the total amount of ecosystem services for a region and each city. The unit of the amount of ecosystem services is 'score×km^2'.

$$S = \sum (Si \times Ai) \qquad (1)$$

where S (Supply) is the number of capacities of different land cover classes to provide ecosystem services, Si (score) is the score of capacities of different land cover classes to provide ecosystem services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide ecosystem services.

$$D = \sum (Di \times Ai) \qquad (2)$$

where D (Demand) is the amount of the relevant demands for ecosystem services of humans living in the different land cover classes, Di (score) is the score of relevant demands for ecosystem services of humans living within the different land cover classes, and Ai (Area; km^2) is the area of each kind of land cover corresponding to the relevant demands for ecosystem services of humans living.

$$Bi = Si - Di \qquad (3)$$

$$B = \sum (Bi \times Ai) \qquad (4)$$

where B (Budget) is the amount of the budget of demand and supply of the targeted ecosystem service, Bi (score) is the score of the Supply (Si) minus the score of the Demand (Di) of the targeted ecosystem service, and Ai (km^2) is the area of each kind of land cover corresponding to the targeted ecosystem service.

4) Identifying spatial and quantitative mismatch of ecosystem services supply and demand on a regional scale

This step is to identify spatial and quantitative mismatches of ecosystem services for the entire region and local cities by analysing and mapping the distribution of the values of the supply-demand budget.

If the amount of supply equals to the amount of demand for an ecosystem services of a city or a region, it means that this city or region’s amount of supply matches the amount of demand for this ecosystem services. The author defined such areas as having a balance or match for this ecosystem services.

If the amount of supply exceeds the amount of demand for an ecosystem services of a city or a region, it means that this city or region has a ‘surplus’ in this ecosystem services. The author defined such areas as having a surplus for this ecosystem services. On the contrast, if the amount of demand exceeds the amount of supply for an ecosystem services of a city or a region, it means that this city or region has a 'deficit'. The author defined such a city as a 'deficit city' for this ecosystem services.

5) Defining service balancing city, service providing city, service benefiting city

Ecosystem services spatial relations were being explored to be a scientific basis to support regional environmental cooperation. Fisher et al (2009) and Syrbe & Walz (2012) introduced and developed the concepts of service providing areas, service benefiting areas and service connecting areas:

Service providing areas:

Following Fisher et al (2009), the spatial units are the source of landscape services 'service providing areas'. Service providing areas comprise ecosystems, their populations and physical components (Syrbe & Walz, 2012).

Service beneficiaries and benefiting areas:

Spatial units for Service benefiting areas are according more likely to be urban areas, rural settlements, administrative and/or planning units (Syrbe & Walz, 2012). Benefiting areas may be far distant from the relevant Service providing areas. Service connecting areas: If providing and benefiting areas are not contiguous, the intervening space which connecting providing and benefiting areas, it can be referred to as a service connecting area (Syrbe & Walz, 2012). However, these concepts were defined in landscape scale, and they are not suitable for direct comparison among administrative units i.e., cities.

Spatial differences and the directions of eco-service flows in each of service provisioning cities and service benefiting cities are needed to be identified. According to the effects of natural principles in the watersheds, and monsoon climate, the directions of eco-service flows are suggested to be identified. For instance, water eco-service flows are affected by the terrain in the watershed. The flow directions are from upstream to downstream.

Firstly of all, the 'city' defined in the author's research was a 'complex city system' not only included the central urban area but also included the variety of landscapes in the rural area.

As a 'complex city system' with multiple landscapes, we defined the following type of cities:

Potential Service Balancing City:

A type of complex city system that the sum of the supply-demand budget of a specific ecosystem service in multiple landscapes within the complex city system reaches neutral balance. Although this type of city system has complex ecosystem services flow directions of different landscapes within the system, the neutral balance sum of the ecosystem services supply-demand budget indicates that this type of city was self-sufficient for the specific ecosystem service.

Potential Service Providing City:

A type of complex city system that the sum of the flow exceeds the sum of the demand of a specific ecosystem service in multiple landscapes within the complex city system. Although this type of city system has complex ecosystem services flow directions of different landscapes within the system, the oversupply of the sum of the supply-demand budget indicates that this type of city have potential for some amount of the specific ecosystem service flow after its self-digestion of landscapes within this type of city.

Potential Service Benefiting City:

A type of complex city system that the sum of the demand exceeds the sum of the flow exceeds of a specific ecosystem service in multiple landscapes within the complex city system. Although this type of city system has complex ecosystem services flow directions of different landscapes within the system, the undersupply of the sum of the supply-demand budget indicates that this type of city have potential demand for some amount of specific ecosystem service flow from other city system with oversupply of the sum of the supply-demand budget.

6) Identifying ecosystem services spatial relations at regional scale

This step is to interpret ecosystem services spatial relations and identify inter-city ecosystem services flow directions based on the analysis of the biophysical processes (i.e. river flow directions in a watershed). Through the Digital Elevation Model (DEM), the elevation classification analysis, basin (catchment) delineation, and stream order analysis were simulated and mapped by using Terrain and Hydrology modules of ArcGIS 10.0. A biophysical process is fundamental to identifying a particular ecosystem services flow direction. For example, the author applied stream flow direction analysis in a watershed is used to identify the ecosystem services flow directions relevant to the watershed, such as flooding protection, erosion regulation, water purification etc. Based on DEM, the watersheds (Catchment A-H) in the Yangtze River Delta metropolitan region were delineated, and the flow directions of the rivers were analysed by stream order analysis in the ArcHydro module in ArcGIS 10.0.

Also, local environmental reports such as the Taihu Lake Basin and the Southeast Rivers Water Resources Bulletin (http://www.tba.gov.cn/tba/content/TBA/lygb/index.html), were used for scoring the ecosystem services supply and demand and identifying the ecosystem services flow directions. The previous studies of the positional relations of service providing areas and service benefiting areas provided good reference to describe the positional relations of service providing cities and service benefiting cities. From the perspective of landscape planning, service providing areas and service benefiting areas may overlap to some degree, but gaps are also possible (Fisher et al, 2009).Fisher et al (2009) described patterns of transmission of a service from provision to benefit areas, reflecting the understanding that ecosystems and their beneficiaries are often not co-located. Costanza (2008) introduced three classes of relations: ‘in situ’, ‘local proximal’ and ‘directional flow related’. Syrbe & Walz (2012) provided further explanations of the contributions of spatial relationships: (1) In situ: service providing areas and service benefiting areas are identical, where the services are provided and the benefits are realized in the same area; (2) Omni-directional: where the services are provided in one location, but benefit the surrounding landscape without directional bias; (3) Directional – slope dependent:

service benefiting areas lies downslope (downstream) from service providing areas, i.e. the service is realized by gravitational processes (cold air, water, avalanche, landslide); ‘Directional’ – without strong slope dependence: service benefiting areas lies ‘behind’ the service providing areas, relating to higher-ranking directional effects.

The spatial classification of ecosystem services will deliver ecosystem services with spatial attributes since ecosystem process and function have spatial scale attributes, which results in spatial inconformity between production (supply) and utilization (consumption) of the services to show various characteristics of spatial heterogeneity. Costanza (2008) concluded that these spatial characteristics can be categorized into five main types - global non-proximal, local proximal, directional flow-related, in situ and user movement related. For example, the carbon sequestration service is classified as "global: non-proximal" since the spatial location of carbon sequestration does not matter. The atmosphere is thoroughly mixed and removing carbon dioxide (or other greenhouse gases) at any location is equivalent to removing it anywhere else. The “local proximal” service refers to the spatial proximity of the ecosystem to the human beneficiaries, for example storm protection being of local importance but having no impact on humans distant from it. "Directional flow-related" services are dependent on the flow from production areas to utilization areas. For example, water supply and water regulation are dependent on flows from the upper stream to the lower stream. It can be found that this spatial classification contains geographic features of ecosystem services, and is indispensable for the research on spatial flow characteristics of the services.

7) Defining regional environmental cooperation model

This step is to define regional ecosystem services conservation cooperation models by integrating the cities’ ecosystem services supply-demand budget and inter-city ecosystem services flow directions. There are two core sub-steps to design the ecosystem services conservation cooperation models for a special ecosystem services: firstly, a city with surplus ecosystem services and one with ecosystem services deficit should both be included in the model; secondly, the ‘Surplus City’ (potential service providing areas) delivers ecosystem services to the ‘Deficit City’ (potential service benefiting areas) through biophysical process.

The author combines the ecosystem services supply-demand budget with the ecosystem services flow direction analysis to define potential ecosystem services Conservation Cooperation Models: (1) low possibility to cooperate with other cities when a city is in an independent Catchment itself; (2) cooperation with other cities at a regional scale and a watershed scale.

Following the ecosystem service flow direction analysis, several cooperation types at different administrative levels may be considered:

(1) Cooperation among central municipality and prefecture-level cities in other provinces within the region;

(2) Cooperation among provinces within the region and outside the region;

(3) Cooperation among prefecture-level cities within the region and outside the region.

4.4. Problems/critique

Before going to China for data collection, the research ethics statement had been approved by the research ethics committee in Geography, School of Environmental Science, University of Hull. As a native Chinese, the author had no cultural conflicts in the case areas. This research did not intrude into any participants' physical or mental well-being, privacy and confidentiality. Given that the application of an ecosystem services assessment for decision making in the Yangtze River Delta metropolitan region is a new phenomenon, the author faced the following problems with the acquisition of data for an ecosystem services analysis:

4.4.1. Problems in interviews

For a large scale ecosystem services research in a region over 12000 km^2, three province-level stakeholders (Shanghai Municipality, Jiangsu Province and Zhejiang Province) were involved. In order to capture the perspectives of the three province-level stakeholders, local experts' views from government bodies and local academic bodies that were familiar with definitions of ecosystem services and local condition of the region were finally selected for the research. Moreover, local experts had deeper and more comprehensive knowledge than ordinary people about the seriousness of the damage to ecosystems and the decline of ecosystem services. Therefore, they were able to score and grade the multiple ecosystem services values in the author's study area. During the interviews, the author permitted all the interviewees to use pseudonyms when they signed the ethics forms. The author did not reuse the names of the experts from the academic institutions, or the full names and positions of the experts from government bodies and their departments' names in order to protect their privacy.

4.4.2. Lack of an effective data sharing mechanism

For such interdisciplinary research for decision making in a large scale region, spatial indicators such as biophysical quantification indicators and socio-valuation results are fundamental for ecosystem services values assessment, according to Bukrhard's ecosystem services approach (Palomo et al, 2017). However, no socio-ecological database and effective data sharing mechanisms were established in the Yangtze River Delta metropolitan region, although the socio-ecological systems of this region were developing rapidly and there was high demand for such a database and data sharing mechanisms for conservation-development research and management. The Lack of an effective data sharing mechanism between different institutions made the collection of data difficult in the study area. Local experts could not share some data with each other due to data protection and map security of different institutions.

For assessing the qualitative and quantitative ecosystem services value for the valuation of the local land cover types, the author participated in the process of building an ecosystem services supply-demand balance sheet that combined the views of local experts from different groups (government bodies, academic institutions and a green enterprise) in different administrative units (Shanghai Municipal, Jiangsu Province and Zhejiang Province). For data protection reason, each of the institutions, they showed their results about the ecosystem services values of land cover types but did not share the original resource data with each other. This situation may lead to uncertainty in applying expert knowledge of ecosystem services valuation of different types of land covers.

4.4.3. Rough type and resolution of spatial data

The local land cover data available to the author can use is lacked detailed sub-types for mapping ecosystem services value assessment results. For example, the land cover data only have the primary type of 'forest land' but do not distinguish the sub-types of 'broad-leaved, coniferous and mixed forest', although their ecosystem services values are similar to each other according to the local experts' valuation. If the author could identify the conservation areas only according to the main land cover types, the areas would be too large for conservation planning. Land cover data with a more detailed classification will be helpful for mapping ecosystem services values. In the meantime, since the resolution of the net primary productivity (i.e. 500m) area is at the regional level, it is hard to further map ecosystem services values at a local scale for local decision making.

Chapter 5 Spatial pattern and regionalization of ecosystem services in the Yangtze River Delta Region[2]

5.1. Introduction

Rapid urbanization has altered many ecosystems, causing a decline in many ecosystem services, generating serious ecological crisis. To cope with these challenges, in this chapter, the author reports application of an ecosystem services approach framework comprising five core steps for identifying and managing hot spots of critical ecosystem services in a rapidly urbanizing region.

This framework was applied in the case study of the Yangtze River Delta metropolitan region. As Chapter 4 indicated, in order to overcome environmental management conflicts and secure ecosystem services, China has proposed the new 'ecological red line policy' (ERP) using an ecosystem service approach as a way to meet its targets (Bai et al, 2016). The demand for regional ecosystem services zonation highlighted the importance of ecosystem services hot spots identification and regionalization.

Some of the previous studies can be considered as part of the comprehensive modern hot spots identification and management of critical ecosystem services:

An example is the incorporation of land use and land cover data in ecosystem service assessments for identifying and scoring critical ecosystem services. For example, Burkhard et al (2012) presented an approach to evaluate the ecosystem service provision of different landscapes (ecosystems) in relation to human activities by using quantitative and qualitative assessment data in combination with land cover and land use information derived from remote sensing and a geographic information system (GIS).

Another aspect is identification of environmental problems, for instance, Gregory et al (2012) proposed a structured decision-making process for the use of species distribution models (SDMs) which was increasingly proposed to address

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[2] The main results of this chapter was published in Cai, W., Gibbs, D., Zhang, L., Ferrier, G. & Cai, Y. (2017) Identifying hotspots and management of critical ecosystem services in rapidly urbanizing Yangtze River Delta Region, China. J Environ Manage, 191, 258-267.

environmental problems (Addison et al, 2013; Guisan et al, 2013; Wintle et al, 2011). In addition, threshold methods have been developed for delineating an ecosystem services hot spot according to expert-based threshold value, for example, Egoh et al (2008) set thresholds of a soil depth (C0.8 m) and litter cover (C70 %) for the ecosystem services soil accumulation in a specific case study.

Additionally, a few studies synthesized these studies for hot spot identification and management of critical ecosystem services. Building on previous research, the author synthesized them into a comprehensive framework for priority conservation. In practice, the case study used detailed local land cover classification systems that made the new framework more suitable for the practical situation in the Yangtze River Delta metropolitan region.

To carry out comprehensive function zone delineation under ecological redline policy, it is fundamental and necessary to identify and managing hot spots and cold spots of critical ecosystem services by using the framework which the author designed. Hence, the aims of this chapter are (1) to present a comprehensive framework to identify and manage hot spots of critical ecosystem services in a rapidly urbanizing region, (2) to apply the framework to the Yangtze River Delta Metropolitan to support regional environmental management.

The research objective of this chapter is to promote major function zones under the ecological red line policy by ecosystem services hot spot and cold spot management for the Yangtze River Delta metropolitan region.

The research questions for this chapter are:

What is the spatial pattern of integrated and single ecosystem services supply hot spots and cold spots for major function zones delineation in the Yangtze River Delta metropolitan region?

What are the comprehensive function zones for regional ecosystem services in the Yangtze River Delta metropolitan region?

5.2. Results

5.2.1. Identifying hot spots and cold spots of critical ecosystem services

1) Natural Causes are decisive factors for the following pattern:

Biodiversity (B), Reduction of Nutrient loss (F), Storage capacity (SOM) (G), Local climate regulation (H), Air Quality Regulation (L), Erosion Regulation (M), Nutrient regulation (N), Water purification (O), Pollination (P), and Recreation & Aesthetic Values (V):

Hot spots were widespread in the southwestern mountainous areas, while cold spots of Biodiversity (B), Reduction of Nutrient loss (F), Storage capacity (SOM) (G) and Local climate regulation (H) were scattered in the northeastern urban areas, those of Air Quality Regulation (L) and Erosion Regulation (M), Water purification (O) and Pollination (P) were widespread in the northeastern plain, and those of Nutrient regulation (N) and Recreation & Aesthetic Values (V), were widespread in the northeastern plain, except the waterbody areas.

Based on my results, the distributions of these patterns were mainly influenced by the spatial distribution of ecosystem types and land forms. The distribution of ecosystems was the dominant natural cause, while the landform was one of the important impact factors of the spatial pattern of ecosystem types.

Groundwater Recharge (K) and Intrinsic Value of Biodiversity (W):

Hot spots were widespread in waterbody areas and the southwest mountainous areas, while cold spots were scattered in the northeastern plain.

For abiotic heterogeneity (A), Nutrient regulation (N): hot spots were distributed in the waterbody areas of the region.

Capture Fisheries (S), Aquaculture (T) and Metabolic efficiency (D):

Hot spots were only in the estuary areas in the region.

2) Human activities are decisive factors for the following patterns

Crops (Q) and Livestock (R):

Contrary to the A-L's distribution, hot spots were widespread in the northeast plain, while cold spots were widespread in the southwest mountainous areas.

Global climate regulation (I) and Flood protection (J):

Hot spots were only distributed in the wetlands of the coastal areas, while cold spots were in the urban areas of the region.

Biotic waterflows (C) and Exergy Capture (Radiation) (E):

Hot spots were widespread in the whole region, while cold spots were distributed in the urban areas of the region.

5.2.2. The spatial pattern of the hot spots and cold spots of ecological integrity, regulating services, provisioning services and cultural services

The hot spots of the four integrated ecosystem services were defined according to the results obtained from the calculation of the equations detailed in the methodology chapter (Chapter 3).

The threshold scores of the four integrated ecosystem services' hot spots and cold spots were used to determine hot spots by combining the mean and the standard deviation (Table.5.1).

Using cultural services as an example (Table 5.1), since the standard deviation was 3 and average was 4, therefore the hot spot values were those exceeding 7, while the cold spot values were lower than 1.

For ecological integrity and regulating services (Fig.5.1 and Fig.5.2), hot spots were widespread in the southwest mountainous areas, while cold spots were scattered in the urban areas of the region.

For provisioning services, hot spots were widespread in the northeast plain including arable land areas, waterbodies and estuary areas, while cold spots were distributed in the southeast mountainous areas. For cultural services, hot spots were widespread in the waterbodies and southwest mountainous areas, while cold spots were scattered in urban areas and rural residential areas in the region.

The distribution and types of the main sources of supply in the four kinds of integrated ecosystem services are different:

(1) The main sources of supply of ecological integrity and regulating services are forest and arable land. Forest is mainly distributed in the southern part, whereas arable land is mainly in the northern part.

(2) Similarly, the main sources of supply of provisioning services are forest and arable land, but arable land contributes more than forest in this service.

(3) The main sources of supply in cultural services are forest and streams and lakes. Streams and lakes are mainly distributed in the Taihu Lake Watershed in Jiangsu Province and Qiandao Lake Watershed in Zhejiang Province.

In the area in Shanghai Municipality, the supply of the four integrated ecosystem services of islands is higher than the supply of coastal areas, and the supply of the southern suburban areas is higher than the supply of northern urban areas (Fig. 5.1 and Fig.5.2).

The hot spot areas of the four integrated ecosystem services are mainly distributed on the islands in east Shanghai, along the coastal areas of the city and in the southern suburban areas. The main sources of the four integrated ecosystem services are arable land and estuary (ecological integrity/regulating services: arable land and estuary; provisioning services: arable land and estuary; cultural services: arable land and estuary).

In the northern areas in Jiangsu Province, the supply of the four integrated ecosystem services of the southern part of the area is higher than the supply of the northern part of the area (Fig. 5.1 and Fig.5.2). Hot spot areas of the four integrated ecosystem services are mainly distributed in south-east area and in the Taihu Lake Watershed.

The main sources of supply of ecological integrity and regulating services are arable land and forest. Arable land is distributed throughout the area, whereas forest is mainly concentrated in the west of the area.

Unlike ecological integrity and regulating services, the main sources of provisioning services and cultural services are arable land and streams and lakes. Arable land contributes more than streams and lakes in provisioning services, whereas the converse applies for cultural services. Streams and lakes are mainly distributed in the south of Jiangsu in the Taihu Lake Watershed and south-western Jiangsu.

In the southern areas in Zhejiang Province, the supply of the four integrated ecosystem services is generally higher in the southwest region than the northeast (Fig. 5.1 and Fig.5.2). Hot spot areas of the four integrated ecosystem services are mainly distributed across the province except the northeast coastal areas.

The main sources of supply of the four integrated ecosystem services are forest and arable land and the same is for each of the services individually.

Comparing the distribution and main sources of supply of ecosystem services in Shanghai, Jiangsu and Zhejiang, it can be seen that:

(1) Hot spot areas of Shanghai were mainly distributed in suburban areas around the city, including on islands, whereas hot spot areas of Jiangsu were mostly distributed in the southern part and those of Zhejiang were distributed throughout the province, expect the northeast coastal areas.

(2) The supply of ecosystem services of Shanghai and Jiangsu mainly comes from arable land, whereas the supply of Zhejiang mainly comes from forest.

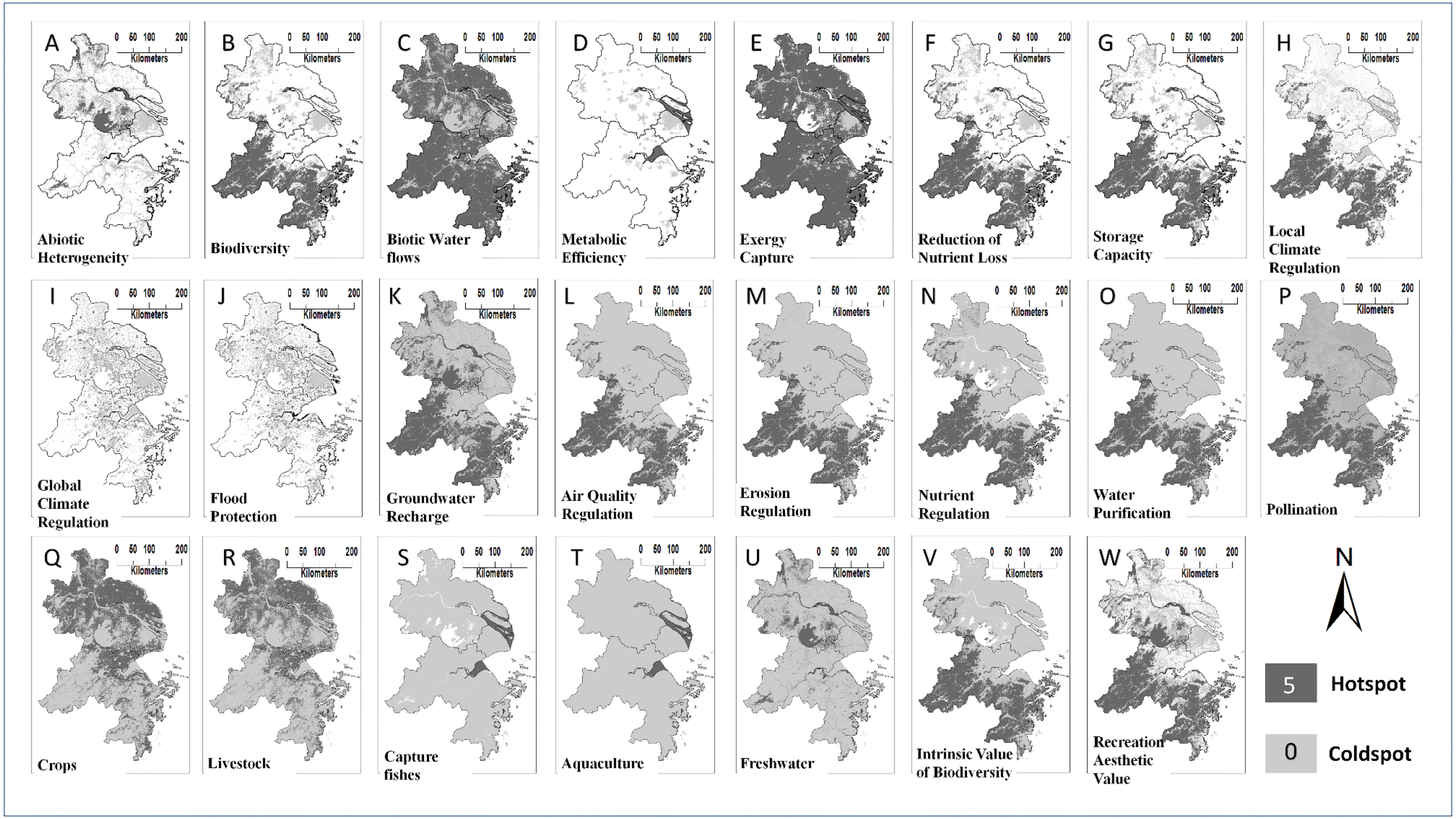


Figure 5.1 Map of multiple ecosystem services hot spots and cold spots in the Yangtze River Delta metropolitan region. The values/colours indicate the supply capacities of different ecosystem services: (from 0/grey（cold spot）to 5/black （hot spot）)

Table 5.1 The table of hot spots and cold spots of ecological integrity, regulating services, provisioning services and cultural services in the Yangtze River Delta metropolitan region

(If Vmax>5, H>X+δ, C <X-δ; H: hot spot; C: cold spot;

Average $\bar{X}$: the mean of ecosystem services values;

STDEV (δ): the standard deviation of ecosystem services values.

STDEV = $\sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}$).

	Ecological integrity	Regulating services	Provisioning services	Cultural services
Standard Deviation	10	11	4	4
Average	19	11	4	4
H>(Average+Standard Deviation)	28	22	8	8
C<(Average-Standard Deviatoin)	9	0	0	1

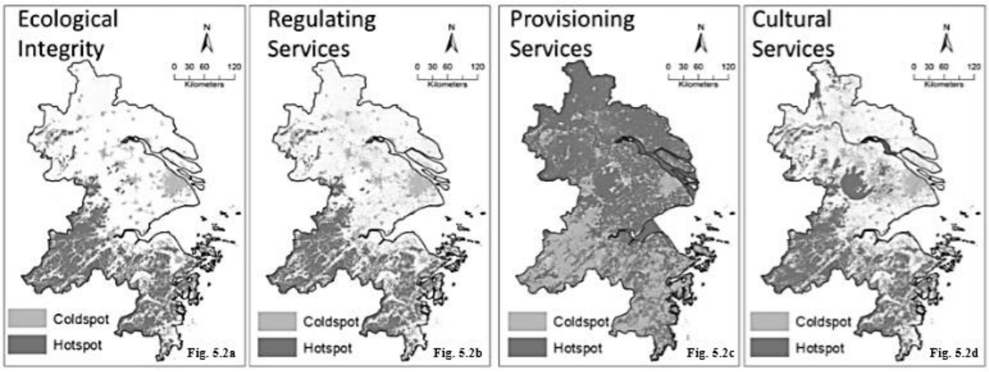


Figure 5.2 The map of hot spots and cold spots of ecological integrity, regulating services, provisioning services and cultural services in the Yangtze River Delta metropolitan region according to Table 5.1

Note: The black colour indicates the hot spots of the four integrated ecosystem services supply; the grey colour indicates the cold spots of the four integrated ecosystem services.

