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Evaluation of Temporal and Spatial Ecosystem Services in Dalian, China: Implications for Urban Planning

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Abstract: The valuation of ecosystem services is critical to understand the current status of ecosystems and to develop an effective planning strategy for ecosystem protection. This study aims to analyse the spatio-temporal changes in ecosystem services driven by land use changes from 1984 to 2013 in Dalian, China. The land use changes are characterized using remote sensing data and then ecosystem service values (ESVs) are assessed using the equivalent factor method, i.e., assigning value coefficients to different land use categories. The total ESV of Dalian reduced significantly by 44.3% from 1984 to 2013, primarily due to the reduction of forests, water and wetlands. Water and climate regulations are the two largest service functions, contributing about 43.6% of the total ESV on average. In addition, ESVs show a spatial variation in different administrative regions, with the central city area having the maximum decreasing rate. Further, ESV changes and distributions are found to have a strong link with city development policies. This study provides an enhanced understanding of the implications of urban policies on ecosystem services, which is essential for sustaining the provision of ecosystem services and achieving sustainable development goals.

Keywords: ecosystem service value; land use change; urban planning; sustainability; Dalian

1. Introduction

Ecosystem services are of fundamental importance to human well-being, health, livelihoods and survival. Ecosystem services can be defined as the goods and services derived, directly or indirectly, from natural ecosystems to sustain and fulfill human life [1,2]. Recently, ecosystems have been under growing pressure from population increases, land use change, urbanisation and climate change, and as a result, the interest in ecosystem services has grown rapidly in the research and policy communities [3,4].

Ecosystem assessments and evaluations have been conducted at varying temporal and spatial scales. For example, the global value of ecosystem services was estimated to be US$ 33 trillion on average in 1997 [1,5], with a loss rate of $4.3–20.2 trillion/year until 2011, depending on which unit values are used. In China, a national ecosystem assessment for the period from 2000 to 2010 was conducted [6], and an overall improvement was reported, apart from for habitat provision, as a result of national conservation policies. Egoh et al. [7] conducted a mapping of ecosystem services at the national scale for South Africa. At the regional and basin scales, ecosystem assessments focus on various biomes, such as the contribution of temperate forests to fresh water supplies [8], the services

delivered by wetlands [9,10] and by agricultural activities [11], and the services in urban areas driven by land use changes [12–14].

Ecosystem valuation, as a direct way of linking ecosystems to human well-being, has many potential uses, ranging from simply raising awareness to the detailed analysis of various policy choices and scenarios [5]. The evaluation methods can be broadly divided into two categories: one is based on the values of unit services [15,16] and the other is based on value equivalent factors in unit areas [2,17,18]. Compared with the unit service value methods, the equivalent factor methods are more intuitive and easy to use and require less data. They are based on equivalent coefficient values per unit area for different categories of biomes, and are usually used in combination with land use data as the land use types can be used as a proxy for ecosystem services when matched with equivalent biomes.

The estimation of ESVs from the perspective of land use data has been applied successfully in many case studies [14,19–22]. Kreuter et al. [13] analysed the changes in ecosystem service values due to urban sprawl in the San Antonio area, Texas, using Landsat data. Roebeling et al. [23] assessed land cover changes and the associated ecosystem service values in European coastal areas based on historical and projected future coastal erosion patterns. Palomo et al. [24] investigated the association between land use changes, conservation policies and ecosystem service delivery with a special focus on protected areas. However, there are few attempts to evaluate the dynamic changes in ESVs at both the temporal and spatial scales and link them to land use policies in different administrative regions. This would support informed decision-making for urban planning.

This study aims to provide an enhanced understanding of how regional development policies affect the ecosystem service values on both temporal and spatial scales. The case study of Dalian City, China, which has experienced unprecedented growth over the last decades, is analysed. The specific objectives are twofold: (1) to characterize the changes in ecosystem service values on both the temporal and spatial scales based on land use data from Dalian City, from 1984 to 2013; and (2) to assess the effects of urban planning on ecosystem service values in different administrative regions. This study will provide scientific evidence for planning regional ecological protection and land use policies, and thus is vital for promoting sustainable development by considering the need to maintain the integrity of ecosystems.

2. Case Study

2.1. Study Area

This study is focused on the city of Dalian, which is located on the southern border of Liaoning Province in northeastern China (Figure 1). The total area of the city is about 1.3×10^4 km^2, administratively consisting of four county-level cities namely Changhai (CH), Wafangdian (WF), Pulandian (PL), and Zhuanghe (ZH), as well as the central city area of Dalian (CDL). The city has witnessed unprecedented growth during the past three decades and now has a municipal population of approximately seven million people. Its location on a peninsula with significant natural resources and its sea life have made it more sensitive to environmental burdens and human interference.

