Sustainability **2015**, *7*, 10365-10387; doi:10.3390/su70810365

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

The Impact of Land Cover Change on Ecosystem Service Values in Urban Agglomerations along the Coast of the Bohai Rim, China

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Academic Editor: Marc A. Rosen

Received: 12 June 2015 / Accepted: 29 July 2015 / Published: 5 August 2015

Abstract: Local ecosystem services have been significantly affected by land cover changes associated with rapid urbanization in China. Based on the 2000 and 2010 land cover data products with 30-m resolution, we examined the similarities and differences in the impacts of land cover change on ecosystem service values (ESV) at three coastal urban agglomerations in China between 2000 and 2010 (Liaodong Peninsula (LP), Jing-Jin-Ji (JJJ) and Shandong Peninsula (SP)). A rapid evaluation method developed by Xie *et al*. (2008) was used to derive an ecosystem service value coefficient. The most significant change was an increase in artificial surfaces, due to urban expansion, which mainly occurred on cultivated land. The greatest loss in total ESV (2273 million Chinese Yuan) occurred in SP, due to the large decrease in wetland areas, because this service has the highest estimated coefficient. The second greatest loss in ESV (893 million Yuan) occurred in JJJ, due to the urban expansion of major cities. In contrast, ESV increased (72 million Yuan) in LP. This study demonstrates that urban expansion does not necessarily lead to a net decline in ESV. In conclusion, land use and land cover policymaking should consider the sustainability of ecosystem services in relation to economic growth.

Keywords: ecosystem services; land cover change; ecosystem service values; urban agglomeration; coast; Bohai Rim

1. Introduction

Ecosystems provide a variety of direct and indirect products and services for human survival, health and welfare [1], which form the foundation of human society [2–4]. The quality and quantity of provisions generated by ecosystem services depend on the structure, process and function of the surrounding natural ecosystem [5]. Yet, global population growth, economic development and urban expansion have placed pressure on ecosystems, resulting in their being substantially degraded, destroyed or transformed. As a result, the effectiveness of ecosystem services has been impeded at multiple scales. Studies on ecosystem services have become increasingly popular to evaluate environmental change, resource management and sustainable development, because these services incorporate society benefits [6]. Assessing the value of ecosystem services that influence human well-being by market price or non-market value is regarded as an important tool to promote the importance of ecosystems and encourage sustainable economic growth.

Costanza *et al.* [1] provided the first classification of the global biosphere into 16 types of ecosystems and 17 types of service functions, from which they estimated the ecosystem service values (ESV) for each category. Subsequently, Costanza *et al.* [7] updated their ecosystem service value coefficient table using current ESV units and land cover change estimates based on data collected between 1997 and 2011. These coefficient values have been widely applied in estimating ESV. Xie *et al.* [8] modified the coefficient values based on those of Costanza *et al.* [1] in 1997 to formulate an accurate ESV-per-hectare for the terrestrial ecosystems in China by surveying approximately 200 Chinese ecologists. The coefficient values were directly applied to several ecosystem service studies in China, in addition to being adjusted for the unique land cover types of China's internal regions [9–12]. Most studies evaluating ESV in China have been primarily based on the method of Costanza *et al.* [1] and Xie *et al.* [8].

In the past five years, most studies have evaluated the ESV of one type of single [13,14] or whole ecosystem in relation to changes at global [15,16], national [17,18] and local [19,20] scales. Several studies have used land cover types as proxies for ecosystems, by matching the land cover types to equivalent biomes, because different biomes have different land cover benefit transfer values [21,22]. At large scales, land cover change represents one of the clearest and most informative indicators of ecosystem impacts at state- and province-level scales [23]. Consequently, several studies have focused on the relationship between ESV and land cover types to determine how land cover change affects the provision of ecosystem services [24,25]. These studies have validated that land cover affects ESV globally, especially in urbanized regions. For instance, land cover change in urban sites is detrimental for several ecosystems [26,27].

Human activities have an unavoidable impact on natural and semi-natural ecosystems in urban agglomerations. Examples of such activities include urban expansion, industrialization and economic growth. As rapid urbanization by the Chinese population continues [28,29], a large number of urban agglomerations have emerged. Urban agglomeration is a modern spatial pattern formed by functional connections between cities or metropolitan areas [30]. It has become the principal economic and urbanization unit for countries to participate in globalization. Unfortunately, some urban agglomerations have caused major changes to land cover due to urban expansion, leading to ecological damage, especially during the process of urbanization in China. Critics have warned that urban expansion has created a Chinese version of urban sprawl and the loss of natural ecosystems [31]. Indeed, a large proportion of land made up of natural ecosystems has been converted to artificial uses to meet the demands of housing, industry and commerce around the cities of China [32], particularly in economically-developed coastal urban agglomerations [33,34].

Our study focuses on the three urban agglomerations along the coast of the Bohai Rim, China. These cities were selected because increasingly noticeable and rapid changes in land cover have had important ramifications on coastal urban agglomerations [35]. The Bohai Rim is the third-largest economic zone in China, after the Yangtze River Delta and the Pearl River Delta. The three urban agglomerations of this study are affected by excessive land reclamation and natural resource exploitation, along with rapid urbanization. For example, groundwater was exploited excessively for domestic, industrial use and agriculture in the three agglomeration region, which have resulted in seriously short supply of water resources and affected the sustainability of the three study areas. All three urban agglomerations are of economic and ecological significance; however, differences exist in the characteristics of land cover change and associated ESV changes. However, few studies have investigated such differences among cities. We aimed to: (1) characterize and compare the change in land cover for these three coastal urban agglomerations from 2000 to 2010 in the context of rapid urbanization; (2) evaluate and compare changes in ESV caused by land cover changes; and (3) provide suggestions for policymaking to mitigate ESV loss by adjusting land cover composition and encouraging sustainable development of coastal urban agglomerations.

2. Materials and Method

2.1. Study Area

The Bohai Rim area is located in the northern part of China's eastern coast (Figure 1). It is an important economic growth area because of its advantageous location and open economic environment. Consequently, this area also has one of the most important concentrations of industry and trade in China [36], in addition to quite high agricultural productivity. The coastal region of the Bohai Rim is a transitional environment between the terrestrial and marine ecosystem. Therefore, the area contains highly diverse ecosystems, including coastal wetlands, shoals, fishponds, saltpans, croplands, forests and grasslands. In the coastal urban agglomerations, rapid urban expansion has generated the occupation, pollution and overexploitation of natural resources. With the continued increase in human demand for space and resources, the cultivated land around the cities, in addition to the coastal and riparian wetlands, is being degraded and transformed by various human activities.

We selected three urban agglomerations along the coast of the Bohai Rim that had contrasting urban expansion and industrial activity; specifically, Liaodong Peninsula (LP), Jing-Jin-Ji (JJJ) and Shandong Peninsula (SP) (Figure 1, Table 1). LP is located in the Liaoning Province to the north of the Bohai Rim. This province was an important heavy industry hub of China and is currently under transformation pressure to a new stage of development. JJJ is located to the west of the Bohai Rim. This area includes Beijing, Tianjin and eight municipalities in Hebei Province. JJJ is dominated by commercial and cultural activities, particularly in Beijing and Tianjin. This area has had the greatest economic growth out of the three study sites. SP is located in Shandong Province to the south of the Bohai Rim. This area encompasses eight municipalities in the coastal area of Shandong Province. It has primarily been subject to urban expansion and includes large urban infrastructure.