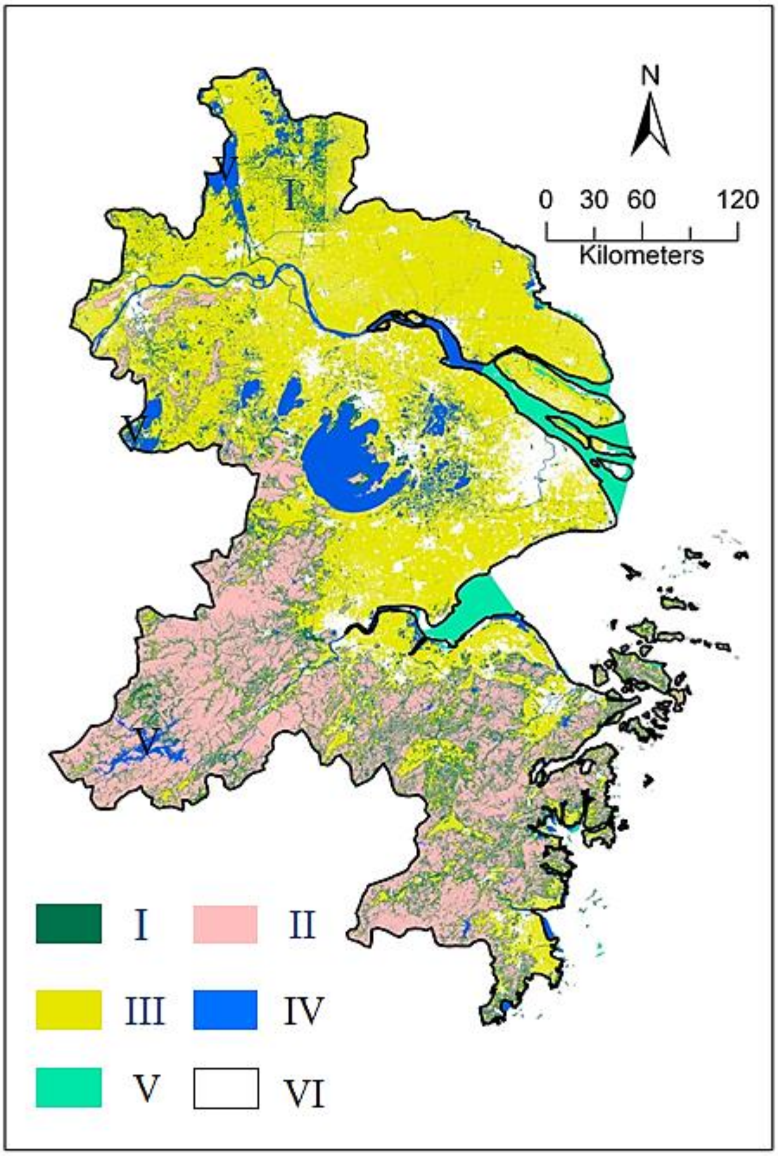


Figure 5.3 Overlap map of the integrated ecosystem services in the Yangtze River Delta metropolitan region

Note: *I: Ecological Integrity Conservation Zone, II: Southwest Mountainous and Hilly Forest Ecological Zone III: Northeast Plain Agriculture Ecological Zone, IV: Aquatic Ecosystem service Zone, V: Eastern Coastal Estuaries Ecological Zone, VI: Urban Development Area (cold spots).*

5.3. Discussion

In this case study, the regionalization and management of critical ecosystem services was completed through overlapping the hot spots and cold spots of the four integrated ecosystem services (Fig.5.3). Six functional zones or types were defined as follows:

5.3.1. Ecological integrity conservation zone (I)

The zone only includes the hot spots of ecological integrity, which are scattered in the whole area except the urban area (Fig.5.3). Since ecological integrity represents the base for the provision of regulating, provisioning and cultural ecosystem services, this zone is vital to support and preserve processes and structures that are essential prerequisites of the ecological ability for self-organization of ecosystems, such as biodiversity (Barkmann et al, 2001).

The main objectives in this zone are to deal with ecological problems: fragmentation of habitats, degradation of ecosystems, and reduced biodiversity. Therefore, there is a need to have ecological planning efforts for biodiversity and ecosystem function conservation.

5.3.2. Southwest mountainous and hilly forest ecological zone (II)

The southwest mountainous and hilly forest ecological zone includes the Tianmu Mountain Nature Reserve in Western Zhejiang, the Qiandao Lake Watershed water source area, and so on (Fig. 5.3.). The forest ecosystem can provide diverse ecosystem services. It is the most important type of ecosystem in the region. It is now confronted with threats mainly from acid rain hazards, expansion of manmade forests, and tourism development. As a result, the ecosystem has been degraded and the quantity of native species has decreased. Effective control over the expansion of manmade moso bamboo forests and coordination between tourism and conservation are important tasks for ecological protection in the region.

This zone is the one with most various types of ecosystem services, including three integrated types (ecological integrity, regulating services and cultural services) and twelve individual types among these the supporting service (ecological integrity) included Biodiversity (B), Storage capacity (G) and Reduction of nutrient loss (F),. The regulating service included Local climate regulation (H), Water purification (O), Erosion Regulation (M), Air Quality Regulation (L), Pollination (P), Nutrient regulation (N) and Groundwater recharge (K) the cultural services included Intrinsic Value of Biodiversity (V and Recreation & Aesthetic Values (W).

In this zone, Local climate regulation (H) and Air Quality Regulation (L) offer assistance in decreasing regional air pollution such as fog and haze. Water purification (O), Erosion Regulation (M) and Groundwater recharge (K) offer assistance in reducing water pollution and floods. Intrinsic Value of Biodiversity (V), Recreation &Aesthetic Values (W) help to meet the demand for leisure activities and tourism caused by the large increasing population.

For environmental conservation, the administrative boundary should be broken to unify the management and conservation of the forest in the region. Further study in ecosystem services hot spots should be done to assist delineation of ecological red lines for protection a payment for ecosystem services (payment for ES) mechanism should be implemented for forest conservation in southwest mountainous and hilly forest ecological zone. The establishment of payment criteria and identification of ecosystem service flow are core questions in payment for critical ecological services. These need to be done on the basis of a precise quantitative assessment and simulation of ecosystem services flow.

For socioeconomic development, ecological development that matches local resources such as ecological agriculture and ecological forestry should be built by making full use of natural resources in this zone. The mountain forest area in this zone is rich in natural scenery tourism resources. Developing tourism forms with ecological characteristics will improve the relationship between human and natural and enhance the sustainable utilization of landscapes in this zone.

(1) Northeast Plain Agriculture Ecological Zone (III)

This zone includes hot spots for two provisioning services: Crops provisioning (Q) and livestock provisioning (R), mainly distributed in the northeast plain. The conservation of the two provisioning services is directly related to food safety for the huge population of the region.

The main landforms of the northeast areas are lowland plain. Arable lands such as irrigated croplands are the dominant ecosystem type in this zone. Habitat fragmentation caused by urban expansion and urban rainstorm floods is serious in this zone. Urban sprawling and developing residential areas have occupied or destroyed many species habitats and greatly decreased the services provided by ecosystems of this region. Therefore, the restriction of urban expansion will be an arduous management task in this region.

Sub zones of ecosystem services should further be delineated and connected with each other to build an ecosystem service network based on the deep analysis of hot spots of multiple ecosystems: ecological integrity sub ecological zones for conservation of biodiversity, storage capacity and reduction of nutrient loss; regulating services sub ecological zones for regulation of local climate, water purification, erosion, air quality, etc.; and cultural services sub-zone for conservation of intrinsic value of biodiversity and recreation & aesthetic values.

5.3.3. Aquatic ecosystem services conservation zone (IV)

Four hot spots of ecosystem services are distributed in the zone: Abiotic heterogeneity (A), Groundwater recharge (K), Freshwater (U) and Recreation & Aesthetic Values (W). Not only does the water supply for regional residents living depend on the rivers and lakes, but also the huge demand for entertainment and leisure activities by regional residents also depends on the conservation of the waterbodies in this zone.

Aquatic ecosystems such as lakes and rivers are the dominant ecosystem type in this zone. This zone could be divided into two subzones: the Qiandao Lake subzone in the south and the Taihu Lake subzone in the north. These two subzones are the main sources of water supply for the whole region. The Taihu Lake subzone is one of the most important freshwater (U) supply zones in the region with prominent ecological and environmental problems. Due to urbanisation and environmental pollution, this sub-zone has seriously degraded organisms and urgently needs remediation. Water pollution and flood are the main ecological risks in these zone areas.

5.3.4. Eastern coastal estuaries ecological zone (V)

The zone includes four services hot spots distributed in the eastern coastal areas: Metabolic efficiency (D), Flood Protection (J) Capture fisheries (S), and Aquaculture (T). The main landforms of the eastern coastal areas are river estuarine plains. Estuaries, salt marshes and shallow sea wetlands are the dominant ecosystem types in this zone. These ecosystems are important transit stations for East Asian-Australian bird migration and a breeding ground for important migratory species in the Yangtze River. The zone is valuable for both its international influence on ecological protection and its function for freshwater aquaculture. A national-level Dongtan Wetland Reserve has been established in the area, but the aquatic ecosystems at the estuary have not yet been protected. The main threats include reclamation of tidal flats, urban sewage emission, transportation facilities, water shipping, terminal construction, and other human activities. Moreover, water pollution and habitat fragmentation are major ecological risks in this zone. Therefore, the protection of coastal wetland and restoration of deteriorated wetland ecosystems will be main objectives in this zone. It is urgent to relieve and reduce the impact of these activities and restore biological habitats. A big protection circle should be designated.

5.3.5. Urban development area (VI)

This zone consists of cold spots for critical ecosystem services in the region. With urban expansion, this zone will have greater demand for ecosystem services. Therefore, the future task is to negotiate the relationship between urban development and ecological protection, and decrease the pressure on natural ecosystem. Thus, constructing eco-city should be taken into serious and urgent consideration for regional sustainable development.

5.4. Summary

Rapid urbanization has altered many ecosystems, causing a decline in many ecosystem services, and generating serious ecological crisis. To cope with these challenges, the author has presented a comprehensive framework comprising five core steps for identifying and managing hot spots of critical ecosystem services in a rapidly urbanizing region.

This chapter is an application of the author’s sub-framework for comprehensive spatial assessment and management of ecosystem services hot spots and cold spots in a metropolitan region.

The case study is for spatial pattern identification and management strategies of the ecological function zone delineation for the ecological red line policy in the Yangtze River Delta metropolitan region.

In this chapter, a new comprehensive framework for ecosystem services hot spot and cold spot identification and environmental management was presented. This framework is targeted to regional-scale ecosystem services hot spot, different-capacity levels and priority area’s management and decision making in rapid urbanization areas. It also will help to delineate the Comprehensive Ecological Functional Zone in Ecological Red Line.

The application of the comprehensive framework in case study revealed the spatial heterogeneity of multiple ecosystem services, which will be helpful for multiple ecosystem services conservation in this region.

The management strategies of the integrated and primary ecosystem service were the first step for the conservation policy practice in the Yangtze River Delta metropolitan region.

The results in this chapter showed that there was large spatial heterogeneity in the distribution of ecosystem services in the region, high-supply areas of ecological integrity and regulating services aggregately distributing in the southwest mountainous areas while high-supply areas of provisioning services mainly in the northeast plain, and high-supply areas of cultural services widespread in the waterbodies and southwest mountainous areas. The regionalization of the critical ecosystem services was made through the spatial assessment.

However, it was sometimes difficult for local experts to assess ecosystem services with one kind of land cover or ecosystem.

The next chapter will further discuss the application of another sub-framework for large-scale planning in one kind of land cover or ecosystem for sub-function zones in the ecological red line policy.

The chapter 6 will focus on the case study area of 'Two Provinces and One Municipality' area (Zhejiang Province, Jiangsu Province and Shanghai Municipality) for province-level decision support in identification for priority area identification for ecological forest zone and cropland function zone.

Chapter 6 Conservation priority area delineation of cropland and forest in the Yangtze River Delta Region

6.1. Introduction

Cropland and forest are vital to human society but are threatened by human disturbance, especially in rapidly urbanizing regions. Rapid urbanization and growth of population rely greatly on huge demand for crops, which inevitably leads to the loss of croplands and forest and influences the functions of those ecosystems, thereby decreasing their ecosystem services supply to human society (Xu et al., 2014a; Li et al., 2016a).

Moreover, the local academic experts and decision makers agreed that there is a need to identify priority conservation areas first in these types of land cover for regional ecosystem management, since the three main types of land cover account for over 70% of the total area (paddy fields>forest >rainfed cropland) of the Yangtze River Delta metropolitan region. Therefore, it is necessary to delineate conservation priority areas for cropland and forest ecological function zone in the Yangtze River Delta metropolitan region.

To protect the ecosystem function in the ecological function zone, the Jiangsu Province, Zhejiang Province and Shanghai Municipality ('Two Provinces and One Municipality) should cooperate together to support the regional plan of the Yangtze River Delta metropolitan region restricted by conservation policies.

As C1 Leader Advisor said, 'Each strategy of Jiangsu Province, Zhejiang Province and Shanghai Municipality should serve the overall sustainable development strategies of the Yangtze River Delta metropolitan region, which is vital to China's ecological civilization.'

The 2009-2020 Regional Plan of the Yangtze River Delta metropolitan region put forward the general conservation objectives for strengthening ecosystem functions and ecosystem services, establishing conservation priority area for supporting the resource utilization and ecological environment protection.

It contained the following provincial conservation objectives in the resource utilization and ecological environment protection for supporting the regional ecological red line policy:

1) the delineation of more than 3.33 million hm^2 cropland areas for promoting the new ecological cropland function zone;

2) delineation of the mountain ecological forest protection priority area delineation.

The research objective of this chapter is promoting provincial ecological cropland and forest function zones under the ecological red line policy for the Yangtze River Delta metropolitan region.

The research questions addressed in this chapter are:

What are classifications of importance levels of the net primary productivity for ecological cropland and forest function zones of provincial cities in the Yangtze River Delta metropolitan region?

What are the spatial patterns of the clustering patches of large area of habitats by hot spot analysis (Getis-Ord Gi*) in the Yangtze River Delta metropolitan Region?

How can the conservation priority area support decisions on the delineation of the ecological cropland function zone and the ecological forest function zone?

6.2. Results

6.2.1. The decline of arable land in the Yangtze River Delta Region

Previously, arable land conservation was effective only to some extent, since local government did not have clear a delineation of ecological cropland and simply delineated the preliminary arable land conservation area with most of the croplands in the Yangtze River Delta Region.

They only focused on the crop provisioning services of the two types of croplands (paddy fields and rainfed croplands) and did not distinguish the functions and total ecosystem services values of croplands. Because of urban growth and land use change in the plain area of the 'Two Provinces and One Municipality', the area of the paddy fields gradually decreased from 2000 to 2015 at different rates in different five-year periods: -4.50 % (2000-2005), -3.77 % (2005-2010), and -2.82% (2010-2015).

The average negative growth rate of rainfed croplands was -4.64%, but the rate of change over a five year period was highly variable: -0.85 % (2000-2005), -10.24 % (2005-2010), and -2.82% (2010-2015) (JSYB; SSYB; ZSYB). The statistics above means that the previous ecological cropland function zone was effective to some extent between 2010 and 2015, although it is still necessary to improve the delineation method to detect conservation priority area more accurately.

6.2.2. The spatial assessment and priority area identification of rainfed cropland

1) Spatial distribution and proportion of ecological cropland function zone by net primary productivity proxy

In general, the areas of rainfed cropland with highest and high value in supply of the integrated ecosystem services, individually and in total, had a larger proportion than the other values, and they were densely distributed in the north and east of the Jiangsu Province. The very high importance zone was densely distributed in the north of region, which concentrated in the north and east of the Jiangsu Province, while the high importance zone was widely spread in this region (Fig.6.2). This means that, in the rainfed croplands, the area with the highest (1200>= g C/m^3 net primary productivity) and high supply (1000-1200 g C/m^3 net primary productivity) of provisioning services were concentrated in this region, according to the map of net primary productivity (Fig.6.1).

The high importance zone occupied the highest proportion of the rainfed croplands, which means that 35.96% of the total rainfed. The medium importance zone was continuously distributed in the east coastal area of the region, and scattered in the west of Jiangsu Province and the entire Zhejiang Province (Fig.6.2).

In 28.35% of the total area, the supply of the four ecosystem services in these rainfed croplands was at a medium level (800-1000 g C/m^3) assessed by net primary productivity (Fig 6.1). croplands had a high supply of ecosystem services.

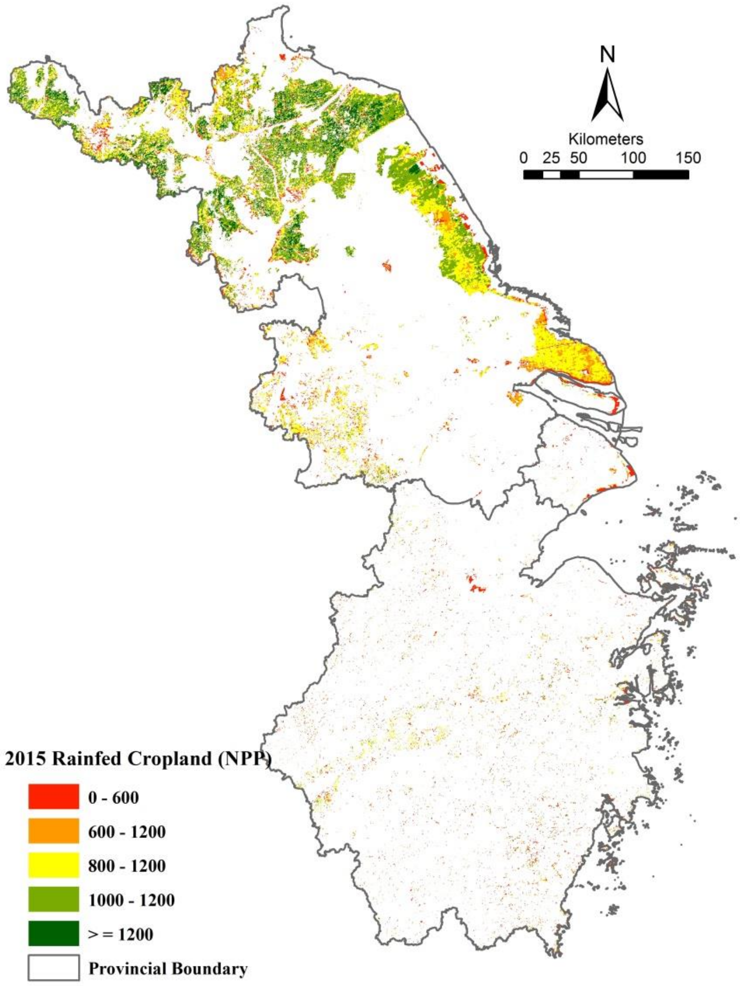


Figure 6.1 Different-level net primary productivity (g/m^3) of rainfed cropland

The low importance zone and the very low importance zone were scattered over the entire region (Fig.6.2), except the middle of the Jiangsu Province.

Although these two levels occupied a small proportion of the total, it was found that the very low importance zone was mainly concentrated in the southeast area of Jiangsu Province, the east coastal area of Shanghai, and the north of the Zhejiang Province, which indicates the concentrated pattern of the rainfed cropland with the lowest supply of the four ecosystem services.

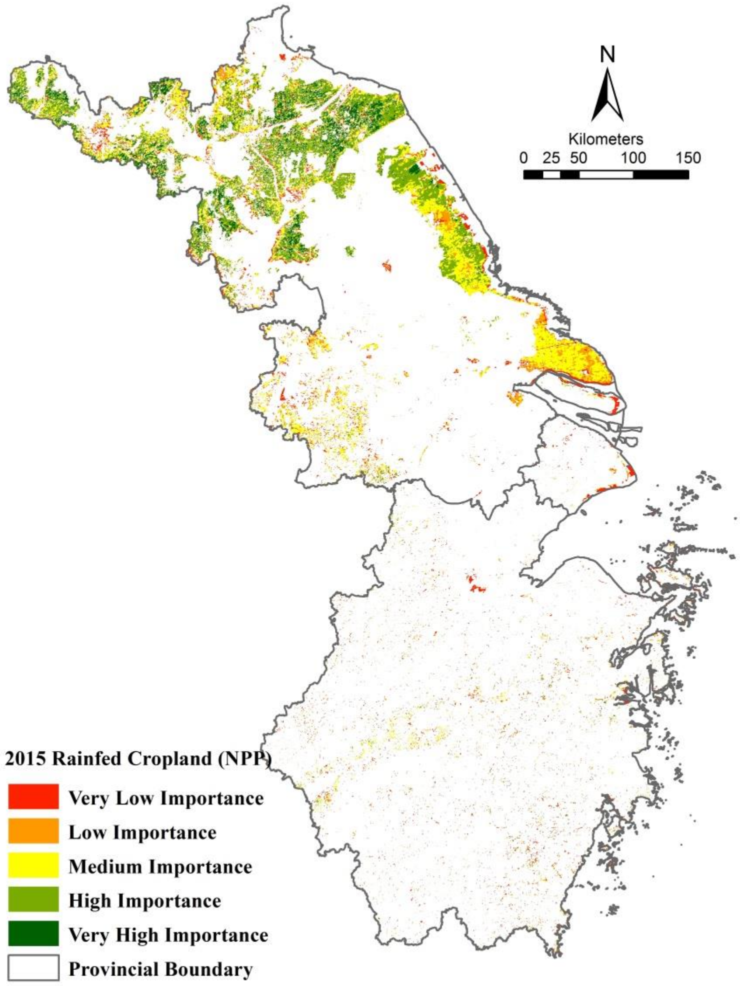


Figure 6.2 Importance of ecosystem function of rainfed cropland

Table 6.1 Importance of ecosystem function of rainfed cropland

	Importance of ecosystem function	Area (km^2)	%
Rainfed cropland			
	Very High Importance	2700.68	9.90
	High Importance	9811.09	35.96
	Medium Importance	7734.40	28.35
	Low Importance	3432.41	12.58
	Very Low Importance	3601.38	13.20

2) The Getis-Ord Gi* hot spot of area of the rainfed cropland

The map of (Getis-Ord Gi*) hot spots analysis illustrated three hot spots of the rainfed cropland (Fig.6.3): the hot spots area with (‘z-score>2.58, p<0.01), the hot spots area with (‘z-score>1.96, p<0.05) and the hot spots area with (‘z-score>1.96, p<0.05). The high z-score and low p-value means that there was 99%, 95% and 90% confidence for a spatial clustering of large-area patches of the rainfed cropland. The largest patch accounted for 19.34% of the hot spots area. The 99% confidence hot spots areas were distributed over linked areas in the east coastal area and concentrated in the north of Jiangsu Province.

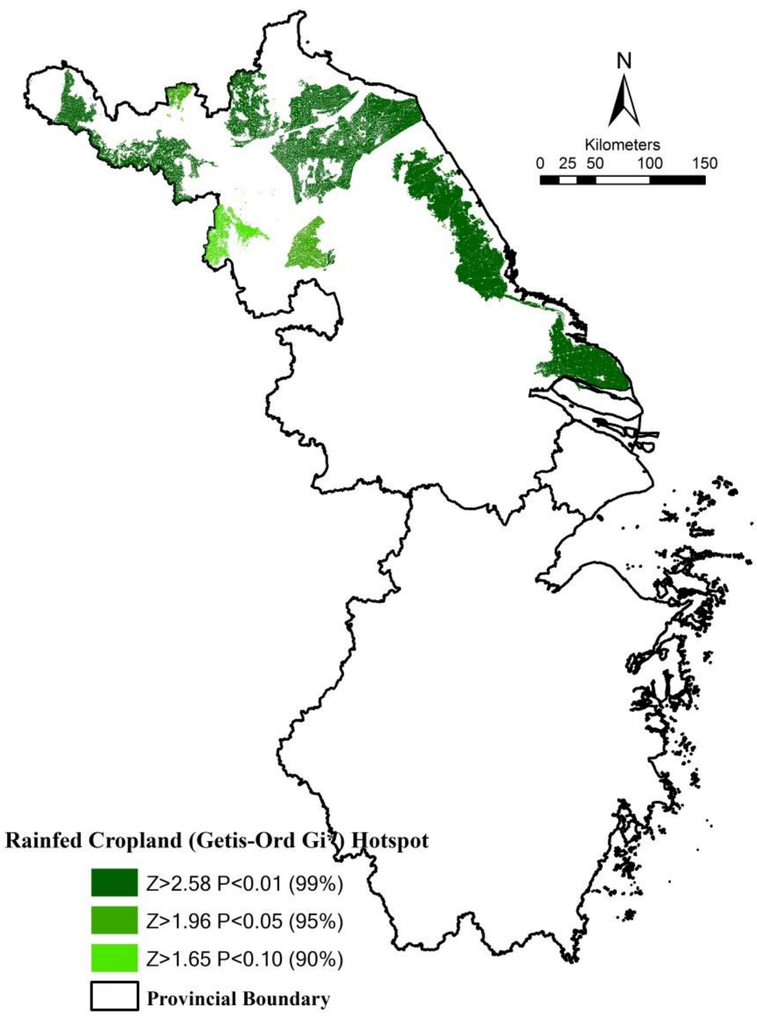


Figure 6.3 Spatial distribution of Getis-Ord Gi* hot spot of the area of the rainfed cropland

3) Priority area identification

The author mapped the areas with highest (the very high importance zone; 1200>=g C/m^3 net primary productivity) and high supply (The high importance zone; 1000-1200 g C/m^3) of the rainfed cropland as possible options for priority area of ecological cropland function zone (Fig.6.4). Through the results, the rainfed cropland with very high importance zone of total supply was considered as the highest quality cropland for primary choice, while the rainfed cropland with high importance zone in total supply capacities was for the secondary choice, and lower value areas can also be options depending on the policy demand of each province.