The city has a warm temperate zone continental monsoon climate with an annual mean air temperature of approximately 10.5 °C. January has the coldest mean monthly air temperature at around −5 °C, and August is the warmest month with a mean air temperature of 24 °C. The area receives about 600 mm of precipitation annually, with more than 60% of precipitation occurring during the flood season from July to September. It has a coastline of about 2.2×10^3 km in length. Due to the aesthetic qualities and temperate climate, it is a destination for tourists. Maintaining a pleasant ecosystem environment is thus beneficial to its economic development.

In the 1970s, the "eco-city" concept was developed by the Man and the Biosphere Programme (MAB) of the United Nations Educational, Scientific and Cultural Organization (UNESCO, Paris, France), which describes a social–economic–natural harmonization system that stimulates rapid socio-economic growth while also achieving a balance with the ecological environment through eliminating waste,

saving energy, reusing resources and so on. In recent decades, China has radically implemented this concept in guiding the city construction and development. In 2011, Dalian city was selected as one of the pilot cities to promote water conservation modernization by the Ministry of Water Resources of China. As part of this, the municipal administration of Dalian has taken several positive actions as a response to the nation's eco-city program. Among them, one infusive action is the city's water conservation modernization plan concerning the future development directions and focuses proposed by the Water Affairs Bureau in 2012 [25]. In an attempt to harmonize social development and ecological conservation, this plan designated three functional zones, namely the ecological protection and water conservation zone (Z1), the high-efficient agricultural zone (Z2), and the water resource saving and environmental governance zone (Z3). Details on the zoning and interactive impacts on the ecosystem services are shown further in Section 4.5. Therefore, the board environmental goals and supportive administration of this municipality make it an especially attractive case study.

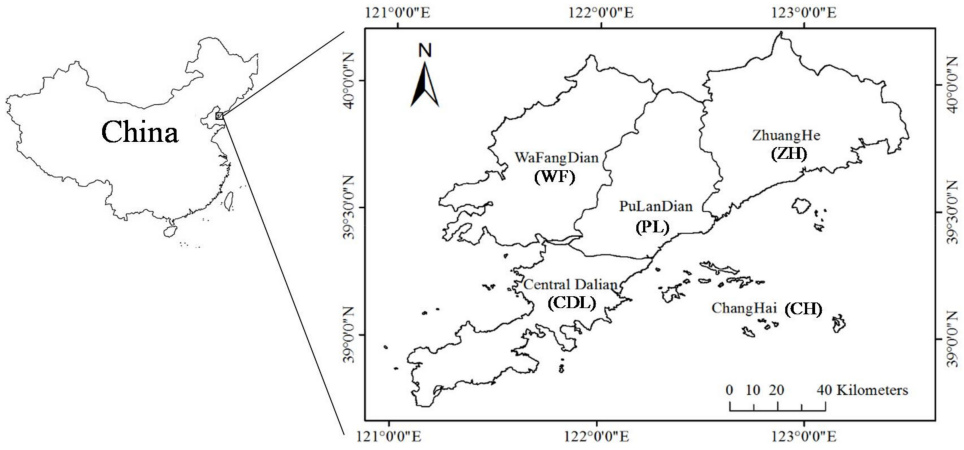


Figure 1. The case study area of Dalian including Central Dalian city and four county-level cities.

2.2. Data Sources

The data used to map the land use changes in Dalian were extracted from the LANDSAT Thematic Mapper (TM) images with a 30 m × 30 m resolution, which were obtained from the US Geological Survey Earth Resources Observation and Science (EROS) Center. The relatively cloud-free images during the same period from June to August of the years 1984, 1988, 1993, 1999, 2002, 2008 and 2013 were selected for comparison. The information for the 20-year city planning for functional zones was obtained from the Water Conservation Modernization Report published by the Dalian Water Affairs Bureau [25]. The regional development policies were obtained from the urban development planning report of Dalian City published by the Urban Development Planning Group [26].

3. Methods

3.1. Land Use Classification

The Landsat TM images were firstly geo-referenced, and rectified to the World Geodetic System (WGS) 1984 Universal Transverse Mercator (UTM) zone 51N using ArcGIS 10.2 [27]. The geometric and terrain corrections of the images were processed using the ENVI 5.1 software, and the errors were limited within 0.5 pixels. After image fusion and enhancement, a false color composite of bands 5, 4 and 3 was selected as the base map for land use classification.

With regard to the land use classification criteria in China and the prevailing land use type in Dalian, eight categories of land use were identified: forest, dry farmland, paddy field, aquaculture, urban, brush grass, wetland and water. Particularly, dry farmland refers to the non-irrigated cultivation primarily of corn and wheat in the study region. The results of the image classification were verified

against the ground truth through field observation and Google Earth maps. The land use classifications of the study area for the years 1984 and 2013 are illustrated in Figure 2.