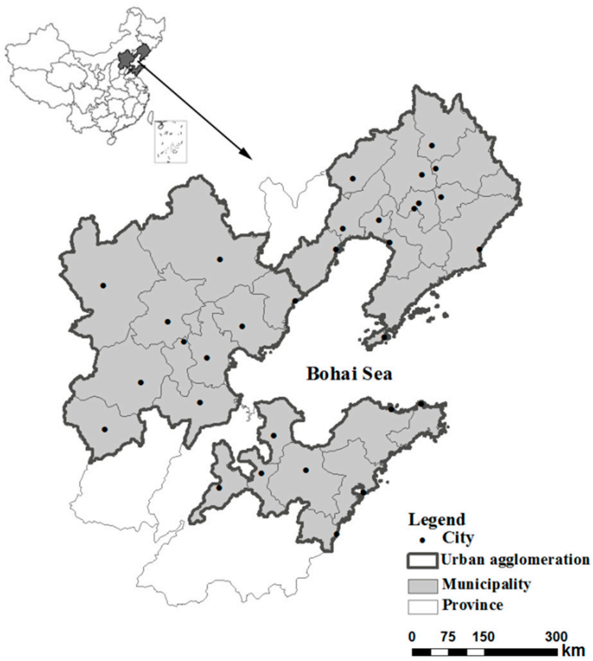


Figure 1. Location of the three urban agglomerations along the coast of the Bohai Rim: Liaodong Peninsula, Jing-Jin-Ji and Shandong Peninsula.

Table 1. Location, natural conditions and social features of the three urban agglomerations. LP, Liaodong Peninsula; JJJ, Jing-Jin-Ji; SP, Shandong Peninsula.

	LP	JJJ	SP
Latitude	38°43′N to 43°29′N	36°01′N to 42°37′N	35°5′N to 38°9′N
Longitude	119°12′E to 125°47′E	113°04′E to 119°53′E	116°11′E to 122°41′E
Area (km^2)	127,200	185,000	73,000
Climate	monsoon climate of warm temperate zone	monsoon climate of warm temperate zone	monsoon climate of warm temperate zone and mid-temperate zone
Rivers	Liao, Dayang, Yingna, Biliu, Dasha	Haihe, Luanhe	Yellow river, Jiaolai, Wei, Dagu
Major cities	Shenyang, Dalian	Beijing, Tianjin	Jinan, Qingdao
Main activities	heavy industry, commerce, fishery, tourism	commerce, culture, industry, agriculture	fishery, salt industry, aquaculture industry, agriculture, tourism
Population density (per square kilometer)	307	401	553
GDP/per capita (USD)	11,739.1	9525.9	11,457.0
National nature reserve	Y	Y	Y

2.2. Land Cover Datasets

The land cover datasets for LP, JJJ and SP in 2000 and 2010 were derived from China's Global Land Cover data product with a resolution of 30 m (GLC30) [37]. The datasets contain 10 land cover types, seven of which were used for the study. The land cover types included cultivated land, forest, grassland, wetland, water bodies, artificial surfaces and bare land (see Table 2 for full definitions).

Table 2. Explanation of land cover type.

Land Cover Type	Definition
Cultivated land	Single-cropping wheat, wheat/corn, single-cropping rice, double-cropping rice, corn, greenhouses, pasture
Forest	Evergreen broadleaf, deciduous broadleaf, evergreen needleleaf, deciduous needle leaf, mixed forests
Grassland	Non-Arctic C3 grasslands, C4 grasslands, scrub grasslands
Wetland	Marsh, forested wetlands, other wetlands
Water bodies	Lakes, reservoirs/ponds and rivers
Artificial surfaces	Impervious area
Bare land	Salt and alkali, sand, gravel, rock, temporally-bare croplands, biological crust

The average overall accuracy of classification over the study period was 79.6% and 83.3% in 2000 and 2010, respectively. The kappa coefficients were 0.78 and 0.81 in 2000 and 2010, respectively. The analysis on changes to land cover type were performed using ArcGIS version 10.0 software. A cross-tabulation detection method was employed to quantify the change in land cover type. A land cover transfer matrix was produced by two-raster layer stacking in each study area between 2000 and 2010. The proportional rate of change for each land cover type in the three study areas was calculated from Equation (1):

$$R = (A_{2010} - A_{2000}) / A_{2000} \times 100 \quad (1)$$

where R represents the proportional change in a given land cover type and A_{2000} and A_{2010} represent the area of the given land cover type in the years of 2000 and 2010.

In addition to the land cover datasets, a 1:4,000,000 Chinese administrative map was used as a reference. The location and extent of the three urban agglomerations was derived from this map based on the methods of Fang *et al.* [36]. In addition, because reclaimed land is changing the coastline, most of the peripheral buildings that extended to the Bohai Rim in 2010 were treated as coastline in 2000 and 2010. Figure 2 presents the final land cover maps.

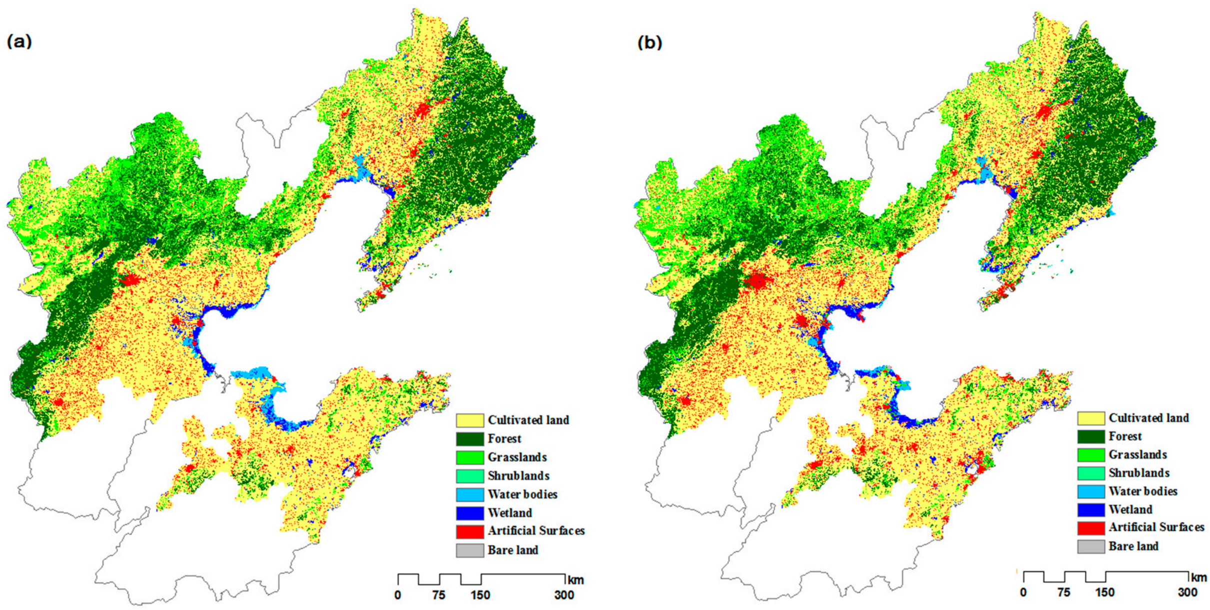


Figure 2. Land cover maps of the three urban agglomerations in 2000 (**a**) and 2010 (**b**).

2.3. Assessment of Ecosystem Service Values

To calculate the mean economic value of the ecosystem services, we used the market value of ecosystem services per unit area developed for application in China by Xie *et al.* [8]. Table A1 provides the classification and definition of each of the ecosystem services. In this method, cropland is the reference value for all ecosystems. Although the method has some potential conceptual and empirical problems, it has been widely used to value China's ecosystem services [38,39]. For the purpose of broadly analyzing the impact of land cover changes on ESV in the three study areas, this valuation method is still considered useful. The assessment of ESV across the three urban agglomerations was computed as follows:

$$ESV = \sum_{k}\sum_{f} A_k \times VC_{kf} \quad (2)$$

$$ESV_f = \sum_{k} A_k \times VC_{kf} \quad (3)$$

$$ESV_k = \sum_{f} A_k \times VC_{kf} \quad (4)$$

where ESV is the total ecosystem service value, ESV_f, is the value of ecosystem service function type "*f*" and ESV_k is the ecosystem service value of land cover category "*k*". A_k is the area (ha) of land cover "*k*"; VC_{kf} is the value coefficient for land cover category "*k*" and ecosystem service function type "*f*".

