Valuation and Management of Mudflats in the Yellow River Delta, China

By

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Abstract

While many coastal wetland valuation studies have been conducted across China, and at different scales, only a few have been conducted in the Yellow River Delta National Nature Reserve (YRDNNR). Furthermore, these studies have been dominated by the use of the static valuation method, which does not fully reflect value trade-offs among ecosystem services and land use types when these change over time. Since deltas are characterized by naturally changing ecosystem conditions, a more complete valuation of the coastal wetland ecosystem in the YRDNNR is desirable. Using the Benefit Value Transfer (BVT) method, I take a dynamic approach that will fill the gap in previous research by reflecting the full range of economic trade-offs among land use types and ecosystem services across varying spatial-temporal scales in the YRDNNR. In addition, my study further considers the impacts of water-sediment regulation, where coordinated annual water and sediment flushing events were initiated behind upper river dams in the early 2000s. Together, I consider these influence on the total economic value (TEV) of the YRDNNR from 2000 to 2015. The study suggests that the water-sediment regulation had a positive impact on the TEV of the YRDNNR. Such information will help the local government and resource managers to understand how this dynamic delta system is changing over time and in response to management intervention. Ultimately, it is hoped this research will lead to solutions to enhance ecosystem services.

Keywords: Coastal wetland valuation, Ecosystem service, Benefit Value Transfer (BVT), Yellow River Delta National Nature Reserve (YRDNNR), Water-sediment regulation

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List of Acronyms

CAS	Chinese Academy of Sciences
IGSNRR	China's Institute for Geographical Sciences and Natural Resources Research
LAC	Library and Archives Canada
YIC	Yantai Institute of Coastal Zone Research
YRDNNR	Yellow River Delta National Nature Reserve
YRCC	Yellow River Conservancy Commission
SFU	Simon Fraser University
TEV	Total Economic Value
TCM	Travel Cost Method
HP	Hedonic Pricing
WTP	Willingness to Pay
CEM	Choice Experiment Method
CVM	Contingent Valuation Method
ESV	Ecosystem Service Value
ArcGIS	Geographic Information System
LUT	Land Use Type
BFT	Benefit Function Transfer
LIMDEP	LIMDEP is an econometric and statistical software that generates statistical results for our regression models

Glossary

Rivers	Lands covered by rivers including canals
Reservoir &ponds	Man-made facilities for water reservation
Bottomland (water body)	Lands between normal water level and flood level
Estuarine waters	Permanent water of estuaries and rivers that being affected by tidal waters
Coastal lagoons	Brackish to saline lagoons with at least one relatively narrow channel connected to the sea
Beach &shore	Lands between high tide level and low tide level
Water supply	Ecosystem service that involves water provided by the Yellow River National Nature Reserve (YRNNR)
Water quality improvement	Ecosystem service that involves improving the water quality of the YRNNR
Climate regulation	Ecosystem service that involves regulating atmospheric processes and weather patterns
Non-consumptive recreation	Refers to activities such as bird watching, boating, and photography, in which participants do no remove resources from the ocean or coast
Cultural	Cultural ecosystem services include aesthetic inspiration, cultural identity, sense of home, and spiritual experience related to the natural environment
Natural habitat and biodiversity	Areas composed of viable assemblages of plant and/or animal species of largely native origin and/or where human activity had not essentially modified an area's primary ecological functions and species composition (International Finance Corporation, 2012)
Shipping	Ecosystem service that involves shipping vessels benefiting from the nature reserve by passing through the reserve
Soil formation and protection	Minimizing soil loss through having adequate vegetation cover, root biomass and soil biota

Chapter 1. Introduction

1.1. Background

Mudflats are deposits of mud, silt and clay found in sheltered intertidal areas in which wave action is relatively low and sediment loads are high. They range from soft muds in the most sheltered inner areas of harbors and estuaries, to firm sands in more wave- and current-exposed areas. Elliott (1998) noted that mudflats typically have low species diversity but support large populations of individual species. Mudflats are critical habitat for migrating shorebirds and many marine organisms, including commercially important species such as the horseshoe crab and a variety of clam species (Naber et al., 2008). Mudflats are crucial not only to the biological communities, but also to providing a variety of ecosystem functions and services that are valuable to humans (Millennium Ecosystem Assessment, 2005). Mudflats provide ecosystem services including provisioning, regulating, supporting, and cultural services (Ma, 2003). Provisioning services of mudflats supply food, fiber, timber, medicine and other products (Ma, 2003). Regulating services of mudflats include water-sediment regulation that absorbs and retains surplus water during the wet season and releases water during the dry season, mitigating both floods and water shortages; storm and flood protection that slows the flow of water with complex root systems that bind the soil, and absorbs wind and wave energy to reduce flooding, riverbank and shoreline erosion, and threats to lives and property; and carbon and nutrient sinks that store carbon and nitrogen in waterlogged soil (Ma, 2003). Supporting services of mudflats act as natural filters to keep water clean; biodiversity provides many wetland plants that have medicinal, food and economic values; and some of the plants are wild relatives of crop species, providing a genetic resource to safeguard the food security of the future generations (Ma, 2003). Cultural services of mudflats offer natural beauty and recreational opportunities to people who enjoy the outdoors and watching wildlife (World Fish Center, 2008).

Mudflats form a major part of my research. My study area is located at the lower Yellow River delta, in the Yellow River Delta National Nature Reserve (YRDNNR).

The Yellow River, “the mother river of China”, is the second longest river in China, after the Yangtze River, and the sixth-longest in the world, at an estimated length of 5,464 km (3398 miles), but over 100th for discharge volume. The Yellow River has basin areas of 752,443 km2 (290,520 miles2) that contain 200,000 km2 (77,000 miles2) of arable land and are home to over 100 million people. The 3,500 km (2,000 miles) upper reaches include the upland swamps and pastures of the Tibetan Plateau as well as gorges in the foothill country and extends to the Gobi Desert in Inner Mongolia. The middle reaches are about 1,200 km (700 miles) from Hekou Town to Zhengzhou, occupying plains and hills in China's Loess Plateau region, where huge amounts of sediment are suspended. The lower reaches, from Zhengzhou to the Bo Sea, are about 800 km (500 miles). Due to sediment accumulation, the riverbed is several meters above the cities and farmlands, forming the world-famous "above ground river". The Yellow River is the most important water resource for the north of China as the environments are drier, which plays an irreplaceable role in economic development and agriculture. Since 1960, over 14 dams have been constructed on the river for hydroelectric power, which is vital to northern China's infrastructure.

Although the Yellow River is a crucial factor in China’s economic development and agriculture, it has also brought many sorrows to China, which is why it has another nickname, “China’s Sorrow”. Between 608 BC and 1938 AD, the Yellow River changed course 26 times, and flooded over 1,500 times. Each year, over 1.6 billion tons of soil flows into the Yellow River, which causes the continual rise and shift of the riverbed. Before damming, it was extremely prone to flooding, and had caused millions of deaths, including the deadliest disaster in human history in 1931, which caused deaths ranging between 2 million and 4 million. Aside from the flooding “sorrows”, new “sorrows” from the Yellow River continued to emerge during recent decades. With global warming becoming an increasing problem, rainfall decline in the Yellow River Basin, and higher water demands for irrigation, industry, etc., the water runoff from the Yellow River has been used up by its lower reaches since 1972, when it ran dry for the first time in recorded history. The longest dry period lasted 226 days in 1997. Drought in the Yellow River region has brought serious challenges to agricultural development and the cities near the Yellow River. However, the no-flow situation at the lower reaches of the Yellow River has improved since water-sediment flow regulation was implemented.

The water-sediment regulation was implemented at the beginning of 2000, and coordinated annual water and sediment flushing events were carried out behind upper river dams. The goals of the regulation are the following. First, to reduce sediment deposition in the channel river beds of the Yellow River, as sediment deposition tends to reduce the river's water flow capacity, thereby increasing the risk of flooding. Second, to scour the river beds of the lower reaches of the river to relieve the drought situation, which improves water supplies for agricultural and industrial production, and more importantly, increases baseflows to benefit water quality and aquatic life in the lower Yellow River deltas including the Yellow River National Nature Reserve.

1.2. Problem Statement

Valuation research involving coastal wetlands was introduced widely with a key publication prepared for the Ramsar Convention, in the international conservation for the conservation of wetlands, and the International Union for the Conservation of Nature (IUCN), and co-authored by the lead investigator (Barbier et al., 1996). Since then, research has emphasized valuing the ecosystem services of mangroves (Barbier 2000, Ronnback 1999) and, more recently, coastal defenses (Costanza et al., 2008). Few studies have addressed the services associated with coastal wetland mudflats in China.

Furthermore, water-sediment regulation significantly improved the no-flow situation, which replenished 13.56$m^3$of water to the nature reserve of the delta, increasing the water surface area of the core zone and the area close to the estuary considerably. As a result, the wetland ecosystem of the estuarine delta has been clearly restored (Li and Sheng, 2011).

Therefore, a more complete valuation of coastal wetland mudflat ecosystem services in the YRDNNR since the introduction of water-sediment flow regulation will help in evaluating the effectiveness of the regulation in terms of improving ecosystem values at the YRDNNR. It will provide crucial information to the Yellow River Conservancy Commission (YRCC) and the local planners of Dongying municipality to aid efforts to keep the YRDNNR healthy.

1.3. Research Objectives

My project's objective assessed changes in the ecosystem services of the coastal mudflats of the Yellow River National Nature Reserve since water-sediment flow regulation was implemented; more specifically, I want to know how the situation for ecosystem services has changed since the instigation of the water-sediment regulation. I addressed the following questions:

- What are the key ecosystem services associated with the mudflats of the Yellow River Delta Nature Reserve, and what are their economic values?
- How have the ecosystem service values changed over time, specifically concerning the period after the instigation of the water-sediment flow regulation? Is there a discernible pattern of response?

To accomplish the above objectives, I will provide an economic valuation of coastal mudflat ecosystems in the YRDNNR. An extensive list of ecosystem services, and valuation of these ecosystem services in the YRDNNR by land use type, will be provided. Unlike other ecosystem valuation studies that use the static (single point in time) and a non-spatial approach, I took a spatial and dynamic approach. This allowed me to capture the key dimensions of environmental change after the water-sediment regulation. I combined the ecosystem service values with spatial data to analyze the dynamics and spatial patterns of ecosystem change.

To carry out this project, I will collaborate with researchers from China's Institute for Geographical Sciences and Natural Resources Research (IGSNRR), and with the Yantai Institute of Coastal Zone Research (both members of the Chinese Academy of Sciences).

Chapter 2. Literature Review

2.1. Overview of Wetland Ecosystem Services and Functions

Wetlands account for a wide variety of habit types, including rivers, shallow coastal waters and coral reefs, which provide numerous ecosystem services, from habitat provision to pollutant removal, floodwater storage, and microclimate regulation. Wetlands also provide essential ecosystem functions including hydrological functions, biogeochemical functions, and habitat functions (Marsden Jacob Associates, 2012). According to the Paulson Institute (The Paulson Institute, 2016), China's coastal wetlands are home to 16 Ramsar sites and 63 important bird areas, which account for 7.28 and 34.1 percent of the total coastal wetland area in China, respectively.

Wetland ecosystem services can be assigned to four broad categories: provisioning services, regulating services, supporting services, and cultural services. Provisioning services are essentially the products obtained from wetland ecosystems, such as fresh water and fish for human consumption. In 2011, the aquatic products yield in China's coastal zones reached 28 million tons, accounting for nearly 20 percent of the global yield (The Paulson Institute, 2016); regulating services are the benefits obtained from the regulation of ecosystem processes such as purifying water body, local climate regulation, intercepting and absorbing nutrients, controlling soil erosion, and protecting coastline (The Paulson Institute, 2016); supporting services stimulate the production of all other ecosystem services such as nutrient cycling, water cycling, and provisioning of habitat. The Coastal wetlands in China provide habitats for over 240 species of migratory water birds along the East Asian-Australasian Flyway (EAAF); and cultural services are non-physical services that people obtain from the coastal wetlands in order to enrich their spiritual life, which include sight-seeing, recreation, bird watching, etc. Table 1 shows a detailed list of ecosystem services for each service category.

Table 2.1 Wetland ecosystem services

Table 1: Wetland ecosystem services

Ecosystem service	Wetland examples
Provisioning	Food (e.g. fish, crustaceans, game, crops (e.g. rice), wild foods, spices etc.).
	Water (both for consumption and as inputs to other production such as irrigation).
	Water storage (wetlands can be a substitute for dams).
	Water transport.
	Fibre, fuel and other raw materials used in economic production.
	Provision of other industrial inputs (e.g. pharmaceuticals).
	Genetic material (e.g. ornamental species)
	Energy (e.g. input to hydropower, or biomass fuels).
Regulating	Hydrological flow regulation and groundwater recharge/discharge (where water is used for consumptive uses).
	Carbon sequestration.
	Climate regulation (macro).
	Local climate regulation and influence on precipitation.
	Water flow regulations and potential mitigation of flood risk.
	Storm and storm surge protection.
	Purification of water as part of a multi-barrier water treatment train.
	Prevention of saline intrusion.
	Purification of air quality.
	Other waste decomposition and detoxification.
	Crop pollination through the provision of habitat for pollinators.
	Pest and disease control through the provision of filtering services and buffers etc.
Supporting	Biodiversity (including connected habitat and provision of vital flow regimes).
	Nutrient dispersal and cycling.
	Soil formation.
	Seed dispersal.
	Habitat to support primary production.
Cultural	Recreational opportunities.
	Provision of destinations for tourism.
	Aesthetic values translating into utility for visitors and changes in land values close to wetlands.
	Provision of cultural values.
	Provision of historical values.
	Source of intellectual and spiritual inspiration.
	Scientific discovery.

Source: MJA based on a review of literature.

(Source: Marsden Jacob Associates, 2012)

Wetland ecosystem services are ultimately derived from the ecosystem functions performed by wetlands. According to Marsden Jacob Associates (2012), there are three wetland ecological functions: hydrological functions, biogeochemical functions, and habitat functions. Hydrological functions include moderation of water flow and subsequent flood protection; storm surge protection; recharge of groundwater systems; protection of shorelines from erosion; and localised climate regulation. Biogeochemical functions include carbon sequestration and storage; water quality treatment; nutrient export; and the subsequent impact on aquatic food chains. Habitat functions include support for biodiversity (habitat for plants and animals).

2.2. Coastal wetland valuation studies in China

In the past two decades, Chinese scientists have conducted many wetland valuation studies on different scales across China (Zhang et al., 2010) that include various wetland sizes, spatial scales, geographic locations, government designation levels. Jiang Bo et al (2016) conducted a literature analysis using Information Share Index (ISI) Web of Knowledge articles from 1995 to 2010 that include the terms 'ecosystem service' and 'ecosystem services' in their titles, which produced 389 articles. A screening process was then conducted to match the Ramsar Convention wetland definition (RCS, 2006), which produced seven articles. Jiang Bo et al. (2016), categorized the seven articles by temporal extent (static or dynamic), ecological and social data (primary or secondary), and assessment methods (process-based models, land cover maps and valuation methods); only one study was found to be dynamic (temporal aspect), which includes trade-offs among ecosystem services across varying spatial-temporal scales.

Although China has made significant progress on wetland economic valuation, its current approaches for measuring ecosystem services are still in the development stage (Zhang et al., 2010). One of the main gaps in their current approach is the domination of the static valuation method, which does not fully reflect value trade-offs among ecosystem services and land use types as they change through time. Specifically, static analyses are unable to meet managers' needs because they cannot account for the full range of economic trade-offs among ecosystem services across varying spatial-temporal scales.

2.3. General Ecosystem Service Valuation Approaches

2.3.1. Direct market valuation approaches

Direct market valuation approaches use data from actual markets, which include Market Price-based approaches, Cost-based approaches, and Production Function approaches. I will explain each approach in the following sections.

The Market Price-based approach is a simple accounting procedure to value environmental goods or services that are traded in markets; this method is only applicable where market data is available, and it should be used for any ecosystem services that have a formal market. This approach is often used to obtain provisioning service values.

The Cost-based approach infers a value of an ecosystem service based on how much it would cost to replace it. The avoided cost method considers the costs and expenditures incurred in avoiding damages related to reduced environmental functionality, which is used quite frequently in relation to coastal wetland hurricane protection, storm protection, and water quality improvement. This approach is mostly used in risk assessment projects, such as airline safety performance, road safety, etc. (The Paulson Institute, 2016). It is useful in wetland valuation because it estimates how changes in the wetland affect the probability of damage occurring. The Replacement Cost method estimates the value of a change in a nonmarket ecosystem service by calculating the cost of replacing the lost or reduced service with restoration of the ecosystem, or with a manmade substitute that provides the same function as the lost ecosystem service was providing. However, this method tends to overestimate costs, and it has limited validity.

The production function approach takes ecosystem service values, usually indirect services, as inputs into another production process, and focuses on estimating ecosystem services arising from regulatory and habitat functions of ecosystems.

2.3.2. Revealed preference approaches

Revealed Preference Approaches are based on observations of individual choices related to an ecosystem service. Revealed preference methods can provide value estimates for both direct and indirect goods. The most common revealed preference methods in the field of ecosystem service valuation are the Travel Cost Method and Hedonic Pricing Method.

The Travel Cost Method (TCM) uses information on observed travel and time expenditures, and its central assumption is that the benefit an individual receives from a particular site is revealed by the cost to visit it. There are some limitations to this method: it is only applicable in a few contexts, it requires large amounts of data, it becomes inaccurate when trips are multipurpose, and it cannot be used by non-use value ecosystem services or ecosystem services that have existence values (such as polar bears). In the context of wetland ecosystem services, TCM has been used to estimate the recreational value people place on wetland sites; for instance, bird watching, fishing, etc.

The Hedonic Pricing (HP) method assumes that the value of the good of interest may be captured via demand for a marketed good; in most cases, HP is used to relate differences in property prices to variables in the surrounding environment (backyard, good view, good neighborhood, etc.). in other words, how would changes in the surrounding environment affect one's WTP for a house? The HP method is typically used to derive recreational and aesthetic value of residential properties, such as how much more I need to pay for a beach front property compared to a regular property.

2.3.3. Stated preferences approaches

The Stated Preference Approaches involve asking people hypothetical questions to determine how individuals value a change in environmental quality. These approaches include the Choice Experiment Method and the Contingent Valuation Method. These methods can be used to establish the extent of collective WTP for a particular environmental change, or willingness to accept compensation in exchange for bearing a loss. Stated Preference contrasts with Revealed Preference, which deduces people's willingness to pay from observations of responses to real choices.