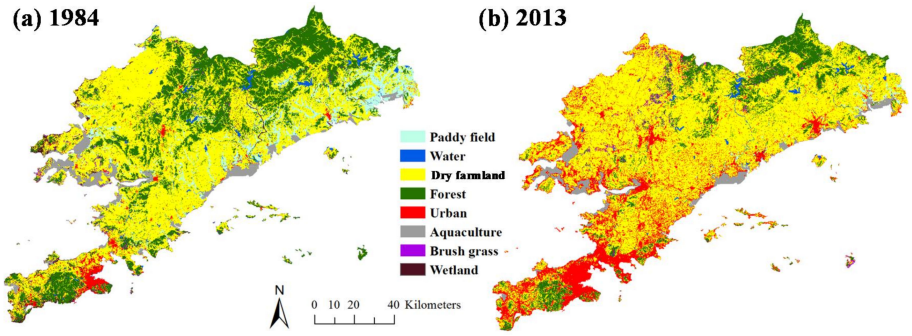


Figure 2. Land use maps of Dalian City in (**a**) 1984 and (**b**) 2013.

3.2. Evaluation of the Ecosystem Service Value

Amongst a variety of methods developed to assess ecosystem service values, the one proposed by Costanza et al. [1] is well-established for global estimates. The method divides the global biosphere into 16 types of biome and 17 types of service function. Xie et al. [17,18] presented the equivalent weighting factors of the ecosystem services by making use of expert evaluations, and applied these factors to modify the value coefficients for ecosystems in China. This method was considered to be more adaptive and practicable in estimating the value of ecosystem services in China, with a variety of applications [20,21,28–31].

In this paper, the equivalent value coefficient method suggested by Xie et al. [18] is used, with the definition of 11 types of ecosystem functions. The value coefficient (yuan/ha/year) for each land use type was obtained, as shown in Table 1. The land use categories in the study area do not exactly match the biome reported by Xie et al. [18] as the most representative biome was used as a proxy. For example, the ESV of the coniferous, broad-leaf mixed forest by Xie et al. [18] was used to represent the land use value of forests, since it is the dominant type of forest in the study region. The service value for urban surfaces was assigned to zero according to the literature [21,29]. An aquaculture pond refers to a managed saline water body for fish or seafood breeding, which certainly possess a service value for food production [32]. However, the ESV for aquaculture has not been documented in detail in the literature. In this case, the ESV for aquaculture was represented using the value of food production functions for the land use type of water. The effects were considered to be minimal due to: (1) changes in the aquaculture area (Figure 3) over the study period were not apparent; (2) the value of food production was relatively lower compared to those of other service functions (Table 1).

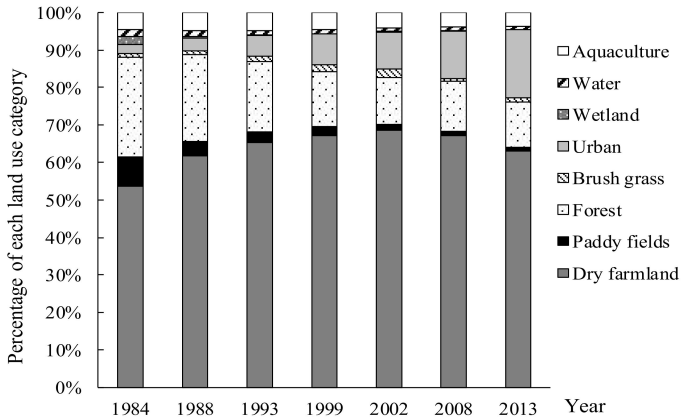


Figure 3. Percentage contribution of each land use category from 1984 to 2013.

Table 1. Ecosystem service value coefficients of different land use types in China (adjusted from Xie et al. [18]).

Ecosystem Services (10^3 yuan/ha/year)		Land Use Category					
		Dry Farmland	Paddy Field	Forest	Grass	Wetland	Water
Supplying services	Food production	2.90	4.63	1.06	1.29	1.74	2.73
	Raw material	1.36	0.31	2.42	1.91	1.70	0.78
	Water supply	0.07	−8.96	1.26	1.06	8.82	28.24
Regulating services	Gas regulation	2.28	3.78	8.01	6.71	6.47	2.62
	Climate regulation	1.23	1.94	23.95	17.75	12.26	7.80
	Waste treatment	0.34	0.58	6.78	5.86	12.26	18.91
	Water regulation	0.92	9.27	11.96	13.01	82.54	348.28
Supporting services	Soil formation and retention	3.51	0.03	9.74	8.18	7.87	3.17
	Nutrients cycling	0.41	0.65	0.75	0.61	0.61	0.24
	Biodiversity protection	0.44	0.72	8.86	7.43	26.81	8.69
Cultural services	Recreation and culture	0.20	0.31	3.88	3.27	16.11	6.44

Once the value coefficient was determined for each land use category, the ESV for each land use type, for each service function, and for the total could be calculated as follows:

$$ESV_i = \sum_f (A_i \times v_{if}) \quad (1)$$

$$ESV_f = \sum_i (A_i \times v_{if}) \quad (2)$$

$$ESV = \sum_i \sum_f (A_i \times v_{if}) \quad (3)$$

where ESV_i, ESV_f and ESV refer to the ecosystem service values of land use type i, service function type f and the total ecosystem service value, respectively. A_i is the area (ha) for land use category i, and V_{if} is the value coefficient (yuan ha^{-1} year^{-1}) for land use type i with ecosystem service function type f.