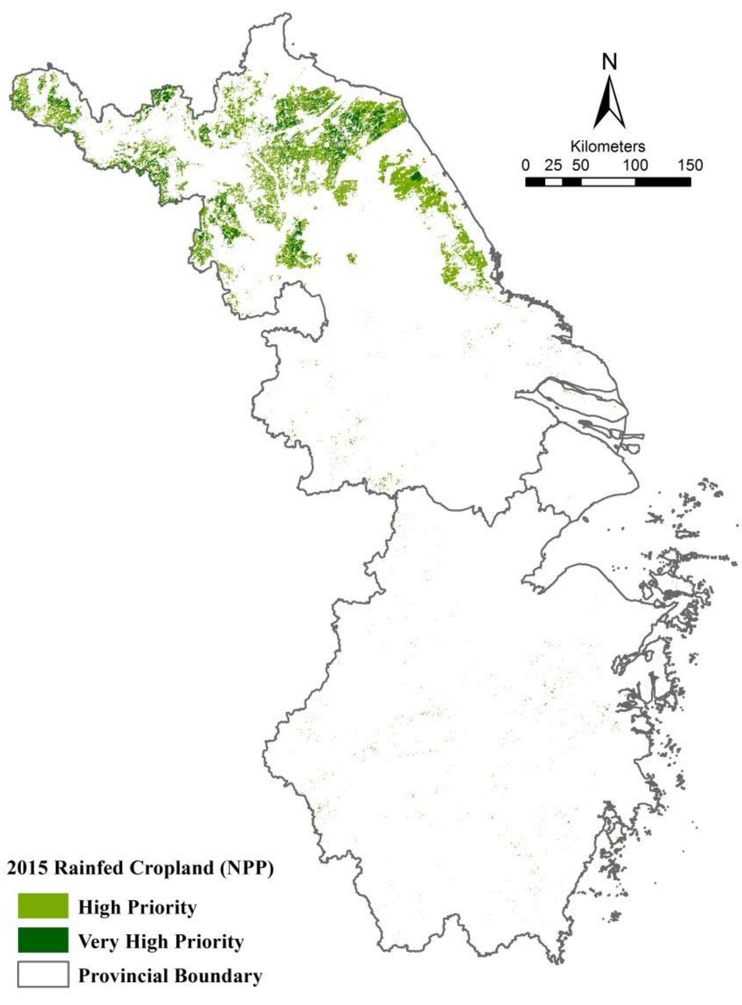


Figure 6.4 Priority conservation area of rainfed cropland ecological function zone (net primary productivity)

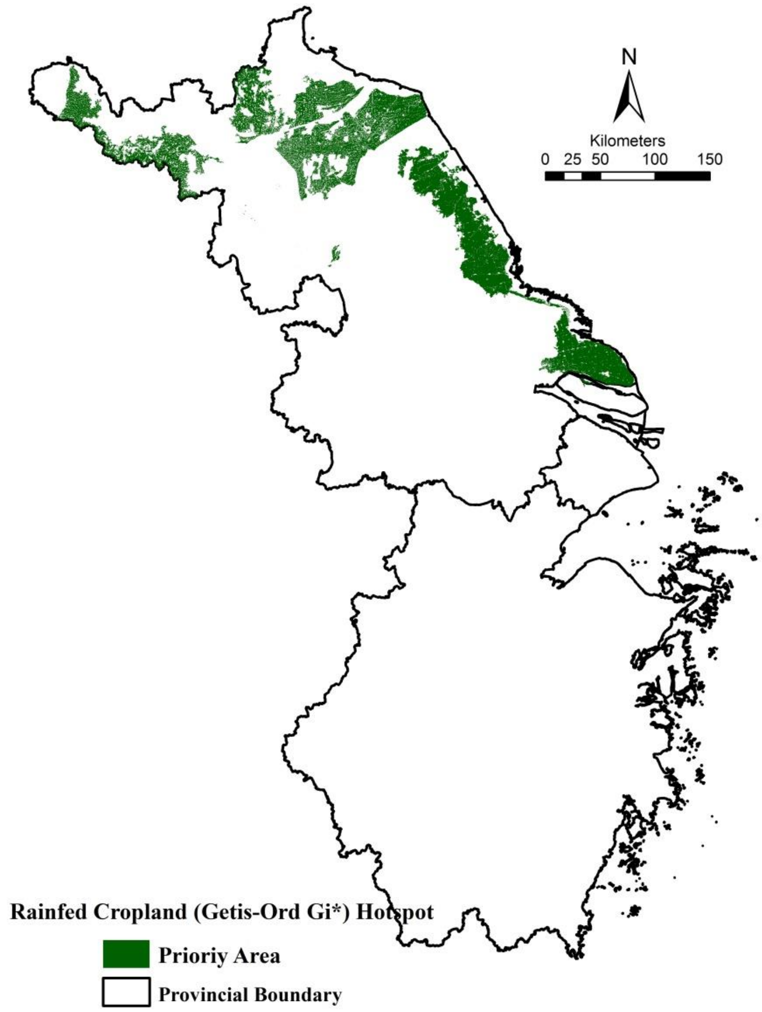


Figure 6.5 Priority conservation area of rainfed cropland by Getis-Ord Gi* hot spot of (area of patches)

In the author's view, the Getis-Ord Gi* hot spots with z-score >2.58 and $p<0.01$ could be a good option as a conservation priority area (Fig. 6.5), since this area not only comprised rainfed cropland patches with relatively high capacities of ecosystem services supply, but also comprised spatial clustering and large-area patches that are good for ecosystem conservation. However, some high-capacity areas in the northwest part of the Jiangsu Province were not spatially clustered.

This will lead to a trade-off problem in the decision making on the ecological cropland in Jiangsu Province.

Due to the obvious pattern in which these areas were continuously distributed in the north of Jiangsu Province, this delineation map was mainly used for delineation of ‘ecological cropland’ in Jiangsu Province.

6.2.3. The spatial assessment and priority area identification of paddy fields

1) Spatial distribution and proportion of different values

In general, the areas with high importance and medium importance supply of ecosystem services individually and in total (there is no supply of fibre providing service in paddy fields) of paddy fields had the largest proportion of the total (Table 2). The high importance zone was densely distributed in the north and east of the Jiangsu Province, expect for the coastal area, while the medium importance zone was widely spread over the whole region (Fig.6.7).

The very high importance zone of the total ecosystem services and each of the four integrated ecosystem services had the smallest proportion (2.38%) of the total (Table.6.2). This zone was concentrated in the north of the region, mainly in Jiangsu Province. This means that, in the paddy fields, the area with the highest supply (1200>= g C/m^3) of the four integrated service according to the net primary productivity (Fig.6.6).

The area with high importance occupied a large proportion of the paddy fields, which means that 34.73% of the total paddy fields had a high supply (900-1200 g C/m^3 net primary productivity) of the integrated ecosystem services.

The medium importance zone had the largest proportion of the total and the widest distribution in the region (Table 6.2). This value area was widely spread over the entire region: the south of Jiangsu Province, most of Shanghai Municipality except the central area, the north plain, and coastal plain and valley in the Zhejiang Province. This means that medium-level (600-900 g C/m^3 net primary productivity) supply of both total and each individual ecosystem services was the main supply level of paddy fields in the region (Fig.6.6).

The very low importance zone and the low importance zone were mainly concentrated in the middle of the region and partly distributed in the middle of the region (Fig.6.6), respectively. The areas with these two values were densely distributed in the middle of Jiangsu Province, the south of Jiangsu Province, the north of Zhejiang Province and Shanghai Municipality. The total and individual supplies of the integrated ecosystem services in these areas were at 300-600 g C/m^3 or below 300 g C/m^3 (Fig.6.6).

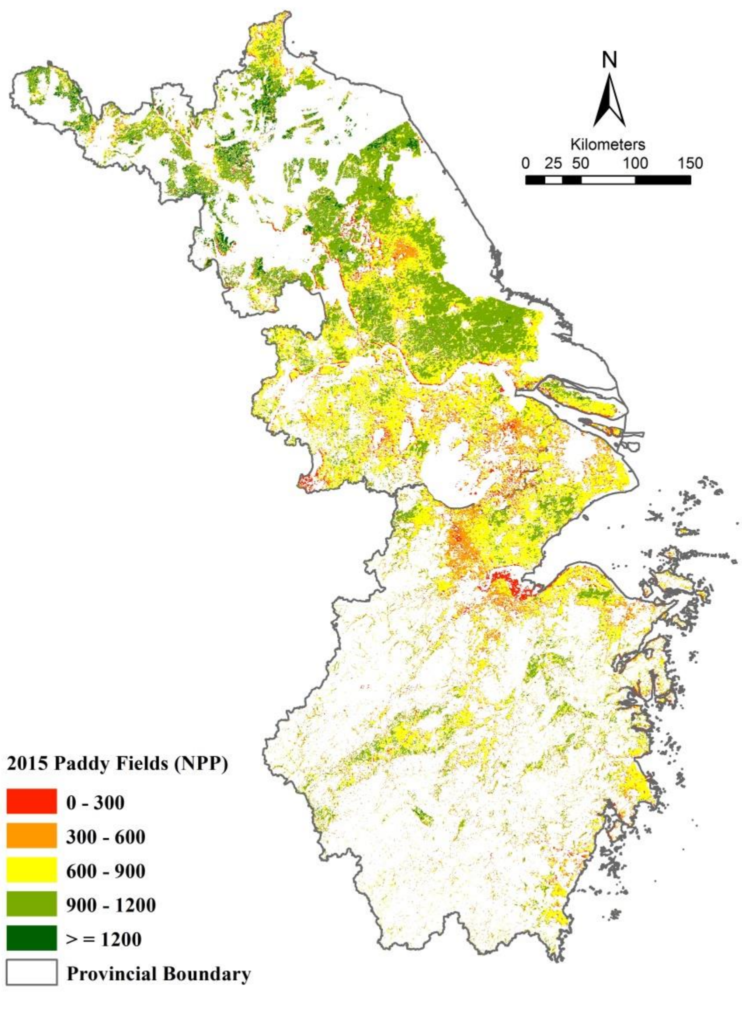


Figure 6.6 Different-level net primary productivity (g/m^3) of paddy fields

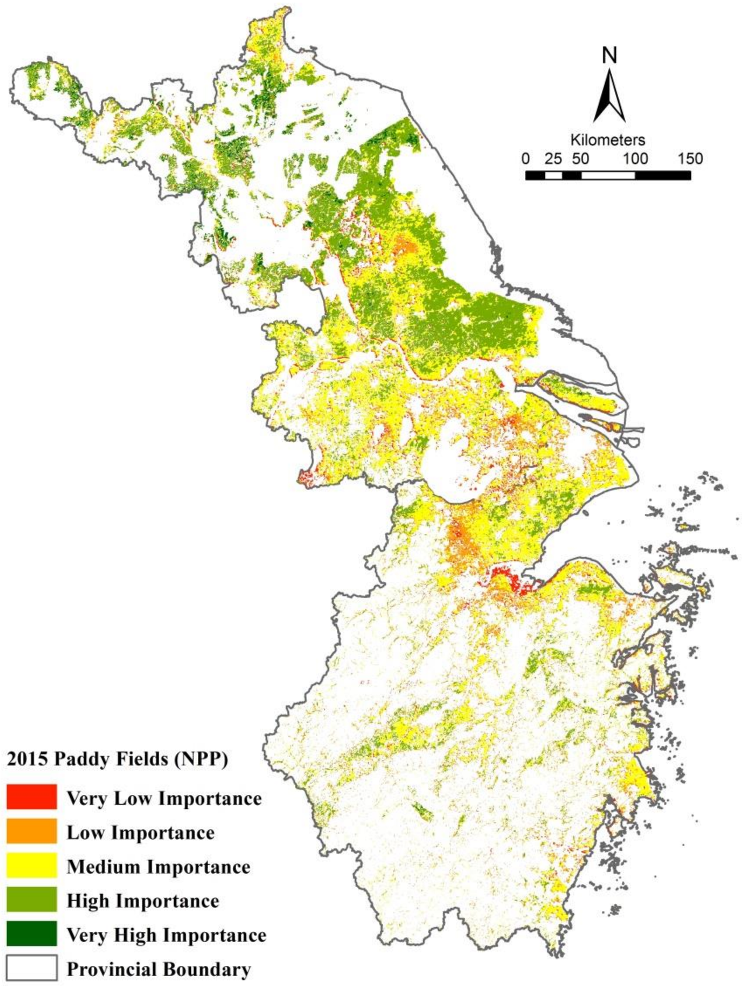


Figure 6.7 Importance of ecosystem function of paddy fields Different-level net primary productivity (g/m^3) of paddy fields

Table 6.2 Importance of ecosystem function of paddy fields

	Importance of ecological function	Area (km^2)	%
Paddy fields			
	Very High Importance	1538.03	2.38
	High Importance	22445.26	34.73
	Medium Importance	26479.26	40.97
	Low Importance	10297.30	15.93
	Very Low Importance	3875.26	6.00

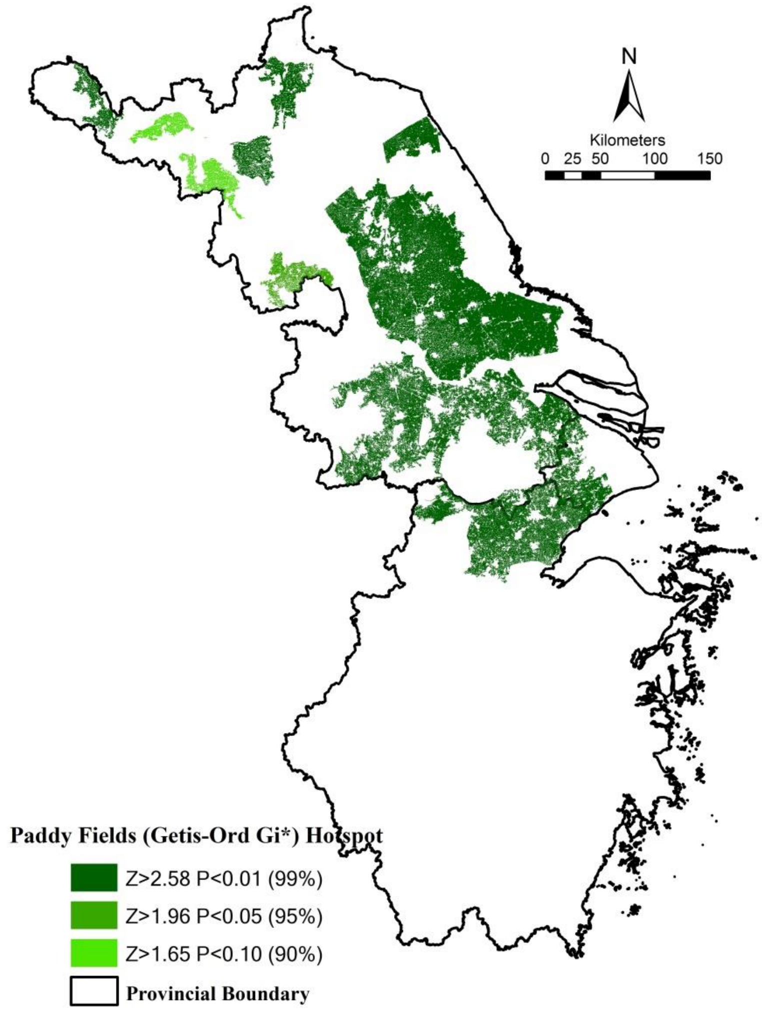


Figure 6.8 Spatial distribution of Getis-Ord Gi* hot spot of the area of paddy fields

2) The Getis-Ord Gi* hot spot of area of the paddy fields

The map of (Getis-Ord Gi*) hot spots analysis illustrated three hot spots of the paddy fields (Fig.6.8): the hot spots area with ('z-score>2.58, p<0.01), the hot spots area with ('z-score>1.96, p<0.05) and the hot spots area with ('z-score>1.96, p<0.05). The high z-score and low p-value means that there was 99%, 95% and 90% confidence for a spatial clustering of large-area patches of paddy fields. The largest patch accounted for 46.20% of the hot spot area. The 99% confidence hot spot areas were clustered in the middle of Jiangsu Province, concentrated in the

Taihu Lake Basin, which included the south of Jiangsu Province, the east of Shanghai Municipality and north of Zhejiang Province, and scattered in north of the Jiangsu Province.

3) Priority area identification

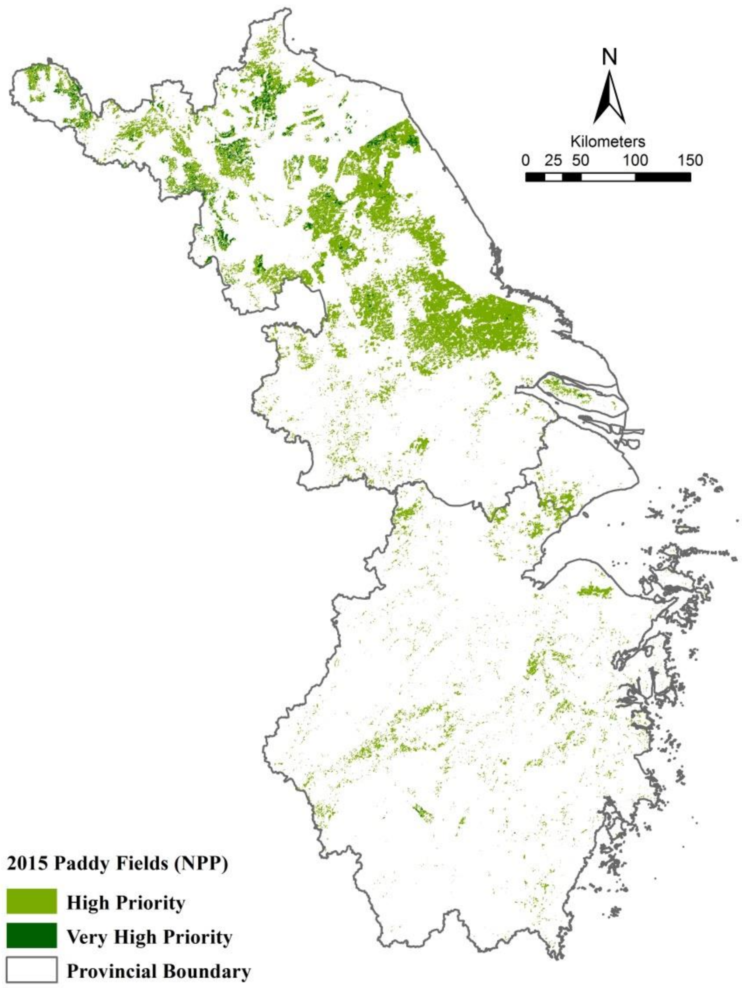


Figure 6.9 Priority conservation area of paddy fields ecological function zone by net primary productivity

The author mapped the areas with highest (The very importance zone; 1200>=g C/m^3 net primary productivity) and high supply (high importance zone; 900-1200 g C/m^3) of the paddy fields as possible options for priority area delineation of ecological cropland zone (Fig.6.9). From the results, the paddy fields with The very importance & 1200>=g C/m^3 net primary productivity were considered as the highest quality cropland for primary choice, while the paddy fields with high importance & 900-1200 g C/m^3 in total supply were for secondary choice, and lower value areas could also be other choices depending on the policy demand of different administrative units. Although the highest supply areas were continuously distributed in the north of Jiangsu Province, the high supply area was also concentrated in the south of Shanghai Municipality and Chongmin Island in Shanghai, and scattered in the lowland area in Zhejiang Province.

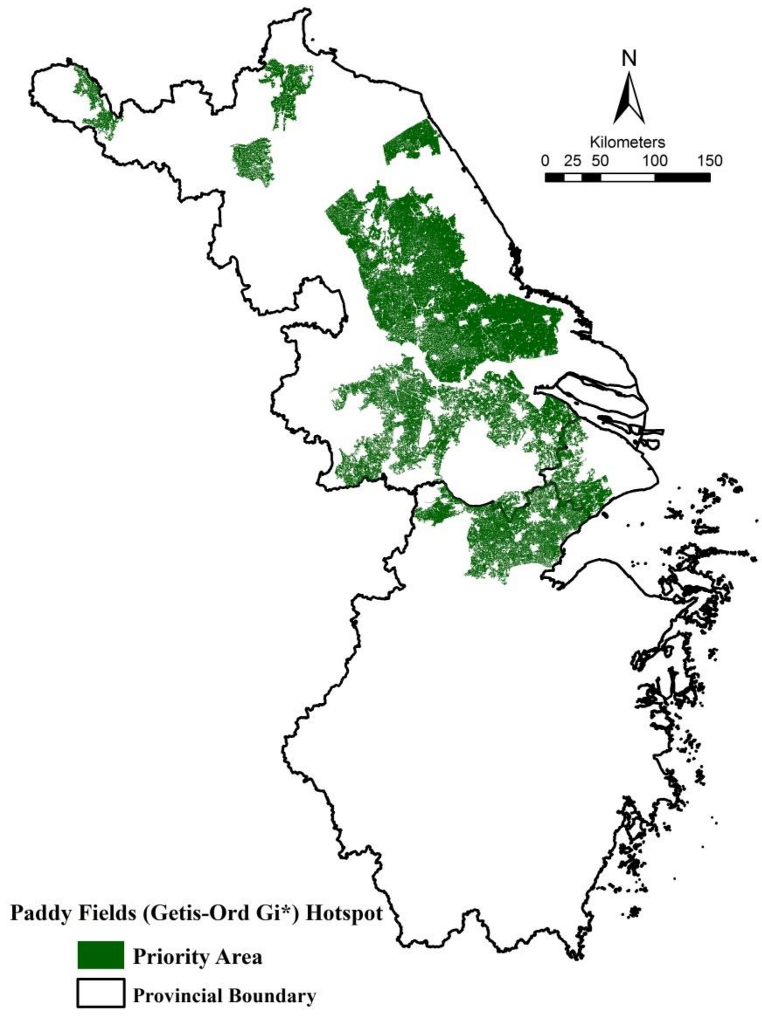


Figure 6.10 Priority conservation area of paddy fields of Getis-Ord Gi* hot spot

(area of patches)

In the author's view, the Getis-Ord Gi* hot spot with z-score >2.58 and p-value <0.01 could be a reference for the conservation priority area of paddy field, since these paddy field areas had large-area and highly clustered patches (Fig.6.10), which are necessary to the ecosystem conservation (Steiner et al., 2008).

However, some of the hot spots were located in the Taihu Lake Basin, which did not have high capacities of ecosystem services, while some of the high ecosystem services capacities areas in Zhejiang Province did not have spatially clustered patches.

This will lead to a trade-off between high ecosystem services capacity area and spatially clustered areas, which will depend on the demand of decision makers. These delineation maps were mainly used for delineation of ecological croplands for all of the three province-level administrative units, especially Jiangsu Province.

6.2.4. The spatial assessment and priority area identification of forest

1) Spatial distribution and proportion of different values

In general, the areas with very high and high values in supply of the integrated ecosystem services individually and totally occupied most of the area of forest, and they were densely distributed in Zhejiang Province (Fig. 6.12).

The very high importance zone ((>=700) g C/m^3) was densely distributed in the south of the region, occupying most of the area in Zhejiang Province. It covered not only the inland area but also the east coastal area of the province.

Moreover, these areas with the highest net primary productivity level (700>= g C/m^3) may indicate a good growing state of growth the forest (Fig.6.11).

As S-1 Scientist said that 'A good net primary production means a very good state of forest ecosystem, which ensures multiple ecosystem services provision.'

The high importance zone ((600-700) g C/m^3) was widely spread in the south of the region, in Zhejiang Province. This supply level had the largest proportion of the total area, which accounted for 57.34% of the total (Table 6.3).

The medium importance zone ((500-600) g C/m^3), the low importance zone ((400-500) g C/m^3) and the very low importance zone ((0-400) g C/m^3) were scattered in south Jiangsu Province, the middle of the region, and mainly distributed in Zhejiang Province, south of the region. These areas had a relative low supply of the ecosystem services in forest (net primary productivity<600 g C/m^3) (Fig.6.11).