The Choice Experiment Method (CEM) is a survey-style approach that focuses on individual attributes of a particular ecosystem. Participants are presented with combinations of attributes and asked to decide upon their preferred combination or rank the alternative combinations. Each combination of attributes has an associated price and therefore the respondents reveal their willingness to pay or willingness to accept each attribute. By repeating this process a number of times and surveying a large number of people, the willingness to pay for changes in attributes can be established. This method is very technical and expensive to implement. CEM tend to produce less contested results and is subject to biases, so it can provide useful insights into values for wetland ecosystem services.

The Contingent Valuation Method (CVM) involves asking people directly their WTP for a change in the quantity or quality of a given environmental service; for instance, how much would you be willing to accept in cash if the entire forest near your house was removed? Some of the flaws in this method include length of time, costly survey, design and implementation challenge, various sources of hypothetical and strategic bias, and framing and elicitation effects. CVM is often used for flood protection, and for other research on threatened habitat and species preservation.

2.4. Benefit Value Transfer Method

Although primary research data is always preferred, the realities of the policy process often dictate that benefit transfer is the only feasible option due to limited time and budget (Johnson and Rosenberger, 2010). Benefit transfer was used as early as the 1980s, but it was not common until the early 1990s when researchers began to formalize procedures and protocols (Brookshire and Neill, 1992; Freeman, 2003; Rosenberger and Loomis, 2003; Rolfe, 2006). Some of the pioneers of Benefit Value Transfer include Krupnick (1993), who notes the feasibility of transferring some environmental impacts as a result of the existence of reliable statistical information. The benefit transfer method was also used for health programs, which are facilitated by good epidemiological studies and information on the costs of mortality and morbidity (Barton, 1999). Recent experiments for water quality and water-based recreation have adopted varying approaches, transferring unit values derived from reviews of several similar studies (Boyle and Bergstrom, 1992). Transferring travel cost demand valuation equation between sites can be controversial (Loomis, 1992). According to Smith et al., 2002; Rolfe, 2006; Navrud and Ready, 2007; Columbo and Hanley, 2008, there is not a set of consensus protocols for appropriate benefit transfer, which left benefit transfer remaining unreliable. Moreover, there appears to be a divergence between methods and protocols suggested by the contemporary academic literature and methods applied by policy analysts (Boyle and Bergstrom, 1992; Wilson and Hoehn, 2006; Columbo and Hanley, 2008). Earlier works distinguished between three broad types of benefit transfer: (1) Unit or fixed value transfer; (2) Transfers adjusted using expert judgments and (3) Function transfer, and more recent works often eliminate ‘expert judgments’ as a distinct transfer method, distinguishing primarily between unit value and function transfers (Brookshire and Neill, 1992; Desvousges et al., 1998; Bergstrom and DeCivita, 1999).

2.5. Benefit Function Transfer Method

Benefit function transfer generally refers to meta-analysis function transfer, which is a study of all available empirical studies and is therefore more comprehensive and broadly applicable for benefit transfer. According to Brander et al., meta-analysis (MA) is concerned with a quantitative analysis of statistical summary indicators and some authors even refer to MA as a quantitative literature review (Stanley 2001). From the expediency point of view, a single MA function that is applicable to many activities and species is better than any single demand function from the empirical research literature that is only applicable to one activity. However, if a review of the database provides good indication matches between policy site and a site with an individual demand function or site-specific WTP function, it is likely that the individual demand function or site specific WTP function will be more accurate than the transfer functions extracted from a meta-analysis. It is necessary to bear the ideal criteria for a valid benefit transfer in mind before using the method to make sure the method is not misused. There are three ideal criteria for a valid benefit transfer proposed by Boyle and Bergstrom (1992): a) the nonmarket commodity valued at the study site must be identical to the nonmarket commodity to be valued at the policy site; b) the human populations affected by the nonmarket commodity at the study site and the policy site have identical characteristics; and c) the assignment of property rights at both sites must lead to the same theoretically appropriate benefit measure (e.g., original study uses WTP and a measure of WTP is desired for the policy site). With more than 15 years of development and assessment of methods regarding benefit value function transfer, the literature has come to a consensus over some but not all issues. Although function transfer might reduce the need for similarity across policy and study sites (Loomis, 1992), there is now a fair degree of consensus that site similarity, including similarity of populations, resources, markets and other site attributes, is an important determinant of transfer validity and reliability.

2.6. Spatial Point Pattern Analysis

According to Brazee and Southgate (1993) and Eade and Moran (1996), the traditional approaches to economic valuation were "lacking a geographic dimension" and failed to appreciate spatial variation, and the spatial dimension to economic valuation has barely been investigated. Furthermore, although existing benefit transfer studies will provide sufficient amount of benefit value transfer data, they did not include any spatial dimension in their paper other than economic value maps; therefore, we are lacking in empirical research in terms of the spatial dimension to economic valuation. Eade and Moran (1996) suggested a few ways of utilizing the "geographic dimension" in order to help us better incorporate spatial data with economic valuation. First, GIS data for natural capital offers an additional framework for monitoring environmental progress at various scales, and it could be used to examine the spatial distribution of sustainability by analyzing value changing patterns for a target service or a range of services under the same category, such as provisioning type services. Second, direct comparisons of economic values between economic value maps in different time frames could be used to predict potential vulnerable areas, so more policies can be implemented to conserve these areas. Third, the economic value maps can be used to examine the spatial sensitivity of economic value; for instance, if we want to find out whether nearby human disturbances affect economic values of ecosystem services such as industrial water pollution, we can perform an analysis that has two scenarios--with human disturbances, and without human disturbances--and see if the economic value maps are affected.

Spatial point pattern analysis is a method for analyzing point patterns that are distributed across an entire study region; in addition, a series of point patterns of the same variable recorded at different times can help determine temporal changes in the locational process (MacGrew et al, 2014). Although spatial point pattern analysis contains only point data and no attribute data, it can still be useful to an ecosystem service valuation project such as mine in many ways. First, a spatial point analysis can be used for a single ecosystem service; for instance, bird nursery areas as a supporting service. To carry out such analysis, we would scan all nursery areas in the study area and represent them as points on the map, then we find out whether these points are spatially dispersed, random, or clustered. If the points are dispersed or clustered, we can be certain that there is a spatial pattern of the bird nursery areas. Although the spatial pattern does not tell us why the bird nursery areas are clustered or dispersed, it has provided us with a good starting point to investigate further on bird nursery areas.

Spatial autocorrelation is another useful tool for ecosystem service valuation. Waldo Tobler (1970) stated that “Everything is related to everything else, but near things are more related than distant things.” This quote became known as Tobler’s Law, but, more importantly, it illustrates the phenomenon of spatial autocorrelation. Methods have been developed to account for spatial autocorrelation that consider both location and attributes when analyzing points and areas, and it measures the arrangement of points or areal units in respect to the proximity of locations and the similarity of the attribute characteristics of these locations (MacGrew et al, 2014). Results of spatial autocorrelation can be ‘positive’ meaning nearby locations have similar values and attribute characteristics; ‘zero’ meaning there is no particular systematic structure on how the pattern is formed and on the values of attributes; and ‘negative’, meaning nearby locations have dissimilar or different values and attribute characteristics. This method allows us to look for spatial patterns based on locational data with multiple attributes attached on each data point. Moreover, spatial autocorrelation data can be further used for spatial interpolation to predict ecosystem services spatial distribution patterns (MacGrew et al, 2014). However, spatial autocorrelation data is rarely used in ecosystem valuation projects as they are difficult to obtain.

Chapter 3. Methodology and Data Sources

3.1. Study area

In 1992, China became a member of the Ramsar Convention[1] on wetland conservation, and the Yellow River Delta National Nature Reserve (YRDNNR) was established, covering 1,530 square kilometers, mainly concentrated on the newest lands created by the river. Due to the large quantity of silt carried seaward by the Yellow River, the delta extends into the sea at a rate of 2.2 km/year with a land accretion of 3,240 ha per year. The YRDNNR is mainly marine and coastal wetlands, including 31,314 ha of marine waters, 38.534 ha of intertidal mudflat and 32,772 ha of intertidal reed marshes. The intertidal mudflats within the reserve provide an excellent habitat for waterfowl. Thousands of geese and ducks, plovers and gulls can be observed during the migration seasons; many other water bird and shorebird species are also observed during summer and winter seasons.

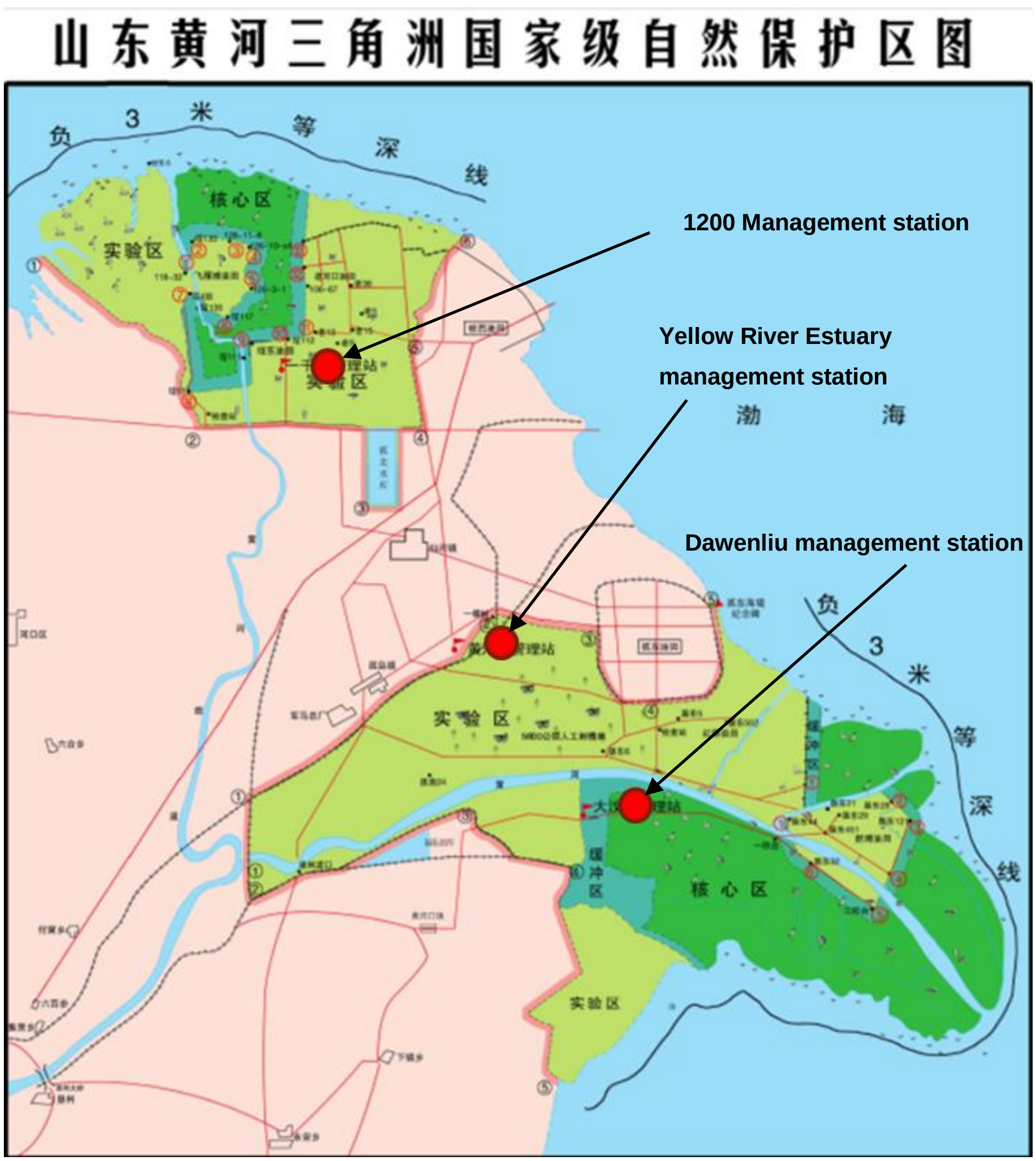
The reserve is managed by Shandong Yellow River Delta National Nature Reserve Administrative Bureau, which was established in December 1992. The Administrative Bureau has full authority over the reserve, and the local communities can continue to do their business (e.g., agricultural activities, fishing) as usual under agreement with the reserve Administrative Bureau. In most cases when there is a conflict, the government will mediate and decide the outcome.

The administrative bureau has three management stations: the 1200 management station, the Yellow River Estuary management station, and the Dawenliu management station (see Figure 3.1), and each station is responsible for a specific area of the reserve. Also, the YRDNNR has three different zones, and each zone has its unique uses. The core zone is where biodiversity and the ecosystem are protected, along with a buffer zone lying between the core and a third, “experimental zone,” where some economic development is permitted. The blue highlighted area in Figure 3.2 is the entire nature reserve, and each zone can be identified based on the legend, which highlights each zone in distinct fashions. It is important to note that my study area will only include

[1] The Ramsar Convention is the convention on wetlands of International importance.

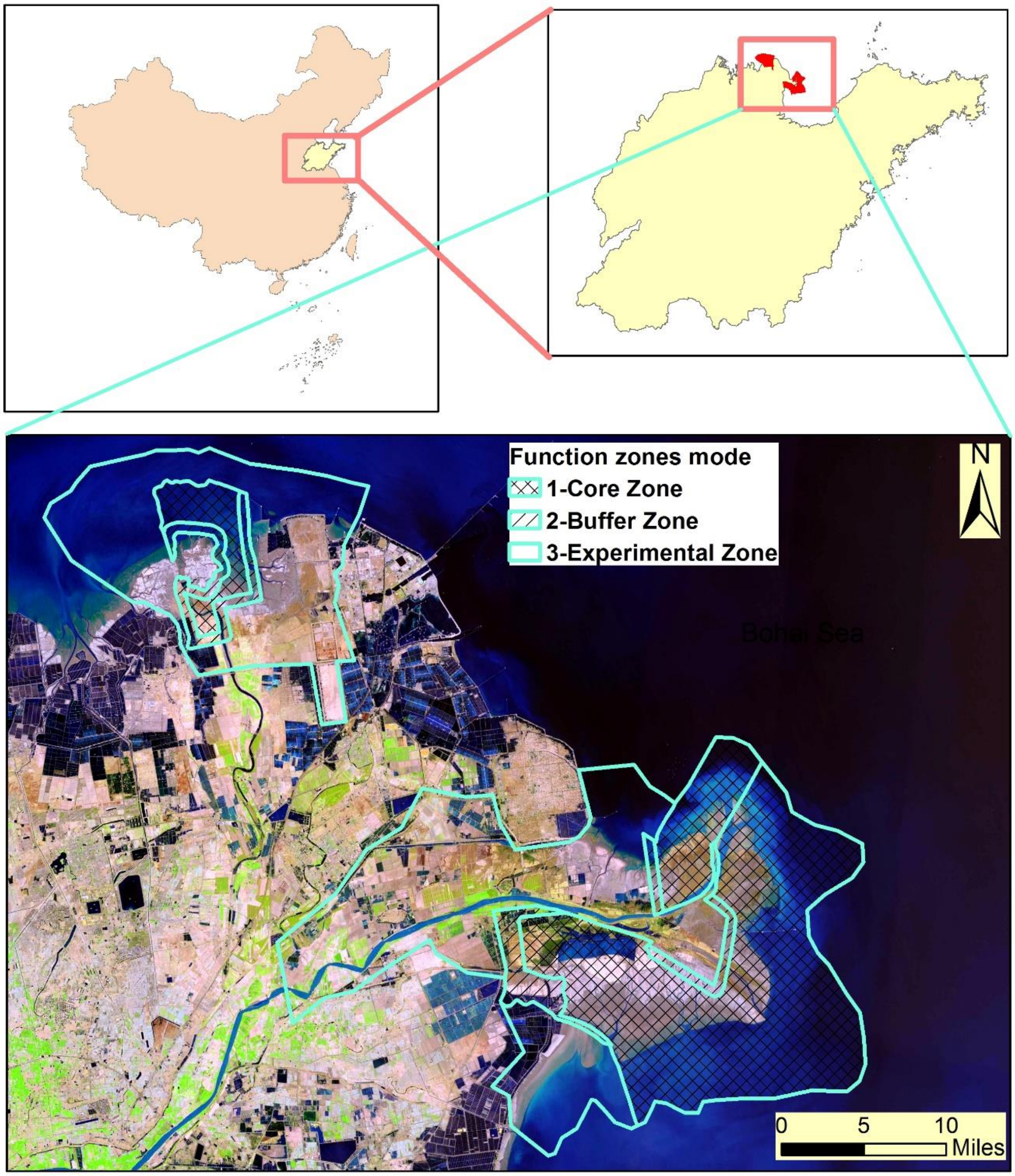
the core zone area managed by Dawenliu station. This area is directly affected by the water-sediment regulation instigated in 2000 (Li and Sheng, 2011) and the point of my research will be to test the effect of the water-sediment regulation on this area in the YRDNNR.

Figure 3.1. Management station locations in the YRDNNR



(Source: Yantai Institute of Coastal Zone Research, CAS)

Figure 3.2. Study area highlighted in red color (core zone managed by Dawenliu station)



(Source: Yantai Institute of Coastal Zone Research, CAS)

3.2. Methodology

I used a 3-step methodology to carry out my research. These steps are described in the following sections.

3.2.1. Step 1: Spatial Analysis

The first step of the spatial analysis was to refine the land use categorization system (see Table 3.1) for China's coastal zone into a specific Yellow River Delta National Nature Reserve (YRDNNR) version to capture the unique land use characteristics of the YRDNNR (see Table 3.2). For example, I "ignored" "Mariculture", as its area is miniscule, as well as "Farmland", and "Grassland" because they are inland wetland land use types, while my research is looking at the coastal wetland ecosystems.

The second step of the spatial analysis was to process the land use area raw data into accessible data. The raw land use area data is shown in Tables A1-3 for each management station within the reserve. As mentioned earlier, I only need the land use area data for Dawenliu management station for my research, so I used Table 3.3 in my research.

The third step of the spatial analysis combined the first step and the second step to make bar graphs by land use type, by year, and by both land use type and year.

The final step of the spatial analysis was to analyze the implication of each graph with the following questions in mind: how each land use type changed over 15 years, whether there are noticeable trade-offs between land use types, and whether there are noticeable trade-offs between water body areas and land areas.