4. Results and Discussion

4.1. Land Use Change Characterization

The land use maps for 1984 and 2013 are illustrated in Figure 2 for comparison. The maps show a substantial increase in urban areas, particularly along the coastal area and in central downtown. Dry farmlands apparently occupied the largest portion of the total area and expanded a great deal from 1984 to 2013, mainly at the expense of forests.

The percentage contributions of land uses from 1984 to 2013 are summarized in Figure 3. Dry farmland shows an average coverage of 64.8% of the total area, followed by forest and urban areas, whereas wetland has the minimum percentage. An increasing trend in dry farmland was observed from 53.7% in 1984 to 68.6% in 2002, but thereafter it decreased slightly to 64.1% in 2013. The paddy fields were distributed in the northeastern area in 1984, whereas in 2013, most of the paddy fields disappeared and were replaced with dry farmland and urban areas (Figure 1). The area of paddy fields reduced greatly from 7.8% in 1984 to 0.7% in 2013. This is related to the local governments' policy to encourage changes in the crop planting structure and develop "water-saving" irrigation, which promoted the conversion from paddy fields to dry farmlands. In addition, paddy fields were transformed into construction land to meet the demands of urbanisation.

Water bodies in the upper northern region are predominantly reservoirs formed by dam construction for the purpose of the water supply. The reservoirs were well maintained throughout the period and the variations in the water surface area are largely due to precipitation variability. On the contrary, the more scattered water bodies in the downtown city were found to decrease dramatically, and this is the major cause of the reduction in total water area, from 229.9 km^2 in 1984 to 108.3 km^2 in 2013. Forests and wetlands experienced a large reduction of 53.8% and 95% from 1984 to 2013. It is

worthy noting that the declining rates of water, forest and wetland were much higher before 1999, compared with those during the period from 1999 to 2013. This is primarily due to the nation's policies on natural resource protection implemented in 1998. The overall decreasing trends of water, forests and wetlands are on one hand due to deforestation and land reclamation and on the other hand due to urban sprawl. From 1984 to 2013, the urban area increased more than seven times, from 321.5 km^2 to 2313.4 km^2, with an average growth rate of 8.3% per year.

The brush grass category was small in area, comparable to that of the wetlands and water. There was no clear increasing or decreasing trend for brush grass, and in the year 2002 it reached the maximum value of 289.5 km^2. This is probably because it was extremely dry, with an annual precipitation of about 405 mm in that year, leading to retarded growth of forests, which were thus identified as brush grass. Aquaculture land is primarily distributed along the southeastern and southwestern coastal areas, which decreased by 23.3% from 1988 to 2013.

4.2. Ecosystem Service Values of Different Land Uses

Using the identified changes in the area of each land use category and the ecosystem service value coefficients in Table 1, the ESVs for the study area were calculated using Equations (1) to (3), as shown in Figure 4. The total ESV for Dalian dropped by 44.3% from 1984 (53.3 $\times$ 10^9 yuan) to 2013 (29.7 $\times$ 10^9 yuan), with an average rate of decrease of 2.0% per year. The degradation of forests, water and wetlands were the primary reasons for the ESV decline. Note that the higher coefficient values of these three land types, especially water and wetlands, also contributed to the total ESV changes. In addition, the annual degradation rate of the total ESV was found to vary, and was calculated to be 2.8% per year from 1984 to 1999, after which it slowed down to 1.2% per year from 2002. This is probably related to the land area changes driven by government policies, as explained in Section 4.1.

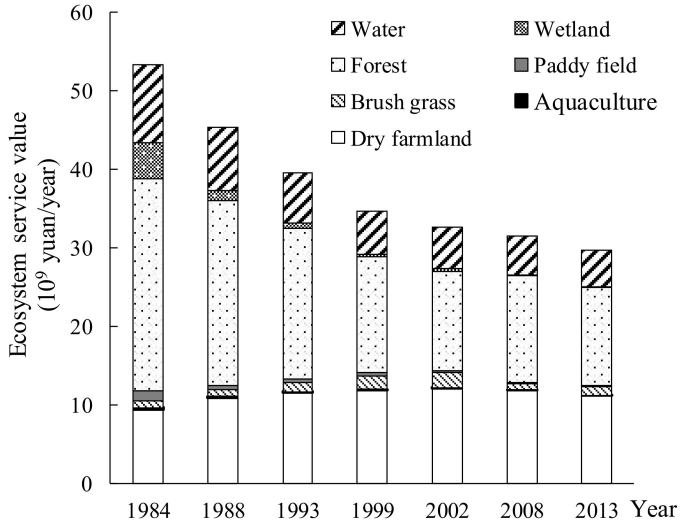


Figure 4. Ecosystem service values of different land uses from 1984 to 2013.