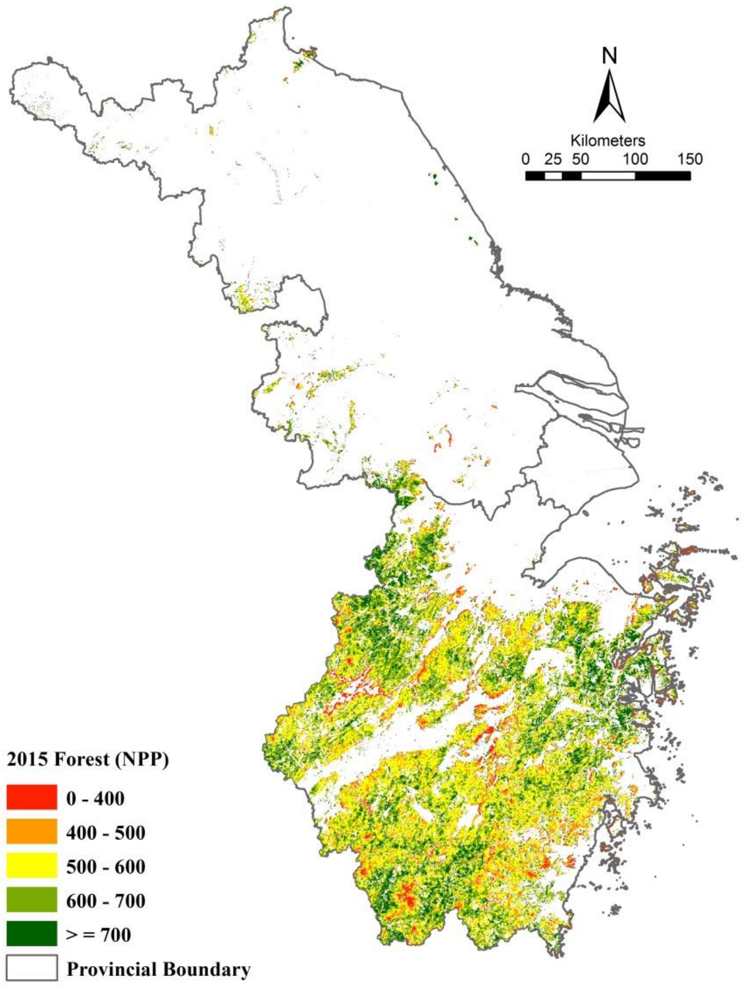


Figure 6.11 Different-level net primary productivity of forest

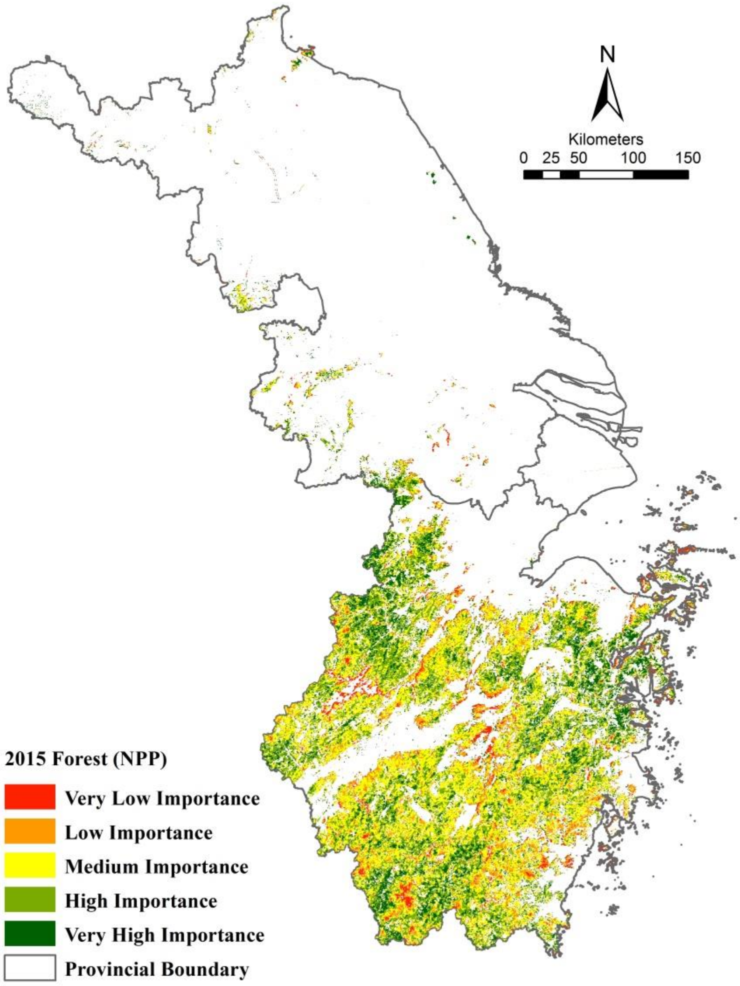


Figure 6.12 Importance of ecosystem function for ecological forest function zone

Table 6.3 Importance of ecosystem function for ecological forest function zone

	Importance of ecosystem function	Area (km^2)	%
Forest			
	Very High Importance	9024.21	15.50
	High Importance	17492.38	30.05
	Medium Importance	21215.81	36.44
	Low Importance	7756.16	13.32
	Very Low Importance	2730.81	4.69

2) The Getis-Ord Gi* hot spot of the area of forest

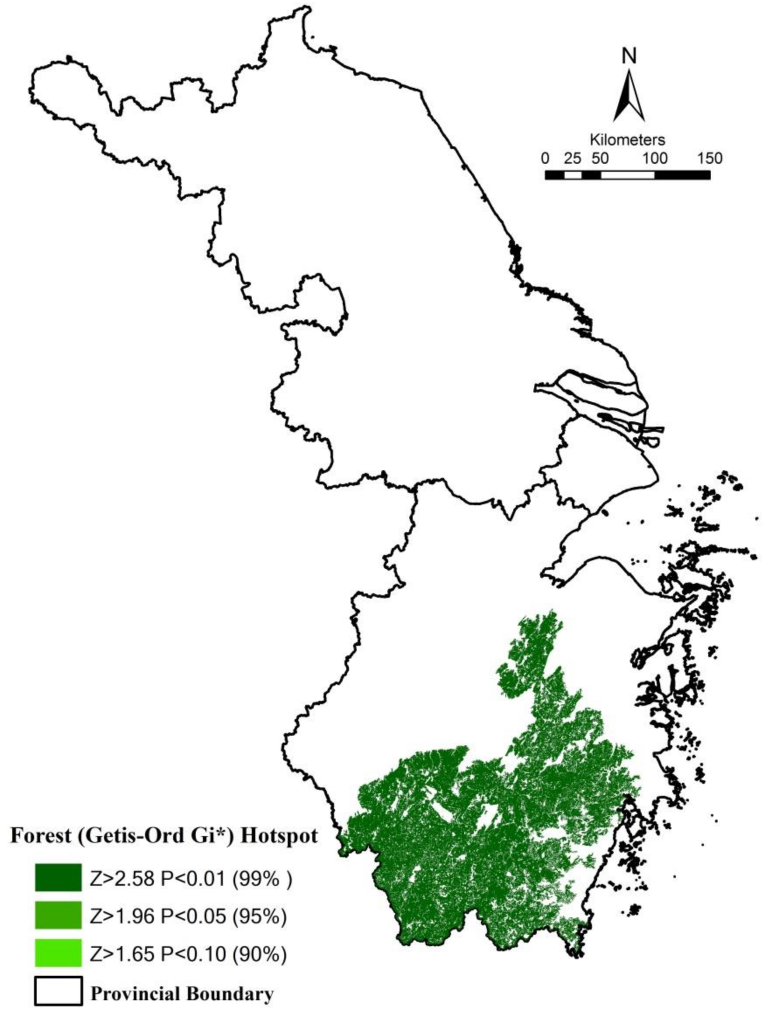


Figure 6.13 Spatial distribution of Getis-Ord Gi* hot spot of the area of forest

The map of (Getis-Ord Gi*) hot spot analysis illustrated three hot spot of the forest (Fig.6.13): the hot spots area with (‘z-score>2.58, p<0.01), the hot spots area with (‘z-score>1.96, p<0.05) and the hot spots area with (‘z-score>1.96, p<0.05). The high z-score and low p-value means that there was 99%, 95% and 90% confidence for a spatial clustering of large-area patches of forest. The largest patch accounted for 99.65% of the hot spot area, which means there was almost no fragmentation in the hot spot area. The areas and patterns of the three confidence hot spots were almost the same. The 99% confidence hot spots areas covered most of the area of the south and part of the middle of Zhejiang Province.

3) Priority area identification

For supporting decisions related to ecological forest protection, the author mapped the very importance zone (net primary productivity>=700g C/m^3,) of the forest as the 'ecological protection forest' area according to the local experts' view (Fig.6.14). Form the results, the forest with the above three criteria was considered as the highest quality forest for conservation.

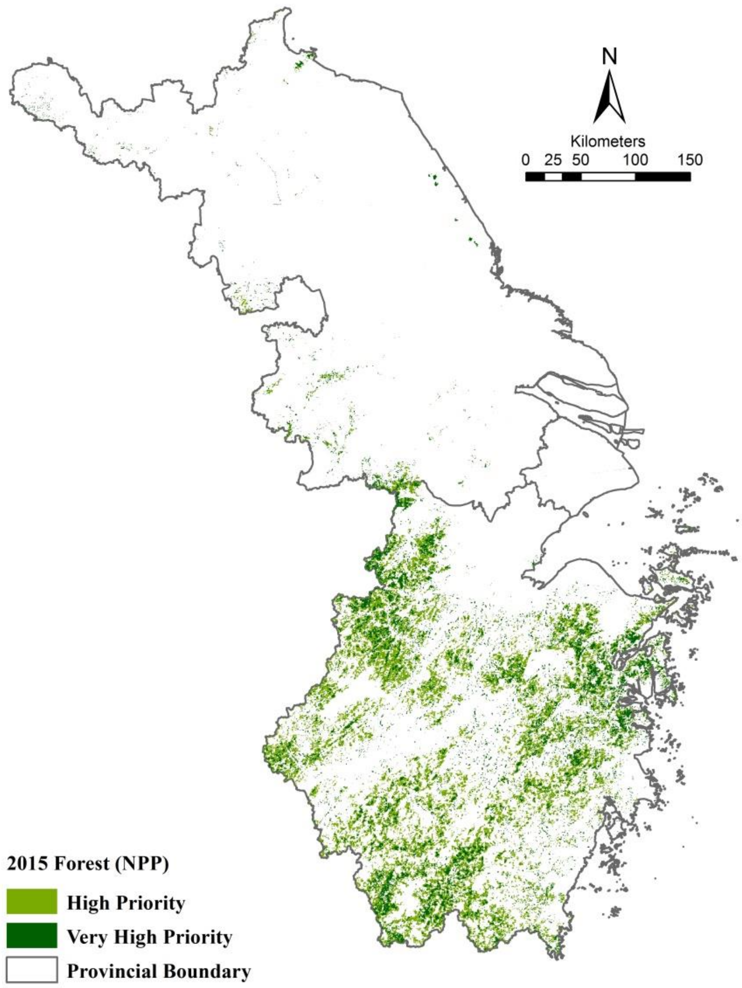


Figure 6.14 Priority conservation area of forest (net primary productivity)

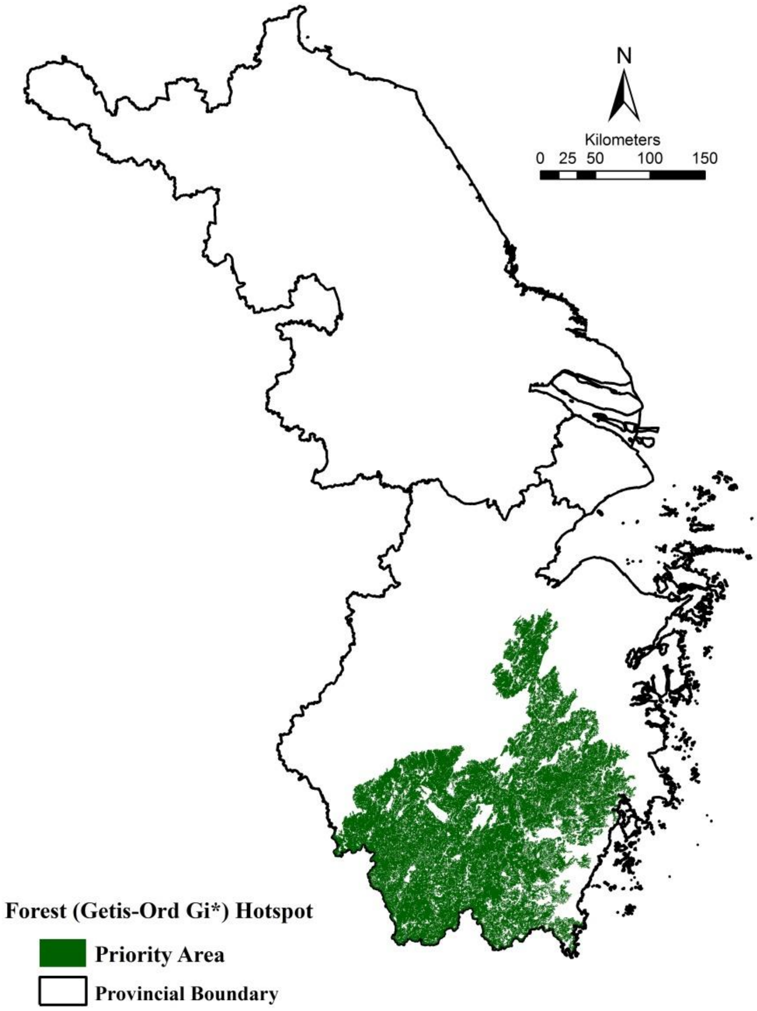


Figure 6.15 Priority conservation area of forest Getis-Ord Gi* hot spot (area of patches)

In the author's view, the Getis-Ord Gi* hot spot with z-score >2.58 and p-value <0.01 could be a reference for the conservation priority area of forest, since these areas had large-area and highly spatially clustered patches, which are necessary to the ecosystem conservation (Steiner et al., 2008). However, this hot spot area included a large area in the south of Zhejiang Province that did not have high capacities of ecosystem services and did not contain the areas with high capacities of ecosystem services in the north of this Province. This again will lead to a trade-off between high ecosystem services capacity areas and spatially clustered areas in decision making.

Through the obvious pattern that these areas were continuously distributed in the Zhejiang Province, this delineation map was mainly used for delineation of 'The ecological forest function zone' in Zhejiang Province.

6.3. Discussion

6.3.1. Net primary productivity, ecosystem function, and ecosystem services

The 'net primary productivity' could be used as a proxy of ecosystem function and total ecosystem services values (Burkhard et al, 2014; Costanza et al, 2007; Palomo et al, 2017).

Moreover, net primary productivity was an ecosystem function proxy strongly linked to the supply of provisioning services such as the supply of food, wood production, production energy crops, and also supporting the supply of regulating services i.e. water regulation, flood control and cultural services (Burkhard et al, 2014; Costanza et al, 2007; Palomo et al, 2017).

The author's priority conservation area delineation based on the assessment of different levels of ecosystem function and total values of ecosystem services were to inform decision making for ecological cropland function zones and ecological forest function zones.

6.3.2. Conservation priority areas in Jiangsu Province, Zhejiang Province and Shanghai Municipality

The author's mapping of conservation priority areas for Shanghai Municipality (especially in Chonming Island) in this chapter was focused on the identification of a 'paddy fields' priority conservation area, which was had the highest value in crop provisioning services in land cover types. According to the author's interview, although Shanghai was mainly located in the urban development area and its main development objective was urbanization rather than ecosystem function, it would also follow the national natural ecosystem and cropland conservation policy, especially in the Chonming Island County. As S-5 Public Officer said, 'Shanghai will strengthen the construction of Chonming Ecological Island for the cropland land conservation in Chonming Island.

The ecological cropland policy is not only important for Shanghai but also for the entire region, since the food production of the arable land in the Chonming Island is important to the food security of over 30 million people, so it is urgent to identify arable land priority conservation areas'.

According to the results of this study, the author's very importance zone was located in the northeast of Chonming Island and south east of Shanghai. However, an S-2 Scientist said, 'Shanghai will have a large pressure on urbanization and population growth in the next five years. Although preventing the loss of cropland will slow down urban growth, the trend of expansion of Shanghai's urban area from the centre to the suburban area will not be stopped hastily.'

The author's mapping of conservation priority areas for Jiangsu Province was focused on the paddy fields and rainfed cropland ecological function zone, since this province is an Agriculture Province for food production in the plain and hill-cropland-low capacity zone.

According to J-4 Public officer, 'Jiangsu Province has an ambition to be an ecological province, although it currently also had a huge pressure on cropland loss and urban growth, like Shanghai Municipality. Its ecological cropland policy's objective of ecosystem management was the balance between the food production and other ecosystem functions.'

Different from the traditional view of food production, the author's interesting finding was that the area of the very high importance zone of ecosystem function of rainfed cropland was much larger than that of paddy fields, while decision makers previously paid much attention on the paddy fields only for crop provisioning services. In the view of J-1 Leader Scientist, 'The cropland conservation of Jiangsu Province is vital to the survival of the local population and regional environment of the Yangtze River Delta metropolitan region, since the most of the cropland of this region is mainly distributed in the Jiangsu Province.'

The author's mapping of conservation priority areas for the Zhejiang Province was mainly focused on the forest ecological function zone, since this province is a forest province which located in the mountainous and hilly-forest-high capacity conservation zone.

As Z-4 officer said, 'Following the national strategy of ecological red line delineation, the priority work of the ecosystem management of Zhejiang Province is delineation of the 'ecological forest protection area' delineation. The ecosystem services approach is a useful tool to identify high-quality forest conservation area.' As Z-2 scientist said that the 'ecological forest function zone with high capacity of ecosystem services will be one of the most important areas of environmental problems protection for the Yangtze River Delta metropolitan region.'

The ecological forest conservation areas that were chosen by the author and local experts amounted to 17.5% of the total area, which will satisfy demands, which the Z-1 Leader Scientist said '20% of forest ecological function area in Zhejiang will give long-time protection for the ecological security of the Yangtze River Delta metropolitan region'.

6.4. Summary

This chapter is an application of the author's sub-framework of ecosystem function for conservation priority areas delineation of specific ecosystems. The case study is to support decisions on provincial priority conservation areas, to support the conservation aims of delineation of priory areas for ecological cropland and ecological forest conservation in the 2009-2020 regional plan of the Yangtze River Delta metropolitan region.

The author applied a spatial indicator (net primary productivity) as a proxy for ecosystem function and total values of ecosystem services to help local experts and decision makers delineate the areas of differing importance within one ecosystem (the methods were described in Chapter 3).

The author's assessment and management framework were proved to be useful for decision making for specified conservation priority area delineation. The views of the local experts, decision makers and the author were sometimes different from each other, this also led to different options between areas with different levels of ecosystem services capacity, and between high-importance-ecosystem function areas and spatially clustered areas in decision making.

The application of this sub-framework was a step in spatial assessment and management of ecosystem function (intermediate ecosystem services) through classifying and priority setting within one kind of ecosystem. In this sub-framework, the mixed methods of proxy, spatial indicators, local experts' knowledge and GIS tools provide more accurate scientific information for decision support in priority conservation areas with high importance of ecosystem functions.

Although environmental planning was a good approach towards ecosystem functions and ecosystem services protection, it is necessary to further study both the supply side and demand side of final ecosystem services and their spatial relations.

The next chapter will apply the sub-framework identifying the mismatch of supply and demand of final ecosystem services and spatial relations for watershed management in the ecological water function zone. This sub-framework will be applied in the case study of inter-city environmental cooperation in different watersheds of sixteen major cities in the Yangtze River Delta metropolitan region.

Chapter 7 Service provisioning cities and service benefiting cities identification in the Yangtze River Delta Region

7.1. Introduction

The Yangtze River Delta metropolitan region is one of the fastest growing regions in China. In recent years, it has witnessed tremendous growth in its public sectors, including industrial and agricultural sectors, besides making impressive progress vis-à-vis urban-rural development.

Many studies and reports have shown that rapid urbanization has caused not only serious pollution of water and soil (Huang et al, 2010; Li et al, 2016b; Reidsma et al, 2012; Ren et al, 2003; Wang et al, 2003; Zhang et al, 2012; Zhang et al, 2017b), but also high occurrence of flood hazards (Yu et al, 2012; Zhang et al, 2008) in the Yangtze River Delta metropolitan region.

At the same time, environmental issues have been on the rise, along with a sharp degradation in the capacity of ecosystem services. In addition, water-related ecological disasters are becoming rampant. In this regard, the region is plagued with the following problems:

(1) Floods have become more frequent and intense. For example, the 1990s witnessed two devastating floods, one each in 1991 and 1998, which caused great economic and social losses (Huang et al, 2010; Zhang et al, 2012).

(2) The overall quality of surface water has rapidly deteriorated. The quality of most rivers and lakes in the region falls below Grade III (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). Nearly all rivers and lakes in cities are black and foul-smelling. Only some headwaters meet or exceed Grade II standard (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). In the backdrop of the prevalent quality-induced water shortage, protection and preservation of drinking water has become a top concern for both the government and the masses.

(3) As the surface water is polluted, the region has to dig even deeper for underground water, which causes serious regional land subsidence. Consequently, chain reactions follow, for example, exacerbated flood threats and damaged engineering geology.

(4) Structural and functional changes induced by regional water pollution in lakes, wetlands, cities, farmlands, and other ecosystems have brought about a series of socio-economic problems.

At the same time, other increasingly serious environmental problems, such as regional acid rain, biodiversity loss, and ecological problems induced by land surface change, are hindering sustainable development in the region (Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a).

These problems disrupt regional ecosystem services. The key is to understand ecosystem services and identify the relationship between socio-economic development and ecosystem services.

There was a need to promote orderly economic development while maintaining effective ecological services. Moreover, by learning about the types, value, and spatial distribution of ecosystem services as well as the ecological pressure on regional development, this thesis aims at consolidating ecological planning theories and practices for social development, thereby giving a boost to regional sustainability.

In order to solve water-related environmental problems in the Yangtze River Delta metropolitan region, some watershed management cooperation mechanisms have been developed.

7.1.1. Policy aims of ecological compensation cooperation pilots

1) Pilot cooperation in Taihu Lake Basin

According to environmental reports provided by the Watershed Department in Jiangsu Province and relevant research (Huang et al, 2010; Zhang et al, 2012), at the end of 2007, Jiangsu Province formulated the 'Pilot Program of Jiangsu Province Taihu Lake Basin for Environmental Resources Payment'.

After the one-year trial implementation in 2008, it was officially issued and implemented in the Taihu Lake basin since 2009. A total of 30 payment-based sections were set up in the Taihu Lake basin, covering five cities along the basin.

According to the characteristics of water environment pollution, three assessment factors (chemical oxygen demand, ammonia nitrogen, and total phosphorus) were determined, and according to the treatment cost of each pollution factor, the payment should be made at a rate of 15,000 yuan per ton of chemical oxygen, and 100,000 yuan per ton of ammonia nitrogen and total phosphorus, respectively, and the final payment is calculated based on water quantity and quality.

In 2011, the Provincial Department of Finance and the Provincial Department of Environmental Protection jointly issued the "Administrative Measures on the Use of Regional Payment-for-Ecosystem-Service Funds for Environmental Resources in the Taihu Lake Basin, Jiangsu Province," specifying the rules for the use and allocation of the funds of both Category A (payment from upstream area to downstream area) and Category B (local payment to provincial financial agencies). All such funds are returned to local areas and exclusively used for the prevention and control of water pollution in river basins and regions.

Regional payment for environmental resources will further strengthen the responsibility of local governments when it comes to environmental protection, increase initiative in pollution control and drive water quality goals to be achieved.

Moreover, the expansion in scope and the detailing of the regional payment is made based on the existing efforts related to regional payment system in the Taihu

Lake basin and Tongyu River areas. Only individual adjustments have been made to the original 45 sections paid for environmental resources (slight change in locations, etc.), and a further 27 sections in each key water system were added according to the needs of basin management.

According to the needs of basin management, unified payment factors and payment criteria should be launched for each basin, and in all the regional sections in the province where environmental resource payments should be made, the three assessment factors of permanganate index, ammonia nitrogen and total phosphorus were adopted.

2) Pilot cooperation in Qiantang River Watershed

According to environmental reports provided by Huangshan-Hangzhou Local Government and relevant research (Huang et al, 2010; Zhou et al, 2016a), Xin’an River originates from Liugujian, which sits 1629 metres above sea level in Xiuning County, Huangshan City. It spans the two provinces of Anhui and Zhejiang, and is the main source of the Qiantang River and the largest inbound river in Zhejiang Province. The basin has a total area of 11,452.5 square kilometres, and the main stream has a total length of 359 kilometres.

Among them, the area within Anhui is 6736.8 square kilometres (5856.1 square kilometres in Huangshan City and 880.7 square kilometres in Jixi County), and the length of the main stream is 242.3 kilometres. The average outbound water volume of the Anhui section of the Xin'an River accounts for more than 60% of the annual average inflow of Qiandao Lake. The water quality meets or surpasses the Class III standard for rivers of surface water all year round. It is the most important strategic water source in the downstream area, the most solid barrier for ecological security in East China, and one of the best rivers in quality terms in the country.

Following coordination at the national level and joint promotion by the two provinces of Anhui and Zhejiang, an agreement was officially signed by two national departments and the two provinces in 2012 to have the pilot program, which had been actively worked on for many years, officially launched at last.

The "Pilot Program" made it clear that the basic principle was "protection prioritised, with reasonable payment; maintaining water quality while striving to improve it; local agencies playing a main role while being under the supervision of the central agencies; monitoring data taken as the governing basis, and further promoting governance with payment policy."

7.1.2. Research objectives

The payment for ecosystem services mechanisms for the ecological red line area is still an emerging environmental ecological policy in the Yangtze River Delta metropolitan region, which is mostly in the research and exploration stage. When it comes to practically establishing a two-way river basin payment for ecosystem services mechanism based on upstream and downstream liability judgment, the local goverments still face many challenges in technological, legal and standard terms.

First is the upstream and downstream liability judgment.

In this two-way river basin payment for ecosystem services mechanism, the key is to judge upstream and downstream liabilities. Currently, the most often adopted and also the most reasonable liability judgment mechanism is the water-quality target assessment system based on trans-boundary cross sections. However, since the Yangtze River Delta river system is located in a tidal river network in which some trans-boundary rivers can be driven by the tide to flow back and forth, it is somewhat difficult to judge the liability subject when it comes to pollution.

Second is the payment for ecosystem services standard.

The payment for ecosystem services standard is closely connected to the amount of the final compensation. Different compensation standards often result in different compensation results and effects. However, at present, there are no scientific and uniform methods for stipulating payment for ecosystem services standards. It is generally held that the valuation of the river basin ecological service function is the major basis for stipulating river basin payment for ecosystem services standards. However, during practical operations, the accounting methods for ecosystem service assessment are not yet complete, and the basic points of data for accounting are hard to acquire, so this assessment method is not widely applied. Currently, the compensation standards are more often decided through upstream and downstream discussions and negotiations, which, however, are inevitably driven by different parties at least in part out of self-interest. Such a method fails to objectively reflect the demands of a polluted river basin for payment for ecosystem services, and as a result cannot guarantee the objectivity of the compensation standards.

According to the above policy aims of the new ecological water function zone delineation, payment for ecosystem services, mechanisms for flooding regulation erosion regulation and water purification needed to be considered in decision making. Thus, the author focused on the three primary ecosystem services related to the environmental problems and relevant ecological compensation pilots, as examples of sub-frameworks for payment for ecosystem services cooperation in the ecological water function zone in this chapter: flood protection, soil erosion regulation and water purification. According to previous definitions (Burkhard et al, 2010; Burkhard et al, 2012): flooding protection refers to the capacity of natural elements dampening extreme flood events; erosion regulation refers to the role that vegetation coverage plays in soil retention and prevention of landslides; water purification refers to the capacity that ecosystems have to purify water.

The research objective of this chapter is promoting inter-city environmental cooperation in the ecological water function zone under the ecological red line policy by ecosystem services supply-demand budget for the Yangtze River Delta metropolitan region. The research questions addressed in this chapter are:

What are the spatial distribution of ecosystem services supply-demand scores and budget of sixteen major cities in the Yangtze River Delta metropolitan region?