Not all of the land cover types in the study areas were assigned a value using this method. The value coefficient for artificial surfaces is not defined in the scheme of Xie *et al.* [8], because perfect matches are not available for the biomes and the land cover types in every case provided by Xie *et al.* [8]. It is not yet possible to determine the value of urban ecosystem services accurately at a global or national level, with smaller scales being recommended (e.g., city level). Because this study was conducted at a regional scale, ecosystem services and their values for artificial surfaces were considered as zero. Table 3 provides an excerpt of the ecosystem services and their market values in Chinese Yuan (CNY), as proposed by Xie *et al*. [8].

Table 3. Excerpt of ecosystem service value per unit area (Yuan ha^{-1}) of different land cover types in China as proposed by Xie *et al*. (2008) [8].

Category	Sub-Category	Wetland	Water Bodies	Forest	Grassland	Cultivated Land	Bare Land	Total
Provisioning	Food production	162	238	148	193	449	9	1199
	Raw materials production	108	157	1338	162	175	18	1958
Regulating	Gas regulation	1082	229	1940	674	323	27	4275
	Climate regulation	6085	925	1828	701	436	58	10,033
	Hydrological regulation	6036	8430	1837	683	346	31	17,362
	Waste treatment	6467	6669	772	593	624	117	15,242
Supporting	Soil formation and conservation	894	184	1805	1006	660	76	4626
	Biodiversity maintenance	1657	1540	2025	840	458	180	6701
Cultural	Providing aesthetic values	2106	1994	934	391	76	108	5609
Total		24,597	20,367	12,629	5241	3548	624	67,006

To describe the spatial heterogeneity of ESV visually, 1 km × 1 km grid cells were defined for the study areas. We first integrated the land cover images with the empty basic grid cells to compute the area of each land cover type. We then calculated variation in ESV for each grid cell and mapped the results.

3. Results

3.1. Change in Land Cover

To understand how land cover is changing in the three urban agglomerations, we calculated the change in area of the different land cover types (Figure 3) and the percentage change (Figure 4) according to Equation (1) between 2000 and 2010. We detected a significant change in land cover from 2000 to 2010 in all three urban agglomerations (Figure 5), which was characterized by an increase in artificial surfaces and a decrease in cultivated land. Thus, cultivated land was lost due to pressure for an increase in artificial surfaces.

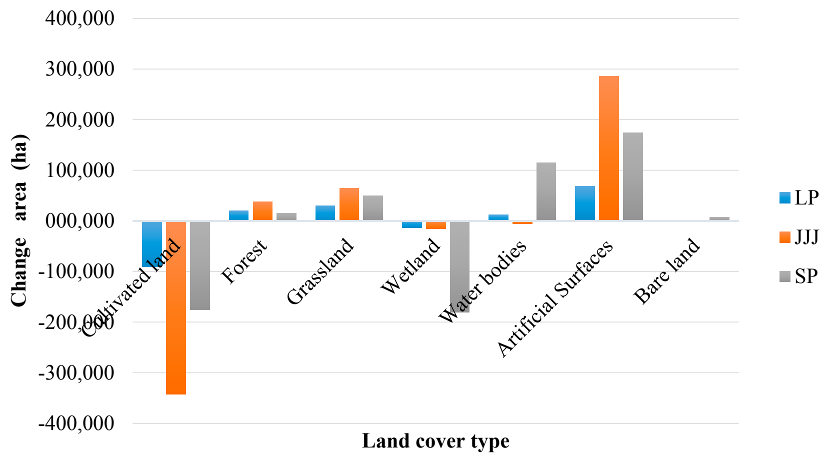


Figure 3. Change in the area of the land cover types in the three urban agglomerations between 2000 and 2010.

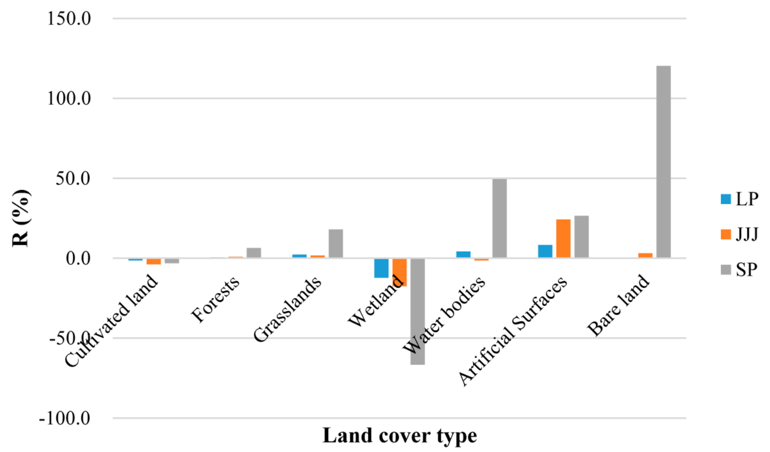


Figure 4. Rate of change in area of the land cover types in the three urban agglomerations between 2000 and 2010.