The ESV generated by each land use category varied with the changes in area (Figure 3) over the study period, since temporally constant coefficients were used. Owing to the relatively high coefficient value and the large area, forests produced the highest ESV of the various land use types, namely 50.5% of the total value in 1984 and 41.8% in 2013. Although dry farmland had a small coefficient value, it was the second largest category, contributing 31% of the total value on average. Although the total area of water was small, it generated an ESV ranging from 15.6% in 1999 to 18.5% in 1984 of the total value due to its high value coefficient. The ESVs of aquaculture, brush grass and paddy fields were relatively lower due to their small land-cover proportions and lower coefficient values, with a combined contribution of less than 5%.

4.3. Ecosystem Service Values of Different Functions

The ecosystem service values provided by 11 individual ecosystem functions were investigated. Note that a change in the land use trends was observed for 1999. The results for the three years 1984, 1999 and 2013 are illustrated in Table 2. Although the ESV of water regulation dropped by 57.5% from 1984 to 2013, it was always the dominant ecosystem function, contributing 30.1%, 23.6% and 22.9% of the total value in 1984, 1999 and 2013, respectively. This is likely due to the extremely strong ability of water and wetlands to regulate hydrological flows, including the provision of water for agriculture, industry and transportation [1,18]. As previously explained, the water bodies were largely maintained in the study area due to reservoir construction, which plays an important role in water regulation. The function of climate regulation contributed on average 18.0% of the total ESV, followed by soil formation and retention (13.9%), and gas regulation (10.5%). These can be attributed to the large forest area, which has a relatively high ability to regulate the climate (e.g., precipitation and air temperature), regulate gas (e.g., balance between CO_2 and O_2), as well as conserve soils. The contribution of other functions was minimal, with less than 10% of the total ESV value.

Table 2. Values of ecosystem functions and proportion of each function of the total ESV for the years 1984, 1999 and 2013, and the overall change from 1984 to 2013.

Ecosystem Service Function	1984		1999		2013		1984–2013 Change
	ESV_f	%	ESV_f	%	ESV_f	%	%
Food production	3.1	5.8	3.1	8.9	2.7	9.3	−11.6
Raw material	1.9	3.5	1.7	4.9	1.5	5.2	−18.8
Water supply	0.5	0.9	0.4	1.3	0.5	1.7	+2.5
Gas regulation	5.0	9.4	3.8	11.1	3.3	11.1	−34.2
Climate regulation	10.0	18.7	6.2	17.9	5.2	17.4	−48.1
Environmental purification	3.4	6.5	2.0	5.8	1.7	5.6	−51.7
Water regulation	16.0	30.1	8.2	23.6	6.8	22.9	−57.5
Soil formation and retention	6.2	11.6	5.1	14.8	4.6	15.4	−25.8
Nutrients cycling	0.6	1.2	0.5	1.5	0.5	1.6	−25.8
Biodiversity protection	4.4	8.3	2.4	7.0	2.0	6.8	−54.5
Recreation and culture	2.1	4.0	1.1	3.2	0.9	3.1	−56.4

All service functions, except for water supply, showed continuous decreasing trends, while the rates of decrease were markedly higher from 1984 to 1999 than those from 1999 to 2013. The water supply function refers to water storage and retention for water provision, therefore the water consumption of paddy fields can have a negative impact on the water supply function, as indicated by the negative coefficient value in Table 1. The decrease in the paddy area contributed to the increase in the value of the water supply, which to some extent offsets the ESV decrease caused by water and wetland decline.

4.4. Spatial Variations of the ESV

The ESV varies in different regions due to the level of socio-economic development and local urban planning. The city governments implemented development programmes for the entire city area from 2003 to 2020 [26]. The programme set out four different development strategies for specific zones in the city in terms of their environmental status: (1) no development in conservation zones, key water systems or wetlands; (2) restricted development in ecologically vulnerable areas with important ecosystem services; (3) priority development in areas that are suitable for construction and with appropriate economic conditions; and (4) optimized development in coastal and urban areas that already have high population densities and are close to environmental carrying capacity. The proportion of specific zones in each region for the four development strategies are summarized in Table 3.

Table 3. The proportion of areas of the four development levels delimited in each region (%).