Can the scientific framework for combing ecosystem services supply-demand budget and spatial relations be applied in promoting the inter-city environmental cooperation in the Yangtze River Delta metropolitan region?

7.2. Results

7.2.1. Spatial pattern of the supply, demand and budget of the four ecosystem services in the Yangtze River Delta metropolitan region based on the matrix

1) Supply

The spatial patterns of the supply capacities of the three ecosystem services were similar in the Yangtze River Delta metropolitan region.

The areas with high capacity (score 3-5) were mainly distributed in the southwest of the region and accounted for over 1/3 of the total area, and the areas with low capacity (score 0-2) of the three services were mainly located in the northeast of the region (Fig.7.1.).

In particular, the areas with a score of 2 for the flood protection service and of the water purification service were distributed in the eastern estuary areas (Fig.7.1.). The areas with scores of 5 and 4 for the flood protection service were dispersed over the whole region with a very small proportion of the total area.

2) Demand

The spatial patterns of the demand for the three ecosystem services were different from those of the supply. The areas with high demand (score 4-5) for erosion regulation were scattered in the coastal plain of the region, while the areas with high demand for flood protection were densely distributed in the urban areas and in the cultivated land area, and areas, which areas with high demand for water purification were concentrated in the urban areas in the northeast of the region (Fig.7.1).

3) Budget

Based on the results of the supply-demand budgets, the areas with high positive scores for the three ecosystem services were densely distributed in the southwest of the region, while the areas with high negative scores were mainly scattered or densely distributed in the northeast of the region (Fig.7.1.). These patterns suggest that there were serious spatial mismatches in supply and demand for the three ecosystem services within the region, especially for water purification service.

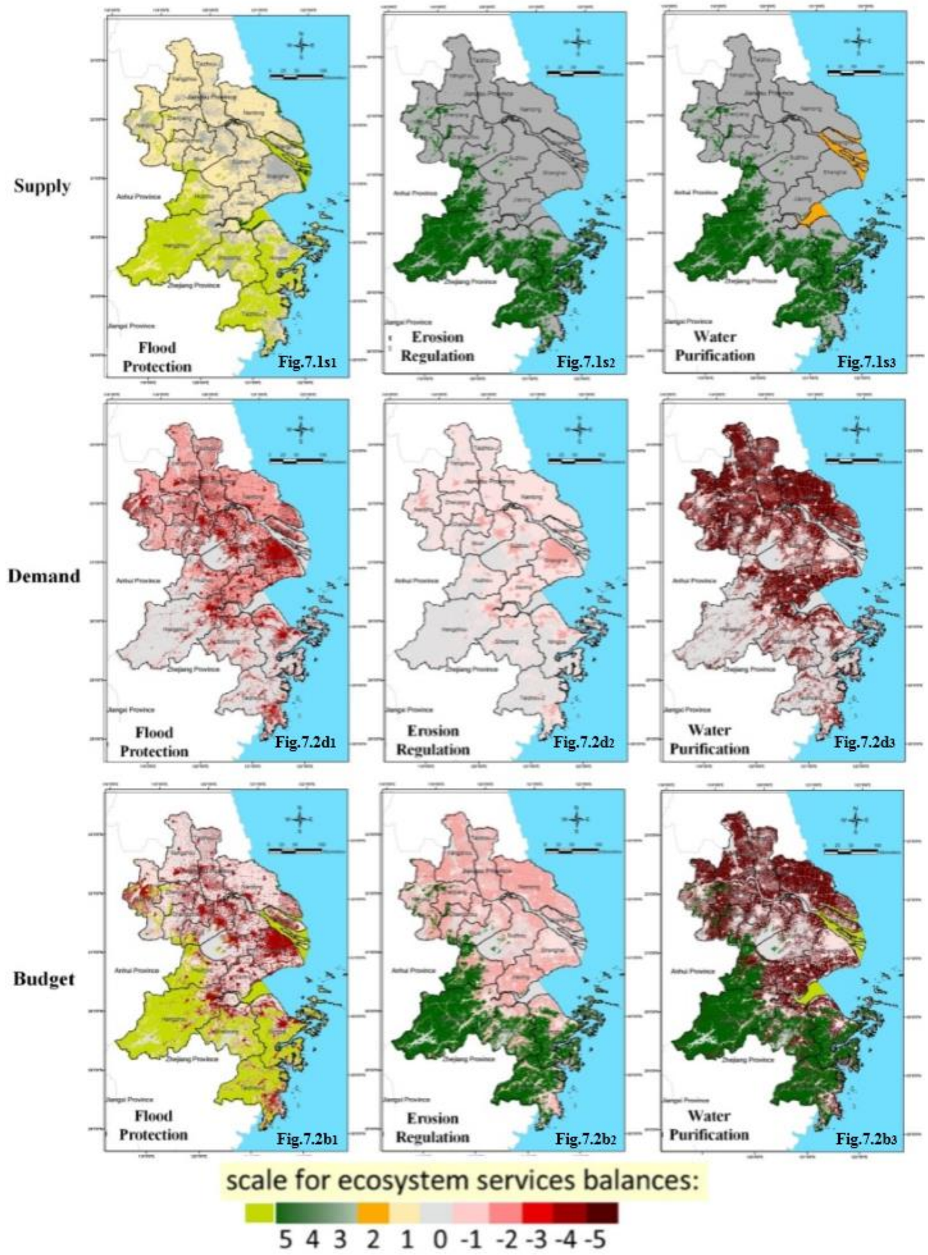


Figure 7.1 Spatial patterns of three ecosystem services supply, demand and budget of the Yangtze River Delta metropolitan region

Note: Supply/Demand/Budget of flood protection service/erosion regulation service/water purification service; Demand; Budget

7.2.2. The supply, demand and budget of the three ecosystem services in the sixteen cities based on the amount

In general, there were wide differences in the amount of supply, demand and budget of the three ecosystem services among the sixteen cities (Table 7.2, Fig.7.6):

1) Supply

The difference between the highest and the lowest amount of supply was extremely large among the sixteen cities, except for the flooding protection service. Among the sixteen cities, except for Jiaxing, the other six cities in Zhejiang Province had higher amounts of the three ecosystem services than the nine cities in Jiangsu Province and Shanghai Municipality.

Hangzhou, Taizhou (Zhejiang Province), Shaoxing and Ningbo were the cities with the greatest supply and Hangzhou had the highest amount. The city with the lowest amount was different for different services i.e. for flooding protection service in Zhoushan, and for both erosion regulation service and water purification service in Shanghai (Table 7.2. Fig.7.6).

2) Demand

The difference between the highest and the lowest level of demand in the amount of supply in the sixteen cities was relatively small.

Shanghai was the city with the greatest demand for erosion regulation service and water purification service, while Nantong was the city with the highest demand for flooding protection service.

Zhoushan was the city with the lowest demand for erosion regulation service, and flooding protection service, and Huzhou was the city with the lowest demand for water purification service.

3) Budget

Based on the results for the supply-demand budget, there were significant mismatches in supply and demand of the three ecosystem services in the sixteen cities of the Yangtze River Delta metropolitan region.

Hangzhou had the highest surplus and Shanghai had the highest deficit in the three ecosystem services. Among the three ecosystem services, erosion regulation service was in surplus across the Yangtze River Delta metropolitan region, while the budgets of flood protection service and water purification service were the deficit.

Except for Huzhou and Zhoushan, the other five cities in Zhejiang Province had a surplus in the three ecosystem services, while Shanghai, the nine cities in Jiangsu Province and Jiaxing in Zhejiang Province had a deficit in the three ecosystem services.

7.2.3. Comparison of relative amount of ecosystem services capacities of different-level cities

The following amount of supply-demand budget in Fig.7.2, Fig. 7.3 and Fig. 7.4 of each of the city was calculated by the formula (1)-(4) in Chapter 3 (3.3.5, 5):

The amount of ecosystem services supply, demand and budget ('Score*Area') is used to estimate the total amount of ecosystem services for a region and each city. The unit of the amount of ecosystem services is 'score×km^2'.

$$S = \sum (Si \times Ai) \qquad (1)$$

where S (Supply) is the number of capacities of different land cover classes to provide ecosystem services, Si (score) is the score of capacities of different land cover classes to provide ecosystem services, Ai (km^2) is the area of each kind of land cover corresponding to the capacities of different land cover classes to provide ecosystem services.

$$D = \sum (Di \times Ai) \qquad (2)$$

where D (Demand) is the amount of the relevant demands for ecosystem services of humans living in the different land cover classes, Di (score) is the score of relevant demands for ecosystem services of humans living within the different land cover classes, and Ai (Area; km^2) is the area of each kind of land cover corresponding to the relevant demands for ecosystem services of humans living.

$$Bi = Si - Di \quad (3)$$

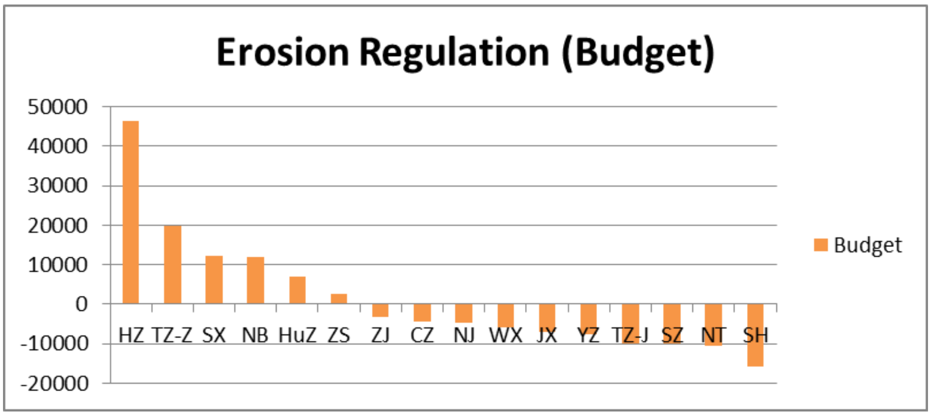
$$B = \sum (Bi \times Ai) \quad (4)$$

where B (Budget) is the amount of the budget of demand and supply of the targeted ecosystem service, Bi (score) is the score of the Supply (Si) minus the score of the Demand (Di) of the targeted ecosystem service, and Ai (km^2) is the area of each kind of land cover corresponding to the targeted ecosystem service.

1) Erosion regulation service

Supply-demand budget:

Figure 7.2 Rank of sixteen prefecture-level cities in the amount of supply-demand budget of erosion regulation service



Note: (Zhejiang province) HZ-Hangzhou, TZ-Z-Taizhou-Zhejiang, SX-Shaoxing, NB-Ningbo, HuZ-Huzhou, ZS-Zhoushan; (Jiangsu province) ZJ-Zhenjiang, CZ-Changzhou, NJ-Nanjing, WX-Wuxi, JX-Jiaxing, YZ-Yangzhou, TZ-J-Taizhou-Jiangsu, SZ-Suzhou, NT-Nantong; (Shanghai Municipal):SH-Shanghai;

According to Fig.7.2 and Table 7.2:

The five cities with the greatest supply-demand budget of erosion regulation service were: Hangzhou>Taizhou -Z> Shaoxing>Ningbo>Huzhou.

The five cities with the smallest supply-demand budget of erosion regulation service were: Shanghai> Nantong> Suzhou>Taizhou-Jiangsu Province>Yangzhou.

These cities are suggested to give more financial aid to service-providing cities and restrict excessive cultivation and urban expansion according to their different rankings.

For erosion regulation service, Hangzhou contributed most, with nearly half of the total surplus of this service in the selected cites (46.51%).

Cities with higher contributions would need more payments from service recipient cities (beneficiaries) for forests and grasslands conservation according to their different rankings.

In percentage terms (Table 7.2), Nantong had the largest deficit, 19.91% of the total deficit in this service.

2) Flood protection service

Supply-demand budget

According to the following Fig.7.3 and Table 7.2:

The five cities with the greatest supply-demand budget of flood protection service were: Hangzhou>Taizhou-Zhejiang Province> Shaoxing>Ningbo>Huzhou.

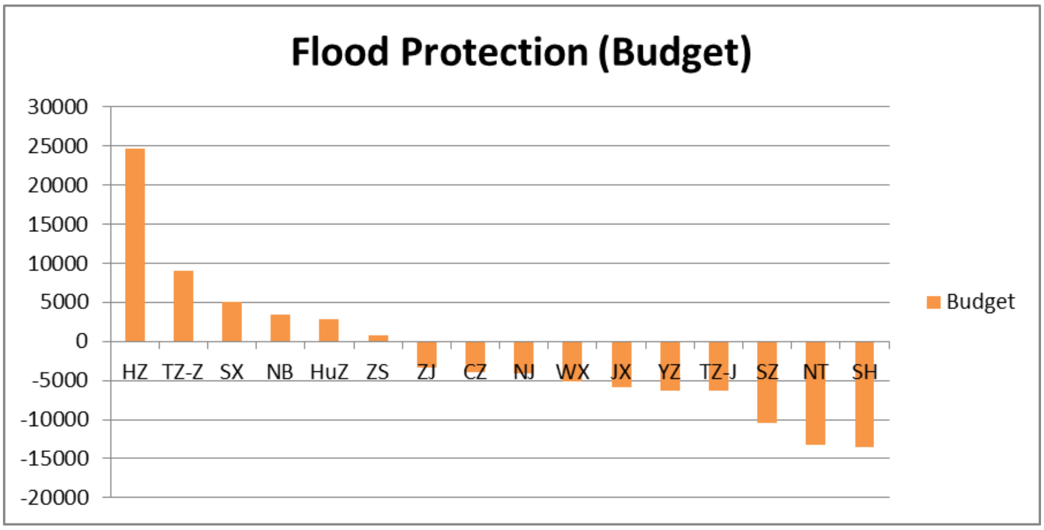
For flood protection, Hangzhou contributed most, according to over half of the total surplus of this service in the selected cites (53.84%).

Cities with higher contributions would need more payments from service recipient cities (beneficiaries) for conservation of inland marsh, barelands, forests and estuaries according to their different rankings.

The five cities with the smallest supply-demand budget of flood protection service were: Shanghai> Nantong> Suzhou>Taizhou-Jiangsu Province>Yangzhou.

Shanghai had the largest deficit, amounting to 18.69% of the total deficit of this service. These cities are suggested to give more financial aid to service providing cities and to restrict urban expansion according to their different rankings.

Figure 7.3 Rank of sixteen prefecture-level cities in the supply-demand budget of flood protection service



Note: (Zhejiang province) HZ-Hangzhou, TZ-Z-Taizhou-Zhejiang, SX-Shaoxing, NB-Ningbo, HuZ-Huzhou, ZS-Zhoushan; (Jiangsu province) ZJ-Zhenjiang, CZ-Changzhou, NJ-Nanjing, WX-Wuxi, JX-Jiaxing, YZ-Yangzhou, TZ-J-Taizhou-Jiangsu, SZ-Suzhou, NT-Nantong; (Shanghai Municipal):SH-Shanghai

3) Water purification services

Supply-demand budget

According to Fig 7.3 and Table 7.2:

For water purification service, Hangzhou contributed most, is with nearlt three quarters of the total surplus of this service in cites (71.57%).

The five cities with the greatest supply-demand budget of water purification service were: Hangzhou>Taizhou –Z> Shaoxing>Ningbo>Huzhou.

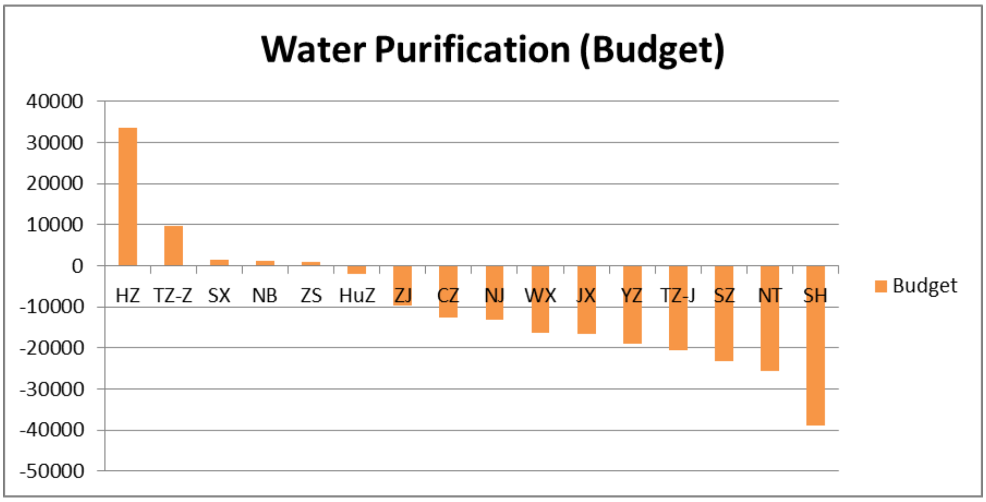
In percentage terms (Table 7.2), Nantong had the largest deficit, with 19.64% of the total deficit of this service.

Cities with higher contributions would need more payments from service recipient cities for conservation of forests, shrublands and grasslands conservation according to their different rankings.

The five cities with the smallest supply-demand budget of water purification service were: Shanghai> Nantong> Suzhou>Taizhou-Jiangsu Province>Yangzhou.

These cities are suggested to give more financial aid to service providing cities and restrict excessive cultivation and urban expansion according to their different rankings.

Figure 7.4 Rank of sixteen prefecture-level cities in the supply-demand budget of water purification service



Note: (Zhejiang province) HZ-Hangzhou, TZ-Z-Taizhou-Zhejiang, SX-Shaoxing, NB-Ningbo, HuZ-Huzhou, ZS-Zhoushan; (Jiangsu province) ZJ-Zhenjiang, CZ-Changzhou, NJ-Nanjing, WX-Wuxi, JX-Jiaxing, YZ-Yangzhou, TZ-J-Taizhou-Jiangsu, SZ-Suzhou, NT-Nantong; (Shanghai Municipal):SH-Shanghai;

7.2.4. Comparison of relative amount of ecosystem services capacities in cities of three provinces

There is large difference in ecosystem services budget of cities in different provinces' in the Yangtze River Delta metropolitan region:

The Shanghai Municipality and cities in Jiangsu Province were poor in the ecosystem services budget in all of the three ecosystem services. This implies that Shanghai Municipality and cities in Jiangsu Province did not have enough ecosystem services budget to prevent ecological risk in flooding, soil and water loss and water pollution problem. This certainly made huge negative implies on the present sustainability of the Shanghai Municipality and Jiangsu Province from the ecosystem services assessment view.

Cities in Zhejiang Province were rich in the three ecosystem services budget, except the deficits in Zhenjiang. This implies that most of the cities in Zhejiang Province had a good state in ecosystem services budget of flood protection service, erosion regulation service and water purification service, except that Zhenjiang in Zhejiang Province had risk in flooding, soil and water loss and water pollution problem.

7.2.5. Delineation of catchments for the Yangtze River Delta metropolitan region

The catchments for the Yangtze River Delta metropolitan region were divided by the author into:

(1) Catchments to the North of the Yangtze River: these were catchment A1 comprising most areas in the north of Nanjing and in the south of Yangzhou, catchment B comprising most areas of Nantong, and catchment D comprising a small part of areas in the south of Taizhou-Jiangsu Province;

(2) Catchments to the South of the Yangtze River: catchment A2 comprising most areas in the south of Nanjing and Zhenjiang, catchment C (Taihu Lake Basin comprising Changzhou, Wuxi, Suzhou in Jiangsu Province, Huzhou and Jiaxing

in Zhejiang Province, and Shanghai Municipality except Chongming Island);

(3) Catchments of the river watersheds in the south of Zhejiang Province: catchment E1 (Xin'anjiang Watershed which is a sub-watershed of the Qiantang River Watershed upstream of Xin'anjiang Reservoir outside the Yangtze River Delta metropolitan region), catchment E2 (a sub-watershed of the main stream of the Qiantang River Watershed), catchment E0 (Cao'e river watershed which is a sub-watershed of the Qiantang River Watershed), catchment F (Yong River Watershed which comprises the north of Ningbo), catchment G which comprised some small streams which flow into the sea and the south of Ningbo, and catchment G (Ling River Watershed which comprised most of the areas of Taizhou-Zhejiang Province). Zhoushan was an independent catchment since it was a prefecture-level city on the island.

According to the Digital Elevation Model, the terrain of the region is high in the west and low in the east, and high in the south and low in the north (Fig.7.5):

The plain areas are mainly distributed in the eastern areas of the catchments in the north of the Yangtze River and the Taihu Lake Basin (D), and in the northern areas of the catchments of the river watersheds in the south the Zhejiang Province. The elevation of the plain areas was below 10 metres.

The hilly areas are mainly distributed in the western areas of the catchments to the north of the Yangtze River and the Taihu Lake Basin (D). The elevation of the hilly areas was between 10-30 metres.

The mountainous areas are mainly distributed in the eastern areas of the catchments in the north of the Yangtze River and the Taihu Lake Basin (D), and in the catchments of the river watersheds in the south the Zhejiang Province. The elevation of the mountainous areas in the eastern areas of the catchments in the north of the Yangtze River and the Taihu Lake Basin (D) was mainly between 30-300 metres, while the elevation of the mountainous areas in the catchments of the river watersheds in the south of Zhejiang Province were mainly between 300-2000 metres.

7.2.6. Defining service provisioning cities and service benefiting cities

Cities with higher contributions would need more economic payments from service recipient cities (service benefiting cities) for forest conservation according to their different rankings.

According to the supply-demand budget, the sixteen cities in the Yangtze River Delta metropolitan region were divided into four types: service balancing cities, service providing cities, service benefiting cities and service connecting cities.

Zhoushan is a ‘service balancing city’ in flood regulation service, erosion regulation service, and water purification service. Zhoushan almost reached balance in supply-demand budget in the services of flood regulation, erosion regulation and water purification. However, as an island city, geographically separated from others cities in this region, it is difficult for Zhoushan to provide water services to other cities.

The service providing cities of flood regulation service and erosion regulation service (Fig.7.6) in this region are six cities in Zhejiang Province: Hangzhou, Taizhou, Shaoxing, Ningbo, Huzhou and Zhoushan. All the other ten cities are service benefiting cities for these three services.

The service providing cities for water purification service are four cities: Hangzhou, Taizhou, Shaoxing and Ningbo. All the other eleven cities are the service benefiting cities of these three services.

The service providing cities of flood regulation service, erosion regulation service and water purification service, Hangzhou, Taizhou, Shaoxing, Ningbo and Huzhou are mainly distributed in Zhejiang Province in the south of the region, while the service benefiting cities for these services are concentrated in the northern part, in Jiangsu Province and Shanghai Municipality.

7.2.7. Regional payment for ecosystem services cooperation and ecosystem restoration models

The following cooperation models are recommended by integrating the results of the supply-demand budget of the four ecosystem services in the sixteen cities with ecosystem services flow direction analysis (Table 7.2, Fig.7.5 and Fig.7.6).

(1) Cooperation between cities at watershed scale for flood protection service, erosion regulation service and water purification service

In the Yangtze River Delta metropolitan region, Changzhou, Wuxi and Suzhou in Jiangsu Province, Hangzhou, Huzhou and Jiaxing in Zhejiang Province, and Shanghai in the Taihu Lake Basin, are closely connected by a river network (Fig.7.5 and Fig. 7.6).

Hangzhou had a surplus in flood protection service, erosion regulation service and water purification service and Huzhou had a surplus in flood protection service and erosion regulation service but deficit in water purification service, while the others in the Taihu Lake Basin all had a deficit in flood protection service, erosion regulation service and water purification service.

According to river flow direction analysis, part of Hangzhou was upstream as a potential service providing area for flood protection service, erosion regulation service and water purification service, and Huzhou was upstream as a potential service providing area of flood protection service and erosion regulation service.

The other cities in the basin were downstream cities, as and the potential service benefiting areas of flood protection service, erosion regulation service and water purification service.

For this reason, payment for ecosystem services cooperation for flood protection service, erosion regulation service and water purification service at a watershed scale among these cities in the Taihu Lake Basin is recommended.

(2) Low possibility for cooperation with other cities at watershed scale for flood protection service, erosion regulation service and water purification service

Zhoushan, Taizhou, Shaoxing and Ningbo are in an independent catchment respectively. In these four cities, the amount of supply of flood protection service, erosion regulation service and water purification service exceeds demand.

However, each city currently had low possibility to cooperate with other cities in flood protection service, erosion regulation service and water purification service due to indirect biophysical processes in the watershed. So, the author suggests enhancing the demand for three ecosystem services for the improvement of the urban living environment of these cities.

Nantong is also mainly located in an independent catchment, but the amount of demand exceeded the amount of supply in each city. The match between supply and demand of the three ecosystem services would be realized only by enhancing the inner-city ecosystem restoration i.e. afforestation.

The north of Nanjing and Yangzhou are in catchment (A1), while South of Nanjing and Zhenjiang are in the Catchment (A2). They are all deficit cities in flood protection service, erosion regulation service and water purification service. The ecological restoration model for flood protection service, erosion regulation service and water purification service between cities in the catchment is recommended.

Table 7.1 The supply, demand and budget score matrix of the three ecosystem services for land cover types in the Yangtze River Delta metropolitan region

Land cover	FP			ER			WP		
	S	D	B	S	D	B	S	D	B
Urban Land	0	4	-4	0	1	-1	0	1	-1
Rural Residential Land	0	5	-5	0	1	-1	0	2	-2
Arable land	1	2	-1	0	2	-2	0	5	-5
Forest	3	0	3	5	0	5	5	0	5
Shrublands	0	0	0	4	0	-4	4	0	4
Grasslands	1	0	1	5	0	5	4	0	4
Bareland	4	0	4	0	0	0	0	0	0
Inland marshes	5	0	5	0	0	0	0	0	0
Salt marshes	1	0	1	0	0	0	0	0	0
Streams and Lakes	1	0	1	0	0	0	1	0	1
Estuaries	3	0	3	0	0	0	2	0	2
Shallow Sea Wetlands	0	0	0	0	0	0	0	0	0

Notation: FP-Flood Protection, ER-Erosion Regulation, WP-Water Purification; S-Supply, D-Demand, B-Budget.