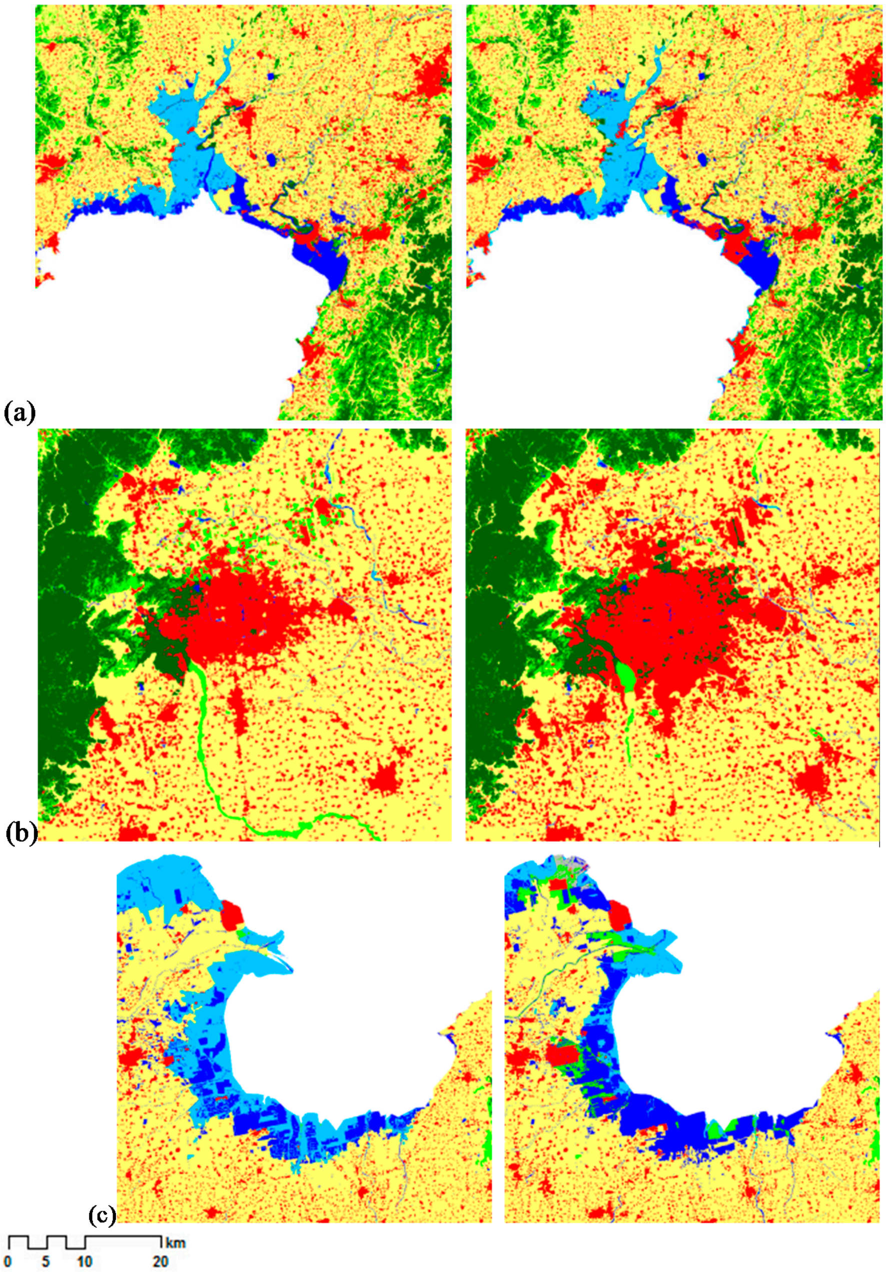


Figure 5. Examples of land cover transitions in LP, JJJ and SP. Left and right columns represent the years 2000 and 2010, respectively. (**a**) Wetlands in LP (wetland to cultivated land); (**b**) urban expansion in Beijing, JJJ (cultivated land to artificial surfaces); (**c**) wetland degradation in Laizhou Bay, SP (wetland to water bodies). Data source: GlobeLand30 [37].

There was a net increase in artificial surfaces and a large reduction in cultivated land in LP. The artificial surfaces of urban areas increased by 8.3% (68,199 ha), from 820,003 ha in 2000 to 888,202 ha in 2010. In contrast, cultivated land decreased by 90,446 ha. Wetlands, which are one of the most important ecosystems for regulating services, decreased by 12.3% over the 10-year period. Forest and grassland increased by 19,943 ha and 30,037 ha over the study period, respectively. The transition matrix reveals that 100,823 ha (1.6%) of cultivated land converted to artificial surfaces, mainly involving the creation of construction from the urban-rural fringe; while a large area (65,740 ha, 60,267 ha and 12,648 ha, respectively) of forest, grassland and water bodies were transformed into cultivated land, respectively (Table A2).

A similar trend in land cover change was detected in JJJ compared to LP. JJJ had the largest changes in cultivated land, artificial surfaces, forest and grassland cover compared to the other two areas. The artificial surfaces expanded very quickly, with an increase of 285,960 ha, representing a growth rate of 24.3%. In contrast, cultivated land decreased from 8,915,849 ha total land area to 8,573,052 ha over the 10-year period. However, forest and grassland increased by 0.9% (37,560 ha) and 1.7% (64,022 ha), respectively, during the 10-year period. The transition matrix showed that artificial surfaces primarily increased at the expense of cultivated land (Table A3). This result demonstrates the urbanization trend, particularly in the peripheral area around the major cities and the marine reclamation area in the coastal region.

Out of all three urban agglomerations, the greatest loss in wetland cover was detected in SP, at a rate of 66.7% (180,473 ha) (Table A4). A large percentage of wetlands (73,083 ha, representing 27% of total land area) was converted to water bodies for aquaculture and saltpans at the interface between seawater and land in the Laizhou Bay. SP also had a large reduction in cultivated land and a significant increase in artificial surfaces over the 10-year period (Figure 3). SP had the highest rate of change in land cover, with the exception of cultivated land, for all three urban agglomerations (Figure 4). The expansion of urban areas occurred at the expense of cultivated land and wetlands in SP, which shrank by 221,472 ha and 11,493 ha, respectively (Table A4).

3.2. Estimation of Change in Ecosystem Service Values

Using the estimated change in the size of each land cover type, together with the ESV coefficients reported by Xie *et al*. (2008) [8] (Table 2), we calculated the total ESV and its variation according to Equation (2) for 2000 and 2010 (Figures 6 and 7). Based on Equations (3) and (4), the variation in the values was calculated between the two years for each ecosystem service category and each land cover type in our study areas (Figures 8–11, Tables A5–A7). We found that forest produced the largest proportion of the total ESV in LP and JJJ (57% and 46%, respectively). This result indicates that forests are important in these two urban agglomerations. Unlike LP and JJJ, cultivated land was the primary land cover type for ESV in SP.

Between 2000 and 2010, the total ESV in LP slightly increased from 86,657 million Yuan in 2000 to 86,729 million Yuan in 2010（Figure 6）, with a net increase of 72 million Yuan (Figure 7). There was an increase in almost all ecosystem services in LP, except food production (Figure 8a). Hydrological regulation was the dominant function and had the largest increase in LP. The net ESV gains from increased forest, grassland and water body coverage were 252 million Yuan, 158 million Yuan and 246.2 million Yuan, respectively. These gains were higher than the losses caused by a decrease in cultivated land and wetland, explaining the increased ESV increased in in LP (Figure 10a).

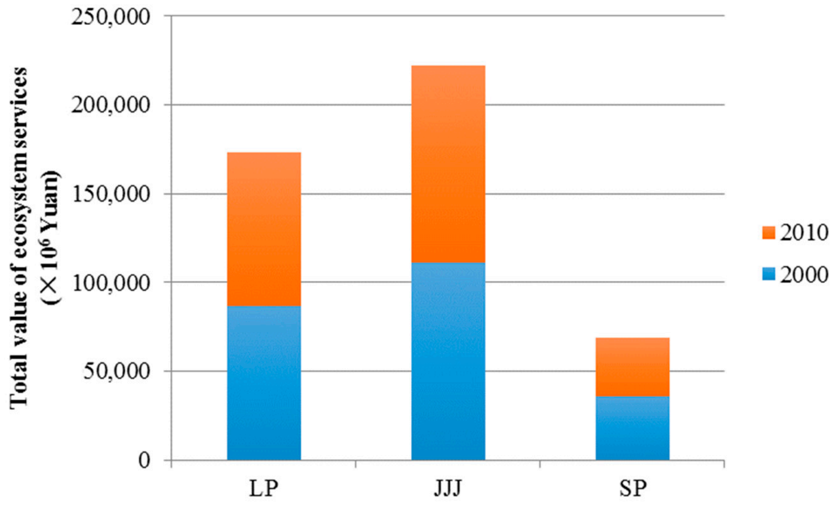


Figure 6. Total value of ecosystem services in LP, JJJ and SP in 2000 and 2010.