Table 3.1 Land use classification system for China's Coastal Zone

Land Use Classification System and its Definition for China's Coastal Zone

Level 1		Level 2		Description
Code	Name	Code	Name	
1	Farmland			Lands for agriculture
		11	Paddy	Farmlands with water resource guarantee and irrigating facilities using for rice growing
		12	Dry-land	Lands for cultivating without irrigating facilities; dry croplands and lands growing vegetables
2	Forest			Lands growing trees including arbor, shrub, bamboo and lands for forestry use
		21	Forest	Natural or man-made forest with canopy cover greater than 30%
		22	Woods	Lands covered by trees with canopy cover between 10-30%
		23	Shrub	Lands covered by trees less than 2 meters high, the canopy cover > 40%
		24	Other forest	Lands such as tea-garden, orchid and non-grownup forest
3	Grassland			Lands covered by herbaceous plant with coverage grater than 5%, including shrub-grass for pasture and the woods with cover canopies less than 10%
		31	Dense-grass	Grassland with canopy cover grater than 50%
		32	Moderate-grass	Grassland with canopy cover between 20-50%
		33	Sparse-grass	Grassland with canopy cover between 5-20%
4	Built-up			Lands used for urban and rural settlements and factories and transportation facilities
		41	City	Lands used for cities and counties
		42	Rural settlement	Lands used for settlements in villages
		43	Isolated industrial-mining	Lands used for factories, quarries, mining, oil-field slattern outside cities and lands for special uses such as transportation and airport
5	Inland freshwaters (Freshwater wetlands)			Lands covered by natural fresh-water bodies or lands with facilities for irrigation and water reservation in inland area
		51	Rivers	Lands covered by rivers including canals
		52	Lakes	Lands covered by lakes
		53	Reservoir and ponds	Man-made facilities for water reservation
		54	Bottomland	Lands between normal water level and flood level
6	Coastal saltwater (Saltwater wetlands)			Wetlands on the coast with saline waters
		61	Beach and shore	Lands between high tide level and low tide level
		62	Estuarine waters	Permanent water of estuaries and rivers that being affected by tidal waters
		63	Estuarine delta	Alluvial low plain in estuary area, usually composed of sandy island, sandbank and spit
		64	Coastal lagoons	Brackish to saline lagoons with at least one relatively narrow channel connected to the sea
		65	Shallow water (along coast)	Areas at low tide depth of 6 m below sea level, including gulfs and straits
7	Human made (saltwater) wetland	71	Saltern/Salt field	Salt exploitation sites on the shoals, usually including evaporation ponds, crystallizing ponds and ancillary facilities
		72	Mariculture	Ponds usually constructed and managed for commercial aquaculture production
8	Unused	81	Unused	Lands that is not put into practical use or difficult to use and has very sparse vegetation, such as saline land, bare soil, bare rock, and so on

(Source: Yantai Institute of Coastal Zone Research, CAS)

Table 3.2 Land Use Types Present in the YRDNNR

Land Use Types Present in the YRDNNR
Rivers
Reservoir & ponds
Bottomland (water body)
Beach and shore
Estuarine waters
Estuarine delta
Coastal lagoons

Table 3.3 Dawenliu Management land use area (unit: ha)

Nature Reserve area (station)#	Land Use Category Level 1	Year	2000	2005	2010	2015
		Land Use Category Level 2	Core Zone	Core Zone	Core Zone	Core Zone
2 (Dawenliu)	7 (Inland freshwaters)	51 (Rivers)	0	0	138.18	256.56
		53 (Reservoir and ponds)	0	0	0	6.95
		54 (Bottomland)	0	2428.72	5399.57	5382.56
	8 (Mudflats)	61 (Beach and shore)	11842.1	8908.06	10616.99	10598.78
		62 (Estuarine waters)	173.13	1028.63	128.69	562.94
		63 (Estuarine delta)	16456.89	22964.55	18959.56	19335.92
		65 (Coastal lagoons)	23068.17	19040.56	18569.69	17544.94
		Total	51540.29	54370.52	53812.68	53688.65

3.2.2. Step 2: Assigning Ecosystem Services to Land Use Types for the YRDNNR

According to much empirical benefit transfer research, each land use type (LUT) contains various ecosystem services (ES). I will assign all ecosystem services in the YRDNNR to land use types based on four YRD ecosystem valuation papers that contain ecosystem service and land use type mapping (Li et al. 2013., Han Mei& Zhang Xiao-hui, 2009., Liu Jiang, 2008., and Li Lin, 2011).

I gathered mapping tables from all four YRD papers and combined them together with the purpose of creating a universal mapping table for the YRDNNR (see table 3.4). I then used a “two check marks” rule to create the universal mapping table (see table 3.5) for the Yellow River Delta National Nature Reserve. As mentioned in section 3.2.1, I removed “Grassland”, “Farmland”, and “Mariculture”, as I decided to exclude these land use types from my study area. [2]

Table 3.4 Mapping ES to LUT using four papers from the YRD (labelled A to D[3])

		Land Use Types																							
		Shallow area				Riverine Wetland				Mudflat Wetland				Grassland				Mariculture				Fish Ponds			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Ecosystem Services	Food production			√								√													√
	Material production										√			√		√	√	√			√				
	Nitrogen production																								
	Climate regulation					√		√			√	√		√	√	√	√								
	Water supply						√	√																	
	Water reserve and flood control													√		√	√								
	Water Purification					√		√			√			√		√	√								
	Erosion control and soil protection						√	√			√	√		√		√	√								
	Nutrient cycling	√			√	√			√	√			√					√			√				
	Habitat provision	√			√	√			√	√	√		√	√				√			√				
	Tourism	√		√	√	√		√	√	√	√	√	√	√		√	√	√			√				
	Cultural	√		√	√	√		√	√	√	√	√	√	√		√	√	√			√				
	Biodiversity	√		√		√		√			√	√													
	Land creation						√																		
	Shipping				√		√		√	√	√	√													

[2] Each ecosystem service must have at least two check marks to stay in the mapping table.
[3] Paper A, "Modern Yellow River Delta Wetland Ecosystem Service Function Value Assessment Study” by Li et al., 2013.
Paper B, “Value Estimates of the Dominant Ecosystem Services in Yellow River Delta Wetland” by Han Mei& Zhang Xiao-hui, 2009.
Paper C, “Valuation on the Ecosystem of Coastal Wetlands in the Yellow River Delta” by Liu Jiang, 2008.
Paper D, “Research on Ecosystem Services Evaluation of the Modern Yellow River Delta Wetland based on 3S technology” by Li Lin, 2011.

Table 3.5 Universal LUT and ES mapping for the YRDNNR using "two check marks" rule

		Land Use Types		
		Shallow area	Riverine Wetland	Mudflat Wetland
Ecosystem Services	Climate regulation		√	√
	Water supply		√	
	Water Purification		√	
	Erosion control and soil protection		√	√
	Recreation	√	√	√
	Cultural	√	√	√
	Habitat provision	√	√	√
	Shipping		√	√

The next step is to translate the land use type names in Table 3.5, which are "Shallow area", "Riverine Wetland", and "Mudflat Wetland", into land use type name in the land use data, which are "Rivers", "Reservoir and ponds", "Bottomland (water body)", "Beach and shore", "Estuarine waters", "Estuarine delta", and "Coastal lagoons". I made another table for this step (see Table 3.6) based on land use classifications from 15 Yellow River delta studies, ten of which are in Chinese.

Table 3.6 LUT translation from original LUT names to desirable LUT names

Shallow area	>>>>>	Coastal lagoons	Reservoir& ponds	
Mudflat Wetland	>>>>>	Estuarine delta	Beach&shore	
Riverine Wetland	>>>>>	Rivers	Bottom land (water body)	Estuarine waters

With Table 3.6, I was able to create my final mapping table, which is later used in the ecosystem service value (ESV) calculation process (see Table 3.7).

Table 3.7 Final LUT and ES mapping

		Land Use Types						
		Rivers	Reservoir& ponds	Bottomland (water body)	Beach& Shore	Estuarine waters	Estuarine delta	Coastal lagoons
Ecosystem Services	Water supply	√		√		√		
	Water quality improvement	√		√		√		
	Climate regulation	√		√	√	√	√	
	Non-consumptive recreation	√	√	√	√	√	√	√
	Cultural	√	√	√	√	√	√	√
	Natural habitat and biodiversity	√	√	√	√	√	√	√
	Shipping	√		√	√	√	√	
	Soil formation and protection	√		√	√	√	√	

3.2.3. Step 3: Calculating Total Economic Value (TEV) for the YRDNNR for each year

Once I completed the land use type and ecosystem service mapping table (Table 3.7), and the land use area table of my study area (Table 3.3), I was able to calculate the total economic value for each land use type for all my data point years, which are 2000, 2005, 2010, and 2015.

The first step using the BVT approach was to process the dataset. My original raw dataset is shown below (Table 3.8).

Table 3.8 Raw BVT dataset

Obs	Province/ City	Study Area (Wetland)	Year of research	Wetland type	Study area (km2)	Flood control and storm buffering (RMB/ha)	Water supply	Water quality improvement	Gas regulation	Climate regulation	Nonconsumptive recreation	Cultural	Natural habitat and biodiversity	Shipping	Soil formation and protection
1	Anhui	Anqing Yangtze Riverine Wetland	2010	Lacustrine	1043.52	23449.47869	1188.285802	1111.622202		17680.54278	5491.030359	54191.58234	1935.755903		5682.689359
2	Anhui	Shengjin Lake	2008	Lacustrine	333.4	16676.66467	15296.94061	11367.72645	7078.584283		1760.64787	1247.75045	827.8344331		
3	Anhui	Chao Lake Basin	2006	Lacustrine	15595.57		79717.50952	9836.767749	6270.370368	19122.73806	2057.635598		6266.523122		16320.66029
4	Anhui	Wetland in Yangtze River Basin (Anhui)	2006	Lacustrine	15471.45	14268.21662	1557.061555	6989.002324	32939.38189		975.3449095	785.9638237	508.6788892		
5	Hubei	Natural reserve of Yangtze river	2004	Riverine	19		9757.894737	106.1578947		2189		2134.315789	52968.10526		11588.68421
6	Hubei	Baoan Lake	1992	Lacustrine	39.3	24735.44529	3073.536896	3967.938931	22603.51145						
7	Hubei	Hong Lake	2003	Lacustrine	414.12	25069.18285	4926.108374	3747.730127	544.9145175			3204.50594	2128.006375		2208.466145
8	Hubei	Chinese Sturgeon Natural Reserve, Yangtze R	2005	River wetland	80		5472.5	10375			3063.75	7472.5	36518.75	7560	
9	Hubei	Liangzi Lake	2005	Lacustrine	379.46	12122.48985	2424.497971	33415.90681	9618.932167			6113.951405	2424.497971		8222.21051
10	Hubei	Zhangdu Lake	2008	Lacustrine	185	66468.64865	46252.97297	990.972973		3404.432432	1081.621622	1000.324324	2588.594595		
11	Hunan	Dongting Lake	2004	Lacustrine	2625	192404.9524	89904.7619	106.2857143			22405.33333		18739.80952	5284.571429	747.8095238
12	Jiang Su	Tai Lake (National Tourism Resort)	2007	Huaman-Made	160	59.375		77.90625	46.5		1406.1875	11	635.04375		
13	Jiang Su	Heavy Polluted Area in Tai Lake Basin	2007	Lacustrine	5271.56		4924.538467	4482.544067	559.606644	608.9279075	1086.964769		1069.892024		777.7583865
14	Jiang Su	Tai Lake	2003	Lacustrine	2427.8	33388.25274	103517.5879	135.9255293	29738.85823		3365.186589	366.5870335	2500.205948	218.3046379	4.118955433
15	Jiang Su	Tai Lake	2007	Lacustrine	2338	12609.06758	12639.0077	1142.001711		8763.90077	4208.725406	6325.919589	196.7493584		
16	Jiang Su	Hongze Lake	2005	Lacustrine	1597	11070.75767	2003.757044	1565.435191	5879.774577			807.7645585	322.6675016		
17	Jiang Su	Yangtze River Coastal Zone	2008	Rivermouth Wetland	13092	26823.25084			424.6868317	2008.860373	46761.381	587.3816071			19369.08035
18	Jiang Su	Yangtze River Coastal Zone	2008	Rivermouth Wetland	13092	2731.439047			35.13596089	151.2373969	4359.914452	577.451879			229.147571
19	Jiang Su	Tai Lake	2008	Lacustrine	36940	17300	7000	17200	12000		100900			37000	100
20	Jiangxi	Poyang Lake	2002	Lacustrine	3950	40379.74684	300.7594937	35341.77215	11189.87342				2523.291139		2170.632911
21	Shan Dong	Yellow River Delta Wetland	2013	Coastal zone wetland	5450	1146.788991		2060.550459		881.6513761	1298.165138	2031.192661			346.7889908
22	Shan Dong	Yellow River Delta Wetland	2009	Coastal zone wetland	5450					3277.06422	1335.779817	1055.045872	1416.513761		1381.651376
23	Shan Dong	Yellow River Delta Coastal Wetland	2009	Coastal zone wetland	5450	12549.90826	2880.366972	6793.394495	1264.220183		26239.44954	3721.834862			440
24	Shan Dong	Yellow River Delta	2011	Coastal zone wetland	5450	24271.55963			7620.183486	26447.70642	4134.862385	4134.862385	8790.825688		10662.38532
25	Shan Dong	Yellow River Delta Wetland	2011	Coastal zone wetland	5450	1110.091743		1867.889908		792.6605505	1260.550459	2022.018349	1194.495413		313.7614679
26	Shan Dong	Yellow River Delta Wetland	2012	Coastal zone wetland	5450	9869.724771	2592.66055	7332.110092		3277.06422	1335.779817	1055.045872	1416.513761		1381.651376
27	Shanghai	Yangtze river estuary	1998	Coastal zone wetland	2150		716.2790698	1585.209302	534.9302326			6133.023256	1328.511628		4186.046512
28	Shang Dong	Yellow River Delta Wetland	2006	Coastal zone wetland	3746.26	37.37060428		1489.774869	1592.131886	1688.770934	94.49424226		613.9456418		
29	Shan Dong	Yellow River Delta Wetland	2007	Coastal zone wetland	14588			6376.809021	789.4803948	2827.22923		1363.688648	1456.570469		1650.462024
30	Shan Dong	Yellow River Delta Wetland	2010	Coastal zone wetland	3334.27	16132.46678	4237.809176	11984.63232		5356.494825	2183.386468		2315.349387		2265.563377
31	Shan Dong	Yellow River Delta Wetland	2004	Coastal zone wetland	8330.214	8210.713434		4444.543682	1462.627491		873.9271284		2029.719765		290.7488331
32	Shan Dong	Yellow River Delta Wetland	2011	Coastal zone wetland	26300			5853.231939	1579.087452	5480.608365		1713.688213	1821.673004		2209.505703
33	Shan Dong	Yellow River Delta Wetland	2009	Coastal zone wetland	2933.8371	2062.14585		3469.858637		1472.474392	2341.643304		2218.937105		582.8544468
34	Shan Dong	Yellow River Delta Wetland	2013	Coastal zone wetland	6685.41	7062.465877		7644.525915	1689.330946	6084.904292		2274.256927	2677.081884		2252.635216
35	Shan Dong	Yellow River Delta Wetland	2005	Coastal zone wetland	2550.858			5422.152076	864.8501798	3785.490999		1680.583553	1385.600453		1625.621654
36	Shan Dong	Yellow River Delta Wetland	2012	Coastal zone wetland	1111.2287	2258.760955		21174.75908		2384.747622	49134.80006		2060.781907		6443.318104
37	Shan Dong	Yellow River Delta Wetland	2006	Coastal zone wetland	1839.955		5695.791473	29239.84554	1114.157683		4016.402575		2130.486887		14902.53838
38	Shan Dong	Yellow River Delta Wetland	2007	Coastal zone wetland	1639.63			6512.749828	578.4054939	2345.426102		1098.9089	1334.871282		1313.748224
39	Shan Dong	Yellow River Delta Wetland	2009	Coastal zone wetland	2123.81	6355.99936	6488.339352	4081.998861	5280.62774		13876.66505		5292.375495		8.366567631
40	Shan Dong	Yellow River Delta Wetland	2005	Coastal zone wetland	1165.8235	3602.603653	34653.61609		3.834199602				2487.512046		
41	Shan Dong	Yellow River Delta Wetland	2001	Coastal zone wetland	6021.02	14251.23982	426.8379776	681.4792178	3740.279886		1074.419284		912.8021498		
42	Shan Dong	Yellow River Delta Wetland	2006	Coastal zone wetland	6000			103.3333333		375	1240		15098.33333		
43	Shan Dong	Yellow River Delta Wetland	2013	Coastal zone wetland	5124.69	65564.94149		25562.52183		161961.0162	4097.808843		1853.770667		56003.38752
44	Shan Dong	Yellow River Delta Wetland	2002	Coastal zone wetland	4588			112.6852659	306.0156931		137.3147341		193.766347		79.77332171

Using the raw BVT dataset, I was able to make an ecosystem service value table (Table 3.9) that has averages, medians, maxes, and mins for each ecosystem service.

Table 3.9 Ecosystem service value table

MODEL: Average values	Flood control and storm buffering (RMB/ha)	Water supply (RMB/ha)	Water quality improvement (RMB/ha)	Gas regulation (RMB/ha)	Climate regulation (RMB/ha)	Non consumptive recreation (RMB/ha)	Cultural (RMB/ha)	Natural habitat and biodiversity (RMB/ha)	Shipping (RMB/ha)	Soil formation and protection (RMB/ha)
AVG	22388.50806	17905.97687	7583.455173	5770.69977	11765.33123	10116.10233	4350.429	5057.495891	12515.72	5492.564582
MEDIAN	12609.06758	4926.108374	4444.543682	1579.08745	3052.146725	2183.386468	1697.136	1982.737834	6422.286	1638.041839
MAX	192404.9524	103517.5879	35341.77215	32939.3819	161961.0162	100900	54191.58	52968.10526	37000	56003.38752
MIN	37.37060428	300.7594937	77.90625	3.8341996	151.2373969	94.49424226	11	193.766347	218.3046	4.118955433

The second step of the calculation is to determine the values per hectare for each land use type. This calculation makes use of two core components: first, the economic value table that has the "average", "median", "max", and "min" for each ecosystem service (see Table 3.9); and, second, the land use type and ecosystem service mapping table (see Table 3.7). I used the data in the highlighted row in table 3.9 in the calculation, which is the average monetary value per hectare for each ecosystem service.