Scale from 0 / 1 / 2 / 3 / 4 / 5 / = no / low/ relatively low/ medium/ high/ very high/ relevant capacity or demand (Burkhard et al., 2009, 2012, 2014)

Table 7.2 The amount of supply, demand and budget of three ecosystem services (Budget) of sixteen cities in the Yangtze River Delta metropolitan region

Province	City	FP			ER			WP		
		S	D	B	S	D	B	S	D	B
Zhejiang	**Hangzhou**	37192.95	12580.05	24612.90	55799.76	9391.44	46408.32	55957.51	22521.72	33435.79
	Taizhou-Z	18362.32	9325.78	9036.54	26752.79	6980.61	19772.18	26446.62	16834.84	9611.78
	Shaoxing	14605.68	9538.62	5067.06	20025.34	7837.11	12188.23	19921.69	18463.31	1458.38
	Ningbo	14858.42	11445.92	3412.50	19632.80	7557.60	12075.20	19586.43	18407.13	1179.30
	Zhoushan	2077.04	1321.10	755.94	3371.65	904.39	2467.26	12845.27	14903.94	1030.80
	Huzhou	10325.05	7494.54	2830.51	12942.15	6077.47	6864.68	3216.32	2185.52	-2058.67
	Jiaxing	3480.89	9370.37	-5889.48	127.35	7023.49	-6896.14	305.90	16916.21	-16610.31
Jiangsu	**Zhenjiang**	3803.69	7120.00	-3316.31	2046.60	5407.04	-3360.44	3028.50	12615.93	-9587.43
	Changzhou	4400.34	8398.65	-3998.31	1306.05	5780.17	-4474.12	1588.60	14191.99	-12603.39
	Nanjing	4367.53	8502.00	-4134.47	1523.20	6359.68	-4836.48	2121.72	15301.62	-13179.90
	Wuxi	7518.65	12715.24	-5196.59	3857.05	9797.13	-5940.08	3871.93	20291.54	-16419.61
	Yangzhou	6364.86	12617.43	-6252.57	1062.08	8663.64	-7601.56	4592.32	23686.96	-19094.64
	Taizhou-J	7011.37	13383.05	-6371.68	2750.85	12762.03	-10011.18	1532.09	21984.08	-20451.99
	Suzhou	8116.22	18625.45	-10509.23	151.95	10186.31	-10034.36	3984.11	27163.26	-23179.15
	Nantong	8983.04	22245.66	-13262.62	295.10	10879.19	-10584.09	1286.16	26810.37	-25524.21
Shanghai	**Shanghai**	5488.08	19036.37	-13548.29	10.44	15915.92	-15905.48	325.21	39122.35	-38797.14
Total				-18951.35			20131.94			-150790.39

Note: FP-Flood Protection Service, ER-Erosion Regulation Service, and WP-Water Purification Service; S-Supply, D-Demand, B-Budget

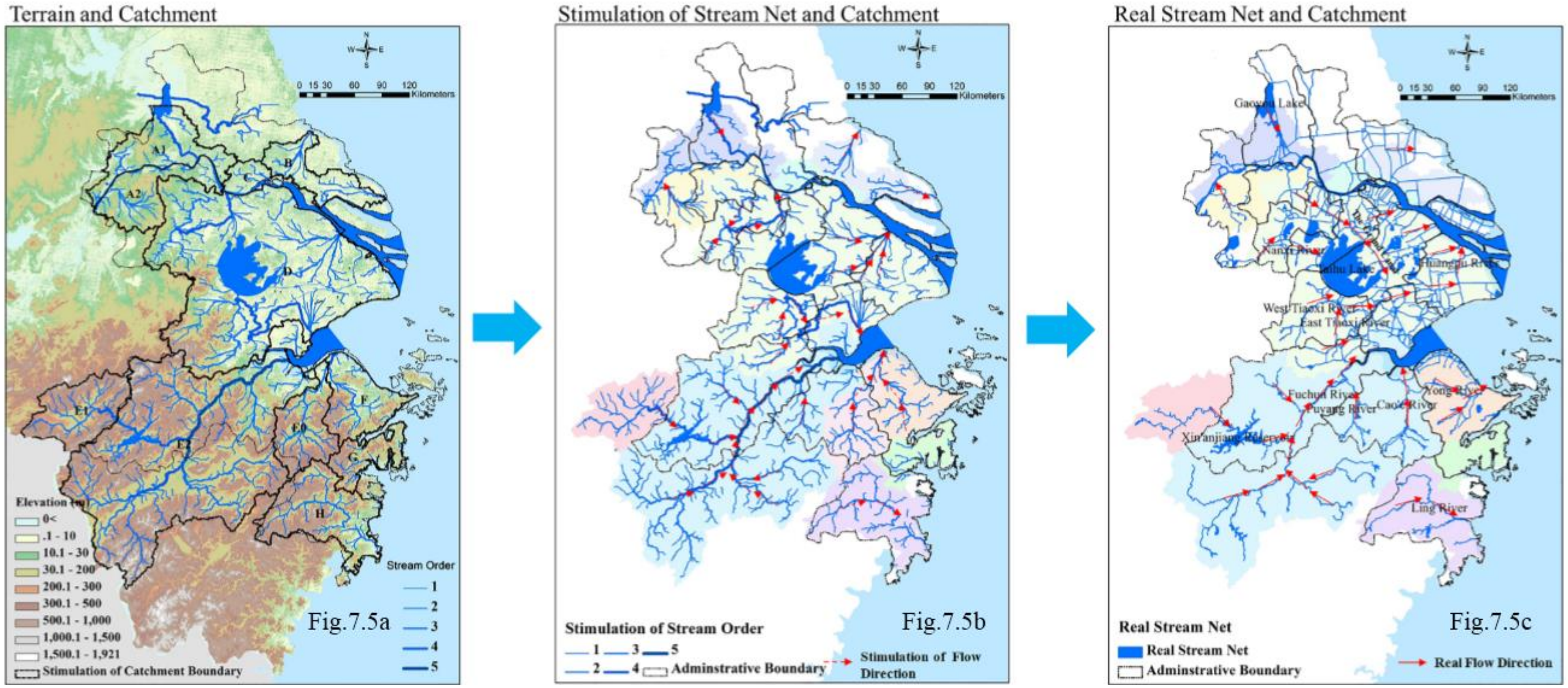


Figure 7.5 Terrain, catchment, stream net and flow directions in the Yangtze River Delta metropolitan region

Note: The 'A1-H' were Natural Catchment Numbers in Terrain and Catchment Map (Left); The '1-5' were numbers of stimulation stream order numbers in Stimulation of Stream Net and Catchment Map (Middle); The dashed arrows in the Stimulation of Stream Net and Catchment Map (Middle) indicated the flow directions only due to the terrain; The solid arrows in the Real Stream Net and Catchment Map (Right) indicated the actual flow directions influence by human actives).

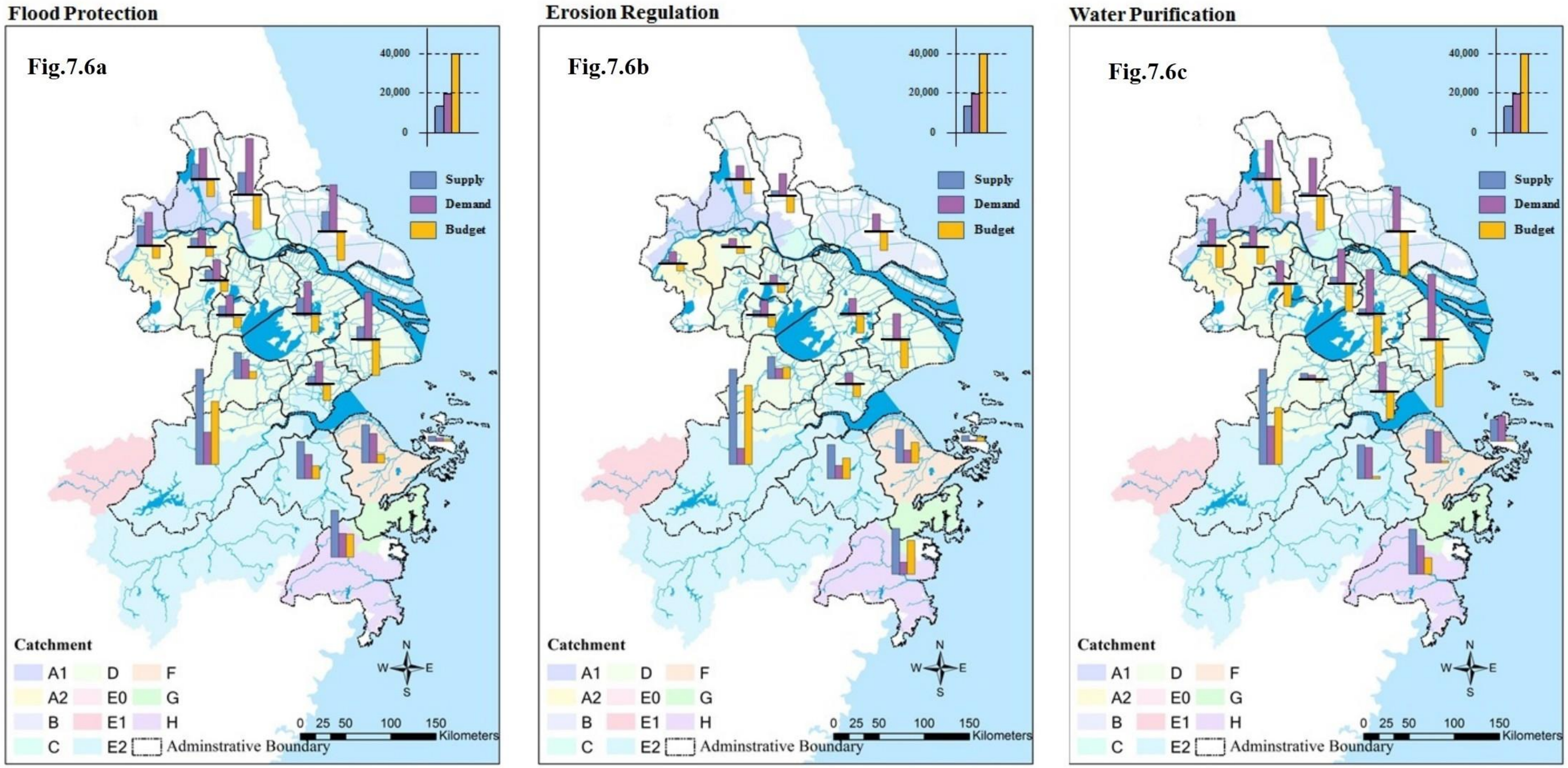


Figure 7.6 Spatial distribution of supply-demand budgets of three ecosystem services of sixteen cities in the Yangtze River Delta region

Note: The ‘A1-H’ were Natural Catchment Numbers in Terrain and Catchment Map; Blue Column: Amount of Supply; Purple Column: Amount of Demand; Yellow Column: Amount of Budget

7.3. Discussion

7.3.1. The mismatch of ecosystem services supply and demand in the Yangtze River Delta metropolitan region

As described in previous chapters, the results of both the supply-demand budget matrix and the budget of the amount of supply and demand of the sixteen cities showed that there was significant spatial mismatch in the flood protection service, erosion regulation service and water purification service in the Yangtze River Delta metropolitan region. The southwest part of the region, including Hangzhou, Ningbo, Shaoxing, Taizhou and Zhoushan in the Zhejiang, had considerable surplus supply in the four ecosystem services, while the middle and northeast part, including Jiaxing in the Zhejiang Province, and nine cities in Jiangsu and Shanghai had seriously supply deficits.

The cause of this spatial mismatch in supply and demand of ecosystem services was due to variability in plant functional traits and other environmental conditions, as well as variation in human influence on ecosystems. Spatial variation in socioeconomic conditions also makes the demand for ecosystem services dependent upon location as well (Wei et al., 2017).

In the Yangtze River Delta metropolitan region, over 80% of forests were mainly distributed in the hilly and mountainous areas in the seven cities of the Zhejiang Province. In Hangzhou, in particular, hilly and mountainous areas accounted for 65.5%, while plain areas accounted only for 26.4%, and waterbodies accounted for 8%. Forests including broad-leaved forest, coniferous forest and mixed forest have a high capacity for ecosystem services (Li, 2008).

Yet, in the Yangtze River Delta metropolitan region, since the reform and opening up in China, and with rapid urbanization, urban land and rural residential land has developed in the plain areas of the coast including Jiangsu, Shanghai and part of Zhejiang. These two landscape types had high demand for flood protection, water purification and erosion regulation services (Burkhard et al., 2012).

7.3.2. Promoting payment of ecosystem services standard

As far as the actual application is concerned, payment for ecosystem services cooperation is closely linked with ecosystem functions and ecosystem services (Bouma & van Beukering, 2015; Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012; Zhou et al, 2016a). The application of ecosystem service theory in payment for ecosystem services cooperation is mainly as follows: the fundamental starting point for determining the payment criteria is the ecosystem services provided by the recipient (Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012).

The core issue of payment for ecosystem services cooperation is the payment criteria (Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012). Only by having reasonable payment criteria in place can the long-term continuation of projects based on payment for ecosystem services be ensured (Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012).

Currently, there are many methods for determining the payment criteria for different objects, and the fundamental starting point is the ecosystem services provided by the recipient (Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012). In theory, the value of ecosystem services is still a reasonable criterion as it not only compensates for different regions in a fair and objective manner, but also drives the whole project to pay more attention to the ecosystem services itself and also improves management efficiency (Bremer et al, 2014a; Bremer et al, 2014b; Huang et al, 2010; Zhang et al, 2012).

Therefore, in the design of payment for ecosystem services, it is necessary to further improve the method of value-accounting for services based on a good understanding of the connotation of ecosystem services and the clear definition of the supply of different services, so that the payment criteria will better reflect the ecosystem services and improve the benefits of protection.

The scores of Burkhard's ecosystem services supply-demand matrixes represented the dimensionless grades of non-monetary ecosystem service value, but it cannot be directly used for ecosystem service quantity comparison until it can be transferred into comparable amounts. The advantage of the city ecosystem services budget based on Burkhard developed in this thesis is to provide an alternative proxy of semi-quantitative amounts to be a payment criteria for intercity cooperation payment for ecosystem services cooperation.

7.3.3. Spatial relations of selected ecosystem services and flow direction at watershed scale

Previous studies of the spatial relationships between service providing areas and service benefiting areas provide a good reference point to describe the spatial relations of service providing cities and service benefiting cities. From the view of landscape planning, service providing areas and service benefiting areas may overlap to some degree, but gaps are also possible (Fisher et al, 2009).

Fisher et al. (2009) described patterns of transmission of a service from provision to benefit areas, reflecting the understanding that ecosystems and their beneficiaries are often not co-located. Costanza (2008) introduced three classes of relations: 'in situ', 'local proximal' and 'directional flow related'. Fisher et al, (2009) and Syrbe and Walz (2012) made further explanations of the contributions spatial relationships.

From the results of ecosystem services budget analysis, the potential ecosystem services should be delivered or flow from the service providing cities to the service benefiting cities for environmental cooperation. But the real ecosystem services flowed through real wind and river networks which connected the service providing cities and the service benefiting cities, and flowed from upstream and downstream of the wind and rivers according to the natural rules.

For example, since the water purification service, flood regulation service could only be delivered through river network. The flow directions of the local rivers indicated the real ecosystem services delivering flow directions. The flow directions of the local rivers were influenced by both the terrain and human disturbance. The local directions influenced by the terrain can be stimulated by river orders, since lower order rivers flowed into the higher order rivers. The real ecosystem services flow directions could be changed by human activities, such as change of river network and creation of artificial river networks. Therefore, the cooperation of the service providing cities with the service benefiting cities should consider both of the potential ecosystem services flow directions and the real ecosystem services flow directions according to natural rules. The inter-city cooperation should consider the catchment and watershed boundaries.

From the results of ecosystem services budget analysis, the potential ecosystem services should be delivered or flow from the service providing cities to the service benefiting citeis for environmental cooperation.

In situ:

The flow directions of the water services in Zhoushan are considered as ‘In situ’. As an island city which is separated from the mainland, the flood regulation service, erosion regulation service and water purification service are provided and the benefits contained within Zhoushan Island.

Directional:

For flow direction at the watershed scale, according to the stream order shown in Figure7.5, firstly there were two main natural flow directions of the rivers in the catchments in the north of the Yangtze River. One was from the north (Gaoyou Lake) to south into the Yangtze River. The other was from the west to the east into the sea. Secondly, the flow directions in the plain areas in the Taihu Lake Basin were: three main streams of a high order flowing from the hilly and mountainous areas in the southwest (1) to the northeast plain area directly into the Yangtze River; (2) to the east plain area directly into the Yangtze River; (3) to the south plain area into the Qiantang River. However, the natural flow directions were obstructed by the Great Canal and the Taihu Lake, and led by the Huangpu River. (1) The artificial river (the Great Canal) changed the river flow directions and made the flow from the north to the south into Taihu Lake. (2) The natural rivers flowing from the west to the east into Taihu Lake mainly comprised the East and West Tiao River and the South River. (3) The Huangpu River gathered the flows of the waterbodies in the Taihu Lake Basin into the estuary of the Yangtze River. Thirdly the Yong River flowed from west to east into the sea, and the real direction of the Cao'e River was mainly from south to northwest into the Hangzhou Bay. Fourthly, the real stream flow directions in the Qiantang River Watershed (the West Region) flowed from the south to the north into the Hangzhou Bay, while the main streams of the Yong River Watershed and the Ling River Watershed (the East Region) flowed from west to east into the sea.

For flood protection and water purification services, since the flow directions are influenced by the variety of terrain in the watersheds, the spatial relations between upstream and downstream in the watershed should be the scientific basis for water services management cooperation. In the case study, for prefecture-level cities in the Taihu Lake Basin (B2), it is recommended that Shanghai, and prefecture-cities in Jiangsu and Zhejiang Province need to carry out trans-provincial coordination mechanisms for water source conservation (Figure 7.6). Meantime, in order to protect the water service providing cities in Taihu Lake Basin (B2), it is necessary for Huzhou, which is located in the upstream drainage areas of this basin, to establish funds for protection of mountainous water resources and soil and water conservation to share protection responsibilities with downstream water service benefiting cities. As a water service sink, it is suggested that Shanghai cooperates with prefecture-level cities in Jiangsu Province: Suzhou, Wuxi, Changzhou, Zhenjiang South, and Jiaxing in piloting a 'double eco-compensation mechanism' pilot, for industrial pollution and agricultural non-point source pollution in the Taihu Lake Basin.

7.3.4. Inter-city cooperation model in the Yangtze River Delta metropolitan region

To cope with mismatches of ecosystem services supply and demand on a regional scale, cooperation among different administrative units (i.e. in this case cities) within the region is needed. Due to the complexity and diversity of regional influence factors, multiple models of regional cooperation are needed.

For some models, all cities' participation is required, but for others, just some cities' involvement is needed. Also, the rights and obligations of each city in each model may be different. For this reason, this research presented a procedure or framework with seven steps that was put into practice in the study of the ecosystem services conservation cooperation in the Yangtze River Delta metropolitan region.

Firstly, surplus and deficit cities were identified by calculating the supply-demand budget of each city for a specified ecosystem services. Secondly, the potential service providing city (surplus city) and the potential service benefiting city (deficit city) were defined by the ecosystem services flow direction analysis.

Then, through combining the ecosystem services supply-demand budget with flow direction analysis, a two-scale regional ecosystem conservation and payment for ecosystem services cooperation models was developed, i.e. cooperation models between cities at watershed scale for flood protection service, erosion regulation service and water purification service., and also cities that had low possibility of cooperation with other cities were identified.

These models will promote inter-city ecosystem conservation and payment for ecosystem services cooperation for water purification by the identification of potential service providing cities, potential service connecting cities and potential service benefiting cities:

Following the ecosystem service budget and flow direction analysis, several cooperation types at different administrative levels could be considered:

(1) Province-level city cooperation in the region;

(2) Prefecture-level-city cooperation in the region;

(3) Cooperation between the central municipality and prefecture-level city;

(4) Cooperation between provinces in the region and outside the region.

For the water purification service, erosion regulation service and flood regulation service, since the flow directions are influenced by the variety of terrain in the watersheds, the spatial relations between upstream and downstream in the watershed should be the scientific basis for watershed management cooperation. Different levels of cooperation are recommended based on the results:

(1) Province-level city cooperation in the region: delivering the surplus of the selected services from Zhejiang Province to Jiangsu Province and Shanghai Municipality

For the water purification service, Hangzhou in Zhejiang Province is both the service providing city in the Qiantang River Watershed and the service connecting city of the Taihu Lake Basin and Qiantang River Watershed. It is recommended that Hangzhou takes more responsibility in water sources conservation and water purification service.

For promoting eco-compensation mechanism in the Taihu Lake Basin, it is recommended that inter-city cooperation in Taihu Lake Basin (D) be established for water purification, flood protection and erosion regulation between the service providing cities (Huzhou in Jiangsu Province, Hangzhou in Zhejiang Province) and service benefiting cities (Shanghai Municipality, and Suzhou, Jiaxing, Changzhou, Zhenjiang, Wuxi in Jiangsu Province).

(2) Prefecture-level city cooperation in the region: delivering surplus of selected services from Huzhou to prefecture-level cities in Jiangsu Province in the Taihu Lake Basin

For the prefecture-level pilot mechanism for water purification in Jiangsu Province, whether and how the cities need to cooperate depended on their locations in the watershed:

a) Changzhou, Wuxi and Suzhou in Jiangsu Province, Jiaxing, Hangzhou and Huzhou in Zhejiang Province and Shanghai Municipality should cooperate on the water purification service in the Taihu Lake Basin;

b) The potential service benefiting cities (the downstream deficit cities) were Changzhou, Wuxi and Suzhou in Jiangsu Province, Jiaxing in Zhejiang Province, and Shanghai, while Hangzhou and Huzhou were potential service providing cities (the upstream surplus cities) in the Taihu Lake Basin. The surplus of the water purification service could be transported from the upstream surplus cities to the downstream deficit cities.

In order to protect the water service providing cities in the Taihu Lake Basin (D), it is necessary for Huzhou which is located in the upstream drainage areas of this basin to establish funds for mountainous water resources protection and soil and water conservation to share the protection responsibilities with downstream water service benefiting cities. At the same time, it is recommended that Shanghai Municipality, prefecture-cities in Jiangsu and Zhejiang Province in the Taihu Lake Basin need to undertake a trans-provincial coordination mechanism for water pollution control.

For promoting Jiangsu upstream and downstream double-compensation for water purification policy, service providing cities and service benefiting cities can be identified through flow direction in the river network and the relative amount of the contribution and their responsibilities can be allocated through the new approach.

(3) Cooperation between the central municipality and prefecture-level city: Delivering surplus of water purification service from Huzhou and Hangzhou to Shanghai Municipality through river network in the Taihu Lake Basin

As a potential service benefiting city of the three ecosystem services, it is suggested that Shanghai cooperates with the prefecture-level cities in Jiangsu Province:

Suzhou, Wuxi, Changzhou, Zhenjiang South, and Jiaxing to undertake a ‘double eco-compensation mechanism’ pilot, for industrial pollution and agricultural non-point source pollution control in the Taihu Lake Basin.

(3) Cooperation between provinces in the region and outside the region:

Delivering water purification service from Xin'anjiang Watershed in Anhui Province outside the region to Xin'anjiang Reservoir in Zhejiang Province

For promoting the Xin'anjiang Watershed payment mechanism for reservoir conservation, the relative contributions of Chun'an county in Hangzhou (service benefiting cities) in Zhejiang Province to Huangshan (service providing cities) in Anhui Province can be calculated, through building supply-demand budgets for water purification, flood protection and erosion regulation.

(4) Low possibility for cooperation:

Last but not least, the ecosystem services budget and flow analysis also indicated that there was low possibility for cooperation in water purification services between Nanjing, Nantong, and Yangzhou in Jiangsu Province, without artificial infrastructures, because these cities were separated by independent catchments.

7.4. Summary

In earlier studies, attempts were made to calculate the quantitative assessment of ecosystem services mismatches (Baró et al, 2015) and the mapping of ecosystem services mismatches has been carried out on different scales (Kroll et al., 2012; Boithias, et al., 2014).

Previous work on spatial relations between service provisioning areas, service benefiting areas and service connecting areas has explained the flow directions of ecosystem services delivery (Costanza, 2008; Fisher et al, 2009; Syrbe & Walz, 2012). However, few studies have combined ecosystem services supply-demand budgets with an analysis of ecosystem services spatial relations in order to develop a useful approach for promoting regional environmental cooperation.

In rapidly urbanizing regions, ecosystem services supply and demand mismatches have been becoming more and more prominent. Regional cooperation urgently requires scientific information to assess and map ecosystem services supply-demand budgets and to develop a relevant delivery mechanism for decision making.

In order to address these problems, this thesis has presented a general framework or procedure with seven steps to study regional ecosystem services conservation cooperation.

Through the case study of the Yangtze River Delta metropolitan region, the thesis has analyzed the spatial mismatch of supply and demand of three ecosystem services related to current ecological compensation mechanism in the water function zone (flood protection service, erosion regulation service and water purification service) by combining expert-based assessment of supply and demand with defined regional ecosystem services conservation cooperation models.

The result showed that there were significant spatial mismatches in supply and demand of the four ecosystem services among the sixteen cities in the Yangtze River Delta region, and in particular southwest areas had a considerable surplus in the four ecosystem services, while the middle and northeast areas had serious deficits.

Through combining the ecosystem services supply-demand budget with flow direction analysis, the thesis defined the regional ecosystem conservation and payment for ecosystem services cooperation models i.e. potential cooperation models between cities at the watershed scale for water purification. These findings may not only improve existing cooperation mechanisms in the Yangtze River Delta metropolitan region, but this approach can also be applied to other metropolitan regions in China.

Chapter 8 Conclusions

Based on the theories and methods of ecosystem services, combined with expert knowledge, remote sensing and GIS technologies, this dissertation developed a comprehensive framework of ecosystem services assessment and decision support for rapid urbanization regions. Through this framework, the spatial characteristics, supply-demand relationship and flow direction of ecosystem services in the Yangtze River Delta Region are analysed and evaluated.