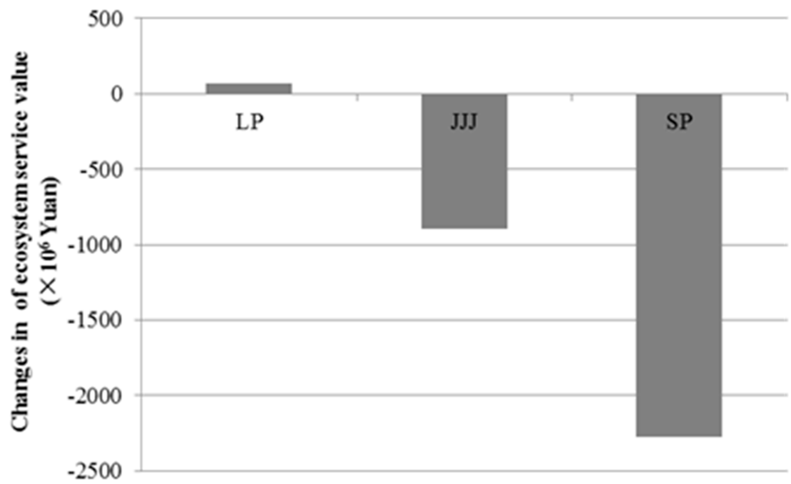
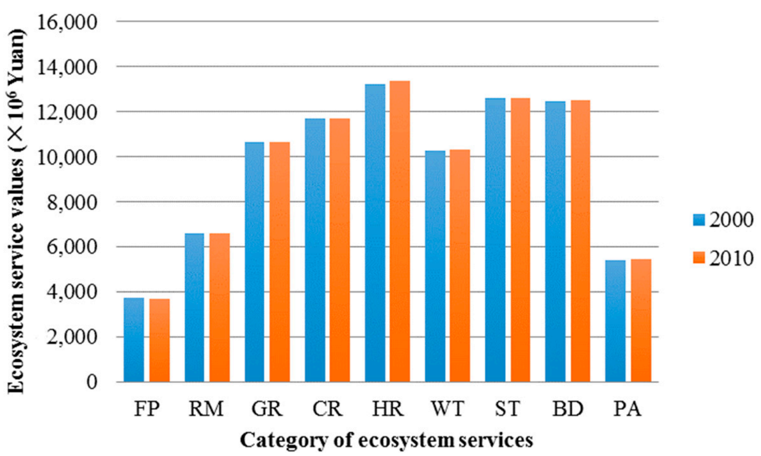
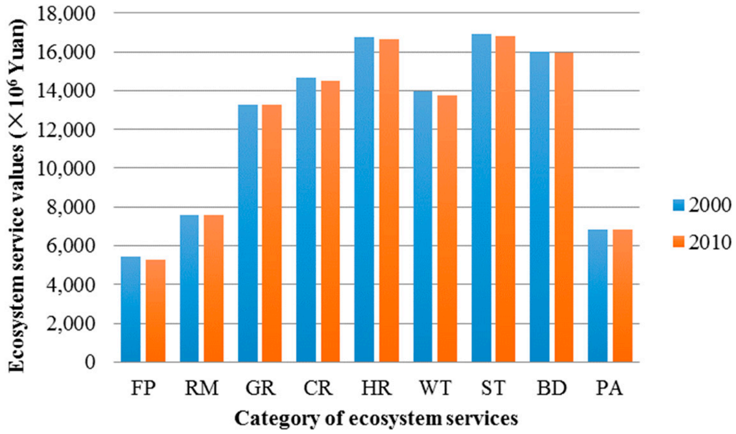


Figure 7. Changes in the total ecosystem service value in LP, JJJ and SP in 2000–2010.

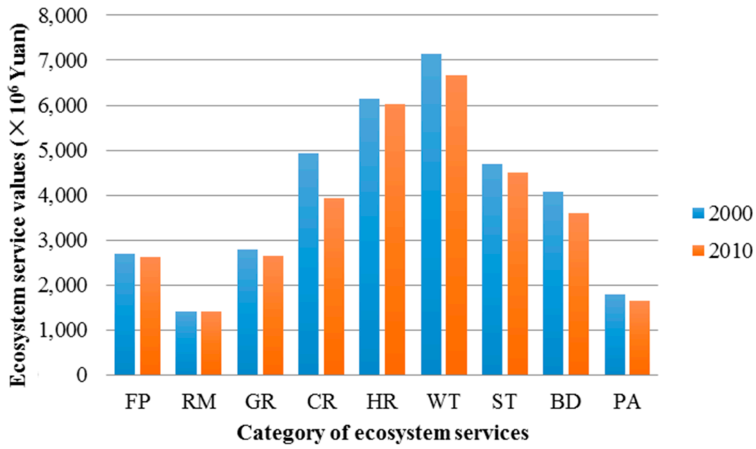


(a)

Figure 8. *Cont.*



(**b**)



(**c**)

Figure 8. Value of ecosystem service category (ESV_f) in LP (**a**), JJJ (**b**) and SP (**c**) in 2000 and 2010.

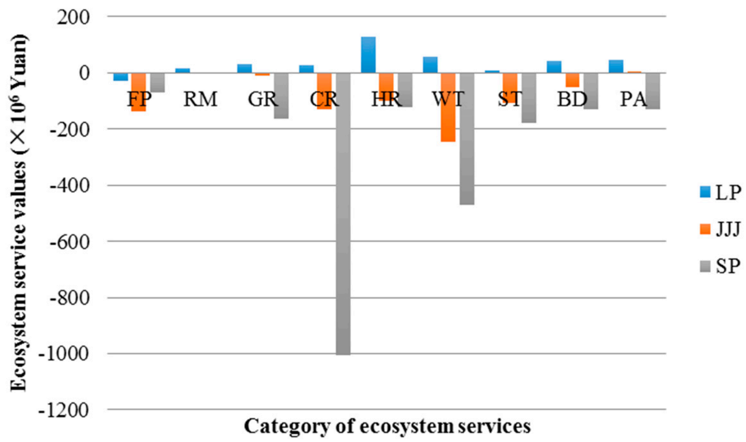
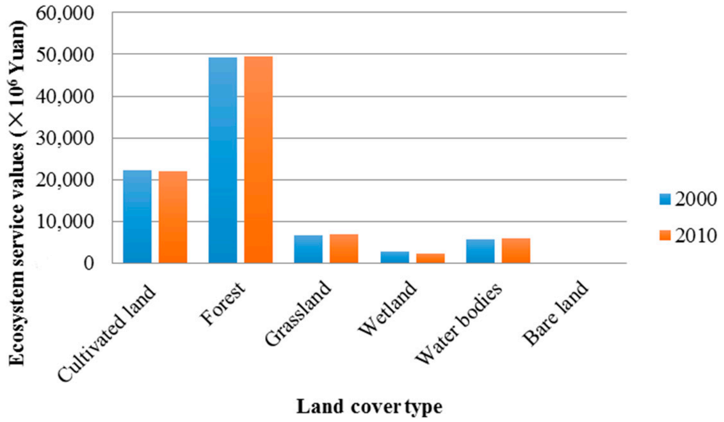
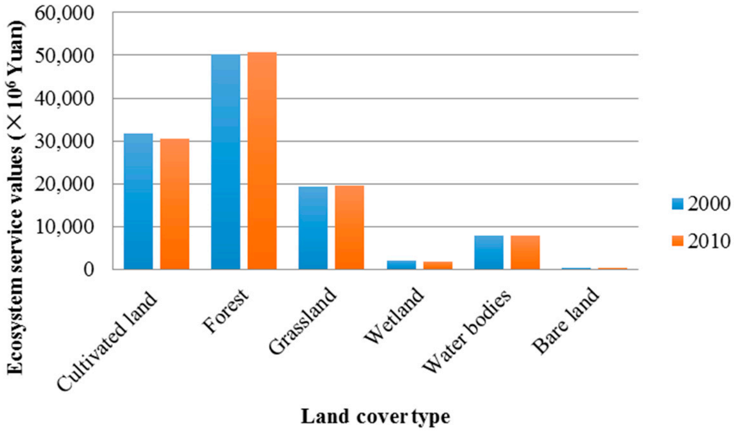


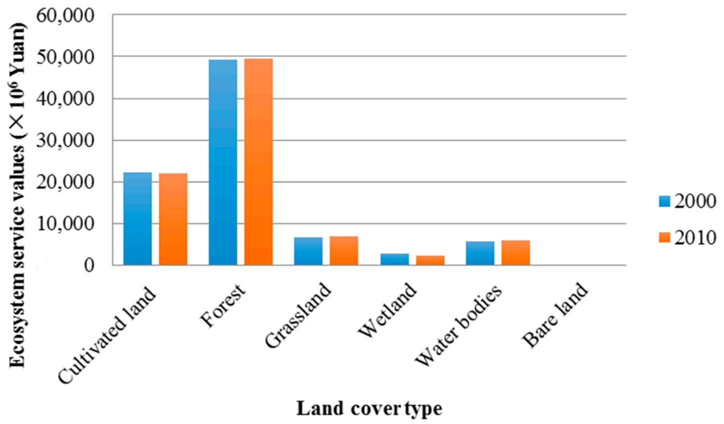
Figure 9. Changes in the value of the ecosystem service category (ESV_f) in 2000−2010.