	None	Restricted	Prioritized	Optimized
CDL	49.6	18.2	8.7	23.4
PL	50.5	29.1	13.8	6.6
WF	46.4	24.3	11.3	18.0
ZH	74.0	8.1	13.3	4.7
CH	67.3	1.9	30.8	0.0

Figure 5a shows the results of the total ESV for the four county-level cities of WF, PL, ZH and CH, as well as the central city area of Dalian (CDL). The results show that ZH contributed the most to the total ESV over the study area, accounting for 41.3% on average from 1984 to 2013, followed by WF (21.7%) and PL (20.7%). The CH city had a minimum total ESV due to its small area. The decreasing rate of ESV differed between the regions over the past 30 years; CDL decreased the fastest, with an annual rate of −2.0%, followed by WF (−1.8%), CH (−1.8%), PL (−1.8%) and ZH (−1.0%). However, the total regional ESV was largely associated with the area coverage; to make it more comparable, the net ESVs were computed by dividing the total ESVs by the respective areas, as shown in Figure 5b.

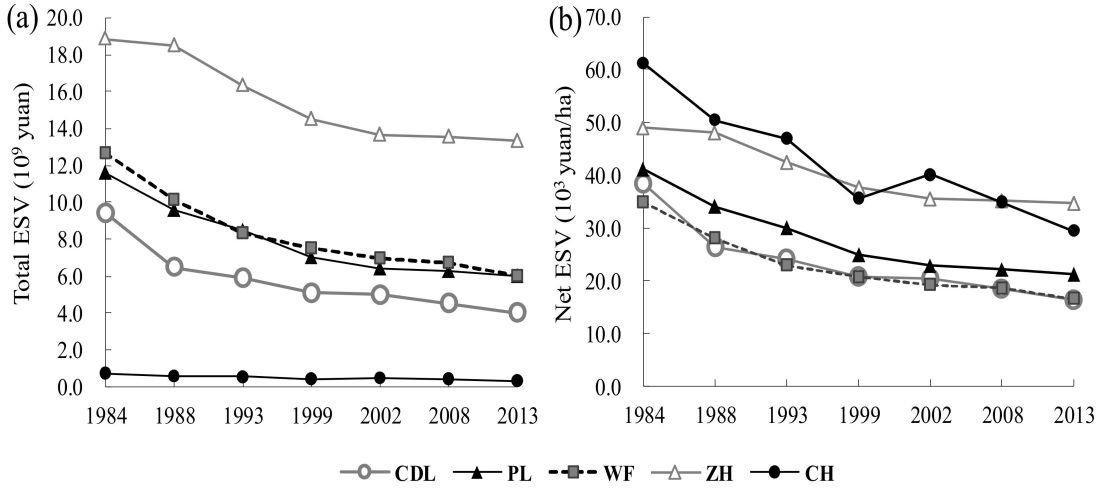


Figure 5. Ecosystem service values of the five administrative regions (CDL, PL, WF, ZH and CH) in Dalian, (**a**) total ESVs and (**b**) net ESVs by dividing the total ESVs by the respective areas.

ZH and CH had higher net ESV values than the other three regions. This was primarily due to the delimitation of larger non-development zones, covering 74.0% and 67.3% of the total areas for ZH and CH, respectively, which strictly protected the forest and water surfaces, delivering higher ESVs. All regions showed a continuous decreasing trend except for CH, where an increase can be observed between 1999 and 2002, after which it decreased sharply until 2013. The decrease after 2002 can be attributed to the fact that 30.8% of the total CH area was projected as a prioritized exploration zone, which focuses on promoting the economic growth and urban development. This can also be verified by the transformation of land use from water and forest to urban type in CH after 2002. The net ESV for CDL, PL, and WF were relatively lower due to the small portion of conservation areas as well as the continuous urban development.

4.5. Implications of ESV on Urban Planning

As introduced in Section 2.1, the Water Affairs Bureau of Dalian proposed a water conservation modernization plan that designates the city into three functional zones, namely Z1, Z2 and Z3, as shown in Figure 6 on the basis of the 2013 land use map.