8.1. Problems in current research and practice

In the research methods, Burkhard's method lacks the expansion application in a rapidly urbanising region. In the research process, the research on the assessment and decision support of ecosystem services lacks frameworks for a rapid and effective framework suitable for rapid urbanising regions. On the research scale, in the past, the research and practice of ecosystem services assessment in China and the Yangtze River Delta region mostly focused on the provincial and municipal scale and lacked the research on the cross-administrative boundary and regional scale. In terms of research content, most of the existing research on decision support of ecosystem services starts from one aspect, but lacks the comprehensive research on functional regionalization, red line delineation and inter-city environmental cooperation. For instance, the ecological red line policy was still in a pilot stage in the Yangtze River Delta metropolitan region. By the national arrangements, the provinces and cities in the YRD metropolitan region are embarking on the delineation of ecological red lines and ecological functional zones. For example, Jiangsu Province has completed the delineation of provincial ecological red lines, while Nanjing has completed the work at the municipal scale. Due to different understandings and definitions of ecological red lines, the delineation results may vary even though the delineated zones are in the same province. Moreover, Zhejiang Province has completed functional ecological zoning. For two identical zones, there can be two division versions. Now that the results are not even unified within a province, there may be greater differences when more provinces are involved, and convergence can be more difficult. Therefore, it is imperative to have unified zoning at the regional scale.

8.2. Answering research questions for meeting research objectives

8.2.1. Objective 1: Develop a general framework guiding ecosystem services approach from problem to decision making

1) What is the framework for ecosystem services approach from problem to decision making?

Step 1: Identification of major environmental problems and definition of ecosystems conservation objectives;

Step 2: Classification of ecosystem types combining CORINE with local expert knowledge;

Step 3: Identifying and scoring multiple ecosystem services;

For spatial pattern and regionalization of ecosystem services in the Yangtze River Delta Region, the author designed the following steps:

Step 4: Defining and mapping hot spot and cold spot of multiple ecosystem services;

Step 5: Regionalization of multiple ecosystem services.

For further delineation of conservation priority area delineation of cropland and forest in the Yangtze River Delta Region:

Step 1: Importance classification of ecological function zone by net primary productivity

Step 2: Identification of large and spatial clustering habitats

Step 3: Conservation priority area decision support

For inter-city environmental cooperation decision support, the author designed the following steps to identify service provisioning cities and service benefiting cities identification in the Yangtze River Delta Region.

Step 1: Identifying relevant ecosystem services for specific environmental problems and cooperation;

Step 2: Establishing ecosystem services supply-demand budget matrix

Step 3: Calculating the amount of cities' ecosystem services supply-demand budget:

Step 4: Identifying spatial and quantitative mismatch of ecosystem services supply and demand on a regional scale

Step 5: Defining service balancing city, service providing city, service benefiting city, service connecting city

Step 6: Identifying ecosystem services spatial relations relevant to biophysical process at regional scale

Step 7: Defining regional payment for ecosystem services and ecosystem conservation cooperation model

8.2.2. Objective 1: Problems identification and driving forces for the decline of the ecosystem services in the Yangtze River Delta region

1) What are the pressures driving by urbanization and economic growth, the state of ecosystem and the stock of ecosystem services, and aims of environmental management responses for mitigating negative impact on ecosystem services in the Yangtze River Delta metropolitan region?

To identify the causes of the decline of total ecosystem services in the Yangtze River Delta Region, the author applied the driver-pressure-state-impact-response analysis in problems identification:

The pressures driven by urbanization and economic growth were change of land cover/use, major environmental problems, i.e. land resources problems, water resources problems, air resources problems, reduction in arable land in constant reduction in natural ecological space. The habitat fragmentation and reduced biodiversity showed the poor state of main ecosystems. There were large differences in the stock of ecosystem services of main land covers i.e. the forest and the arable land. To response the negative impacts on the regional ecosystems and the stock of the regional ecosystem services, the author summarizes the development and points the problems of ecological function zoning under ecological red line policy for the Yangtze River Delta metropolitan region.

8.2.3. Objective 2: Comprehensive regionalization of multiple ecosystem services in the Yangtze River Delta Region

1) What is the spatial pattern of multiple ecosystem services in the Yangtze River Delta region?

There was large spatial heterogeneity in the spatial pattern of ecosystem services *in the Yangtze River Delta Region.* The high values of supporting services and regulating services aggregately distributed in the southwest mountainous areas, while their low values were widely spread in the north plain area. One the contrast, the high values of provisioning services mainly in the northeast plain, while their low values were concentrated in the southwest of the region. The high values of cultural services were widespread in the waterbodies and southwest mountainous areas, while their low values scattered in the northeast urban areas.

Natural Causes are decisive factors for the following pattern:

High values were widespread in the southwestern mountainous areas, while low values of Biodiversity (B), Reduction of Nutrient loss (F), Storage capacity (SOM) (G) and Local climate regulation (H) were scattered in the northeastern urban areas, those of Air Quality Regulation (L) and Erosion Regulation (M), Water purification (O) and Pollination (P) were widespread in the northeastern plain, and those of Nutrient regulation (N) and Recreation & Aesthetic Values (V), were widespread in the northeastern plain, except the waterbody areas.

Groundwater Recharge (K) and Intrinsic Value of Biodiversity (W): High values were widespread in waterbody areas and the southwest mountainous areas, while low values were scattered in the northeastern plain.

For Abiotic heterogeneity (A), Nutrient regulation (N): High values were distributed in the waterbody areas of the region.

Capture Fisheries (S), Aquaculture (T) and Metabolic efficiency (D): High values were only in the estuary areas in the region.

Human activities are decisive factors for the following patterns:

Crops (Q) and Livestock (R): Contrary to the A-L's distribution, high values were widespread in the northeast plain, while low values were widespread in the southwest mountainous areas.

Global climate regulation (I) and Flood protection (J): High values were only distributed in the wetlands of the coastal areas, while low values were in the urban areas of the region.

Biotic waterflows (C) and Exergy Capture (Radiation) (E): High values were widespread in the whole region, while low values were distributed in the urban areas of the region.

Hot spots and cold spots of the twenty four single ecosystem services and the four integrated services were regionalized and managed in six function zones: Ecological Integrity Conservation Zone (I), Southwest Mountainous and Hilly Forest Ecological Zone (II), Northeast Plain Agriculture Ecological Zone (III), Aquatic ecosystem services Conservation Zone (IV), Eastern Coastal Estuaries Ecological Zone (V), and Urban Development Area (VI). The management strategies were targeted to the specific environmental problems identified in Chapter 4 in each of the ecological functional zone. These strategies were for indirectly integrative ecosystem services management by land cover management according to ecological functional zoning principles.

2) How to make quick assessment of the capacities of multiple ecosystem services in a rapidly urbanising region?

Step 1: Identification of major environmental problems and definition of ecosystems conservation objectives

Combining analysis of regional professional materials at different spatial and temporal scales, e.g. environmental assessment reports, land cover/ land use, with fieldwork and local experts' consultation, regional major environmental problems can be defined.

Step 2: Classification of ecosystem types combining CORINE with local expert knowledge

To address the difference of land cover in different regions, local land cover or ecosystem classification may be used to adjust the names and types of land cover or ecosystems of CORINE classification.

Step 3: Identifying and scoring critical ecosystem services

Firstly, identification of critical ecosystem services should be based on Millennium-Ecosystem Assessment and the classification of ecosystem services in Burkhard et al. (2012) and scored by Burkhard's method. Secondly, for scoring critical ecosystem services, the Burkhard's method constructs an ecosystem services matrix combining land cover information in assessment of the state of ecosystems and their capacities to supply ecosystem services based on MEA and Burkhard's ecosystem services classification system (Burkhard et al., 2012). Thirdly, the score adjustment of each critical ecosystem service should be made by using local expert knowledge. In addition to using local expert knowledge, ecosystem quality or deterioration grade map may also be used to adjust the original scores of ecosystem services.

8.2.4. Objective 3: Conservation priority area delineation of cropland and forest in the YRD Metropolitan Region

1) Where are the hot spots of ecosystem functions and services for cropland and forest in the Yangtze River Delta Region?

   For rainfed cropland eco-function hot spot,

   a. The area of the Very High Importance Function Zone is 2700.68 km^2, 9.90% of total area. The Very High Importance Zone was considered as an option of priority conservation area, which densely distributed in the north of region, which concentrated in the north and east of the Jiangsu Province

b. The (Getis-Ord Gi*) hot spot area was an option of the priority conservation area. It distributed over linked areas in the east coastal area and concentrated in the north of Jiangsu Province.

For paddy fields eco-function hot spot,

a. The area of the Very High Importance Function Zone was 1538.03 km^2, 2.38% of the total area; High Importance Function Zone was 22445.26 km^2, 34.73% of total. The Very Importance Zone and High Importance Zone were possible options for priority area delineation of ecological cropland zone. The Very High Importance Function Zone and High Importance Function Zone were considered as an option of the priority conservation area. The Very High Importance Zone were continuously distributed in the north of Jiangsu Province, while the High Importance Function Zone was concentrated in the south of Shanghai Municipality and Chongmin Island in Shanghai and scattered in the lowland area in Zhejiang Province.

b. The (Getis-Ord Gi*) hot spot area was an option of the priority conservation area. It clustered in the middle of Jiangsu Province, concentrated in the Taihu Lake Basin, which included the south of Jiangsu Province, the east of Shanghai Municipality and north of Zhejiang Province, and scattered in north of the Jiangsu Province.

For forest eco-function hot spot,

a. The area of the Very High Importance Function Zone was 9024.21 km^2, 15.50% of the total area. The Very High Importance Zone was considered as an option of priority conservation area. It was densely distributed in the south of the region, occupying most of the area in Zhejiang Province. It covered not only the inland area but also the east coastal area of the province.

b. The (Getis-Ord Gi*) hot spot area was an option of the priority conservation area. It occupied 40.18% of the total area. It covered most of the south of Zhejiang Province and clustered in the middle of the Zhejiang Province.

2) How to identify conservation priority area of ecosystem functions and services for main ecosystems at regional scale?

In the case study, firstly, the author suggests to applying a spatial indicator (net primary productivity) as a proxy for ecosystem function and total values of ecosystem services to help local experts and decision makers delineate the areas of differing importance within one ecosystem; secondly, the spatial pattern of different-levels of net primary productivities assessed by local expert knowledge should be revealed; thirdly, the spatial distribution of the different-level importance area of integrative ecosystem services provision should be mapped and revealed for the priority area; in the meantime, the author suggests to apply the hot spot analysis (Getis-Ord Gi*) to the identification of the clustering patches of habitats with large area. This step is to identify those areas where its forest or cropland ecosystem were not highly disturbed by human activities in habitat fragmentation problem; finally, the decision makers' view should be discussed.

8.2.5. Objective 4: Service provisioning cities and service benefiting cities Identification in the Yangtze River Delta Region

1) What is spatial pattern of ecosystem services supply-demand budget and spatial relations for inter-city environmental cooperation?

a) Identify significant spatial mismatches in supply and demand of the three ES among 16 cities in the YRD metropolitan region, and the southwest part had much surplus in the three ES while the middle and northeast part had seriously deficit

Supply

The areas with high capacity (score 3-5) were mainly distributed in the southwest of the region and accounted for over 1/3 of the total area, and the areas with low capacity (score 0-2) of the three services were mainly located in the northeast of the region.

Demand

The areas with high demand (score 4-5) for erosion regulation were scattered in the coastal plain of the region, while the areas with high demand for flood protection were densely distributed in the urban areas and in the cultivated land area, and areas, which areas with high demand for water purification were concentrated in the urban areas in the northeast of the region.

Budget

Based on the results of the supply-demand budgets, the areas with high positive scores for the three ecosystem services were densely distributed in the southwest of the region, while the areas with high negative scores were mainly scattered or densely distributed in the northeast of the region.

b) Identify significant mismatches in relative amount supply and demand of the three ES among 16 cities

For erosion regulation service,

Hangzhou contributed most, with nearly half of the total surplus of this service in the selected cites (46.51%), while Nantong had the largest deficit, 19.91% of the total deficit in this service.

For flood protection service,

Hangzhou contributed most, according to over half of the total surplus of this service in the selected cites (53.84%), while Shanghai had the largest deficit, amounting to 18.69% of the total deficit of this service.

For water purification service,

Hangzhou contributed most, is with approximately three quarters of the total surplus of this service in cites (71.57%), while Nantong had the largest deficit, with 19.64% of the total deficit of this service.

c) Define service balancing cities, service providing cities, service benefiting cities.

Zhoushan is a 'service balancing city' in flood regulation service, erosion regulation service, and water purification service.

The service providing cities of flood regulation service and erosion regulation service are: Hangzhou, Taizhou, Shaoxing, Ningbo, Huzhou and Zhoushan. All the other ten cities are service benefiting cities for these three services.

The service providing cities for water purification service are: Hangzhou, Taizhou, Shaoxing and Ningbo. All the other eleven cities are the service benefiting cities of these three services.

The service providing cities of flood regulation service, erosion regulation service and water purification service, Hangzhou, Taizhou, Shaoxing, Ningbo and Huzhou are mainly distributed in Zhejiang Province in the south of the region, while the service benefiting cities for these services are concentrated in the northern part, in Jiangsu Province and Shanghai Municipality.

2) What are inter-city watershed cooperation by water-related ecosystem services budget in the Yangtze River Delta metropolitan region?

Province-level city cooperation in the region: delivering the surplus of the selected services from Zhejiang Province to Jiangsu Province and Shanghai Municipality

Prefecture-level city cooperation in the region: delivering surplus of selected services from Huzhou to prefecture-level cities in Jiangsu Province in the Taihu Lake Basin

Cooperation between the central municipality and prefecture-level city: Delivering surplus of water purification service from Huzhou and Hangzhou to Shanghai Municipality through river network in the Taihu Lake Basin

Cooperation between provinces in the region and outside the region:

Delivering water purification service from Xin'anjiang Watershed in Anhui Province outside the region to Xin'anjiang Reservoir in Zhejiang Province

Low possibility for cooperation:

Last but not least, the ecosystem services budget and flow analysis also indicated that there was low possibility for cooperation in water purification services between Nanjing, Nantong, and Yangzhou in Jiangsu Province, without artificial infrastructures, because these cities were separated by independent catchments.

8.3. Can the author's ecosystem services approach framework be applied to other urbanising regions in China?

The author believed that the ecosystem services assessment and environmental management framework can be used in other rapidly urbanising region which has similar problems in loss of the total values in ecosystem services driven by urban growth and economic growth in China, i.e. the Beijing-Tianjing-Hebei metropolitan region or the Pearl River Delta metropolitan region. One potential application area is the Beijing-Tianjin-Hebei metropolitan region. The Beijing-Tianjin-Hebei metropolitan region incorporates the three major administrative regions of Beijing Municipality, Tianjin Municipality and Hebei Province, which are made up of a total of 164 county-level administrative units and a total land area of 216,600 square kilometres. The terrain is inclined from northwest to southeast, and has various types of landforms, such as Bashang plateau, Yanshan Mountains and Taihang Mountains in the west, and vast piedmont plains, low plains and coastal plains in the middle and southeast. This area has a typical temperate semi-humid semi-arid continental climate, with the precipitation decreasing from southeast to northwest. Regional land use also presents a spatial pattern of transiting from southeast cropland land to northwest forestry land.

The Beijing-Tianjin-Hebei region represents a representative area for comprehensive agricultural development in China. With the rapid development of the social economy, the region has also paid a large price in resources and environmental terms. This manifested as excessive consumption of natural resources, which is unsustainable. In particular, the shortage of water resources has become the main limiting factor that restricts local socio-economic development. The deterioration of the environment has not been effectively curbed; the environmental pollution in the city is still serious, the soil erosion in the Taihang Mountains and Yanshan Mountains and the desertification on the Bashang plateau have been aggravated, the plains and lakes have shrunk or even disappeared, the coastal and estuarine ecosystems have deteriorated, and land subsidence, seawater intrusion and sand storms occur frequently. On the whole, except for the productive supply function of ecosystem services in the region, most of the other service functions have been reduced or degraded to varying degrees. The decrease in the value of ecosystem services in Beijing was due primarily to the sharp decrease in farmland area, followed by the reduction in grassland area, by 24.21% and 5.46% respectively during the period from 1990 to 2010 (Zhang et al, 2017a; Zhang et al, 2017c). The Tianjin area from 1990 to 2010 saw a dramatic decrease in grassland area, followed by the reduction of farmland and also forest areas – their ecosystem service values decreased by 20.47%, 6.43%, and 3.76%, respectively; in the same period. In Hebei Province, the ecosystems in which the value of ecosystem services declined include water bodies, farmland and grassland, with a rate of decline of 4.63%, 2.53% and 1.58%, respectively (Zhang et al, 2017a; Zhang et al, 2017c). Based on the above circumstances, the study of ecosystem service spatial assessment framework in the Beijing-Tianjin-Hebei region and the division of their ecosystem service zoning will provide a sound reference for the formulation of national land development policies and effectively guide the orderly development and utilisation of land resources throughout the country.

Another potential application area is the Pearl River Delta metropolitan region. The Pearl River Delta metropolitan region, located in the south-central part of Guangdong Province, incorporates the major administrative regions of the seven cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Zhongshan and Dongguan, as well as Huicheng District and Huiyang District in Huizhou City, Huidong County and Boluo County, and Duanzhou District, Dinghu District in Zhaoqing City, Gaoyao City and Sihui City., with a total area of 4.1×104 km^2. The Pearl River Delta, a compound delta formed by the sediments brought by the Xijiang River, Beijiang River, Dongjiang River and its tributary Tanjiang River, Suijiang River and Zengjiang River, is the largest alluvial plain in South China, and has a subtropical marine monsoon climate with abundant rainfall, sufficient quantity of heat and a hot rainy season. The average annual rainfall is up to 1,800 mm, the annual sunshine duration is 2,000 h, and the average annual temperature is 21.4-22.4°C. The zonal soil is mainly made up of latosolic red soil and red soil developed from sandstone, shale and granite parent materials. The permanent population of the Pearl River Delta region in 2006 was 44.01 million, accounting for 47.30% of the permanent resident population of Guangdong Province. The total production value was 2141.8 billion yuan, accounting for 81.73% of the total value of the province.

The Pearl River Delta region is one of the most developed and densely populated regions in China. As the frontier of China's reform and opening up, the Pearl River Delta has achieved remarkable strides in social and economic development. However, with the economic boom, land use in the Pearl River Delta region has undergone tremendous and rapid changes. A large number of agricultural lands have been converted into land for construction, resulting in the dramatic decrease of arable land resources. At the same time, the tremendous adjustments of internal structure of the land and the destroyed regional ecological balance have threatened the sustainable and sound development of regional ecological security and social economy. From 1990 to 2006, the land use in the Pearl River Delta region underwent tremendous changes (Haas & Ban, 2014; Zhang et al, 2016).

Rapid urbanisation and industrialisation have led to the continued expansion of construction lands, taking up a large amount of cultivated land, forest land, and water areas. The industrialisation of agriculture has resulted in the conversion of a large number of cultivated lands to fish ponds, and the water area has continued to increase. Since the main supporters of ecosystem service functions in the Pearl River Delta region are forest land, water areas and arable land, the conversion of the cultivated land and forest land into construction land or fish ponds has brought about a significant loss to ecosystems, especially when it comes to the formation and maintenance of soil, climate regulation, gas regulation, and food production. Moreover, the net decrease in the value of regional ecosystem services was 2.791 billion yuan (Haas & Ban, 2014; Zhang et al, 2016). There is a significant negative correlation between construction land and ecosystem service functions. The expansion of the former leads to the reduction of ecosystem service value, but forest land has a significant positive correlation with ecosystem service functions, and the increase in the proportion of the forest land will be conducive to the cultivation of ecosystem service functions(Haas & Ban, 2014; Zhang et al, 2016). Therefore, it is obvious that violent human activities have significantly affected the ecosystem service functions, bringing about a marked a decline in regional natural ecosystem service functions. The author’s ecosystem services assessment framework was suitable to identify problems driven by the human disturbance to the ecosystem services, and response to the decline by ecological function zoning and inter-city cooperation.

8.4. Contributions and limitations

8.4.1. Contributions for ecosystem services assessment and environmental planning and cooperation

1) The author identified, and managed ecosystem services supply hot spot and set up ecosystem services supply-demand budget for inter-city watershed environmental cooperation in the Yangtze River Delta Metropolitan region.

2) The author summarized the spatial priority area and regional environmental cooperation strategies for the provincial ecological cropland and ecological forest areas.

3) The author revealed the spatial and quantitative mismatches of supply, demand and budget of the four ecosystem services of sixteen cities in the Yangtze River Delta metropolitan region

4) The author distinguished the surplus cities and the deficit cities in the Yangtze River Delta region;

5) the author identified the flow directions of the four ecosystem services at regional scale and watershed scale; (5) the author defined the two-scale regional ecosystem conservation cooperation models i.e. the cooperation models between cities at watershed scale for flooding Protection, erosion regulation and water purification.

6) This thesis provided valuable information for environmental planning and management in a rapid urbanizing region and helped improve China’s ecological red lines policy at regional scale. The author developed the

ecosystem services assessment and environmental management framework for priority conservation area and inter-city environmental cooperation. The application of this framework was succeed in the large-scale ecological functional zoning: it was easier for local decision makers to identify the current state and spatial distribution of area with high supply capacities of integrated ecosystem services and single ecosystem services which were valuable for priority conservation, and of area with low integrative ecosystem services supply capacities which might be valuable for restoration and development depending on the demands of local decision makers. The applied value of this sub-framework was mainly in managing large-scale regional ecosystem services supply through different land cover/use or ecosystems planning.

8.4.2. Limitations and future research for ecosystem services assessment and environmental planning and cooperation

It is undeniable that the method put forward in this dissertation had some limitations. Firstly, although this framework included local environmental reading and preliminary score adjustment process, it could not completely avoid the uncertainty in expert scoring method. The method to score for each ecosystem services mainly by land use/cover and local expertise is relatively subjective and suitable for the region short of data and this has greatly been argued (Schröter et al., 2012; Burkhard et al., 2014; Villamagna et al., 2013; Schulp et al., 2014; Wolff et al., 2015). To reduce the uncertainty of using local expert knowledge, some of the scientific process is going to be involve in the author's future ecosystem services assessment to improve scientific quality of the ecosystem services assessment matrix, i.e. confidence report, careful choice of the respondent pool, use of consensus rounds (Jacobs et al, 2015). Similarly, based on the score matrix, the author accounted the amount of supply, demand and budget of a city for ecosystem services and this was a relative amount and not an actual amount. As Burkhard et al. (2012) pointed out, this relative amount may be transferred into the actual amount (i.e. an energy unit). Secondly, the author's research only considered each city as the ecosystem services budget unit in order to discuss the inter-city ecosystem services cooperation model at a regional scale. In fact, a city, especially a Chinese city, composed of different landscapes which had different ecosystem services supply and demand and difference within a city may be meaningful to analyze the mismatch or match of supply and demand of ecosystem services. This will certainly ignore the spatial-relations of multiple landscapes within a city at a local scale (Costanza, 2008). These shortcomings need to be improved in future research.

If the author had more ecosystem quality data for the entire region, the author can use measurable factors such as the changes of water quality classification to reveal how rapid degradation of waterbody ecosystems corresponds to the rapid urbanization in the cases in the Yangtze Region Delta Region. Ren et al., (2003) examined the water quality at five sampling sites along the course of Shanghai's Huangpu River between 1947 and 1996. The analysis revealed that there was a strong positive correlation between proportion of urban land use (i.e. residential and industrial) and worsening water quality classifications. The water quality at each sampling site was classified according to the Chinese Government standard for water quality issued in 1988 (GB 3838-88). This standard includes the following five water classifications (Ren et al., 2003).

For future study, the greatest challenge in ecosystem service mapping and decision making is that there were cross linking relationships in ecosystem services (Cavender-Bares et al, 2015; Cord et al, 2017; Maes et al, 2012b). The interaction and relationship among ecosystem services were highly nonlinear (Cavender-Bares et al, 2015; Cord et al, 2017; Maes et al, 2012b). Attempts for mapping and decision for trade-off and synergy of ecosystem services was in process (Cavender-Bares et al, 2015; González-Esquivel et al, 2015; Grossman, 2015; Maes et al, 2012b; Sanon et al, 2012). Trade-offs means that the supply of some ecosystem services is influenced by the increase or decrease of the usage of other ecosystem services (Bouma & van Beukering, 2015; Li et al, 2014). Synergy means that two or more ecosystem services are strengthened simultaneously (Bouma & van Beukering, 2015; Li et al, 2014). Decision making of trade-off and synergies required long-term research and variety of database supported for the preliminary research in complex relationship among ecosystem services (Cavender-Bares et al, 2015; Cord et al, 2017; González-Esquivel et al, 2015; Grossman, 2015). The author considers that future decision making based on ecosystem services assessments in such a region as the Yangtze River Delta metropolitan should focus on the construction basic research database first, and then introduces the study of the trade-off and synergy of ecosystem services into environmental management.

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Appendix

Appendix 1

Main interview questions with local experts:

- Who am I? My major, department and institution? My main research objectives and questions?

1) Research background of local experts

• Please introduce your research area and your institution or department?

• What is your role in your institution or in your department?

2) Problems identification analysis of causes for the decline of the ecosystem services in the Yangtze River Delta region

- What are the environmental problems in the Yangtze River Delta region?
- What are the historical and current reasons of these environmental problems?
- What are relationships between these environmental problems an ecosystem services?

3) Scoring the capacities of main ecosystems (land cover types) to supply/demand for ecosystem services

- What do you think the capacities of main ecosystems (land cover types) to support ecological integrity and to supply ecosystem services /demand for ecosystem services? Please give your score (scale: 0-5) refer to the original table in Burkhard et al 2012, and explain the brief reason of your correction scores.

4) The policy orientation of the regional environmental planning and management under the ecological redline policy

- What are the requirements and objectives of the regional ecological function zone under the ecological redline policy?

- Do you think it necessary to strengthen the ecosystem services assessment based environmental planning and cooperation? How?

- What are the current and future payment for ecosystem services pilots in watersheds in the Yangtze River Delta region? Do you think it necessary to identify opportunities in establishing future payment for ecosystem services pilots?