(**a**)



(**b**)



(**c**)

Figure 10. Value of land cover types (ESV_k) in LP (**a**); JJJ (**b**) and SP (**c**) in 2000 and 2010.

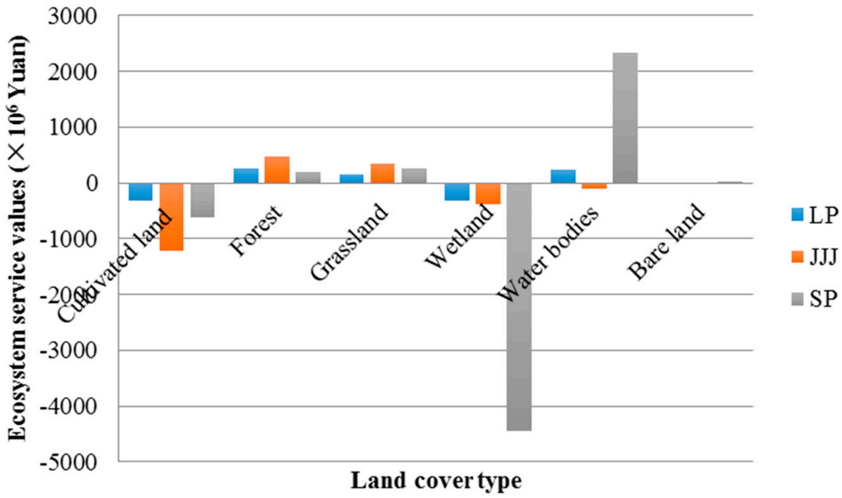


Figure 11. Changes in value of land cover types (ESV_k) in 2000−2010.

In contrast to LP, the total ESV of JJJ significantly declined over the 10-year period, with a net decrease of 893 million Yuan (Figure 7). All of the ecosystem service categories decreased in JJJ, except for a minor gain in landscape aesthetics. The decline was caused by a major decrease in the ESV of cultivated land (Figure 10a), which caused 1216 million Yuan in ESV losses. During the study period, the largest decline in cultivated land occurred in JJJ, most of which was converted to artificial surfaces for urban expansion. The coefficient value of the ecosystem services for artificial surfaces was considered to be zero for the purposes of our study; therefore, the transition yielded a relatively high contribution to ESV losses. There was only a minor decrease in ESV for wetland and water bodies, because their areas did not change much in JJJ.

Similar significant losses in ESV were detected for SP, like JJJ. Total ESV declined from 35,674 million Yuan in 2000 to 33,402 million Yuan in 2010 (Figure 6), with a decrease of 2273 million Yuan (Figure 7). This decline was 2.5-times greater than that recorded in JJJ. All of the ecosystem service categories were subject to losses in ESV (Figure 8c). The climate regulation function value decreased the most (1006 million Yuan), primarily due to the large decline in wetland ESV (4439 million Yuan), with a very high coefficient value. Although there was a major increase in water bodies (114,409 ha), this contribution towards improving ESV could not compensate the losses caused by the decrease in wetlands, which was responsible for the decrease in total ESV in SP (Figure 10c).

Overall, land cover change from 2000 to 2010 resulted in a net change in ESV in all three urban agglomerations. LP showed minor gains in total ESV, while, JJJ showed significant ESV losses because of the transition from cultivated land to artificial surface. SP showed the greatest ESV losses, mainly because of the conversion of wetlands, which are very valuable ecosystems (in terms of the estimated coefficient in this study), to water bodies and artificial surfaces with relatively low and zero estimated coefficient values.

3.3. Spatial Distribution of the Change in Ecosystem Service Values

Based on the grid cells, we obtained the spatial distribution in the variation of total ESV change for LP, JJJ and SP between 2000 and 2010 (Figure 12). This confirmed that the coastal regions and the urban periphery had more ESV losses than other areas in the three study areas in general. The major decline in ESV in the hinterlands was mainly caused by cultivated land being replaced with artificial surfaces in all three study areas, particularly on the periphery of Beijing and Tianjin in JJJ (Figure 12b). ESV loss was caused by coastal wetlands being converted to artificial surfaces with low service levels in Caofeidian District and New Binhai District of Tianjin in JJJ. However, the large loss of ESV in the coastal areas of Laizhou Bay in SP (Figure 12c) was caused by coastal wetlands being converted to emerging artificial water bodies (saltpans and aquaculture), with lower ESV coefficients.

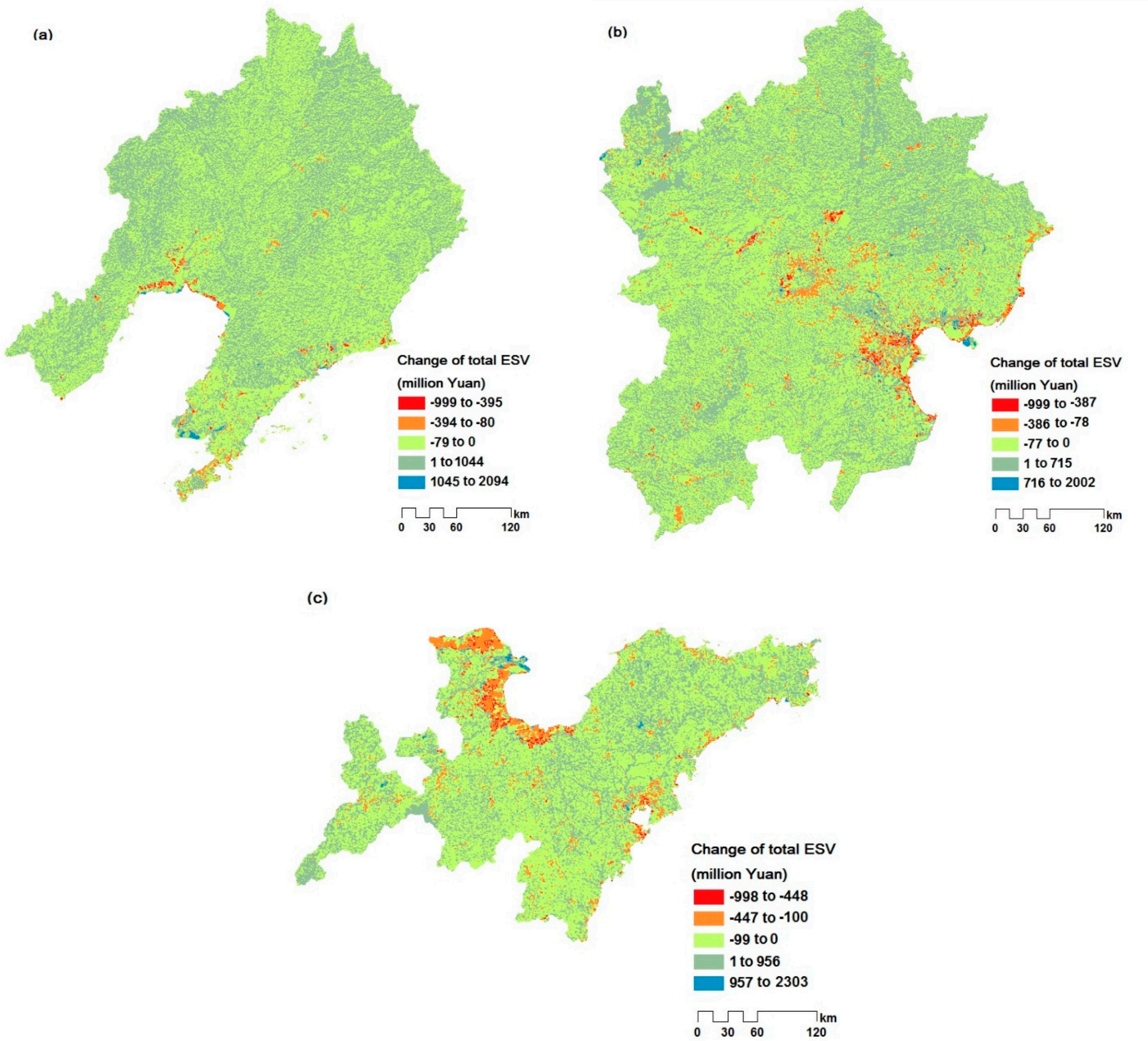


Figure 12. Spatial distribution in the variation of total ESV in LP (**a**); JJJ (**b**) and SP (**c**) between 2000 and 2010.