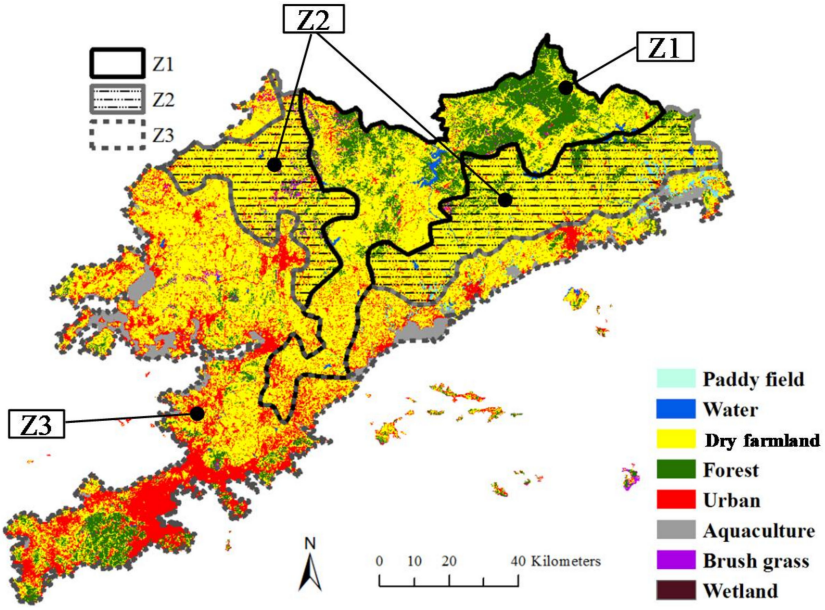


Figure 6. Functional zones (Z1, Z2 and Z3) of Dalian City for future development.

Conservation policy-making should be based on the actual ecological situation, which in turn works as a primary force driving city development. Based on the land use condition of 2013, the net values for regulatory, supply, support and cultural services were analysed for each zone (Figure 7). Z1 had a higher average annual precipitation of 700 to 800 mm, which contributed to the growth of forests and the formation of water surfaces. As shown in Figure 6, about 60.0% of the forest and 58.4% of the water surfaces over the whole study area are located in Z1, delivering a higher net ESV for regulatory, support and supply services in this zone. As a result, very limited urban development is planned for Z1. The development focuses are twofold: (1) to protect the water source area to meet the water demand in terms of both quality and quantity; and (2) to enhance forest growth and protection, as the area suffers from severe soil erosion and flash floods due to the steeper land and low hills.

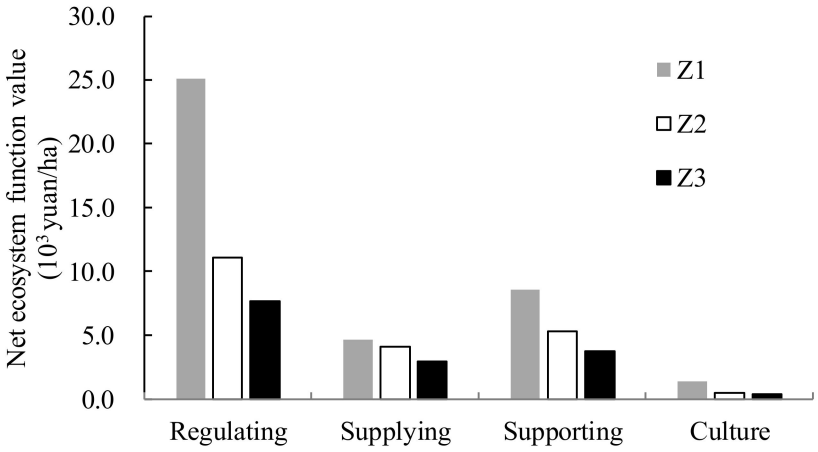


Figure 7. Net values of the regulatory, supply, support and cultural service functions calculated based on the land use classification in 2013 for the three zones.

Z2 consists of partial WF and ZH, of which 82.6% of the area was covered by agricultural dry farmland. The total supply service was relatively high, and comparable to Z1. However, in terms of food production services only, Z2 had the highest net value of 2.6×10^3 yuan/ha, followed by Z1

(2.2×10^3 yuan/ha) and Z3 (1.7×10^3 yuan/ha). Therefore, with the large coverage of dry farmland and high food production service value, future agricultural developments are planned for Z2.

Z3 is the city's core urban area, with industrial development and economic growth. On the basis of the land use map in 2013, about 81% of the total urban area falls in this zone. Since the coefficient value of urban areas is zero, the ecosystem function values for Z3 are the smallest of the three zones. Therefore, the future city development strategy should address the environmental and ecological problems arising from economic growth. The major negative effects include water shortages due to the large demand for water use, high risk of inundation due to the increase of impervious urban surfaces, and water pollution due to urban sewage and industry wastewater discharge. Therefore, to pursue a good ecological environment in urban areas and to improve the living standard and quality of life of urban residents, Z3 should focus on water resource conservation, flood control, pollution treatment, as well as ecological landscape construction.

4.6. Methodological Limitations

The ESV statistical method used in this study was originally proposed by Costanza et al. [1,2], then modified by Xie et al. [17,18] for ecosystems in China, who derive ESVs by multiplying the area of a specific land use type by the corresponding ecosystem coefficient. As such, the limitations of this method primarily come from two aspects: the classification of land use and the application of coefficient values. For the land use change analysis that was performed, the reliability of the results depended strongly on the accuracy of the interpretation of the TM images. A challenge is presented by the fact that different land use categories can produce very similar spectral signatures, making clear identification difficult. The spatial resolution of the land use map can be another influential factor. For example, a finer resolution may produce more detailed types of land use for a given domain, leading to a different estimated ESV [21,33].