Appendix 2

Appendix 2.1 Process score table of the Shanghai team for assessment of ecosystem services capacities

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation & Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		4	4	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		4	3	3	2	4	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

Appendix 2.2 Process score table of the Jiangsu team for assessment of ecosystem services capacities[3]

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation & Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		5	5	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		5	4	3	2	5	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

[3] Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right): The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

Appendix 2.3 Process score table of the Zhejiang team for assessment of ecosystem services capacities[4]

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation & Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land		0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0
Rural residential land		1	1	1	1	1	1	1		0	0	0	0	0	0	0	0	0		1	0	0	0	0		0	0
Arable land		3	2	5	2	5	1	3		3	1	1	0	0	0	0	0	0		5	5	0	0	0		1	0
Grasslands		3	5	4	4	4	5	5		2	3	1	1	0	5	5	0	0		0	3	0	0	0		3	3
Shrublands		3	4	2	3	3	4	2		1	0	0	0	0	5	5	5	2		0	2	0	0	0		2	2
Forest		3	5	5	4	5	5	5		5	5	3	3	5	5	5	5	5		0	0	0	0	0		5	5
Inland marshes		3	2	4	4	4	3	5		2	2	4	2	0	0	4	0	0		0	2	0	0	0		0	0
Salt marshes		2	3	4	3	3	3	5		1	0	5	0	0	0	2	0	0		0	2	0	0	0		3	0
Streams and Lakes		4	4	0	4	4	3	4		2	1	1	2	0	0	1	0	0		0	0	3	0	5		5	4
Estuaries		3	3	0	5	5	3	2		0	0	3	0	0	0	3	3	0		0	0	5	5	0		4	3
Shallow sea wetlands		2	2	0	3	3	4	1		3	5	0	0	0	0	5	0	0		0	0	5	5	0		4	2
Bareland		3	3	0	0	0	0	0		0	0	1	1	0	0	0	1	0		0	0	0	0	0		4	0

[4] Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right): The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

Appendix 2.4 Final score table for assessment matrix illustrating the capacities of main land cover classes to support ecological integrity to supply ecosystem services[5]

	Ecological integrity	Abiotic heterogeneity	Biodiversity	Biotic water flows	Metabolic efficiency	Exergy Capture(Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	**Regulating services**	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	**Provisioning services**	Crops	Livestock	Capture Fisheries	Aquaculture	Freshwater	**Cultural services**	Recreation & Aesthetic Values	Intrinsic Value of Biodiversity
Urban Land	**0**	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0
Rural residential land	**7**	1	1	1	1	1	1	1	**0**	0	0	0	0	0	0	0	0	0	**1**	1	0	0	0	0	**0**	0	0
Arable land	**21**	3	2	5	2	5	1	3	**5**	3	1	1	0	0	0	0	0	0	**10**	5	5	0	0	0	**1**	1	0
Grasslands	**30**	3	5	4	4	4	5	5	**17**	2	3	1	1	0	5	5	0	0	**3**	0	3	0	0	0	**6**	3	3
Shrublands	**21**	3	4	2	3	3	4	2	**18**	1	0	0	0	0	5	5	5	2	**2**	0	2	0	0	0	**4**	2	2
Forest	**32**	3	5	5	4	5	5	5	**39**	5	4	3	2	5	5	5	5	5	**0**	0	0	0	0	0	**10**	5	5
Inland marshes	**25**	3	2	4	4	4	3	5	**14**	2	2	4	2	0	0	4	0	0	**2**	0	2	0	0	0	**0**	0	0
Salt marshes	**23**	2	3	4	3	3	3	5	**8**	1	0	5	0	0	0	2	0	0	**2**	0	2	0	0	0	**3**	3	0
Streams and Lakes	**23**	4	4	0	4	4	3	4	**7**	2	1	1	2	0	0	1	0	0	**8**	0	0	3	0	5	**9**	5	4
Estuaries	**21**	3	3	0	5	5	3	2	**9**	0	0	3	0	0	0	3	3	0	**10**	0	0	5	5	0	**7**	4	3
Shallow sea wetlands	**15**	2	2	0	3	3	4	1	**13**	3	5	0	0	0	0	5	0	0	**10**	0	0	5	5	0	**6**	4	2
Bareland	**6**	3	3	0	0	0	0	0	**3**	0	0	1	1	0	0	0	1	0	**0**	0	0	0	0	0	**4**	4	0

[5] Note: Assessment matrix illustrating the capacities of main land cover classes to support ecological integrity (column at the left side), to supply ecosystem services (the three columns at right): The values indicate the following capacities: 0 = no relevant capacity; 1 = low relevant capacity; 2 = relevant capacity; 3 = medium relevant capacity; 4 = high relevant capacity; and 5 = very high relevant capacity (after Burkhard et al., 2012; Burkhard et al., 2009). The highlight score was the different process score in each expert group.

Appendix 2.5

The supply, demand and budget score matrix of the four ecosystem services for land cover types in the Yangtze River Delta metropolitan region: after (Burkhard et al, 2012)

Land cover	FP			ER			WP		
	S	D	B	S	D	B	S	D	B
Urban Land	0	4	-4	0	1	-1	0	1	-1
Rural Residential Land	0	5	-5	0	1	-1	0	2	-2
Arable land	1	2	-1	0	2	-2	0	5	-5
Forest	3	0	3	5	0	5	5	0	5
Shrublands	0	0	0	4	0	-4	4	0	4
Grasslands	1	0	1	5	0	5	4	0	4
Bareland	4	0	4	0	0	0	0	0	0
Inland marshes	5	0	5	0	0	0	0	0	0
Salt marshes	1	0	1	0	0	0	0	0	0
Streams and Lakes	1	0	1	0	0	0	1	0	1
Estuaries	3	0	3	0	0	0	2	0	2
Shallow Sea Wetlands	0	0	0	0	0	0	0	0	0

Note: FP-Flood Protection, ER-Erosion Regulation, WP-Water Purification; S-Supply, D-Demand, B-Budget.Scale from 0 / 1 / 2 / 3 / 4 / 5 / = no / low/ relatively low/ medium/ high/ very high/ relevant capacity or demand

Appendix 3

Example of ecosystems in the Yangtze River Delta region:

Forest ecosystem:

Broad-leaved forest in Taimu Mountain in Zhejiang Province (source: author)

Coniferous forest in Taimu Mountain in Zhejiang Province (source: author)

Mixed forest example 1 in Taimu Mountain in Zhejiang Province (source: author)

Mixed forest example 2 in Taimu Mountain in Zhejiang Province (source: author)

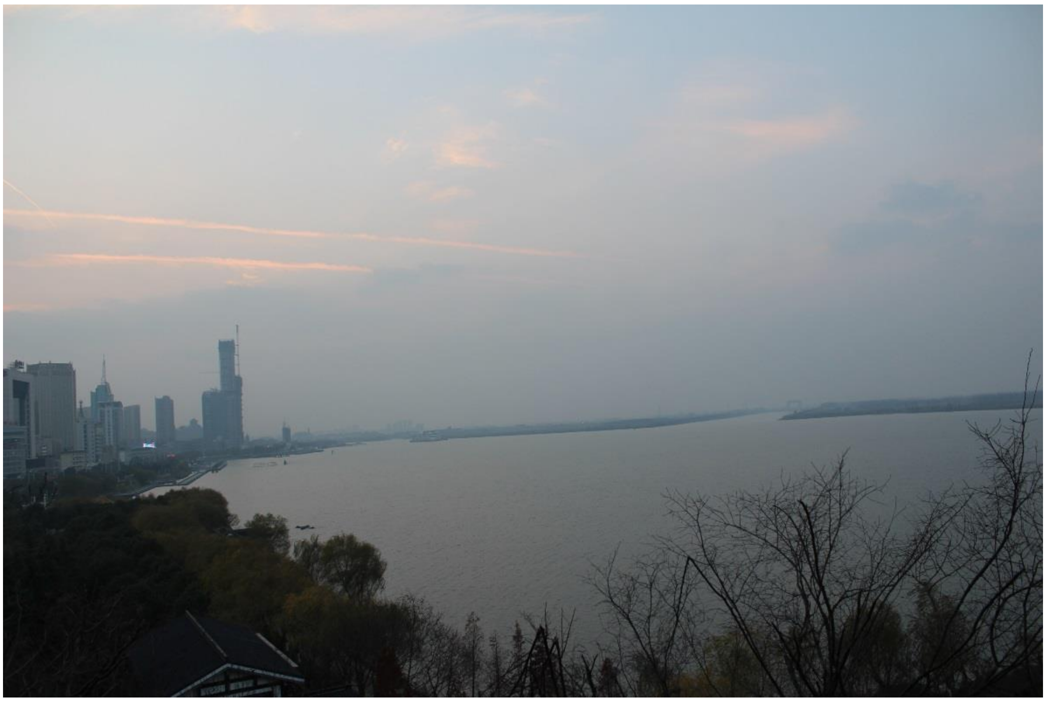
Cropland ecosystem:

Cropland in the Yangtze River Delta Region (source: author)

Streams and lakes ecosystem:

Culture pond in Taihu Lake Basin (source: author)

West Lake in Hangzhou in Zhejiang Province (source: author)



River bend in Zhenjiang in Jiangsu Province (source: author)

The author in the river bank in Zhenjiang in Jiangsu Province (source: author)

Wetland ecosystem:

Wetland in Chongming Island in Shanghai Municipality (source: author)

Appendix 4

Policy aims and orientations from local government documents and experts

Policy aims of strengthening regional ecological function zoning for the Yangtze River Delta region

(Source: Environmental reports collected from one of the environmental supervision departments for East China and East China Normal University**)**

In accordance with the national arrangements, the provinces and cities in the Yangtze River Delta region are embarking on the delineation of ecological red lines and ecological functional zones. For example, Jiangsu Province has completed the delineation of provincial ecological red lines, while Nanjing has completed the work at the municipal scale. Due to different understandings and definitions of ecological red lines, the delineation results may vary despite the fact that the delineated zones are in the same province.

Moreover, Zhejiang Province has completed ecological functional zoning. For two identical zones, there can be two division versions. Now that the results are not even unified within a province, there may be greater differences when more provinces are involved and convergence can be more difficult. Therefore, it is imperative to have unified zoning at the regional scale.

However, ecological functional zoning requires detailed geo-ecological spatial data. With the available incomplete data of the Yangtze River Delta region, the credibility of ecological red lines and ecological functional zones that have been delineated is doubtful. Based on incomplete regional database of the Yangtze River Delta, we have made initial attempts in ecological functional zoning. The results serve as reference only and need to be refined in the future.

Policy aims of watershed management and ecological compensation

(Source: Environmental reports collected from one of the watershed departments in Jiangsu Province and East China Normal University**)**

Measures for Improving Water Environment in River Basins

Water pollution is a basin-related problem and must therefore be managed at the basin level. Developed countries have accumulated rich experience and lessons in governing basin water environment.

First of all, basin management requires accurately dividing the boundaries of the basin and sub-basins.

The water environment problem in the Yangtze River Delta region involves multiple basins. Each basin has a different background, state of pollution, and influencing factors. Therefore, the management of water environment must accurately define boundaries at the basin level, as this is helpful in determining pollutant sources and their distribution. In addition, boundary division is relatively easy for the tree-like drainage systems affected by humans in mountains. However, it can be hard for plain river networks that are vulnerable to human impact. Meanwhile, obscure boundaries would clearly hinder the management of water environment. At the same time, a large catchment area in the Yangtze River Delta region can be defined by the Grand Canal, Lixia River, and Tongyang River in the north of the Yangtze River. This catchment area involves two basins: Huaihe River and Yangtze River. Furthermore, another large catchment area is formed by the Taihu Lake basin and the Qiantang River basin in the south of the Yangtze River, as well as several small water systems in Eastern Zhejiang.

The final catchment area is an independent area composed of the islands in Shanghai and Zhejiang. Meanwhile, artificial grand canals that run through the Taihu Lake basin have changed the scope of catchment areas and the direction of water flow. The renovation and control of many artificial river courses within the basin has completely changed the natural water collection process. In this backdrop, it is necessary to redefine the boundaries of sub-catchment areas in Taihu Lake basin.

Secondly, it is essential to define the objectives of unified water ecological environment management.

It is clear that transit rivers in the Yangtze River area affect the water environments in Jiangsu and Shanghai, especially the safety of water sources and water intakes along the Yangtze River in the two places. Meanwhile, water environment governance involves the coordination of various provinces and cities in the Yangtze River basin. Defining clear and unified water ecological management objectives will not only effectively facilitate coordination in determining the layout of industrial belts along the Yangtze River, but also help control the total discharge of pollutants in relevant areas and reduce the stress on water environment.

In 2008, the *Overall Plan for Comprehensive Management of Water Environment in the Taihu Lake Basin* was implemented. The document called for carrying out comprehensive management under the plan; promoting the restoration and protection of water ecosystems in the basin on project basis; promoting orderly flow of water bodies through scheduling methods; strengthening comprehensive management of the basin under institutional guarantee; and actively promoting health assessment of the Taihu Lake under scientific and technological support. In recent years, the water quality of the Taihu Lake has improved. However, the past governance goal and priority were the improvement of water quality in the Taihu Lake. For the entire basin, there was a lack of a unified goal, especially in the downstream area. As a result, water pollution problems have frequently arisen across provinces (between Jiangsu and Shanghai, Jiangsu and Zhejiang, and Zhejiang and Shanghai). Therefore, it is necessary to strengthen the research and definition of a unified water ecological environmental goal in the Taihu Lake basin.

Moreover, a unified standard for water pollution emission of the basin should be strictly enforced.

The water environment issue is essentially about economic development. From an economic point of view, the upstream area is usually economically backward. In order to reduce the cost of economic development, a low pollution emission standard is usually preferred and the treatment pressure is shifted to the downstream area. However, even if a strict emission standard is adopted in the downstream area, the improvement of water quality is hardly guaranteed. In addition, the governments of the upstream area try to lower the standard to attract high-consuming and high-polluting enterprises, which leads to pollution transfer. Therefore, a unified wastewater discharge standard in line with the situation of the entire basin must be implemented to realise the overall objective of the basin, and the supervision over the implementation of the discharge standard should be effectively strengthened.

In addition, the implementation of basin emission rights and ecological compensation systems should be accelerated, and fair development of upstream and downstream areas should be promoted.

The rules for implementing the emission trading system should be clarified and the role of the government in supervising and managing the emission trading process should be reinforced. According to the principles of "Those who protect get the benefits" and "Those who are responsible for pollution make compensation", an ecological compensation mechanism for trans-boundary water pollution should be determined and a public fund for regional ecological compensation should be established.

Furthermore, there is a need to establish a multi-party water management mechanism to address water risks in the basin.

Multi-party water management involves the management of water resources and water environment. It also incorporates the governance of water environment and water safety.

It calls for realising these tasks through gradual enhancement of people's level of awareness that encourages exchange and dialogue among stakeholders to balance the interests of all parties. Enterprises are large-scale stakeholders. Their awareness of rights and sense of responsibility, once aroused, are important strategic resources. Increasing interaction between enterprises and consumers can lead to the formation of the best management model for the basin. Meanwhile, technical support and action strategies participated by multiple parties, including water footprint estimation, water safety assessment, and water health diagnosis, should be provided and relevant measures on this basis should be taken. At the same time, platform construction that calls for concerted efforts should be started, including the broadening of potential partners. The goal is to form an efficient information-sharing network by organising various forms of training courses, seminars, and advanced forums. Different parties should be involved to develop standards and multi-participation policies should be advocated.

An early warning system for water quality monitoring and water pollution prevention and control in the basin should be established.

This system includes a real-time monitoring network of water pollution, upstream and downstream water information exchange platform, emergency response plan for water pollution control, and infrastructure construction. In terms of the monitoring layout, it is important to expedite the shift from monitoring of regular sections to monitoring of water function areas and drain outlets into rivers. Based on the needs of pollutant receiving red line management in water function areas, the layout of water quality monitoring sites in the basin (district) should be further improved to form a modern monitoring network structure with integrated stationary-point monitoring, patrol monitoring, and automatic detection.

Efforts should be made to improve supervision and monitoring of water function areas, measurement and monitoring of drainage outlets into rivers, emergency response monitoring of drinking water safety, and ecological monitoring of rivers and lakes to keep them healthy. Moreover, the strictest monitoring system for water resources protection should be established to lend support for stringent management. Furthermore, a quick and shared Water Information Exchange Platform should be built to master information on water quality changes in a timely manner and provide support for effective decision-making. Simultaneously, emergency response planning and infrastructural construction should be reinforced to ensure that any incident can be quickly and effectively controlled.

The realisation of aforementioned goals would not be possible without a unified and authoritative basin management agency.

It requires not only the coordination of various administrative agencies within the basin but also the establishment of relevant laws and regulations at the national level.
The payment for ecosystem services mechanisms for the ecological red line area is still an emerging environmental ecological policy in the Yangtze River Delta metropolitan region, which is mostly in the research and exploration stage. When it comes to practically establishing a two-way river basin payment for ecosystem services mechanism based on upstream and downstream liability judgment, the local goverments still face many challenges in technological, legal and standard terms.

First is the upstream and downstream liability judgment.

In this two-way river basin payment for ecosystem services mechanism, the key is to judge upstream and downstream liabilities. Currently, the most often adopted and also the most reasonable liability judgment mechanism is the water-quality target assessment system based on trans-boundary cross sections. However, since the Yangtze River Delta river system is located in a tidal river network in which some trans-boundary rivers can be driven by the tide to flow back and forth, it is somewhat difficult to judge the liability subject when it comes to pollution.

Second is the payment for ecosystem services standard.

The payment for ecosystem services standard is closely connected to the amount of the final compensation. Different compensation standards often result in different compensation results and effects. However, at present, there are no scientific and uniform methods for stipulating payment for ecosystem services standards. It is generally held that the valuation of the river basin ecological service function is the major basis for stipulating river basin payment for ecosystem services standards. However, during practical operations, the accounting methods for ecosystem service assessment are not yet complete, and the basic points of data for accounting are hard to acquire, so this assessment method is not widely applied. Currently, the compensation standards are more often decided through upstream and downstream discussions and negotiations, which, however, are inevitably driven by different parties at least in part out of self-interest. Such a method fails to objectively reflect the demands of a polluted river basin for payment for ecosystem services, and as a result cannot guarantee the objectivity of the compensation standards.

Appendix 5

Research ethics statement

APPENDIX C

A PROFORMA FOR

STAFF AND POSTGRADUATE RESEARCH STUDENTS BEGINNING A RESEARCH PROJECT

Department of Geography, Environment and Earth Sciences

Research Proposer(s): Wenbo Cai………………………

Programme of Study (postgraduate students)…………PhD in Human Geography

Research Title:

Assessment and Management of Regional Ecosystem Service: a Case study in Yangtze River Delta Region, China

Research (brief):

By connecting land cover information from GIS analysis and remote sensing with expert knowledge, this research will be a scientific basis for improving environmental policy for Yangtze River Delta Region Integration at national scale, for regional cooperation mechanism construction for Yangtze River Delta Region at regional scale and for ecological planning and management at regional scale.

The methodology of my research will include spatial analysis, survey and interview:

(1) Spatial analysis:

At regional scale, remote sensing land cover and land use with 30 m resolution are used to analyse the main characters of the pattern and types of ecosystems in Yangtze River Delta Region. And, digital elevation model and population data will be help for assessment and zonation.
At local scale, remote sensing LULC data high resolution will be applied in ecosystem classification, pattern and dynamics in the typical study area-Shanghai. The accuracy of ecosystem classification will be validated by high resolution LULC data with 1m or higher resolution.

(2) Data Collection and interviews:

Data Collection:

It is still necessary for me to get advice from local ecological experts about how to transfer land cover and land use categories into ecosystem categories. In particular, I will get advice from experts in department of geography in East China Normal University, and make use of some of their previous research as my reference data since this department has advantage in ecology and GIS research and has studied the Yangtze River Delta Region for a long time. Then, ground truthing will be conducted according to the local experts' advice to further calibrate my spatial data.
Interviews:

Semi-structured interviews which targeted to regional and local governments, institutions and related NGOs will be applied. I plan to interview several NGOs and environmental, planning and other departments of Shanghai government, Jiangsu and Zhejiang principal governments whose responsibilities are related to regional cooperation and ecosystem services. But I cannot say an accurate number of interviews now, because I do not know which department will respond to me effectively. The answers of the interviewees will be open but related to the following themes:

(1) Why regional decision makers set up current cooperation mechanisms (especially eco-compensation mechanisms) and how these mechanisms work;

(2) Whether they are willing to cooperate with each other by regional ecosystem service management in the future or not;

(3) Where the regional ecosystem services come from and where these ecosystem services going to.

In China, besides government agencies, currently there is no institution has the power to organize regional cooperation mechanism. And, the decision of governments was seldom affected by other institutions. Besides the field work of ecosystem survey, my interview plan is (1) to interview the government about the progress and problems in construction and management of current eco-compensation related regional cooperation mechanisms, and their willingness for future eco-compensation related cooperation and ecological planning; (2) I will also interview related non-government organizations to get support information about the progress and problems in current eco-compensation related cooperation mechanisms. So, the people I will talk to are government and related institutions, and they cannot be divided into different groups. Therefore, I can say there is not any focus group in my interview and survey plan.

Time	City	Activity	
November	Hangzhou	Survey main categories of local ecosystem and Interview Environmental and Land Use Government Agencies of Provincial Government for Zhejiang Province	2-3 weeks
December	Nanjing	Survey main categories of local ecosystem and Interview Environmental and Land Use Government Agencies of Provincial Government for Jiangsu Province	2-3 weeks
December	Suzhou	Interview local institutions about typical eco-compensation mechanism	2-3 weeks
January	Zhenjiang	Survey main categories of local ecosystem and interview local experts for Jiangsu Province	2-3 weeks
January	Shanghai	Survey main categories of local ecosystem and Interview Department of Environmental Protection of Shanghai Government , Shanghai Municipal Administration of Afforestation & City Appearance and so on	2-3 weeks

Source of Research Funding (where appropriate) …China Scholarship Council …

Proforma Completion Date: …19/10/2015…………

This proforma should be read in conjunction with the ethical principles. It should be completed by the researcher. It should be sent on completion, together with a brief *(maximum one page) summary of ethical issues raised by the proposed research, for approval to the Geography Ethics Officer prior to the beginning of any research.*

I aware that ethical issues may be arising in my research mainly related to issues of confidentiality and privacy, or lack of anonymity.

During my interviews, firstly, I will ask for the willingness of potential interviewees to participate my interview. Then, I will provide enough information about the project for the participant to be able to give informed consent. Please see attached information letter below. Secondly, if they accept, I will continue to ask the interviewees whether they are willing to give me their personal information such as names or contact information. If they allow, we will sign a privacy protection agreement before starting my interview. Their information will only be used in my research report or publications. If not, personal information of the anonymity of interviewees will not appear in my research report, and I will only list the name of the department of the institution instead. Thirdly, I will ask whether they allow me to use recording equipment or not. If not, I will write down the process of interview by hand.

The following security of personal data, retention issue may be arising in my research. I will hold it in a secure location, whether electronic or hard copy in order to protect the security of personal data. For example, locked cabinet, password-protected files and shared drives, encrypted lap-top. I will be particularly aware of movable storage media such as USB sticks, lap-tops.

Part A

1. Will your research involve animal experimentation? No

   If the answer is 'YES' then the research/teaching proposal should be sent direct to the University Ethics Committee to be assessed.

2. Will your research involve human participants? YES

   If the answer to both questions is 'NO', there is no need to proceed further with this proforma, and research may proceed (however, please send a copy of the form to the Ethics Officer). If the answer is 'YES' please answer all further relevant questions in part B.

Part B

3. Will the research involve people under 18 years of age? No

   If yes, have you taken the following or similar measures to deal with this issue?

   (i) Informed the participants of the nature of the research? Y / N

   (ii) Ensured their understanding? Y / N

   (iii) Gained the non-coerced consent of their parents/guardians? Y / N

4. Will you obtain written informed consent from the participants? YES

   If yes, please include a copy of the information letter requesting consent

   If no, what measures will you take to deal with obtaining consent?

All participants will be notified with clear written and/or oral information on the purpose, methods and use of the research, and they will have opportunity to ask further questions. Participants will not be put under pressure to participate, and will be able to withdraw from all or part of the research at any time. Informed consent from participants will be sought, and where appropriate ask participants to sign an agreement confirming participants are willing to participate and understand the nature of the project.

In China, formal ethics forms can be used in interviews. Sometimes, formal ethics forms might be a pressure for the minority of interviewee due to the complexity of the ethics forms. Nevertheless, all Chinese participants will receive information about the research and records of their consent will be kept. For interviewees, this process will be part of the email exchange that is the basis of their recruitment, with the consent information sent as attachments as part of background about the project. Such participants will want to know what the project is about and so will read these and only accept an interview when they consent to the description of their role in the research – so their emails agreeing to be interviewed and their participation in a subsequent interview will be a record of such consent.

5. Issues for participants. *Please answer the following and where you respond YES in any case, state how you will manage perceived risks:*

a) Do any aspects of the study pose a possible risk to participants' physical well-being?	NO
b) Will any important information about the research be deliberately withheld from the participants?	NO
c) Are there any aspects of the study that participants might find humiliating, embarrassing, ego-threatening, in conflict with their values, or be otherwise emotionally upsetting?*	NO

d) Are there any aspects of the study that might threaten participants' privacy (e.g. questions of a very personal nature; observation of individuals in situations which are not obviously 'public')?* NO

e) Does the study require access to confidential sources of information (e.g. medical records)? NO

f) Could the intended participants for the study be expected to be more than usually emotionally vulnerable (e.g. medical patients, bereaved individuals)? NO

*Note: if the intended participants are of a different social, racial, cultural, age or sex group to the researcher(s) and there is **any** doubt about the possible impact of the planned procedures, then opinion should be sought from members of the relevant group.

6. Might conducting the study expose the researcher to any risks

NO

A full risk assessment will be conducted prior to fieldwork in China and adhered to in line with GEES and UoH policy.

7. Is the research being conducted on a group culturally different from the researcher?

NO

8. Does the research conflict with any of the Department's research principles? (please see attached list, page 7). NO

9. Will the research require the consent of any outside organisation?

No

Name of Researcher

Wenbo Cai………

Signature Wenbo Cai Date ………19/10/2015……………

This research proposed in this proforma must gain recommendation for approval from the Geography Ethics Officer. Once this is gained, formal approval will be given by the Geography Ethics Committee.

It is recommended that the research referred to in this proforma is given approval by the Geography Ethics Committee. Y / N

Name of Ethics Officer

Signature ……………………………… Date…………………………………