4. Discussion

Here, we detected noticeable changes in land cover and ESV among three urban agglomerations in China. The total ESV of LP slightly increased, due to an increase in forest, grassland and water body cover, the higher coefficient values of which offset most of the decreases caused by the loss of cultivated land and wetland to artificial surfaces. The degradation of coastal wetlands primarily occurred on the southwestern shore of Panjin Municipality, where some scattered wetland patches were converted to cultivated land. However, the decrease in total wetland area in LP was minimal, because the main wetland area is located in the Shuangtaihekou National Nature Reserve in the Liaohe River Delta. This reserve was established in 1988, with the aim to protect the coastal estuary wetland ecosystem. Thus, the wetland area in LP is protected by effective natural reserve laws and policies. The increase in artificial surfaces due to large-scale urban expansion occurred at the expense of water bodies and grasslands, primarily in Shenyang, Panjin and Yingkou municipalities along the coastal area.

JJJ had a net loss in total ESV, because of the largest absolute increase in artificial surface area in the three study areas. The conversion of cultivated land to artificial surfaces due to urban expansion was the strongest driver in JJJ. Beijing and Tianjin were the largest hotspots for urban expansion in JJJ between 2000 and 2010. The cultivated land on the periphery of Beijing and Tianjin in 2000 gradually disappeared and almost completely vanished with the expansion of Beijing and Tianjin until 2010. This expansion occurred because there was an urgent need to accommodate the increasing population and growing economy. In addition to artificial surfaces occupying cultivated land around the city, they also occurred as a result of land reclamation in the coastal area of the Caofeidian District and New Binhai District in Tianjin, mainly due to the construction of ports and harbor industry [40]. This phenomenon resulted in the loss of wetlands at the shoals on the coast of the Caofeidian District and New Binhai District. Consequently, land reclamation contributed to the loss of a proportion of coastal wetland areas in JJJ [41]. The expansion of artificial surfaces around the city and in the urban clusters in the interior of JJJ should be strictly controlled to avoid ESV loss. Coastal areas should receive more ecological protection; however, to date, the focus has been on economic development.

The greatest reduction in ESV occurred in SP, due to the largest absolute loss of wetland coverage. The coastal wetland was substantially degraded and disappeared because of conversion to artificial water bodies dominated by saltpans and aquaculture, especially in the coastal area of Laizhou Bay [42]. Because Laizhou Bay is an important extensive saltpan and aquaculture zone in China, local economic income is highly dependent on the salt industry and aquaculture and has been subject to targeted state-led industrialization and economic growth policy pressure. In addition, local residents had low awareness about wetland ecosystem services, resulting in intertidal-mudflat wetlands being extensively and excessively utilized for saltpans and aquaculture. Consequently, pressure for economic growth by the local community has heavily influenced land use policies and decision-making processes. As a result, wetlands were primarily converted to other land cover types, including water bodies (aquaculture and saltpans), cultivated land and grassland. Wetlands urgently require protection and validation of their importance as ecosystem services to improve the quality of the ecological environment in SP [43].

We detected the main negative and positive factors associated with the trends in changing land cover. These factors are interrelated and often have a synergistic impact on ecosystem services. Urban expansion and industrial construction had a strong negative impact on the ecosystem service values estimated in this study. The conversion of cultivated land to artificial surfaces was the most recurrent land cover change. Urban land increased by 8.3%, 24.3% and 26.6% in the three study areas, respectively. In addition, new saltpans and aquaculture construction occurred at the cost of coastal wetlands, leading to a substantial decline in wetland coverage. While the amount of wetland loss varied among the three study areas, it was universally a major contributor to total ESV loss. This is because wetland ecosystems have the highest estimated coefficient values. Consequently, the decline in cultivated land and wetland coverage contributed the most to ESV loss. However, China's national green infrastructure programs, which aim to protect the environment, represented highly relevant positive drivers for ESV gains. The National Forest Conservation Program, the Grain for Green Program and the Great Wall of China Program are implemented by the Chinese government to increase forested and grassland areas. The programs are widespread and were initiated in 2000 [44]. The hilly and mountainous areas of eastern LP and the western and northern areas of JJJ are included in the Three-North Shelterbelt Development Program and the JJJ Sand Prevention Program implemented by national forestry key programs [45]. These long-term and large-scale projects are beneficial to decelerate total ESV losses.

Under current economic development pressures, many natural landscapes have been lost or degraded. Similar declines in ESV have been detected during the urbanization of different parts of China. Our understanding about the reliability of ESV will be aided by comparing our findings with those obtained in other urban areas. Wang *et al.* [12] applied the coefficients proposed by Xie *et al.* [8] to estimate spatio-temporal variations of ESV in China. Their calculations indicated that the total ESV of China decreased by 243.4 billion Yuan from the 1980s to 2010 due to land use changes. This decrease was mostly attributed to the loss of important woodland and water areas. Jan Haas *et al.* [38] employed the method proposed by Xie *et al.* [8] to estimate environmental impacts using ESV in JJJ, the Yangtze River Delta and the Pearl River Delta. The decrease in ESV in JJJ from 1990 to 2010 was calculated to be 9045 million Yuan, with losses being attributed to an increase in built-up areas. At the urban scale, Li *et al.* [39] detected a decrease of 19.3% in the value of ecosystem services provided by Chang Zhou's natural and semi-natural land from 1991 to 2006, with the 1.3% annual decrease being attributed to the conversion of farmland to other uses. Our results support all of these preceding studies; specifically, the reduction in natural and semi-natural ecosystems, ecosystem services and functions is the result of changes in land cover.

The method adopted here has several limitations. For instance, our ESV estimates are based on the usefulness of the links between land cover types and ecosystem service categories. This method has been criticized as having low resolution, high uncertainty and high variation arising from the complex, dynamic and nonlinear properties of ecosystems [46,47]. However, accurately calculated coefficients have less impact on dynamic analyses over time than on cross-sectional analyses, because the value of the coefficients tend to influence estimates of directional change to a lesser extent than they affect estimates of the magnitude of ecosystem values at specific points in time [24]. Our study focused on variations in ecosystem services that influence human well-being over time. To this information, we added high-resolution land cover data (30 m) to calculate land cover and to assess ESV to obtain further precise spatial results. Therefore, the ESV unit in our study is credible at a regional scale; however, it may not provide an accurate assessment of the true value of ecosystem services.

In addition, we were not able to estimate monetized ESV for artificial surfaces, because we assumed that the well-known valuation of built-up land was zero. In fact, the levels of supply and demand of ecosystem services in urban areas are highly heterogeneous [48]. The developed land produces increasing levels of significant negative ecosystem service values because of air, water, solid waste and other pollution. However, the green urban areas play a relevant and positive role in the provision of ecosystem services [49]. For example, parks in urban areas provide aesthetic values for residents [50]. Ecosystems in urban and rural areas have important ecological roles in urban and regional studies and are expected to be a valuable asset in future studies of urbanization, providing insights about the interaction between natural ecosystems and human households. Therefore, it is necessary to extract reliable coefficient values for urban areas in future studies.

