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Variations in ecosystem service value in response to land use changes in Shenzhen

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ABSTRACT

Urban sprawl significantly impacts ecosystem services and functions. The exact impacts, however are difficult to quantify and are often neglected in policy making. The evaluation of ecosystem services is conducive to clarifying the ecological and environmental changes caused by urbanization. The objective of this study is to investigate variations in ecosystem services in response to land use changes during urbanization. The aim is to provide useful information and advice for policy makers concerned with sustainable development. Shenzhen, one of the fastest growing metropolitan areas in China, is selected as the study area. A fast evaluation method for ecological service values based on land use change was proposed and applied to the city for 1996, 2000 and 2004. The total value of ecosystem services in Shenzhen was 2776.0 million Yuan in 1996, 2911.4 million Yuan in 2000 and 2544.7 million Yuan in 2004 respectively, with a decrease of 231.3 million Yuan from 1996 to 2004 mainly due to the decreasing areas of woodland, wetland and water body. The combined ecosystem service value of woodland, wetland, water body and orchard was over 90% of the total value. Water supply and waste treatment were the top two service functions with high service value, contributing about 40% of the total service value. The results suggest that a reasonable land use plan should be made with emphasis on protecting wetland, water body and woodland, which have the highest ecosystem service value.

1. Introduction

Ecosystem service valuation has been a hot topic in ecological economic research. Ecosystem services can be defined as the conditions and processes through which natural ecosystems and the species that comprise them, sustain and fulfill human life (Daily, 1997), or the goods and services provided by ecosystem which contribute to human welfare, both directly or indirectly (Costanza et. al., 1997a,b). There is a growing volume of literature on ecosystem service valuation. For example, Lewandrowski et al. (1999) estimated the costs to regional economies from setting aside land to protect ecosystem diversity. Bolund and Hunhammar (1999) analyzed the ecosystem services generated by ecosystems within the urban area. Woodward and Wui (2001) used a meta-analysis to assess the relative value of different wetland services. Kreuter et al. (2001) estimated changes in land-use and ecosystem service values due to urban sprawl in the San Antonia area, Texas. Konarska et al. (2002) made a comparison of NOAA-AVHRR and Landsat TM datasets and evaluated the scale

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dependence of ecosystem service valuation. Sutton and Costanza (2002) estimated global marketed and non-marketed economic value from two classified satellite images with global coverage at 1 km^2 resolution. Xie et al. (2003) modified the value coefficient of Chinese ecosystem based on Costanza et al.'s parameters. Curtis (2004) described a new approach to valuing ecosystem services and goods, using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. Peng et al. (2005) analyzed the economic value of urban ecosystem services and took Shenzhen City as a case study. Nuñez et al. (2006) estimated the economic value of Chilean temperate forests as they contribute to maintain fresh water supply. Hein et al. (2006) analyzed the spatial scales of ecosystem services, and examined how stakeholders at different spatial scales attach different values to ecosystem services.

Shenzhen is one of the fastest growing metropolitan areas in China, which means that urban sprawl may significantly impact ecosystem services and functions. Such effects, however are difficult to quantify and are seldom taken into account in the policy making process. The objectives of this study are: (1) to assign specific value coefficients for Shenzhen and determine whether they can be used to evaluate changes in ecosystem services in the local area; (2) to estimate variations in ecosystem services value in response to land use changes during urbanization; and (3) to provide useful information and advice to policy-making for sustainable development of municipalities.

2. Methodology

2.1. Study Area

Shenzhen (22°27′ N to 22°52′ N, 113°46′ E to 114°37′ E) is a coastal city in southern China, located on the Pearl River Delta Region and directly north of Hong Kong (Fig. 1). The total terrestrial area of Shenzhen is 0.19 million ha, and the coastline of the city is 229.96 kilometers. Shenzhen has a mild, subtropical maritime climate with plenty of rainfall and sunshine. The annual average temperature is 23.7 °C, with the highest reaching 36.6 °C and the lowest 1.4 °C. Since its establishment in 1979 as a special economic region, Shenzhen has experienced rapid urbanization and economic development. During the past two decades, the areas of woodland, cropland, wetland and unused land have significantly decreased, while the urban area has expanded. The GDP of Shenzhen increased from only 0.2 billion Yuan in 1979 to 342.2 billion Yuan in 2004. The population density of Shenzhen in 2005 reached 54.9 person/ha. These combined factors make appropriate case study for assessing the changes in ecosystem services due to rapid urban sprawl.