Table 3.10 Total economic value for each land use type

	Unit: RMB	Land Use Types						
		Rivers	Reservoir &ponds	Bottomland (water body)	Beach & shore	Estuarine waters	Estuarine delta	Coastal lagoons
Ecosystem Services	Water supply	17905.97687		17905.97687		17905.97687		
	Water quality improvement	7583.455173		7583.455173		7583.455173		
	Climate regulation	11765.33123		11765.33123	11765.33123	11765.33123	11765.33123	
	Non consumptive recreation	10116.10233	10116.10233	10116.10233	10116.10233	10116.10233	10116.10233	10116.10233
	Cultural	4350.428778	4350.428778	4350.428778	4350.428778	4350.428778	4350.428778	4350.428778
	Natural habitat and biodiversity	5057.495891	5057.495891	5057.495891	5057.495891	5057.495891	5057.495891	5057.495891
	Shipping	12515.71902		12515.71902	12515.71902	12515.71902	12515.71902	
	Soil formation and protection	5492.564582		5492.564582	5492.564582	5492.564582	5492.564582	
	Total RMB/ha	**74787.07387**	**19524.027**	**74787.07387**	**49297.64183**	**74787.07387**	**49297.64183**	**19524.027**

Then, I replaced the check marks in the land use type and ecosystem mapping table (Table 3.7) with the averaged values for each ecosystem service in the ecosystem service value table (Table 3.10) and finally obtained the total per hectare RMB[4] values for each land use type (Table 3.11).

[4] RMB (人民币) is the official Chinese monetary currency

Table 3.11 Total RMB value per hectare generated by each land use type

Land Use Types	Total RMB/ha
Rivers	74787.07387
Reservoir &ponds	19524.027
Bottomland (water body)	74787.07387
Beach & shore	49297.64183
Estuarine waters	74787.07387
Coastal lagoons	19524.027
Estuarine delta	49297.64183

The final step of the BVT calculation is to apply the land use type per hectare values in Table 3.14 to the land use area table of my study area (Table 3.6): more specifically, the total economic value for each land use type for each year is calculated by multiplying the per hectare value for each land use type by its corresponding area, as described below:

$V_i\ (LU_t) = A_i\ (LU_t)\ X\ V\ (LU_t)$ **(1)**

where $V_i\ (LU_t)$ = total economic value of land use type (t) for year (i),

$A_i\ (LU_t)$ = area of land use type (t) for year (i), and $V\ (LU_t)$ = total economic value per hectare generated by land use type (t).

With eq. (1), I was able to calculate the total economic value for the YRDNNR (study area) by adding all land use type economic values with eq. (2).

$V_i = \sum_t^n V_i\ (LU_t)$ **(2)**

where V_i = Total Economic Value (TEV) for the YRDNNR for year $_i$, and $V_i\ (LU_t)$= TEV for land use type t for year i.

3.3. Data Source

The two sets of data used in my project, a spatial dataset and benefit value transfer value dataset, were both provided by the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences. The Yantai Institute of Coastal Zone Research (YIC) is affiliated with the Chinese Academy of Sciences (CAS) and is the sole

Chinese academic institution that specializes in comprehensive research of the coastal zone.

The spatial dataset contains many data categories, including land use data for the YRDNNR, the land use categorization system, land use maps of the YRDNNR generated by ArcGIS[5], and land use area data. Land use data for the YRDNNR for 2000, 2005, 2010, and 2015 were constructed using China's coastal zone remote sensing categorization system developed by Zhi et al (2014), and Landsat TM/ETM+/OLI remote sensing data for 2000, 2005, 2010, and 2015 (downloaded from United States Geological Survey website, http://glovis.usgs.gov/). The land use categorization system consists of eight level one categories and 24 level two categories. In addition, all maps were made based on DEM, NDVI, Soil maps of YRDNR, and field research notes. Land use area tables for each management station within the reserve were also included.

The benefit value transfer dataset contains 44 Chinese mainland ecosystem service valuation papers, 27 of which are inland studies that we provided by Dr. Xiaowei Li of Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, and the rest of the papers are Yellow River delta ecosystem service valuation studies that were provided by Dr. Xiyong Hou, also of the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences.

[5] ArcGIS is a geographic information system (GIS) for working with maps and geographic information.

Chapter 4. Results

4.1. Spatial Analysis

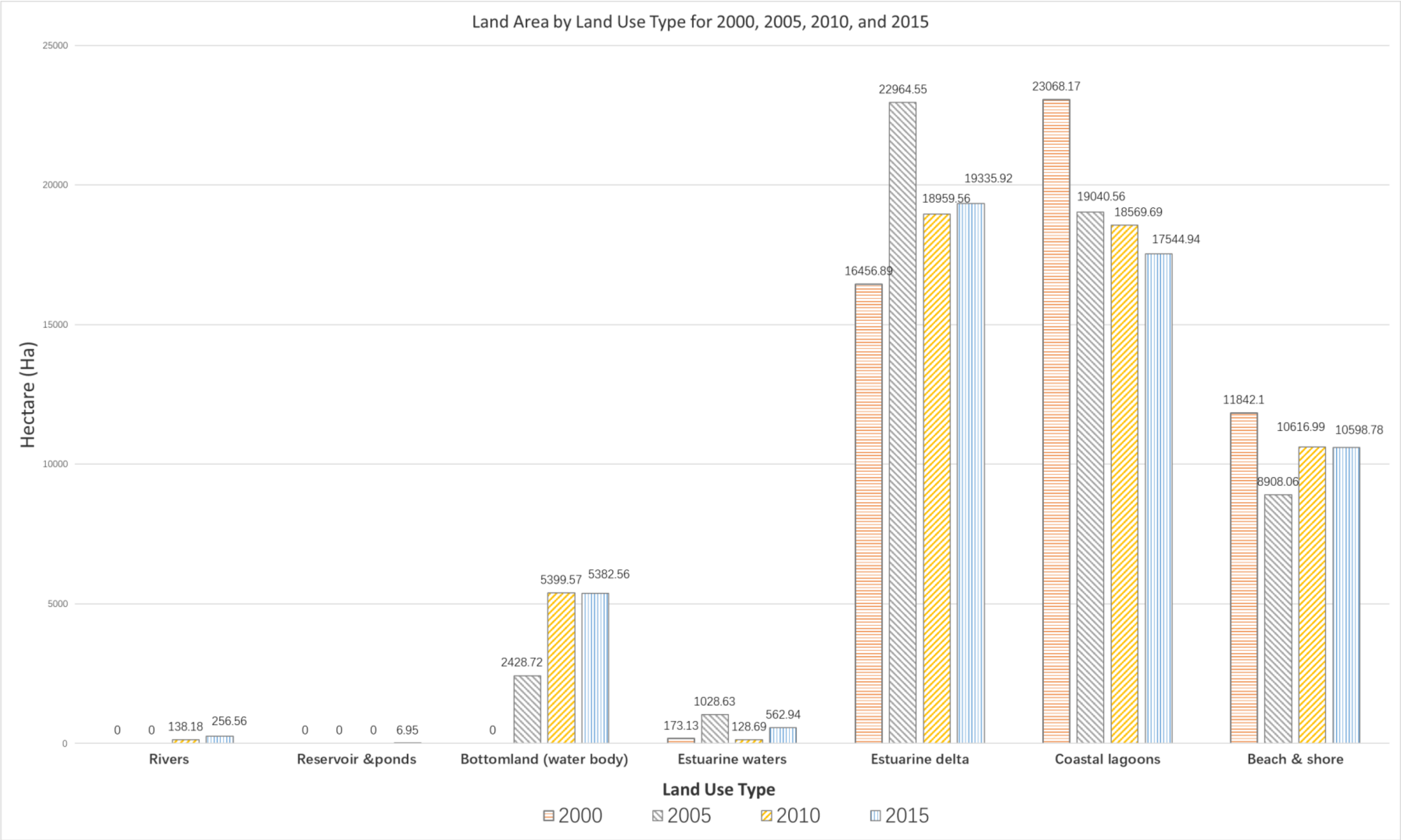
Since the spatial changes and total economic values in my study are closely related, it is crucial to discuss the spatial changes for my study area before discussing the economic values.

Figure 4.1 shows areas for each land use type in 2000, 2005, 2010, and 2015. Rivers and reservoir & ponds have areas under 300 hectares, which can be considered insignificant compared to the entire study area, which has up to 54,000 hectares. Therefore, rivers and reservoir & ponds will not make any impact on the total economic values (TEV) of my study area even if they contain many valuable ecosystem services.

All land use types have somewhat noticeable area changes except for rivers and reservoir & ponds. Next, I will describe these changes in detail for each land use type. Coastal lagoons were at their highest point in 2000, which went down dramatically in 2005, then continued to go down at a much slower rate till 2015. Estuarine Delta increased dramatically from 2000 to 2005. Beach and Shore had decreased sharply from 2000 to 2005, then went back up to 10,616.99ha in 2010. Bottomland (water body) did not exist in 2000, had 2,428.72ha in 2005, then went up dramatically in 2010. Estuarine waters had an unstable trend in areas, which went up in areas in 2005 almost ten times compared to its area in 2000, then went down to 128.69ha in 2010 and back up to 562.94ha in 2015.

In conclusion, all land use types except rivers and reservoirs & ponds will potentially impact the TEV of the YRDNNR. In addition, if we take a closer to look at the trend of area change for the five land use types, we can clearly see the trade-offs in areas among estuarine delta, coastal lagoon, and bottomland (water body).

Figure 4.1 Land Area by Land Use Type for 2000, 2005, 2010, and 2015



4.2. Total economic value (TEV) results for each Land Use Type (LUT) and entire study area for each year using Benefit Value Transfer (BVT) method

First, let's look at the total economic value (TEV) for the entire study area. Figure 4 shows the TEV for the YRDNNR in RMB using the Benefit Value Transfer (BVT) method. The TEV for the YRDNNR was 1.8584 billion RMB (0.296 billion USD) in 2000, 2.2016 billion RMB (0.351 billion USD) in 2005, 2.2444 billion RMB (0.357 billion USD) in 2010, and 2.2822 billion RMB (0.363 billion USD) in 2015. We can clearly see a steady upward trend throughout the 15-year period. Next, I will break down the TEV for the YRDNNR into individual land use types to find the reason/s behind this upward TEV trend.

Figure 4.2 TEV for the study area in 2000, 2005, 2010, and 2015

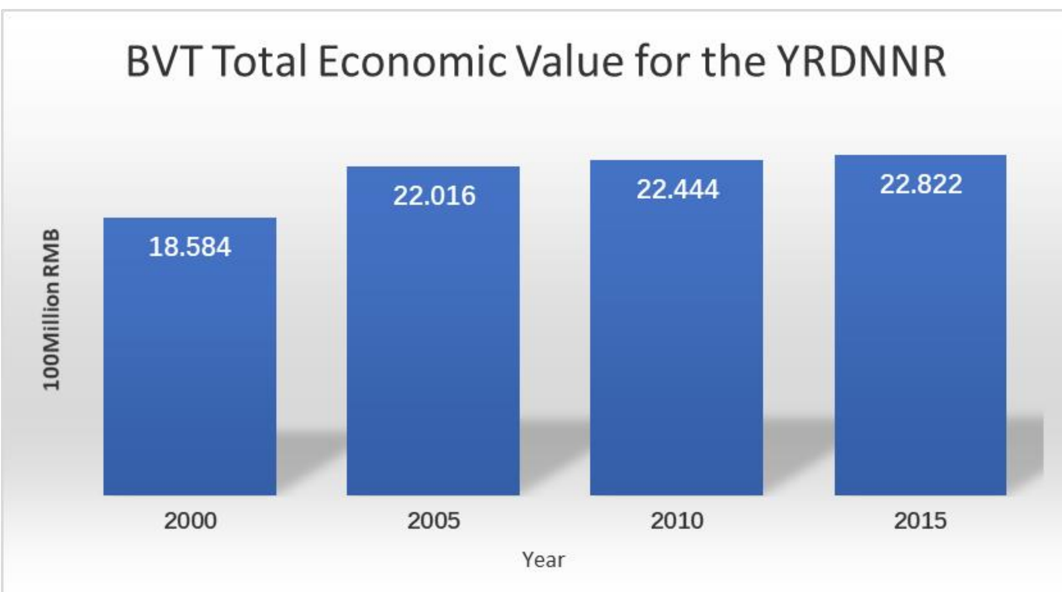


Table 4.1 shows the TEV for each land use type and Figure 4.2 shows the TEV trends for each land use type from 2000 to 2015. The TEV trend in detail for each land use type is as follows. Both river and reservoir& ponds have negligible TEVs, which will not have any impacts on the TEV trending. Beach & shore had TEV of 0.5838 billion RMB (0.09 billion USD) in 2000, 0.4391 billion RMB (0.07 billion USD) in 2005, 0.5234 billion RMB (0.083 billion USD) in 2010, and 0.5225 billion RMB (0.0832 billion USD) in 2015. Beach & shore had a constant steady TEV trend in general, except that there was a distinct decline from 0.5838 billion RMB (0.093 billion USD) in 2000 to 0.4391 billion RMB (0.07 billion USD) in 2005, followed by increases to 0.5234 billion RMB (0.083 billion USD) and 0.5225 billion RMB (0.0832 billion USD) in 2010 and 2015, respectively.

Coastal lagoons had TEV of 0.4504 billion RMB (0.072 billion USD) in 2000, 0.3717 billion RMB (0.059 billion USD) in 2005, 0.3626 billion RMB (0.058 billion USD) in 2010, and 0.3425 billion RMB (0.0545 billion USD) in 2015. Coastal lagoons' TEV declined sharply from 0.4504 billion RMB in 2000 to 0.3717 billion RMB in 2005 (0.072 to 0.059 billion USD) and continued decreasing from 2005 to 2015. Estuarine delta increased sharply from TEV of 0.8113 billion RMB in 2000 to 1.1321 billion RMB in 2005 (0.129 to 0.18 billion USD) and decreased to 0.9347 (0.149 billion USD) and 0.9532 billion RMB (0.152 billion USD) in 2010 and 2015, respectively. Estuarine delta had a very noticeable leap in TEV from 0.8113 billion RMB in 2000 to 1.1321 billion RMB (0.129 to 0.18 billion USD) in 2005. Bottomland's TEV had a steep upward trend throughout the 10-year period from 2000 to 2010 and stayed almost the same in TEV for 2015. Estuarine waters had TEV of 0.0129 billion RMB (2.054 million USD) in 2000, 0.0769 billion RMB (12 million USD) in 2005, 0.0096 billion RMB (1.528 million USD) in 2010, and 0.0421 billion RMB (6.7 million USD) in 2015. The general trend for estuarine waters' TEV is rather elusive, but it is important to note that it increased by about 600% in TEV (2.054 million USD to 12 million USD) from 2000 to 2005. Bottomland (water body) had TEV of zero in 2000, 0.1816 billion RMB (28.922 million USD) in 2005, 0.4038 billion RMB (64.31 million USD) in 2010, and 0.4025 billion RMB (64.104 million USD) in 2015[6].

[6] USD/RMB = 6.28, data retrieved from XE currency, https://www.xe.com/, 2018/04/19

Table 4.1 TEV table by land use type for 2000, 2005, 2010, and 2015

Unit:100Million RMB	Year			
Land Use Types	2000	2005	2010	2015
Rivers	0.000	0.000	0.103	0.192
Reservoir &ponds	0.000	0.000	0.000	0.001
Bottomland (water body)	0.000	1.816	4.038	4.025
Estuarine waters	0.129	0.769	0.096	0.421
Estuarine delta	8.113	11.321	9.347	9.532
Coastal lagoons	4.504	3.717	3.626	3.425
Beach & shore	5.838	4.391	5.234	5.225
Total	18.584	22.016	22.444	22.822

Figure 4.3 TEV by land use type for 2000, 2005, 2010, and 2015

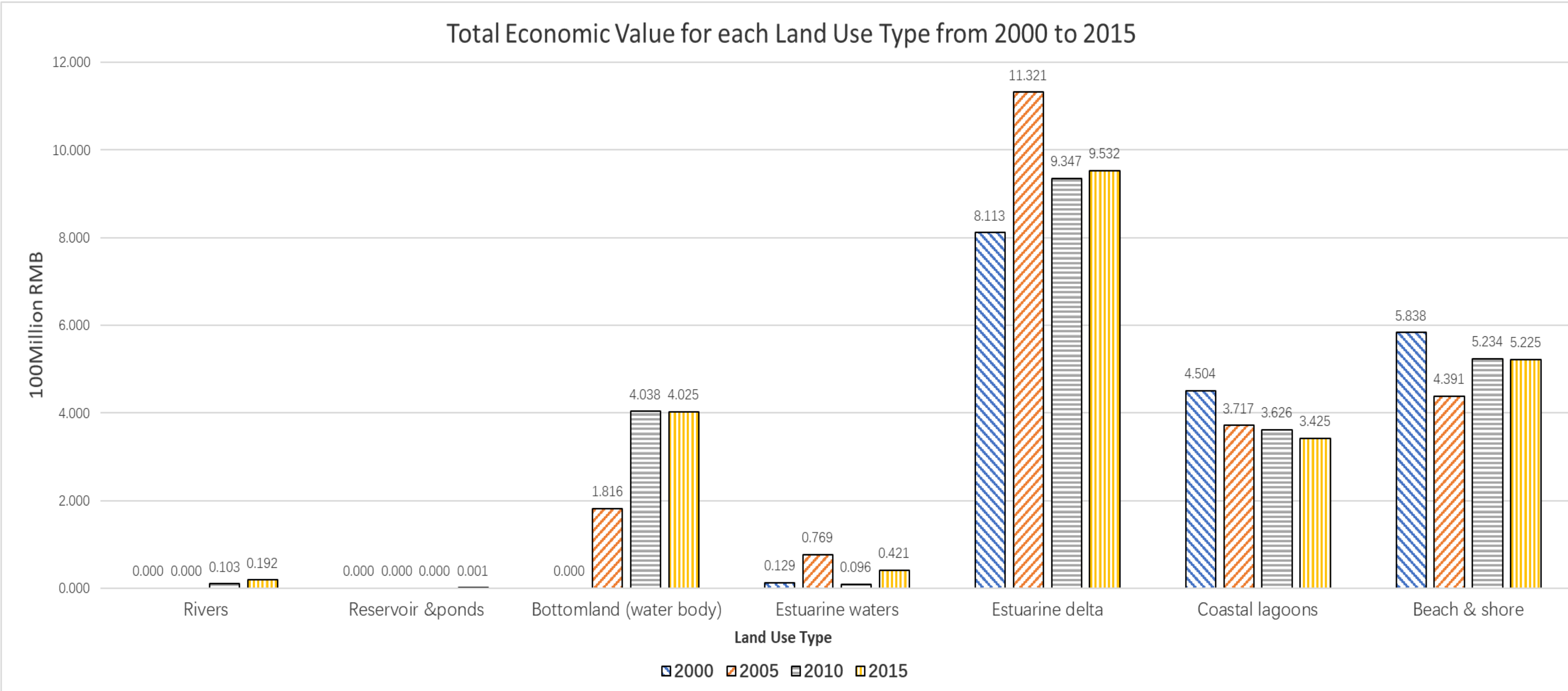


Figure 4.3 shows the TEV using BVT for each land use type in 2000, 2005, 2010, and 2015. This figure will help us to identify the main drivers for the TEV of my study area. Because the BVT is calculating TEV for each land use type by using Eq. (1), which is to multiply the area of an individual land use type by its per unit value (RMB/ha), the main drivers of the TEV for each individual land use type are its area and per unit value (RMB/ha). In the following paragraph, I will identify land use types with significant TEVs based on Figure 4.3 and determine whether their TEV is driven by their area, by their per unit value, or by both based on Table 3.14 (per unit value table) and Figure 4.1 (land use area bar chart).