5. Conclusions

We explored the similarities and differences in ESV in three urban agglomerations by evaluating the impacts of land cover change on ecosystem service values over a 10-year period (2000 to 2010). The changes in land cover trends were similar in all three coastal urban agglomerations. Changes were dominated by urban expansion to convert natural and semi-natural land cover to urban land, with cultivated land being largely occupied in the peri-urban areas of the major cities. Meanwhile, differences in the magnitude and rate of impact of land cover change on ESV were really obvious.

This study demonstrated that urban expansion in coastal areas may not necessarily lead to a net decline in ESV, if there are substantial increases in natural land with greater estimated coefficients. For instance, like SP and JJJ, there was a rapid increase in artificial surfaces in LP due to urban expansion; however, the total ESV in LP increased because of the effective national sustainable forestry (national green infrastructures) and natural wetland reserve policies. Thus, the negative impacts of urban expansion on ecosystem services could be offset by positive changes to natural landscapes, because a change in ESV depends on the interaction of changes of various land cover types over time.

This study highlights the important links between land cover change and impacts on ecosystem service values. The transformation of land cover types leads to a change in the structure and function of ecosystem services. However, when the capacity of the ecosystem to deliver ecosystem service functions is depleted because of land cover change, the intermediate- and long-term gains from economic growth may exceed the short-term gains, because degraded environmental quality may lead to economic losses. In China, while natural land should be used sustainably in the process of rapid urbanization, the need to balance economic, social and ecological benefits is becoming increasingly urgent. Therefore, land use and land cover policymaking processes should be aimed at balancing ecological resources with economic growth.

Acknowledgments

This research is supported by the National Natural Science Foundation of China (No. 41171097), National Twelfth Five-year Science and Technology Plan (2012BAK12B03) and the 985 Project of Beijing Normal University (Beijing-Tianjin-Hebei strategy research of ecological civilization). We thank Lisa Naughton-Treves and Axing Zhu from Department of Geography, University of Wisconsin-Madison, Jun Chen, Yuejing Ge and Dianting Wu for the help and valuable advice. We also thank Rebecca May, Jun Yin and Jianke Guo for help in correcting some of the grammar issues. We are especially grateful to the National Geomatics Center of China for supplying land cover data.

Author Contributions

Yushuo Zhang conceived and designed the study. Lin Zhao and Jiyu Liu processed and calculated the data. Yuli Liu and Cansong Li performed research and analyzed the data. Yushuo Zhang wrote the paper. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Appendix

Table A1. Classification and definition of ecosystem services.

Category	Sub-Category	Definition
Provisioning	Food production	Edible plant and animal goods transformed from solar energy
	Raw materials production	Raw materials derived from solar energy that can be used as construction materials or alike
Regulating	Gas regulation	Maintenance of atmospheric chemical composition balance, absorbing SO_2, fluoride and N_xO_y
	Climate regulation	Regulation of regional climate, e.g., increased precipitation and decreased temperature
	Hydrological regulation	Fresh water filtration, retention, storage and supply
	Waste treatment	Removal or breakdown of excess of xenic nutrients and compounds, dust agglutination
Supporting	Soil formation and conservation	Accumulation of organic materials, function of root and biological materials in soil retention, nutrient cycling and accumulation
	Biodiversity maintenance	Sources of genes for wild animals and plants, habitats for wild animals and plants.
Cultural	Providing aesthetic values	Potentials in providing recreational, cultural and artistic values

Table A2. Land cover conversion matrix from 2000 to 2010 in LP (ha).

Types	Cultivated Land	Forest	Grassland	Wetland	Water Bodies	Artificial Surfaces	Sea
Cultivated land	5,961,304	65,740	60,267	9933	12,648	52,909	3513
Forest	83,537	3,650,615	177,428	3228	4299	1806	121
Grassland	94,243	177,372	1,035,023	917	4535	4629	179
Wetland	1471	1774	230	86,380	3746	137	1395
Water bodies	16,495	3229	2173	3977	247,348	749	20,586
Artificial Surfaces	100,823	3037	12,212	2068	8536	759,715	1645
Sea	258	98	283	1971	1695	51	49,880

Table A3. Land cover conversion matrix from 2000 to 2010 in JJJ (ha).

Types	Cultivated Land	Forest	Grassland	Wetland	Water Bodies	Artificial Surfaces	Bare Land	Sea
Cultivated land	8,252,262	17,590	138,624	8071	52,742	103,708	51	3
Forest	38,668	3,750,365	225,357	357	5936	2556	20	0
Grassland	262,057	206,168	3,253,537	2802	15,221	4059	1229	295
Wetland	6606	100	8149	36,701	19,042	848	0	163
Water bodies	65,312	363	5636	23,982	276,875	4393	4	8280
Artificial Surfaces	288,339	5557	53,928	11,321	19,959	1,059,523	129	22,362
Bare land	164	12	1232	71	178	5	5682	0
Sea	25	0	179	3435	201	20	4	6749

Table A4. Land cover conversion matrix from 2000 to 2010 in SP (ha).

Types	Cultivated Land	Forest	Grassland	Wetland	Water Bodies	Artificial Surfaces	Bare Land	Sea
Cultivated land	5,275,197	914	5828	42,874	29,680	69,636	4	635
Forest	15,413	218,416	15,533	81	203	325	1653	2
Grassland	28,671	14,053	248,290	31,262	2237	908	845	26
Wetland	53,199	106	1353	98,529	188,507	1129	64	2826
Water bodies	5944	0	993	73,083	3764	105	489	5788
Artificial Surfaces	221,472	1081	3714	11,493	6121	581,365	26	2169
Bare land	368	1743	594	7419	189	33	2965	10
Sea	116	16	78	5897	606	42	0	25,160

Rows and columns contain data between 2000 and 2010, respectively.

Table A5. Total ecosystem service values (ESV) change in 2000 to 2010 (×10^6 Yuan).

	LP			JJJ			SP		
	2000	2010	Variation	2000	2010	Variation	2000	2010	Variation
Total ESV	86,657	86,729	72	111,386	110,492	−893	35,674	33,402	−2273

Table A6. Changes in the value of ecosystem service category (ESV_f) in 2000 to 2010.

	LP			JJJ			SP		
	ESV(×10^6 Yuan)			ESV(×10^6 Yuan)			ESV(×10^6 Yuan)		
	2000	2010	Variation	2000	2010	Variation	2000	2010	Variation
FP	3722	3693	−29	5414	5275	−139	2702	2634	−69
RM	6583	6600	18	7563	7562	−1	1408	1404	−4
GR	10,643	10,676	33	13,284	13,272	−11	2802	2639	−162
CR	11,682	11,712	29	14,643	14,514	−129	4927	3921	−1006
HR	13,249	13,377	128	16,737	16,639	−98	6143	6020	−123
WT	10,272	10,329	57	13,997	13,751	−246	7136	6665	−472
ST	12,620	12,629	9	16,942	16,834	−108	4687	4509	−178
BD	12,467	12,510	43	16,001	15,948	−52	4082	3593	−129
PA	5418	5466	48	6807	6809	2	1788	1657	−131

Table A7. Changes in the value of different land cover types (ESV_k) in 2000 to 2010.

	LP			JJJ			SP		
	ESV(×10^6 Yuan)			ESV(×10^6 Yuan)			ESV(×10^6 Yuan)		
	2000	2010	Variation	2000	2010	Variation	2000	2010	Variation
Cultivated land	22,204	21,883	−321	31,633	30,416	−1216	19,870	19,247	−623
Forest	49,276	49,528	252	50,334	50,809	474	2985	3178	193
Grassland	6749	6906	158	19,328	19,663	336	1449	1710	262
Wetland	2668	2341	−327	2137	1761	−375	6657	2218	−4439
Water bodies	5761	6007	246	7950	7838	−112	4711	7041	2330
Bare land	0	0	0	4	5	0	4	8	5

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