2.2. Land Use Classification

The land use datasets of Shenzhen (1:50,000) in 1996, 2000 and 2004 are from the Academy of Shenzhen Urban Planning and Design, a Shenzhen municipal research institute. These data sets were acquired mainly by aerial photograph interpretation aided by ground survey and former land use maps. In the data forming process, the same data interpretation methods and the same classification categories were adopted. They are legal data sets for government planning. The original land use categories include two levels of national standard types. In this study, the data sets were reclassified into eight categories, including cropland, orchard, woodland, grassland, build up, water body, wetland, and unused land (Table 1). The land use map was then edited, calibrated and coded in ARCVIEW GIS software for the subsequent calculation of ecosystem service value and spatial analysis.

2.3. Assignment of Ecosystem Service Value

Costanza et al. (1997a,b) classified the global biosphere into 16 types of ecosystems and 17 types of service functions and then

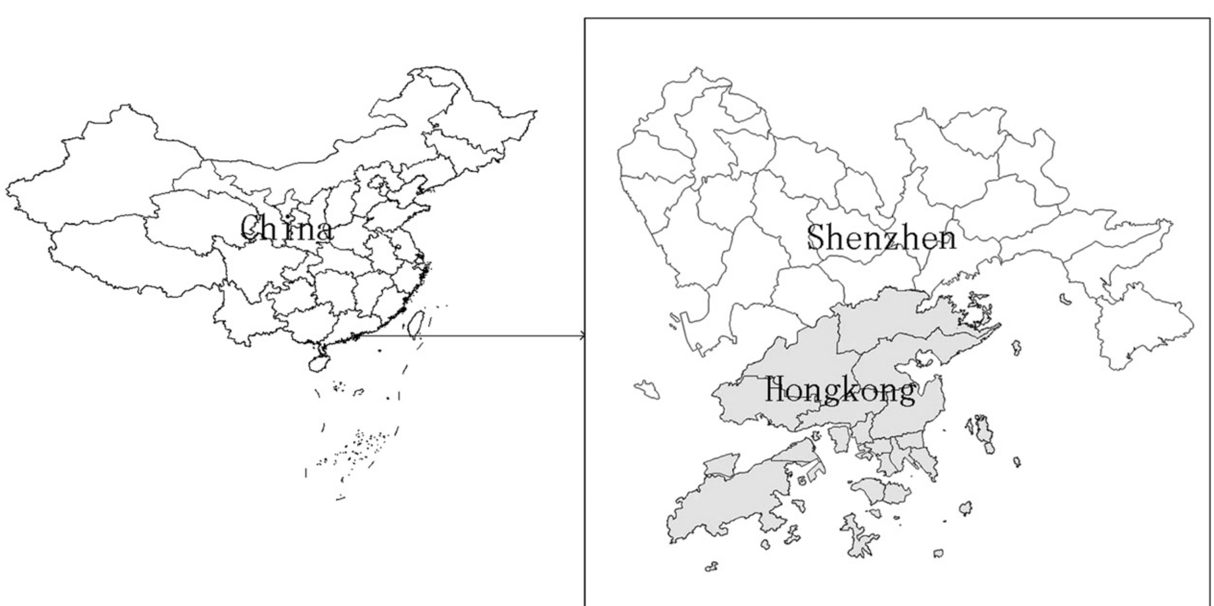

Fig. 1 – The study area.

Table 1 – Land use category in Shenzhen.

Categories	Definition
Cropland	Paddy field, glebe field, irrigable land and vegetable field
Orchard	Orchard that is occupied by fruit, tea, mulberry, rubber trees
Woodland	Arbor, bamboo, bush forest and protection forest along the roads, railways and coastal lines
Grassland	Natural grassland and manmade grassland
Build up	Land used for industrial, commercial, residential, transportation ends
Water body	Rivers, reservoirs fishery and lakes
Wetland	Mainly mangrove marsh
Unused land	Lands unused or difficult for using

estimated their ecosystem services value. Based on Costanza et al.'s parameters, Xie et al. (2003) extracted the equivalent weight factor of ecosystem services per hectare of terrestrial ecosystems in China and modified the value coefficient of Chinese ecosystem (Table 2). The equivalent weight factor listed in Table 2 was obtained by surveying 200 Chinese ecologists and can be applied to different regions across china by localizing the average natural food production (Xie et al., 2003). One factor is equal to the economic value of average natural food production of cropland per hectare per year. Generally, the natural food production is proposed to be 1/7 of the actual food production. With Shenzhen, the average actual food production of cropland was 5893 kg/ha^2 from 1996–2004 and the average price for grain was 1.15 Yuan/kg in 2004. The ecosystem service value of one equivalent weight factor for Shenzhen is therefore 968.09 Yuan.