Table 4.2 Share of each land use type in total area of 2000, 2005, 2010, and 2015

Year/LUT	Rivers	Reservoir &ponds	Bottomland (water body)	Estuarine waters	Estuarine delta	Coastal lagoons	Beach & shore
2000	0.00%	0.00%	0.00%	0.34%	31.93%	44.76%	22.98%
2005	0.00%	0.00%	4.47%	1.89%	42.24%	35.02%	16.38%
2010	0.26%	0.00%	10.03%	0.24%	35.23%	34.51%	19.73%
2015	0.48%	0.01%	10.03%	1.05%	36.01%	32.68%	19.74%
4-year Average	0.18%	0.00%	6.13%	0.88%	36.35%	36.74%	19.71%

Figure 4.4 Share of each land use type in total area of 2000, 2005, 2010, and 2015

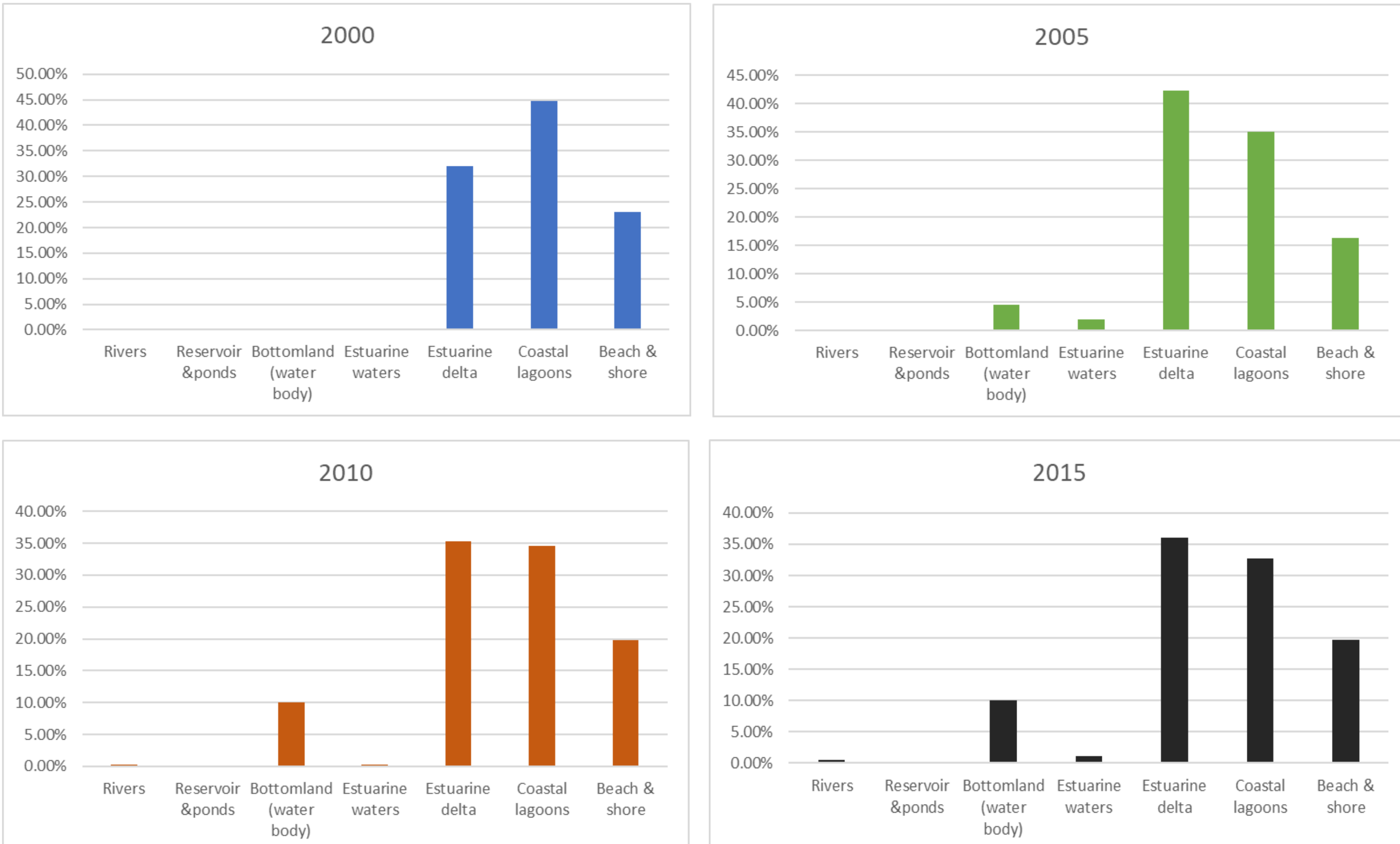


Table 3.14 shows the value per unit (RMB/ha) generated by each land use type, which I will use to examine the TEV driver for each land use type. From Figure 4.3, we can clearly see that bottom land, estuarine delta, coastal lagoons, and beach & shore have significant TEVs in comparison to the rest of the land use types.

According to Table 3.14, bottom land (water body) has a per unit value of 74787.074 RMB/ha, which is the highest unit value among all land use types; however, based on the land use type area bar charts in Figures 4.4, bottom land had notably larger proportions in area than rivers, reservoir& ponds, and estuarine waters but had smaller proportions in area than bottomland (water body), estuarine delta, coastal lagoons, and beach& shore, which was 6.13% on average from 2000 to 2015 (Table 4.2). Therefore, unit value is the main TEV drivers for bottomland, and area is the weaker TEV driver compared to unit per value.

Estuarine delta has a per unit value of 49297.642 RMB/ha, which is slightly higher than the average level of unit value for all land use types. In addition, as the land use type area bar charts indicate, estuarine delta also has a dominating share in area compared to other land use types, averaging 36.4% from 2000 to 2015 (Table 4.2). Therefore, the strongest TEV driver for estuarine delta is its areas, and per unit value is the weaker TEV driver.

Coastal lagoons has per unit value of 19524.027 RMB/ha, which is the lowest among all land use types; however, according to Table 4.2, coastal lagoons had an average area proportion of 36.74%, which is the highest among all land use types. Therefore, area is the strong TEV driver for coastal lagoons and unit per value will be considered as a TEV driver as well, but a lot weaker.

Beach & shore had a per unit value of 49297.642 RMB/ha, which is above the average unit value for all land use types. As the land use area bar charts (Figure 4.4) indicate, beach & shore had a greater proportion of the areas than other LUTs, and was ranked third among all land use types at 19.7% (Table 4.2) from 2000 to 2015. Therefore, LUT area is the stronger TEV driver for beach & shore between unit per value and LUT area, and unit per value is the moderate TEV driver.

Table 4.3 shows the importance of bottomland (water body), estuarine delta, coastal lagoons, and beach & shore in influencing TEV. This influence is divided between two factors, unit value and area. The importance is indicated as “Strong”, “Moderate”, or “Weak”. Table 4.3 suggests that estuarine delta has the most influence on TEV among all land use types, and since the unit values stay constant in my BVT calculations, changes in TEV of the YRDNNR depend highly on changes in the area of estuarine delta.

Table 4.3 Influence of Bottomland, Coastal lagoons, Estuarine delta, and beach & shore on Total Economic Value (TEV)

Land use types	Importance of TEV influential factors	
	Unit Value	Area
Bottomland (water body)	***	*
Estuarine delta	***	***
Coastal lagoons	*	***
Beach & shore	**	**

Note: (*) = Weak; (**) = Moderate; (***) = Strong

Chapter 5. Discussion

My first research question is “What are the key ecosystem services associated with the mudflats of the Yellow River Delta National Nature Reserve, and what are their economic values?”. Finding the total ecosystem service values requires three steps. First, segment the study area by land use type (Table 3.2). Second, find the value of ecosystem services associated with each land use type by plugging in benefit transfer values by land use type and using an ecosystem service mapping table (Table 3.10). Third, obtain total economic values results for each land use type (Table 3.13) and for the entire study area (Figure 4.2).

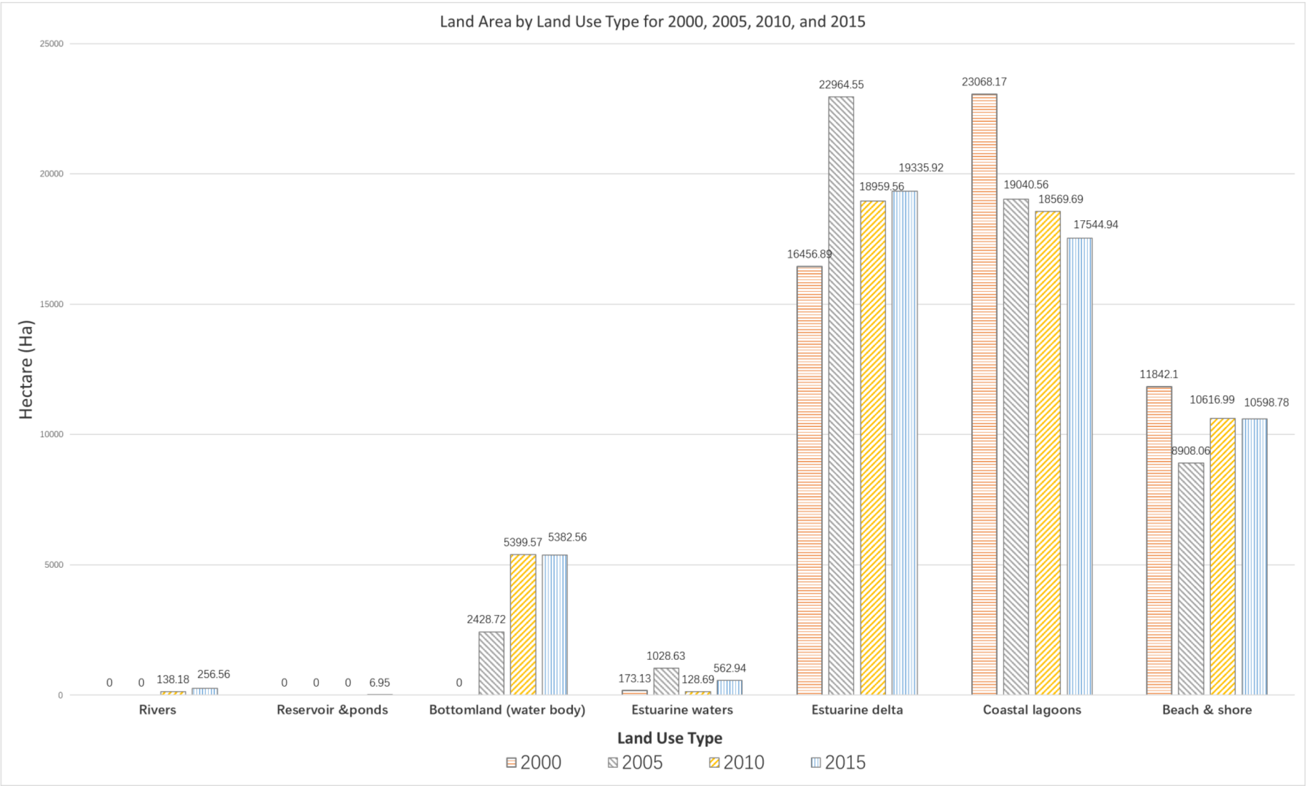
My second research question is “How have the ecosystem service values changed over time, specifically considering the period following instigation of the water-sediment flow regulation? Is there a discernible pattern on response?” Overall, the total economic value (TEV) for ecosystem services in the YRDNNR had an upward trend from 2000 to 2015. It makes sense that the overall TEV for the YRDNNR was increasing from 2000 to 2015 because the water-sediment regulation conducted in the early 2000s would improve the drought situation in the Yellow River delta, which would increase the TEV in the YRDNNR.

Why does the TEV of Ecosystem Services in the YRDNNR increase from 2000 to 2015?

The reason behind the upward trend of the TEV for the YRDNNR from 2000 to 2015 is explained as follows: The TEV for the YRDNNR is calculated by adding the TEVs of all land use types in the YRDNNR, so both the area changes for each land use type and the unit value for each land use type will be crucial to land use type TEVs and study area TEV.

Figure 4.1 (reproduced below as Figure 5.1) indicates that from 2000 to 2005, the areas for bottomland (water-body), estuarine waters, and estuarine delta increased to 5399.57ha, 1028.63ha, and 22964.55ha, respectively. This can be explained by the increased water flow from the upper-reaches of the Yellow River that resulted from the water-sediment regulation. Coastal lagoons and Beach & shore’s area decreased to 19040.56ha and 8908.06 from 2000 to 2005, respectively, which is explained by the land use area increases from bottomland, estuarine waters, and estuarine delta. As stated at the end of the Chapter 4, among all land use types, estuarine delta has the greatest influence on the YRDNNR's TEV; therefore, the upward trend of the estuarine delta's area contributes the most to the YRDNNR's TEV.

Figure 5.1 Land Area by Land Use Type for 2000, 2005, 2010, and 2015



In conclusion, the trend of the YRDNNR's TEV is directly related to the trade-offs between its land use types. And the land use trade-offs are caused by the water-sediment regulation instigated in the early 2000s. The rational explanation is: after the implementation of water-sediment regulation in early 2000s, the water-flow at lower reaches of the Yellow River including the YRDNNR greatly improved, which resulted in more bottomland (waterbody), estuarine waters, and estuarine delta. This makes sense as these land use types are formed by the scouring effect of water flow; more specifically, coastal lagoons were turned into estuarine waters and delta as the water body become deeper and had a faster rate of flow (Sriyanie, 2013). Therefore, the ultimate reason that explains the upward trend for the YRDNNR's TEV is both the high value per unit[7] and large areas of estuarine delta, which kept YRDNNR's TEV at a steady upward trend from 2000 to 2015 after trading off TEVs with coastal lagoons and beach & shore, which have declining TEVs from 2000 to 2015.

Sensitivity Analysis

From table 3.12, which is the ecosystem service value table for each ecosystem service concluded from 44 studies/data observations, we can see that quite a few ecosystem services had volatile data ranges in terms of max/average/min values. For example, the ecosystem service, cultural, had a max unit value of 54191.58 RMB/ha and a min unit value of 11 RMB/ha. Water quality improvement had a max unit value of 103517.5879 RMB/ha and a min unit value of 77.90625 RMB/ha. From these examples, we can clearly see the credibility issue with this dataset that has only 44 data observations. I tried to mitigate this issue with a sensitivity analysis. First, I eliminated the top and bottom 5 data points in my dataset to reduce volatility, thereby increasing the overall reliability of the dataset (Table 5.1). Second, I calculated TEV results for the study area separately using new max, average, and min values (Table 5.2).

Total economic value results for max values are shown in Figure 5.2. From the figure, we can see that the results show similar upward trend from 2000 to 2015 as before (Figure 4.2) with a distinct leap from 2.79 billion RMB to 3.33 billion RMB (0.44 billion USD to 0.53 billion USD) from 2000 to 2005.

Total economic value results for average values are shown in Figure 5.3. From the figure, we can see the same upward trend as in Figure 5.2, as well as the distinct leap from 2000 to 2005. However, the only difference between Figure 5.3 and Figure 5.2 is that average TEVs have less values in general compared to max TEVs.

Total economic value results for min values are shown in Figure 5.4. As expected, TEV has an upward trend with a leap in values from 2000 to 2005; however, it is important to note that the TEVs are much less in scale compared to TEVs for max and average values, which range from 0.187 to 0.22 billion RMB (29 million USD to 35 million USD).

[7] Unit per value refers to total ecosystem service value generated by a particular land use type per year

Figure 5.5 shows TEVs for max, average, and min values for the study area from 2000 to 2015. We can see that even after the data volatility is reduced by eliminating top and bottom 5 data observations from original value dataset, the data ranges from max TEV to min TEV are still extremely spread out, or in other words, volatile; for example, TEV for year 2000 ranges from 0.187 to 2.79 billion RMB (29 million to 0.44 billion USD), and TEV for year 2015 ranges from 0.22 to 3.45 billion RMB (35 million to 0.55 billion USD).

In conclusion, the sensitivity analysis suggests that there are serious concerns about data reliability and credibility for my dataset. In terms of data reliability, the low number of 44 data observations is far from optimal, and data reliability would be improved by adding more data observations. In terms of data credibility, as the Benefit Value Transfer (BVT) method is becoming more and more prevalent in Chinese wetland ecosystem valuation studies, data credibility could be a serious issue as more studies are transferring values from one another

Limitations of the study

Water-birds such as the red-crowned crane and the white oriental stork have major biodiversity and recreational values and have increased greatly in numbers since the initiation of water-sediment regulation in the early 2000s. This is mainly because the area of suitable habitats for water-birds has increased (Cao, M. et al., 2008). Values involving water-birds were not accounted for in my research project because of a limited research budget and little long-term bird count data and few valuation estimates. Most likely, the TEV of the YRDNNR from 2000 to 2015 would have a more pronounced upward trend if water-bird values were included in the research. Furthermore, as indicated in the ecosystem services and land use type map (Table 3.7), all land use types contain the ecosystem services involving water-birds, which are non-consumptive recreation, cultural, and habitat and biodiversity, and water-birds values do not change when LUT areas do, so, the effects of LUT area change on water-bird values were not fully captured. A potential solution to this problem is to put weights on each LUT in terms of importance to water-birds; for example, most water-birds in the YRDNNR rest on estuarine deltas, which means estuarine delta would increase water-birds value the most, so that assigning a higher weight on estuarine delta would be optimal.