The value coefficients used in this study were based on the results reported by Xie et al. [18], which were temporally and spatially static and did not consider possible variations in the ESVs of equivalent biomes. In fact, the value coefficients of the natural biome may differ for different regions due to the local land use and ecological status, and are expected to increase with time, as the natural resources become more scarce and ecosystems become more stressed [34]. Wang et al. [29] used the market price of foodstuffs in 2010 to calculate the equivalent ESV coefficient values, which were higher than the value reported by Xie et al. in 2008 [35]. Moreover, as this method uses land use proxies, the biomes used as proxies were not always perfect matched with the land use types, which may create a supplemental uncertainty in the ESV estimation [13]. For example, the coefficient value of the food production function of water was applied for aquaculture in this paper, and that for urban areas was regarded as zero, neglecting the negative impacts of pollution (e.g., air pollution, water pollution, waste pollution, etc.). However, for the case study in this paper, the main focus was on the spatiotemporal variations of the ESVs over time, which may reduce and offset the uncertainties, and thus the results are considered reasonable and reliable, particularly in directional and qualitative terms.

Despite the methodological limitations, the ESV can be potentially used as an indicator for policy making as it highlights the benefits of sustainable ecosystem management [21,29,34]. However, it would be going too far to state that the statistical analysis of ESVs with proxy-based mapping in this paper explicitly specifies the implementation of land management plans, due to the inadequate explanation of the underlying driving forces, such as socio-economic and biophysical processes. With regard to this, studies have applied various land use change models that explain the causes and consequences of mechanisms of land use dynamics, and scenario analysis can be a measurable tool for making informed decisions on land use planning and policy [36,37]. Some models are rooted in individual behavior, such as the multi-agent model, which can simulate decision-making by individual agents of land use change by explicitly addressing interactions between individuals [38,39], as well as models based on economic theory that consider the decision making of individual landowners in order to maximize the benefits of the land [40,41]. However, the comprehensive application of

these models is likely to be limited by the requirements of a large number of interacting agents and associated factors [36–39]; moreover, difficulties may arise when upscaling micro-level behaviors to a higher aggregation level for the purpose of land use planning [36,42].

There are other models based on the spatial structures of land cover and land use. One is an empirical–statistical model that empirically relates land use change to driving forces. Bakker et al. [43] conducted a logistical regression analysis between land-use changes and the occurrence of soil erosion and found that the erosion process is an important driver of the abandonment and reallocation of arable land in the western part of Lesvos, Greece. Verburg et al. [44] applied the CLUE-S (Conversion of Land Use and its Effects at a Small Regional Extent) model for the scenario-based simulation of land use change trajectories on Sibuyan Island, Philippines, and in the Klang-Langat watershed, Malaysia. In addition, cellular automata (CA) has become a very common method, which takes the spatial autocorrelation of land use patterns into account [45,46]. It calculates the state of a pixel based on its initial state and the condition of its surrounding pixels following certain transition rules. For example, the SLEUTH Urban Growth Model has been widely applied to predict future urban sprawl in many case studies [47–49].

Therefore, land use modelling using the above approach or an integration of different approaches would be highly beneficial in order to better understand the land use change mechanisms and produce scenarios for better governance and decision-making. Nevertheless, the priority of this paper was to establish a broad indication of the overall changes in ESVs on both the temporal and spatial scales, as well as its link with local planning policies. With less input data required and a lower computational burden, this study is considered suitable for a quick and general understanding of the impact of urban policy on ESV variations, which also suggested that the status of ESVs is, in turn, an indicative measure for land managers to consider when formulating development policies.

5. Conclusions

This study assessed the temporal and spatial changes in ecosystem service values driven by land use changes in Dalian, China. Remote sensing data were used to characterize the land use changes from 1984 to 2013. The results showed a dramatic increase in urban areas, with an average increase rate of 8.3% per year. Dry farmlands and forests accounted for about 80% of the total area on average, whereas other land use categories including water and wetlands had a relatively small area.

The ESVs on both the temporal and spatial scales were assessed based on the land use conditions. The total ESV of Dalian City was reduced from 53.3×10^9 yuan in 1984 to 29.7×10^9 yuan in 2013, mainly due to the reduction of forests, dry farmlands and water bodies. Water regulation is the largest service function, followed by climate regulation and soil formation and retention. In addition, the ESV was found to vary spatially among administrative regions due to different development strategies. ZH had the largest ESV, accounting for 41.3% of the total value for the entire study area, and CDL had the maximum ESV decrease rate of −2.0% per year. ZH and CH had higher net ESV values, mainly due to the larger proportion of non-development zones. Finally, analyzing the ESVs of the three functional zones designated by the water conservation plan justifies the urban planning strategies, which correspond well to the actual ecological status of the zones but suggests different ecosystem service functions for each zone, which should be prioritized in future development.

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