Ecosystem service value of one unit area of each land use category in Shenzhen was then assigned based on the nearest equivalent ecosystems (Table 3). For example, woodland equates to forest, and unused land equates to barren land. It is supposed that the service value of one unit area of orchard equals the average service value of forest and grassland combined. The service values for build up is zero. Although the biomass used as proxies for the land use categories are clearly not perfect matches in every case (Kreuter et al., 2001), they are related. Estimation of the ecosystem service value based on land use data has been applied and prove feasible in other case studies (Bai and Chen, 2004; Mo et al., 2005).

2.4. *Calculation of Ecosystem Service Values*

Once the ecosystem service value of one unit area for each land use category has been extracted, the service value for each land use category, and service function are given in Eqs. (1) and (2).

$$ESV_k = \sum_f A_k \times VC_{kf} \quad (1)$$

$$ESV_f = \sum_k A_k \times VC_{kf} \quad (2)$$

$$ESV = \sum_k \sum_f A_k \times VC_{kf}. \quad (3)$$

ESV_k, ESV_f and ESV refer to the ecosystem service value of land use category "k", value of ecosystem service function type "f" and the total ecosystem service value respectively. A_k is the

Table 2 – Equivalent weight factor of ecosystem services per hectare of terrestrial ecosystems in China.

	Forest	Grassland	Cropland	Wetland	Water body	Barren land
Gas regulation	3.5	0.80	0.50	1.80	0	0
Climate regulation	2.70	0.90	0.89	17.10	0.46	0
Water supply	3.20	0.80	0.60	15.50	20.40	0.03
Soil formation and retention	3.90	1.95	1.46	1.71	0.01	0.02
Waste treatment	1.31	1.31	1.64	18.18	18.20	0.01
Biodiversity protection	3.26	1.09	0.71	2.50	2.49	0.34
Food	0.10	0.30	1.0	0.30	0.10	0.01
Raw material	2.60	0.05	0.10	0.07	0.01	0
Recreation and culture	1.28	0.04	0.01	5.55	4.34	0.01
Total	21.85	7.24	6.91	62.71	46.01	0.42

Xie et al., 2003.

Table 3 – Ecosystem service value of unit area of different land use categories in Shenzhen (Yuan·ha^{-1}·a^{-1}).

	Woodland	Grassland	Orchard	Cropland	Wetland	Water body	Unused land	Build up
Gas regulation	3388.3	774.5	2081.4	484.0	1742.6	0.0	0.0	0.0
Climate regulation	2613.9	871.3	1742.6	861.6	16,554.4	445.3	0.0	0.0
Water supply	3097.9	774.5	1936.2	580.9	15,005.4	19,749.1	29.0	0.0
Soil formation and retention	3775.6	1887.8	2831.7	1413.4	1655.4	9.7	19.4	0.0
Waste treatment	1268.2	1268.2	1268.2	1587.7	17,599.9	17,619.3	9.7	0.0
Biodiversity protection	3156.0	1055.2	2105.6	687.3	2420.2	2410.6	329.2	0.0
Food	96.8	290.4	193.6	968.1	290.4	96.8	9.7	0.0
Raw material	2517.0	48.4	1282.7	96.8	67.8	9.7	0.0	0.0
Recreation and culture	1239.2	38.7	638.9	9.7	5372.9	4201.5	9.7	0.0
Total	21,152.8	7009.0	14,080.9	6689.5	60,709.1	44,542.0	406.6	0.0

area (ha) for land use category "k" and VC_{kf} the value coefficient (Yuan·ha^{-1}·a^{-1}) for land use category "k", ecosystem service function type "f".