In addition, China's current ecosystem service valuation approach is dominated by static valuation, which is one of the main reasons that its approaches are still in the development stage. Static valuation methods do not fully reflect value trade-offs among ecosystem services and land use types, and they usually take the form of single points in time. My research fills this gap by providing a dynamic approach with temporal aspects, which accounts for economic trade-offs among land use types across varying temporal scales (2000, 2005, 2010, 2015). However, there is still room to improve in terms of the reliability of this research, as only 44 data observations are used for the Benefit Value Transfer (BVT) method and this method has limitations.

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Table 5.1 Modified BVT dataset

Flood control and storm buffering (RMB/ha)	Water supply (RMB/ha)	Water quality improvement (RMB/ha)	Gas regulation (RMB/ha)	Climate regulation (RMB/ha)	Nonconsumptive recreation (RMB/ha)	Cultural (RMB/ha)	Natural habitat and biodiversity (RMB/ha)	Shipping (RMB/ha)	Soil formation and protection (RMB/ha)
26823.25084	15296.94061	17200	9618.932167	6084.904292	13876.66505	4134.862385	6266.523122	37000	10662.38532
25069.18285	12639.0077	11984.63232	7620.183486	5480.608365	5491.030359	3721.834862	5292.375495	7560	8222.21051
24735.44529	9757.894737	11367.72645	7078.584283	5356.494825	4359.914452	3204.50594	2677.081884	5284.571429	6443.318104
24271.55963	7000	10375	6270.370368	3785.490999	4208.725406	2274.256927	2588.594595	218.3046379	5682.689359
23449.47869	6488.339352	9836.767749	5879.774577	3404.432432	4134.862385	2134.315789	2523.291139		4186.046512
17300	5695.791473	7644.525915	5280.62774	3277.06422	4097.808843	2031.192661	2500.205948		2265.563377
16676.66467	5472.5	7332.110092	3740.279886	3277.06422	4016.402575	2022.018349	2487.512046		2252.635216
16132.46678	4926.108374	6989.002324	1689.330946	2827.22923	3365.186589	1713.688213	2424.497971		2209.505703
14268.21662	4924.538467	6793.394495	1592.131886	2384.747622	3063.75	1680.583553	2315.349387		2208.466145
14251.23982	4237.809176	6512.749828	1579.087452	2345.426102	2341.643304	1363.688648	2218.937105		2170.632911
12609.06758	3073.536896	6376.809021	1462.627491	2189	2183.386468	1247.75045	2130.486887		1650.462024
12549.90826	2880.366972	5853.231939	1264.220183	2008.860373	2057.635598	1098.9089	2128.006375		1625.621654
12122.48985	2592.66055	5422.152076	1114.157683	1688.770934	1760.64787	1055.045872	2060.781907		1381.651376
11070.75767	2424.497971	4482.544067	864.8501798	1472.474392	1406.1875	1055.045872	2029.719765		1381.651376
9869.724771	2003.757044	4444.543682	789.4803948		1335.779817	1000.324324	1935.755903		1313.748224
8210.713434		4081.998861	578.4054939		1335.779817	807.7645585	1853.770667		777.7583865
7062.465877		3967.938931	559.606644		1298.165138		1821.673004		747.8095238
6355.99936		3747.730127	544.9145175		1260.550459		1456.570469		582.8544468
3602.603653		3469.858637	534.9302326		1240		1416.513761		440
2731.439047		2060.550459			1086.964769		1416.513761		346.7889908
2258.760955		1867.889908			1081.621622		1385.600453		313.7614679
		1585.209302					1334.871282		290.7488331
		1565.435191					1328.511628		
		1489.774869					1194.495413		
		1142.001711					1069.892024		
		1111.622202					912.8021498		
		990.972973					827.8344331		
		681.4792178					635.04375		
		135.9255293							

Table 5.2 Max/Average/Min value for each ecosystem service

	Flood control and storm buffering (RMB/ha)	Water supply (RMB/ha)	Water quality improvement (RMB/ha)	Gas regulation (RMB/ha)	Climate regulation (RMB/ha)	Nonconsumptive recreation (RMB/ha)	Cultural (RMB/ha)	Natural habitat and biodiversity (RMB/ha)	Shipping (RMB/ha)	Soil formation and protection (RMB/ha)
Average	13877.21122	5960.916622	5190.123375	3055.920822	3255.897715	3095.367049	1909.111706	2079.757583	12515.71902	2598.014066
Max	26823.25084	15296.94061	17200	9618.932167	6084.904292	13876.66505	4134.862385	6266.523122	37000	10662.38532
Min	2258.760955	2003.757044	135.9255293	534.9302326	1472.474392	1081.621622	807.7645585	635.04375	218.3046379	290.7488331

Figure 5.2 TEV for the study area from 2000 to 2015 using max values

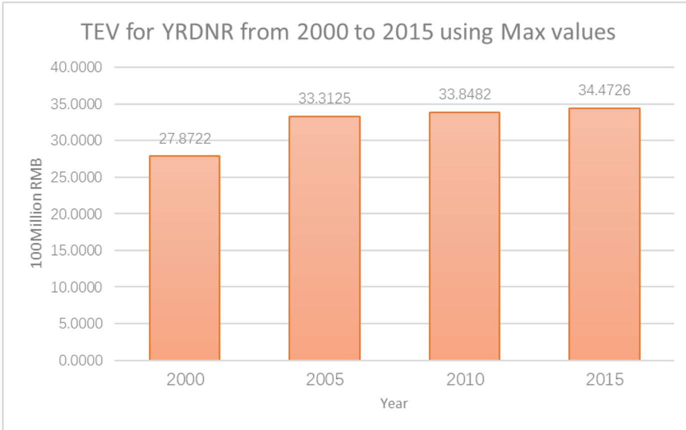


Figure 5.3 TEV for the study area from 2000 to 2015 using average values

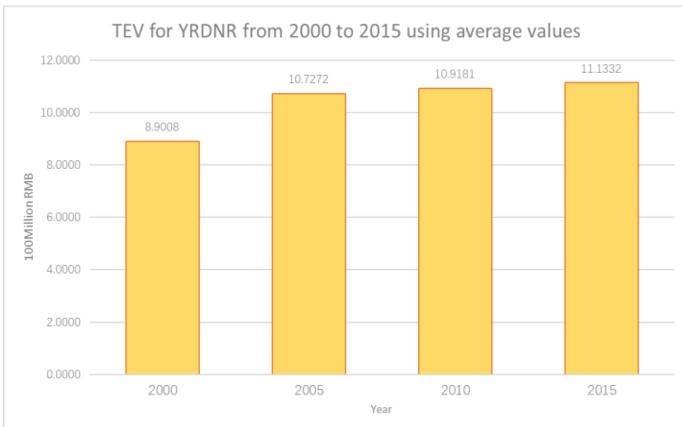


Figure 5.4 TEV for the study area from 2000 to 2015 using min values

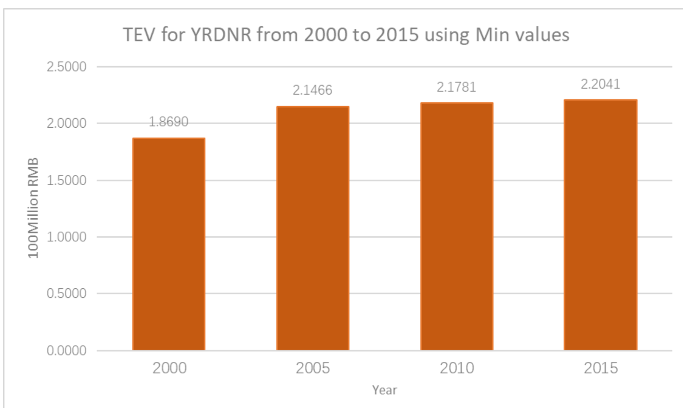
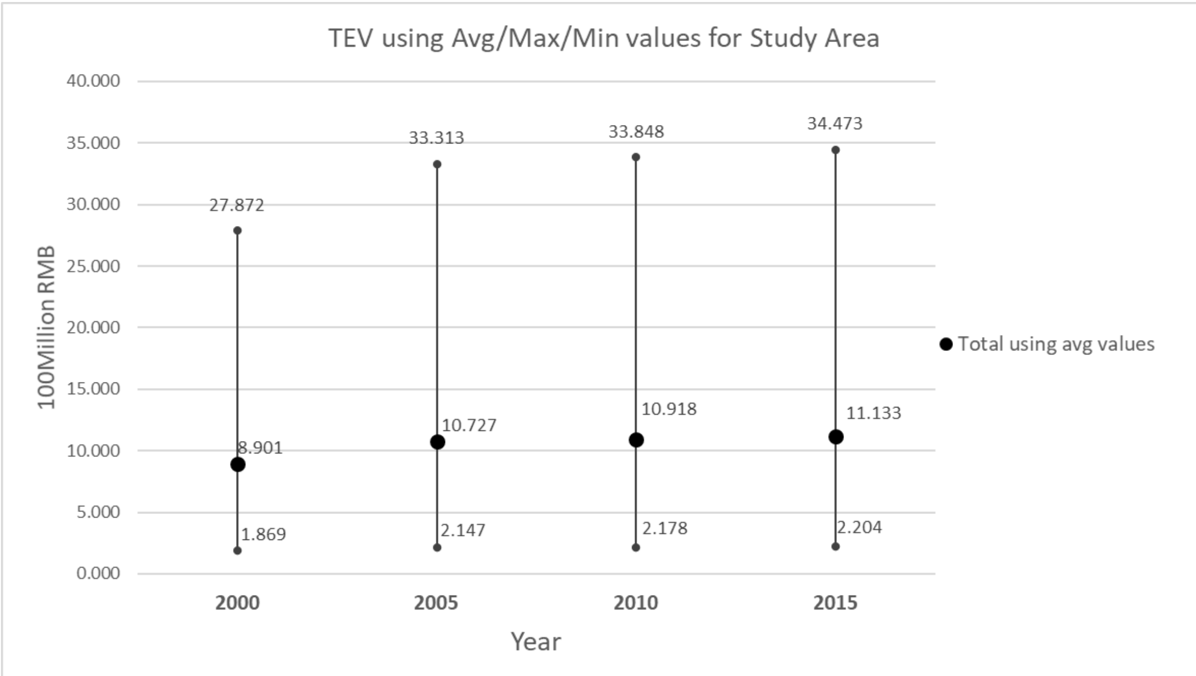


Figure 5.5 TEV using Max/Average/Min values for the study area from 2000 to 2015



Chapter 6. Conclusion

The main findings of this paper include spatial and value aspects. In terms of spatial aspects, some land use types such as rivers and reservoir & ponds have insignificant areas, and therefore have been excluded. From 2000 to 2015, bottomland (water body), estuarine waters, and estuarine delta had an upward trend in area, while coastal lagoons and beach & shore had a downward trend in area. In value aspects, the total economic value (TEV) of the YRDNNR had a steady upward trend from 2000 to 2015, the main reason being the trend of estuarine delta to increase in area while coastal lagoons decreased in area, but estuarine delta has a higher per unit value than coastal lagoons; therefore, the TEV for the YRDNNR went up from 2000 to 2015. Furthermore, the reason that the area of estuarine delta was increasing while the area of coastal lagoons was decreasing is the increased amount of water-flow resulting from the water-sediment regulation. Even though the TEV of the YRDNNR had an upward trend from 2000 to 2015, biodiversity and recreational values from water-birds were not included in my research, and it is possible that the TEV of the YRDNNR would have had a steeper upward trend if water-birds were included.

Management Implications

My study will help the local government and decision makers from two perspectives. First, it provides a detailed land use type and ecosystem service map and total economic values for the study area and for each individual land use type, which identify the valuable land use types in the study area. Second, my study brought in the spatial-temporal aspect for land use types, which keeps track of area changes for each LUT from 2000 to 2015. Using this information, the local government and its decision makers will be able to find the valuable LUTs and the change patterns of their areas, helping them in terms of LUT protection priority, as well as decision making in terms of short-term and long-term sustainability. In addition, these findings can be a useful reference source for future Yellow River delta and YRDNNR related ecosystem valuation studies.

Future Research

Consumption preference changes due to rising income level should be reflected in future research, as my study assumes income level stays constant, which is unrealistic.

However, since preference change cannot be directly measured, an income proxy should be used. More specifically, value tables should be adjusted with income change as consumption level per capita and income level per capita are generally positively related.

In addition, the results would be more accurate if my research included spatial data before the year 2000, which would enable comparison of TEVs for the YRDNNR before and after the water-sediment regulation. Also, as mentioned in the sensitivity analysis section, data credibility is becoming an issue, as more and more Chinese valuation studies are starting to use the BVT method. Therefore, there is a need for more primary valuation research, and it is planned that future research collaboration will develop additional data sets and replace BVT approach with state preference research.

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Appendix A. Study Area Land Use Data

Table A1. Yellow River Estuary Management land use area (unit: ha)

RNO[8]	LU1[9]	Year	2000		2005		2010		2015	
		LU2	Core Zone	Buffer Zone	Core Zone	Buffer Zone	Core Zone	Buffer Zone	Core Zone	Buffer Zone
1	2	21	0	0	0	0.01	0	0	0	0
	3	31	29.62	92.18	0	0	0	0	45.96	0
	7	51	11.81	8.37	10.10	8.37	134.46	2.52	176.05	3.72
		54	0	0	0	0	115.43	4.50	66.68	3.30
	8	62	81.01	0	114.38	0	166.78	0	370.31	0
		63	1426.41	338.72	2356.30	430.89	3024.14	461.52	3904.88	461.52
		65	7259.23	261.22	6327.31	261.22	5367.29	231.94	4244.22	231.94
		Total	8808.10	700.48	8808.10	700.48	8808.10	700.48	8808.10	700.48

[8] RNO = 1 (Yellow River Estuary station), RNO = 2 (Dawenliu nature reserve station); RNO = 3 (“1200 hectare” station).
[9] LU1: Land use categorization level 1; LU2 Land use categorization level 2.

Table A2. Dawenliu Management land use area (unit: ha)

RNO	LU1	Year	2000		2005		2010		2015	
		LU2	Core Zone	Buffer Zone	Core Zone	Buffer Zone	Core Zone	Buffer Zone	Core Zone	Buffer Zone
2	1	12	577.31	940.04	577.31	1145.56	685.12	1050.83	685.12	1111.33
	3	31	3258.61	900.73	428.39	166.57	413.03	136.57	408.54	136.57
		32	0	0	0	0	397.54	118.23	394.53	3.12
		33	0	0	0	0	0	7.80	131.54	0
	6	43	10.18	91.44	10.18	91.43	63.66	7.25	63.66	7.25
	7	51	0	0	0	0	138.18	14.27	256.56	16.98
		53	0	0	0	21.53	0	32.86	6.95	116.76
		54	0	38.83	2428.72	520.31	5399.57	733.42	5382.56	760.88
	8	61	11842.10	551.22	8908.06	129.88	10616.99	233.10	10598.78	233.10
		62	173.13	0	1028.63	0	128.69	13.18	562.94	10.47
		63	16456.89	2874.49	22964.55	3301.65	18959.56	2310.10	19335.92	2455.27
		65	23068.17	0	19040.56	0	18569.69	0	17544.94	0
	10	72	0	0	0	19.82	14.36	739.14	14.36	545.02
		Total	55386.39	5396.75	55386.39	5396.75	55386.39	5396.75	55386.39	5396.75

Table A3 "1200 hectare" Management land use area (unit: ha)

RNO	LU1	Year	2000			2005			2010			2015		
		LU2	FZM1[10]	FZM2[11]	FZM3[12]	FZM1	FZM2	FZM3	FZM1	FZM2	FZM3	FZM1	FZM2	FZM3
3	1	11	0	0	0	0	0	847.19	0	0	815.60	0	0	815.60
		12	218.99	152.00	1089.63	218.99	152.00	3199.05	218.99	152.57	3760.96	218.99	152.57	3517.67
	3	31	0	0	1337.72	0	0	209.48	0	0	209.48	0	0	209.48
		32	432.14	743.44	3461.00	432.13	746.06	3410.75	225.40	274.05	2174.76	225.40	274.05	2171.57
		33	0	21.78	1116.23	0	6.85	728.64	0	2.87	1572.68	0	1.95	1491.86
	6	43	0	16.79	1580.46	0	16.79	2479.39	9.05	23.71	2211.43	9.05	23.71	3235.76
	7	51	151.87	202.29	89.29	151.87	202.29	89.29	73.25	172.84	89.29	151.87	202.29	122.23
		52	0	0.57	73.55	0	0.57	73.55	0	0	0	0	0	0
		53	10.04	0	2234.19	10.04	0	1386.99	10.04	0	1224.87	10.04	0	1224.88
		54	0	0	508.34	0	0	508.34	78.62	29.45	0	0	0	0
	8	61	471.53	487.85	2495.83	553.30	591.52	2785.05	1323.89	1670.77	7741.04	1323.89	1631.87	8036.10
		62	0	0	0	0	0	0	0	0	0	0	38.90	134.60
		63	852.36	1205.66	5600.05	770.26	1047.87	4437.02	0	0	0	206.74	438.81	15.86
		65	3367.07	1053.34	16728.42	3367.40	1053.71	16730.69	3358.03	1043.18	16622.78	3358.03	1043.18	16622.78
	9	71	0	122.78	442.77	0	188.85	507.49	0	198.25	638.19	0	199.17	667.77
	10	72	0	0	0	0	0	0	0	0	0	0	0	307.30
	11	81	0	0	2390.48	0	0	1755.04	206.74	438.81	2086.88	0	0	574.52
		Total	5504.00	4006.50	39147.96	5504.00	4006.50	39147.96	5504.00	4006.50	39147.96	5504.00	4006.50	39147.96

[10] FZM 1 = Core Zone
[11] FZM 2 = Buffer Zone
[12] FZM 3 = Experimental Zone

Appendix B.