Since the biomes used as proxies for the land use categories are clearly not perfect matches as mentioned above, and there are uncertainties of the value coefficients, additional sensitivity analysis is needed in order to test the percentage change in the ecosystem service value for a given percentage change in a value coefficient. In each analysis, the coefficient of sensitivity (CS) was calculated using the standard economic concept of elasticity as follows (Kreuter et al., 2001):

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}} \tag{4}$$

where *ESV* is the estimated ecosystem service value, *VC* is the value coefficient, "i" and "j" represent the initial and adjusted values, respectively, and 'k' represents the land use category. If CS is greater than unity, then the estimated ecosystem value is elastic with respect to that coefficient, but if CS is less than one, then the estimated ecosystem value is considered to be inelastic. The greater the proportional change in the ecosystem service value relative to the proportional change in the valuation coefficient, the more critical is the use of an accurate ecosystem value coefficient (Kreuter et al., 2001).

3. Results and Discussion

3.1. Changes of Land Use

Due to uncertainties in the estimated area of land use, observation of changes in the area of land use categories must be treated with caution. However, if the magnitude of the estimated changes in land use is substantial, it may still be possible to draw general inferences about the effect of perceived changes in land use patterns on ecosystem services (Congalton and Green, 1999; Kreuter et al., 2001). The statistics of the land use changes can be seen from Table 4.

Woodland comprises the largest portion of the total area, over 30% of the total area (Table 4). This woodland is located in the southeast part of Shenzhen (Fig. 2). The area of woodland was 64,646.6 ha in 1996 and 59,475.9 ha in 2004, decreasing by 5170.7 ha, at an average decreasing rate of 1.0% per year. By contrast, the area of grassland was very small, only 420.9 ha in 1996 and decreasing to 47.5 ha in 2004. The estimated size of orchard was relatively large, 21,435.9 ha in 1996 and increasing to 27,876.5 ha in 2004, about 14% of the total area. Cropland also had small size in area, less than 4% of the total area. The area of cropland was 7010.3 ha in 1996 and 7621.0 ha in 2004, with a decrease of 2296.9 ha, by about 30%, and the average annual decreasing rate was 4.8% per year. Wetland and water body both play important roles in ecosystem services and have generally high service value. The estimated sizes were relatively small. The aggregate area of wetland and water body was only about 10% of the total area in Shenzhen, and they even seemed to decrease during urbanization. The area of wetland was 6427.5 ha in 1996 and 3341.7 ha in 2004, mainly located in the southwest coast of Shenzhen, with a decrease of 3085.8 ha. The area of water body decreased by 30.6 ha from 1996 to 2004, approximately 0.2% per year. During the urban development, the area of unused land decreased greatly while the build up increased. From 1996 to 2004, unused land decreased by 14618.7 ha, leaving only 1676.0 ha in 2004, 0.9% of the total area. The averaged annual decrease rate was 24.7% per year. Build up increased in area from 64,624.6 ha in 1996 to 84114.8 ha in 2004, increasing by 43.2%, with an average growth rate of 3.3% per year.

Overall, build up, woodland and orchard were the primary land use categories when the area was considered, contributing to about 80% of the total land use area in Shenzhen. During 1996 to 2004, build up tended to increase in area while woodland tended to decrease.

3.2. Changes of Ecosystem Service Values

By utilizing the value coefficients and areas of land use categories (Tables 3 and 4 respectively), the ecosystem service value of land use category "k", value of ecosystem service function type "f" and the total ecosystem services value of Shenzhen in 1996, 2000 and 2004 could then be obtained through programming in ARCVIEW GIS software following the formulas (1)–(3). These results are shown in Tables 5 and 6.

The total ecosystem services value of Shenzhen was about 2776.0 million Yuan in 1996, 2911.4 million Yuan in 2000 and 2544.7 million Yuan in 2004 (Table 5). From 1996 to 2000, the decline in ecosystem service value caused by the decrease of wetland was offset by value increase in orchard and water body. As a result, the total ecosystem service value increased by 135.4 million Yuan. However, the total ecosystem service

Table 4 – Area changes of land use in Shenzhen.

Land use categories	1996		2000		2004		1996–2004		
	area(ha)	%	area(ha)	%	area(ha)	%	Ha	%	%yr
Woodland	64,646.6	33.2	65,041.5	33.4	59,475.9	30.5	−5170.7	−8.0	−1.0
Grassland	420.9	0.2	39.7	0.0	47.5	0.0	−373.4	−88.7	−23.9
Orchard	21,435.9	11.0	27,580.1	14.2	27,876.5	14.3	6440.6	30.0	3.3
Cropland	7010.3	3.6	7621.0	3.9	4713.4	2.4	−2296.9	−32.8	−4.8
Wetland	6427.5	3.3	6124.5	3.1	3341.7	1.7	−3085.8	−48.0	−7.9
Water body	14,817.5	7.6	16,152.0	8.3	14,786.9	7.6	−30.6	−0.2	−0.0
Unused land	16,294.7	8.4	11,647.9	6.0	1676.0	0.9	−14,618.7	−89.7	−24.7
Build up	64,624.6	33.2	61,466.5	31.5	84,114.8	43.2	19,490.2	30.2	3.3
Total	194,869.1	100.0	194,869.1	100.0	194,869.1	100.0	–	–	–

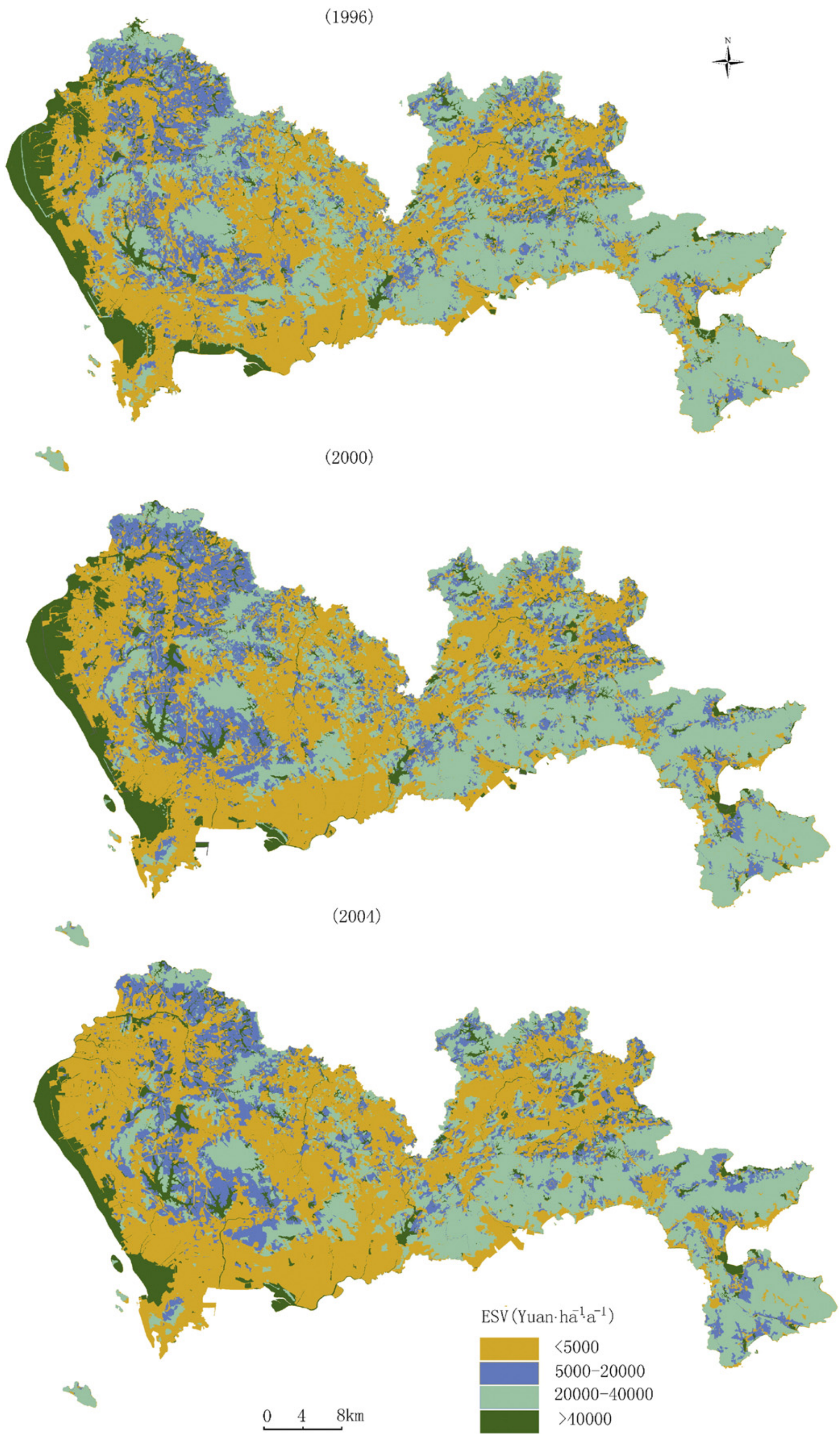

Fig. 2 – (a, b,c) Distribution of the ecosystem services value in Shenzhen in 1996, 2000 and 2004.