Benefit Function Transfer experiment

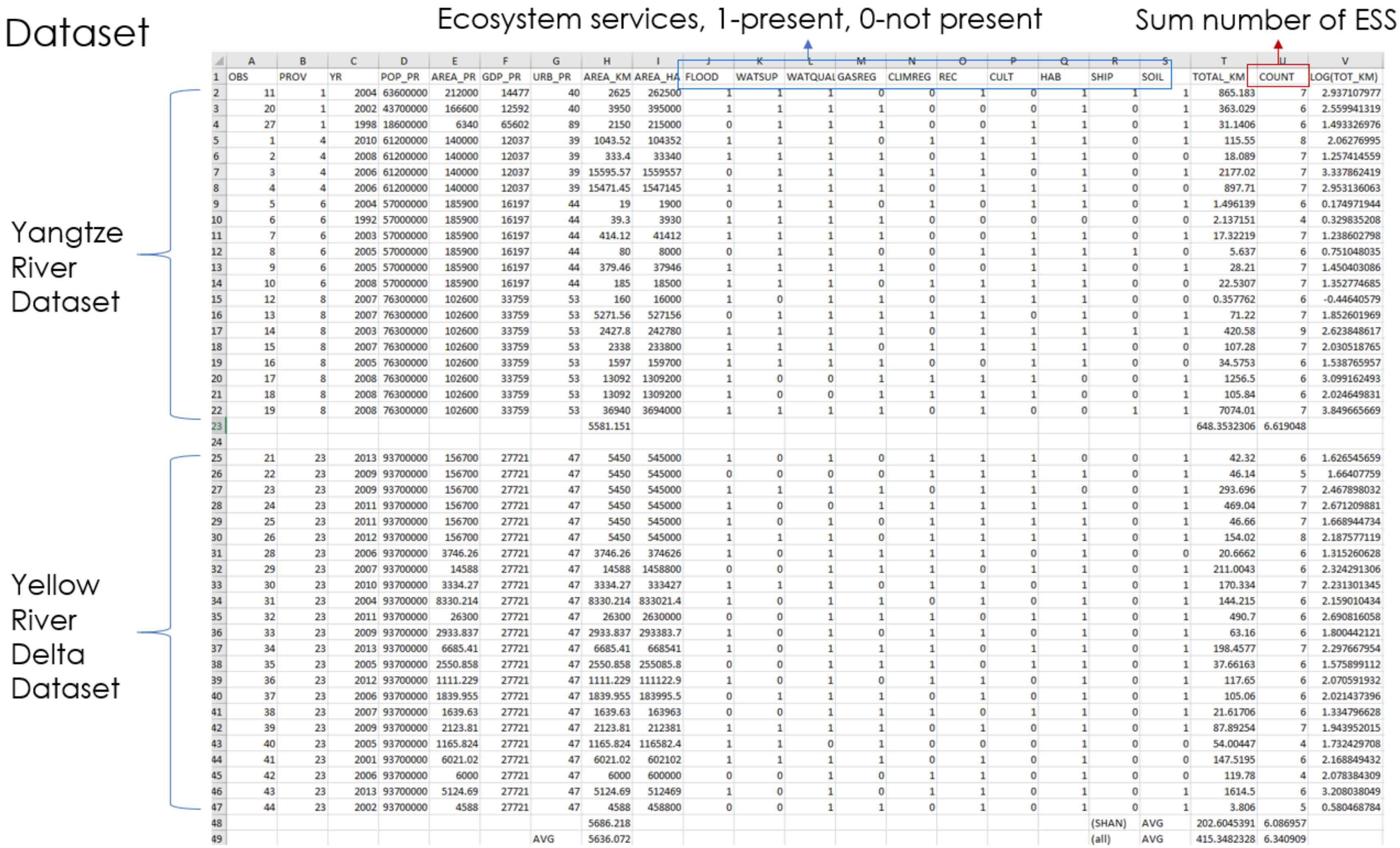
Dr. Knowler and I prepared this section in collaboration. All benefit function transfer relevant results are produced by Dr. Knowler using LIMDEP 9.0[13]. My job was data processing/editing, results production and interpretation.

Data

The reasons for adding the Benefit Function Transfer (BFT) experiment are twofold. First, we wanted to compare results between the benefit value transfer method and the benefit function transfer method to see whether there are noticeable pattern discrepancies between two methods. Second, one of the most important requirements for the benefit value transfer is that the existing studies must exactly match the policy site characteristics; however, my data consists of both inland wetland studies and coastal wetland studies, which do not exactly match my policy site characteristics, a coastal wetland ecosystem; therefore, the benefit function transfer method is introduced in this section. This method is known to construct context-specific value estimates for the policy site that draws on derived relationships between independent and dependent variables from large numbers of observations, so that the site characteristics of a study become less troublesome as meta-regression can explicitly account for any statistically significant effects of variables (Richardson et al., 2015). Although the benefit function transfer method generally produces data that has higher accuracy in comparison with the benefit value transfer method, it requires a large amount of pooled data to ensure validity and reliability, and there are only 44 data points in my dataset, which is why we added this method as an experiment.

[13] LIMDEP 9.0 is an econometric and statistical software that generates statistical results for our regression models.

Figure B1. Benefit Function Transfer (meta-regression) dataset



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	OBS	PROV	YR	POP_PR	AREA_PR	GDP_PR	URB_PR	AREA_KM	AREA_HA	FLOOD	WATSUP	WATQUAL	GASREG	CLIMREG	REC	CULT	HAB	SHIP	SOIL	TOTAL_KM	COUNT	LOG(TOT_KM)
2	11	1	2004	63600000	212000	14477	40	2625	262500	1	1	1	0	0	1	0	1	1	1	865.183	7	2.937107977
3	20	1	2002	43700000	166600	12592	40	3950	395000	1	1	1	1	0	0	0	1	0	1	363.029	6	2.559941319
4	27	1	1998	18600000	6340	65602	89	2150	215000	0	1	1	1	0	0	1	1	0	1	31.1406	6	1.493326976
5	1	4	2010	61200000	140000	12037	39	1043.52	104352	1	1	1	0	1	1	1	1	0	1	115.55	8	2.06276995
6	2	4	2008	61200000	140000	12037	39	333.4	33340	1	1	1	1	0	1	1	1	0	0	18.089	7	1.257414559
7	3	4	2006	61200000	140000	12037	39	15595.57	1559557	0	1	1	1	1	1	0	1	0	1	2177.02	7	3.337862419
8	4	4	2006	61200000	140000	12037	39	15471.45	1547145	1	1	1	1	0	1	1	1	0	0	897.71	7	2.953136063
9	5	6	2004	57000000	185900	16197	44	19	1900	0	1	1	0	1	0	1	1	0	1	1.496139	6	0.174971944
10	6	6	1992	57000000	185900	16197	44	39.3	3930	1	1	1	1	0	0	0	0	0	0	2.137151	4	0.329835208
11	7	6	2003	57000000	185900	16197	44	414.12	41412	1	1	1	1	0	0	1	1	0	1	17.32219	7	1.238602798
12	8	6	2005	57000000	185900	16197	44	80	8000	0	1	1	0	0	1	1	1	1	0	5.637	6	0.751048035
13	9	6	2005	57000000	185900	16197	44	379.46	37946	1	1	1	1	0	0	1	1	0	1	28.21	7	1.450403086
14	10	6	2008	57000000	185900	16197	44	185	18500	1	1	1	0	1	1	1	1	0	0	22.5307	7	1.352774685
15	12	8	2007	76300000	102600	33759	53	160	16000	1	0	1	1	0	1	1	1	0	0	0.357762	6	-0.44640579
16	13	8	2007	76300000	102600	33759	53	5271.56	527156	0	1	1	1	1	1	0	1	0	1	71.22	7	1.852601969
17	14	8	2003	76300000	102600	33759	53	2427.8	242780	1	1	1	1	0	1	1	1	1	1	420.58	9	2.623848617
18	15	8	2007	76300000	102600	33759	53	2338	233800	1	1	1	0	1	1	1	1	0	0	107.28	7	2.030518765
19	16	8	2005	76300000	102600	33759	53	1597	159700	1	1	1	1	0	0	1	1	0	0	34.5753	6	1.538765957
20	17	8	2008	76300000	102600	33759	53	13092	1309200	1	0	0	1	1	1	1	0	0	1	1256.5	6	3.099162493
21	18	8	2008	76300000	102600	33759	53	13092	1309200	1	0	0	1	1	1	1	0	0	1	105.84	6	2.024649831
22	19	8	2008	76300000	102600	33759	53	36940	3694000	1	1	1	1	0	1	0	0	1	1	7074.01	7	3.849665669
23								5581.151												648.3532306	6.619048	
24																						
25	21	23	2013	93700000	156700	27721	47	5450	545000	1	0	1	0	1	1	1	0	0	1	42.32	6	1.626545659
26	22	23	2009	93700000	156700	27721	47	5450	545000	0	0	0	0	1	1	1	1	0	1	46.14	5	1.66407759
27	23	23	2009	93700000	156700	27721	47	5450	545000	1	1	1	1	0	1	1	0	0	1	293.696	7	2.467898032
28	24	23	2011	93700000	156700	27721	47	5450	545000	1	0	0	1	1	1	1	1	0	1	469.04	7	2.671209881
29	25	23	2011	93700000	156700	27721	47	5450	545000	1	0	1	0	1	1	1	1	0	1	46.66	7	1.668944734
30	26	23	2012	93700000	156700	27721	47	5450	545000	1	1	1	0	1	1	1	1	0	1	154.02	8	2.187577119
31	28	23	2006	93700000	3746.26	27721	47	3746.26	374626	1	0	1	1	1	1	0	1	0	0	20.6662	6	1.315260628
32	29	23	2007	93700000	14588	27721	47	14588	1458800	0	0	1	1	1	0	1	1	0	1	211.0043	6	2.324291306
33	30	23	2010	93700000	3334.27	27721	47	3334.27	333427	1	1	1	0	1	1	0	1	0	1	170.334	7	2.231301345
34	31	23	2004	93700000	8330.214	27721	47	8330.214	833021.4	1	0	1	1	0	1	0	1	0	1	144.215	6	2.159010434
35	32	23	2011	93700000	26300	27721	47	26300	2630000	0	0	1	1	1	0	1	1	0	1	490.7	6	2.690816058
36	33	23	2009	93700000	2933.837	27721	47	2933.837	293383.7	1	0	1	0	1	1	0	1	0	1	63.16	6	1.800442121
37	34	23	2013	93700000	6685.41	27721	47	6685.41	668541	1	0	1	1	1	0	1	1	0	1	198.4577	7	2.297667954
38	35	23	2005	93700000	2550.858	27721	47	2550.858	255085.8	0	0	1	1	1	0	1	1	0	1	37.66163	6	1.575899112
39	36	23	2012	93700000	1111.229	27721	47	1111.229	111122.9	1	0	1	0	1	1	0	1	0	1	117.65	6	2.070591932
40	37	23	2006	93700000	1839.955	27721	47	1839.955	183995.5	0	1	1	1	0	1	0	1	0	1	105.06	6	2.021437396
41	38	23	2007	93700000	1639.63	27721	47	1639.63	163963	0	0	1	1	1	0	1	1	0	1	21.61706	6	1.334796628
42	39	23	2009	93700000	2123.81	27721	47	2123.81	212381	1	1	1	1	0	1	0	1	0	1	87.89254	7	1.943952015
43	40	23	2005	93700000	1165.824	27721	47	1165.824	116582.4	1	1	0	1	0	0	0	1	0	0	54.00447	4	1.732429708
44	41	23	2001	93700000	6021.02	27721	47	6021.02	602102	1	1	1	1	0	1	0	1	0	0	147.5195	6	2.168849432
45	42	23	2006	93700000	6000	27721	47	6000	600000	0	0	1	0	1	1	0	1	0	0	119.78	4	2.078384309
46	43	23	2013	93700000	5124.69	27721	47	5124.69	512469	1	0	1	0	1	1	0	1	0	1	1614.5	6	3.208038049
47	44	23	2002	93700000	4588	27721	47	4588	458800	0	0	1	1	0	1	0	1	0	1	3.806	5	0.580468784
48								5686.218										(SHAN)	AVG	202.6045391	6.086957	
49							AVG	5636.072										(all)	AVG	415.3482328	6.340909	

In Figure B1, my meta-regression dataset, we can see that the top section has 21 data observations from the Yangtze River studies, which are inland wetland studies, and 24 data observations from YRD studies, which are coastal wetland studies.

Where "OBS" stands for observations, "PROV" = province, "YR" = publish year, "AREA_KM" = study area in kilometers, "AREA_HA" = study area in hectares, "FLOOD" = flood control, "WATUP" = water supply, "WATQUAL= water quality, "GASREG" = gas regulation, "CLIMREG" = climate regulation, "REC" = recreation, "CULT" = cultural, "HAB" = habitat and biodiversity, "SHIP" = shipping, "SOIL" = soil formation and protection, "TOTAL_KM" = total economic value for each observation study, "COUNT" = the sum number of ecosystem service for each observation study, and "LOG(TOT_KM)" = logged version of "TOTAL_KM".

From Figure B1, the blue highlighted columns are the 10 ecosystem services included in the meta-regression analysis, and I replaced the original data value with zeros and ones, one being present, and zero being not present.

The basic idea of a meta-regression analysis is to use pooled data from other studies to generate a predictive model, and then use this model to estimate economic values for our own study site. The regression model we used is shown below in eq. (3).

$$Y_{Total\_KM} = \beta_0 + \beta_1 X_{SUM} + \beta_2 X_{LOG(AREA\_KM)} \quad \textbf{(3)}$$

where Y_{Total_KM} = dependent variable we used, which is the total estimated ecosystem service value for the wetland, β_0 = constant, X_{SUM} = the first independent variable, which is the sum number of ecosystem services present for a given wetland study, $X_{LOG(AREA\_KM)}$ = the second independent variable, which is the logged area for each wetland study observation. The idea behind Eq. (3) is that I'm assuming the total economic value of YRDNNR are directly influenced by the size of the observation study area and the number of ecosystem services for each existing land use types contained in an observation study.

After running a series of tests on LIMDEP 9.0, we found three viable models (see Figure B2) among the rest of the models in terms of overall goodness of fit (R^2), Durban-

Watson Stat[14], and significance for each independent variable. Then, we had to pick one model out of the three contender models for our meta-regression analysis based on statistical results generated by LIMDEP 9.0 shown in Figures B3, B4, and B5.

Figure B2. Three viable regression models for the BFT method

Linear-Linear: $Y_{Total\_KM} = \beta_0 + \beta_1 X_{SUM} + \beta_2 X_{LOG(AREA\_KM)}$

LIMDEP:LhS=TOTAL_KM; Rhs=ONE(Constant),SUM,LOG(AREA_KM)

Log-Linear: $Log(Y_{Total\_KM}) = \beta_0 + \beta_1 X_{SUM} + \beta_2 X_{LOG(AREA\_KM)}$

LIMDEP:Lhs=LOG(TOTAL_KM);Rhs=ONE(Constant),SUM,LOG(AREA_KM)

Log-Log: $Log(Y_{Total\_KM}) = \beta_0 + \beta_1 Log(X_{SUM}) + \beta_2 X_{LOG(AREA\_KM)}$

LIMDEP:Lhs=LOG(TOTAL_KM);Rhs=ONE,LOG(SUM),LOG(AREA_KM)

[14] Durban-Watson Stat is the number that tests for residual autocorrelation.

Figure B3. The Linear-Linear model

1. Linear-Linear model

```
--> REGRESS; Lhs=TOTAL_KM;Rhs=ONE,SUM,LOG(AREA_KM)$

+----------------------------------------------------+
| Ordinary    least squares regression               |
| Model was estimated Oct 27, 2017 at 00:10:39PM     |
| LHS=TOTAL_KM Mean                 =   415.3482     |
|              Standard deviation   =   1121.385     |
| WTS=none     Number of observs.   =         44     |
| Model size   Parameters           =          3     |
|              Degrees of freedom   =         41     |
| Residuals    Sum of squares       =   .4498563E+08 |
|              Standard error of e  =   1047.478     |
| Fit          R-squared            =   .1680530     |
|              Adjusted R-squared   =   .1274702     |
| Model test   F[  2,    41] (prob) =   4.14 (.0230) |
| Diagnostic   Log likelihood       =  -366.8619     |
|              Restricted(b=0)      =  -370.9096     |
|              Chi-sq [  2]  (prob) =   8.10 (.0175) |
| Info criter. LogAmemiya Prd. Crt. =   13.97424     |
|              Akaike Info. Criter. =   13.97403     |
| Autocorrel   Durbin-Watson Stat.  =  2.0668885     |
|              Rho = cor[e,e(-1)]   =  -.0334443     |
+----------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |t-ratio |P[|T|>t]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|   -2394.15070      1209.92884    -1.979   .0546
 SUM     |    127.578899      163.257478      .781   .4390   6.34090909
 LOGAREA_|    256.971670      97.2139637     2.643   .0116   7.78503220
```

Figure B4. The Log-Linear model

1. Log-Linear model (preferred model)

```
--> REGRESS; Lhs=LOG(TOTAL_KM);Rhs=ONE,SUM,LOG(AREA_KM)$

+----------------------------------------------------+
| Ordinary    least squares regression               |
| Model was estimated Oct 27, 2017 at 00:10:39PM     |
| LHS=LOGTOTAL Mean                 =   4.411119     |
|              Standard deviation   =   1.959685     |
| WTS=none     Number of observs.   =         44     |
| Model size   Parameters           =          3     |
|              Degrees of freedom   =         41     |
| Residuals    Sum of squares       =   55.43272     |
|              Standard error of e  =   1.162763     |
| Fit          R-squared            =   .6643202     |
|              Adjusted R-squared   =   .6479456     |
| Model test   F[  2,    41] (prob) =  40.57 (.0000) |
| Diagnostic   Log likelihood       =  -67.51486     |
|              Restricted(b=0)      =  -91.53001     |
|              Chi-sq [  2]  (prob) =  48.03 (.0000) |
| Info criter. LogAmemiya Prd. Crt. =   .3675559     |
|              Akaike Info. Criter. =   .3673440     |
| Autocorrel   Durbin-Watson Stat.  =  2.0607091     |
|              Rho = cor[e,e(-1)]   =  -.0303546     |
+----------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |t-ratio |P[|T|>t]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|   -5.60666063      1.34309270    -4.174   .0002
 SUM     |     .50224736       .18122547     2.771   .0084   6.34090909
 LOGAREA_|     .87771958       .10791326     8.134   .0000   7.78503220
```

Figure B5. The Log-Log model

1. Log-log model

```
--> REGRESS; Lhs=LOG(TOTAL_KM);Rhs=ONE,LOG(SUM),LOG(AREA_KM)$

+---------------------------------------------------+
| Ordinary    least squares regression              |
| Model was estimated Oct 27, 2017 at 00:10:39PM     |
| LHS=LOGTOTAL Mean                 =   4.411119     |
|              Standard deviation   =   1.959685     |
| WTS=none     Number of observs.   =         44     |
| Model size   Parameters           =          3     |
|              Degrees of freedom   =         41     |
| Residuals    Sum of squares       =   56.88355     |
|              Standard error of e  =   1.177881     |
| Fit          R-squared            =   .6555345     |
|              Adjusted R-squared   =   .6387313     |
| Model test   F[  2,    41] (prob) =  39.01 (.0000) |
| Diagnostic   Log likelihood       =  -68.08326     |
|              Restricted(b=0)      =  -91.53001     |
|              Chi-sq [  2]  (prob) =  46.89 (.0000) |
| Info criter. LogAmemiya Prd. Crt. =   .3933922     |
|              Akaike Info. Criter. =   .3931803     |
| Autocorrel   Durbin-Watson Stat.  =  2.0804603     |
|              Rho = cor[e,e(-1)]   =  -.0402301     |
+---------------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |t-ratio |P[|T|>t]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|   -7.48611563      2.06411209    -3.627   .0008
 LOGSUM  |    2.76987417      1.09156704     2.538   .0151   1.83417314
 LOGAREA_|     .87562981       .10958807     7.990   .0000   7.78503220
```

Figure B3 shows the regression result for the Linear-Linear model. The overall goodness of fit is not good, R^2 is 0.168 and adjust R^2 is 0.127. The constant and independent variables, “LOGAREA”, are significant. And the independent variable, “SUM”, is not significant, which has a p-value of 0.439.

Figure B4 shows the regression results for the Log-Linear model. The difference between my Linear-Linear function and the Log-Linear function is that I’m using the natural logs of my dependent variable, which is Log (Y_{Total_KM}). The overall goodness of fit is very good, which has 0.664 for R^2 and 0.648 for adjusted R^2. All independent variables and the constant are significant.

Figure B5 shows the regression results for the Log-Log model. The overall goodness of fit is also good similarly to the Log-Linear model, which has 0.656 for R^2 and 0.639 for adjusted R^2. All independent variables and the constant are significant.

Table B1. Regression results for all contender models

The dependent variable is TOTAL_KM, which is the total estimated ecosystem service value for the wetland and *t*-statistics for each coefficient are shown in brackets. For all regressions, n = 44.

	(1) **Linear-Linear Model**	**(2)** **Log-Linear Model**	**(3)** **Log-Log Model**
Constant	-2394.1507*	-5.6067***	-7.48611563***
Sum of ESS (SUM)	127.5789	0.5022***	2.7699**
Logged area for each Wetland observation (LOGAREA)	256.9717**	0.8777***	0.8756***
adjusted R^2	0.12	0.65	0.64
F-statistic	4.14 (0.023) *(2, 41)*	40.57 (0.0000) *(2, 41)*	39.01 (0.0000) *(2,41)*
Autocorrelation	2.08668	2.06071	2.08046

Note: Significance levels are: (***) = $p < 0.01$; (**) = $p < 0.05$; (*) = $p < 0.1$

In Table B1, I present the regression results for all three regression models for comparison. We can immediately take out the Linear-Linear model because of its poor goodness of fit and its insignificant independent variable, “SUM”. Then, we decided to use the Log-Linear model over the Log-Log model as it has the best overall model significance (R^2, adjusted R^2, and F-stat) and the significance of all independent variables.

$$\text{Log}(Y_{Total\_KM}) = -5.60666063 + 0.50224736\, X_{SUM} + 0.87771958\, X_{LOG(AREA\_KM)} \quad (4)$$

Eq. (4) is the final form of the Log-Linear model we used for our BFT experiment. Using this formula, I estimated the total economic value (TEV) for the YRDNNR for year 2000, 2005, 2010, and 2015. I will show the process of getting to the TEV for the YRDNNR utilizing the Log-Linear formula in the following section.

Method

The method of getting the TEV for the YRDNNR is simply to plug each individual land use type into Eq. (4) and sum the total values for each land use type to get the TEV for the YRDNNR. I will break it down and explain each part in detail.

Table B2. TEV calculation for the study area in 2000

Model #2 (PREFERRED MODEL, for Individual Land Use Types in 2000										CHECK
New Regression equation	Coefficient	Rivers	Reservoir &ponds	Bottomland (water body)	Estuarine waters	Estuarine delta	Coastal lagoons	Beach & shore	TOTALS	TOTALS
Constant	-5.60666063	-5.607	-5.607	-5.607	-5.607	-5.607	-5.607	-5.607	(SUMMED)	-5.607
SUM	0.50224736	2.009	1.507	1.004	4.018	2.009	4.018	1.507		4.018
LOGAREA_KM	0.87771958	0.000	0.000	0.000	0.482	4.479	4.776	4.190		5.481
Number of ecoservices		4	3	2	8	4	8	3		8
Land use area (KM)		0.000	0.000	0.000	1.731	164.569	230.682	118.421	515.403	515.403
Log value		0.000	0.000	0.000	-1.107	0.882	3.187	0.091		3.893
Total Value (unit:100Million RMB)		0.000	0.000	0.000	0.621	4.534	45.465	2.055	52.675	92.070
RMB/ha		0.000	0.000	0.000	358480.560	27548.941	197089.568	17356.328	102200.913	178637.002

Table B2 is the TEV calculation table for the study area in 2000, and I will use this table as an example to demonstrate each part of the calculation. First, we will plug each individual land use type into Eq. (4), our BFT regression model. Our constant stays the same for every land use type, which is -5.607. Then, I will plug in our independent variable, SUM, by multiplying the coefficient of SUM, 0.502, by the number of ecosystem services corresponding to each land use type. Second, I will plug our second independent variable, LOGAREA_KM, which is the logged area for each land use type, into Eq. (4) by multiplying the coefficient of LOGAREA_KM, 0.8777 by the logged area in units of square kilometers for every land use type. Third, I will sum up the total logged value for each land use type in the "Log value" row, found in the leftmost column. Fourth, I will convert the logged total value back to normalized economic value, which has two separate important steps. First, I will anti-natural log the values in the "Log value" row for each land use type. Second, I will make an error correction[15], which is necessary when converting log-linear model values back into normalized values, by plugging the log values into Eq. (5). Finally, we now have the total value in units of 100million RMB in the row "Total Value (unit:100Million RMB)".

---

[15] An error correction will take place when converting log-linear model values into normalized values. The equation of this error correction is EXP (logged value) *EXP(MSE/2).

$$Y_{Total\_KM} = EXP[Log(Y_{Total\_KM})] * EXP(MSE/2) \qquad (5)$$[16]

Fifth, I will convert the total value in units of 100million RMB into RMB per hectare by multiplying 100 million to get rid of the 100 million units, then divide it by land use area for each land use type in units of hectares, and the final values are in the "RMB/ha" row in the leftmost column.

Results

Spatial analysis

It is crucial to discuss the spatial changes for my study area first before getting into economic values because the spatial changes and total economic values of my study are closely related.

Figure B5 shows areas for each land use type in 2000, 2005, 2010, and 2015. The negligible land use types are rivers and reservoir& ponds, both of which land use types have areas under 300 hectares, which can be considered insignificant compared to the entire study area, which has up to 54,000 hectares (changes every year). Therefore, rivers and reservoir& ponds won't make any impact on the TEV of my study area even if they contain many valuable ecosystem services.

All land use types have some what noticeable area changes beside rivers and reservoir& ponds. I will describe these changes in detail for each land use type in the following: Coastal lagoon was at its highest point in 2000, which was 23068.17 ha, and it went down dramatically to 19040.56ha in 2005, then it kept going down at a much slower rate till 2015. Estuarine Delta increased dramatically from 16456.89ha in 2000 to 22964.55ha in 2005, then it went down to 18959.56ha in 2010 and 19335.92 in 2015. Beach and Shore had 11842.1ha in 2000 and decreased to 8908.06ha in 2005, then it went back up to 10616.99ha in 2010 and stayed almost the same for 2015. Bottomland (water body) did not exist in 2000 and had 2428.72ha in 2005, then it went up to 5399.57ha in 2010 and stayed the same for 2015. Estuarine waters went up in areas

[16] Eq. (5) is anti-natural log of logged value times the anti-natural log of Mean Square Error (MSE).

from 173.13ha in 2000 to 1028.63ha in 2005, then, it went down to 128.69ha, and went back up to 562.94ha.

In conclusion, land use types that will potentially impact the TEV of the YRDNNR are bottomland (water body), beach& shore, estuarine delta, and coastal lagoons. In addition, if we take a closer to look at the trend of area change for the four land use types, we can clearly see the trade-offs in areas among these land use types.

Total economic value for entire study and for each land use type from 2000 to 2015

First, let's look at the TEV for the entire study area. Figure B6 shows the TEV for the YRDNNR in RMB using the Benefit Function Transfer (BFT) method. We can clearly see a steady downward trend throughout the 15-year period. Now that we know the TEV for the YRDNNR has a downward trend, I will break down the TEV into individual land use type values to find out the reason behind the downward TEV trend. Table B3 and Figure B5 show the total economic value of each land use type as well as the grand total for the study area in 2000, 2005, 2010, and 2015.

From the spatial analysis section, we learned that the relevant land use types, which have significant areas and have impacts on TEV for the study area, are "Estuarine delta", "Coastal lagoon", and "Beach & shore", and by looking at Figure B6, we can clearly see that the reason behind the upward trend for the study area TEV is directly related to the upward trend of estuarine delta's TEV, as the TEV for other land use types are negligible in comparison to the TEV of estuarine delta.

Figure B5. Land Area by Land Use Type for 2000, 2005, 2010, and 2015

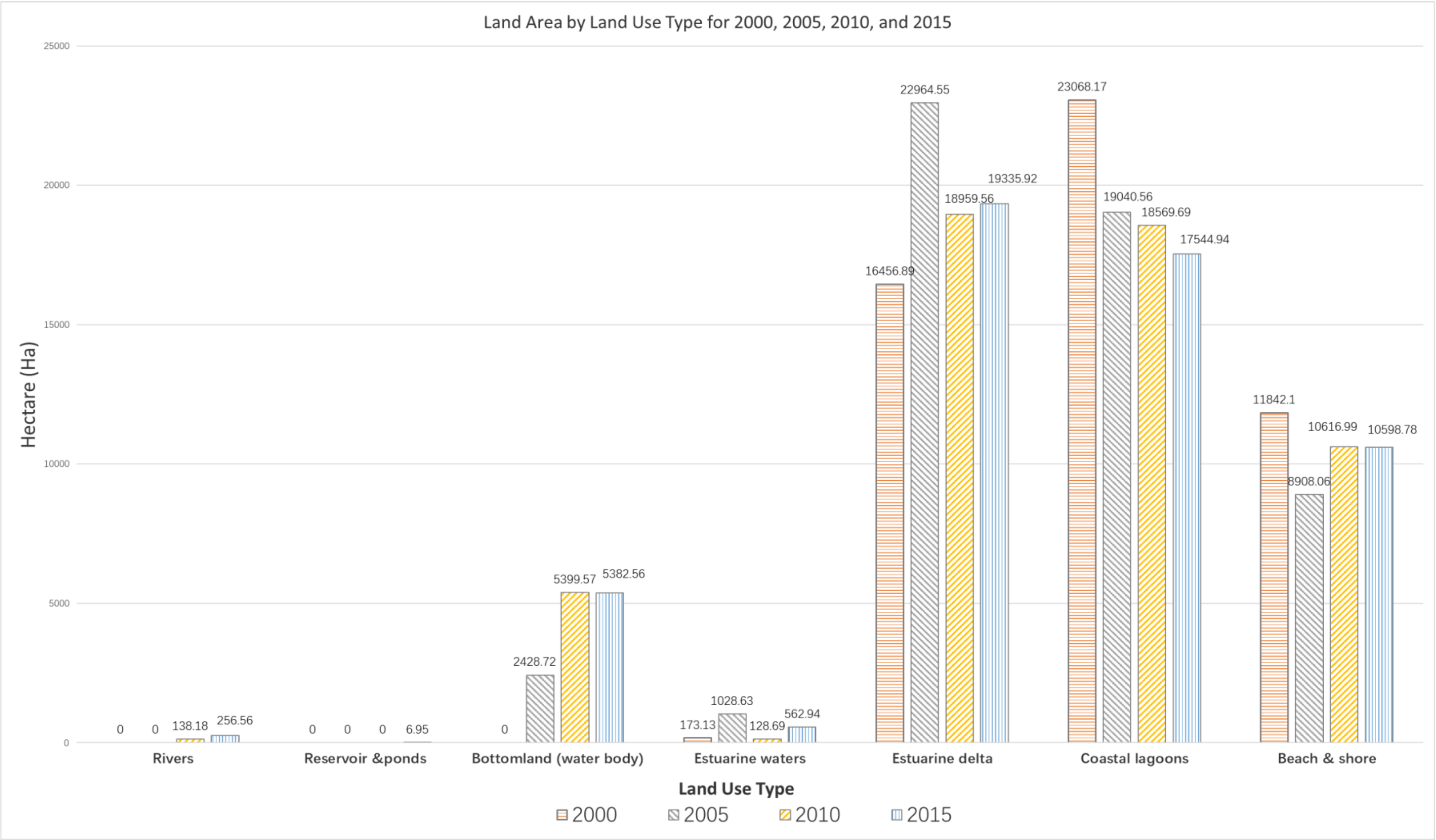
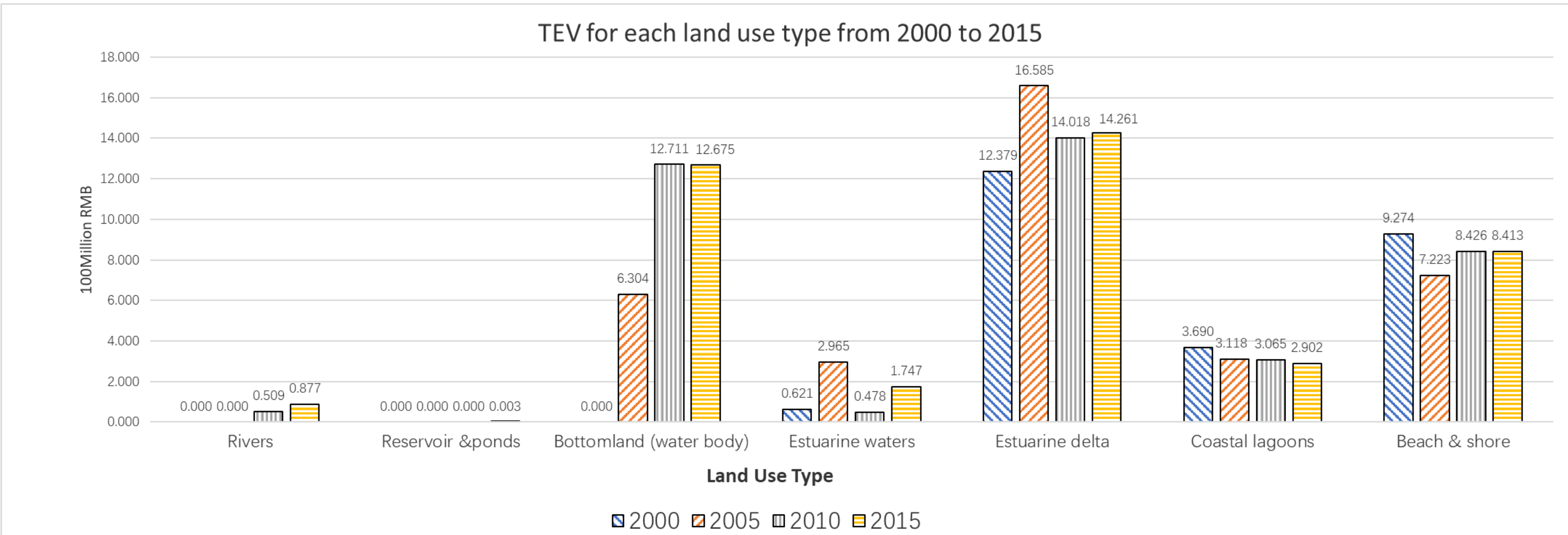


Table B3. TEV by land use type for 2000, 2005, 2010, and 2015 using the benefit function transfer method

TEV (100 Million RMB)/Year	2000	2005	2010	2015
Rivers	0.000	0.000	0.509	0.877
Reservoir &ponds	0.000	0.000	0.000	0.003
Bottomland (water body)	0.000	6.304	12.711	12.675
Estuarine waters	0.621	2.965	0.478	1.747
Estuarine delta	12.379	16.585	14.018	14.261
Coastal lagoons	3.690	3.118	3.065	2.902
Beach & shore	9.274	7.223	8.426	8.413
Total	25.964	36.195	39.207	40.878

Figure B5. TEV by Land Use Type for 2000, 2005, 2010, and 2015



Discussion

Validity and reliability of Benefit Function Transfer (BFT)

According to the most recent research on benefit transfer methods, benefit function transfer, also known as meta-regression analysis, has higher accuracy using pooled data over other valuation approaches, such as benefit value transfer, also known as unit value transfer (Richardson et al., 2015). However, the validity and reliability are dependent on the similarity between the existing study and policy site, the size of the pooled data, and the validity of benefit transfer functions. As mentioned earlier, my data set contains data from both coastal wetland studies and inland wetland studies, and since I use this data set to predict economic values in a coastal wetland ecosystem, I'm presuming that coastal and inland wetland ecosystems are indifferent to one another, which discounts the accuracy of the model. In addition, the size of data set for the BFT model also affects the accuracy of the predictive model, and my data set has only 44 data observations, which is not enough to be robust. Most importantly, function validity is also crucial to the accuracy of the model, and the fact that the BFT formula is used to predict values for individual land use types makes it not ideal, since it is derived from pooled data from other 'complete" studies (which means estimated value data involving many land use types). The only way to fix this problem is to have a meta-regression function for every land use type. This will require meta-data bases dedicated to every land use type, but as of now, there are no other ways around it.

Conclusion

Although using BFT is not ideal in the context of my research, it is useful to compare results between BVT and BFT. Therefore, it is still worth conducting the BFT experiment.