Table 5 – Ecosystem service value of Shenzhen from 1996 to 2004.

		Woodland	Grassland	Orchard	Cropland	Wetland	Water body	Unused land	Build up	Total
ESV (10^4Yuan/yr)	1996	13,6745.7	295.0	30,183.7	4689.5	39,020.8	66,000.1	662.5	0.0	277,597.3
	2000	13,7581.0	27.8	38,835.3	5098.1	37,181.3	71,944.2	473.6	0.0	291,141.3
	2004	12,5808.1	33.3	39,252.6	3153.0	20,287.0	65,863.8	68.1	0.0	254,466.0
1996–2000	10^4Yuan	835.3	−267.2	8651.6	408.5	−1839.5	5944.1	−188.9	0.0	13,544.0
	%	0.6	−90.6	28.7	8.7	−4.7	9.0	−28.5	–	4.9
	%/yr	0.2	−44.6	6.5	2.1	−1.2	2.2	−8.1	–	1.2
2000–2004	10^4Yuan	−11772.9	5.5	417.3	−1945.1	−16894.3	−6080.4	−405.5	0.0	−36675.2
	%	−8.6	19.7	1.1	−38.2	−45.4	−8.5	−85.6	–	−12.6
	%/yr	−2.2	4.6	0.3	−11.3	−14.1	−2.2	−38.4	–	−3.3
1996–2004	10^4Yuan	−10937.6	−261.7	9068.9	−1536.5	−18733.7	−136.3	−594.4	0.0	−23131.3
	%	−8.0	−88.7	30.0	−32.8	−48.0	−0.2	−89.7	–	−8.3
	%/yr	−1.0	−23.9	3.3	−4.8	−7.9	0.0	−24.7	–	−1.1

value decreased by 3667.5 million Yuan from 2000 to 2004. This was mainly caused by the decrease of wetland and woodland. Overall, the net decline in ecosystem service value was about 231.3 million Yuan from 1996 to 2004, mainly due to the decreasing areas of woodland and wetland. For example, the decline of ecosystem service value caused by the decrease of woodland and wetland was about 109.4 million and wetland 187.3 million respectively. The increase of ecosystem service value caused by increasing grassland and orchard was too small to offset the decrease.

Because of the large coefficient value and the large area, the value of ecosystem services produced by woodland was the highest among the eight land use categories, about 50% of the total value. Although the areas of wetland and water body were small, they have the highest value coefficients and thus generated enormous service value nearly as much as woodland. Orchard also generated high services value due to its large area. The aggregated ecosystem service value of woodland, wetland, water body and orchard was over 90% of the total value, indicating that these land use categories, especially wetland (whose area was only 1.7–3.3%, but still generated 8–14% of the total ecosystem service value.), play important roles in ecosystem services.

According to formula (2), the ecosystem service value provided by individual ecosystem functions (ESV_f) were also estimated (Table 6). The contributions of each ecosystem function to overall value of ecosystem services in each year were ranked based on their estimated ESV_f in 1996 and 2004, while the overall rank of each function was based on the average value of each ESV_f through the four years of analysis. The shift in the contribution of each ecosystem function to the total value of the ecosystem services is presented in Table 6 by an upward arrow "↑" for increasing contribution, downward arrow "↓" for decrease in contribution, and a dash "–" for no change. In general, the changes of contribution of each ecosystem function to the total services value were small and the rank order remained nearly the same. The overall rank order for each ecosystem function based on their contributions to overall value of ecosystem services was as follows, from high to low, water supply, waste treatment, soil formation and retention, biodiversity protection, climate regulation, gas regulation, raw material, recreation and culture, and food. Contribution of water supply was the highest (>20%), followed by waste treatment (≈20%), which was likely due the high capability of supplying water and treating waste of wetlands and water bodies.

3.3. Spatial Distribution

The spatial distribution of ecosystem service value of Shenzhen in 1996, 2000 and 2004 can bee seen in Fig. 2. Areas with high services level of over 40,000 Yuan per ha per year were mainly located in the southwest coast, due to mangroves, while those with the services level of 20,000–40,000 Yuan per

Table 6 – Values of ecosystem service functions in 1996 and 2004.

	1996			2000			2004			Overall rank	Tendency
	ESV_f 10^4(Yuan/yr)	%	Rank	ESV_f 10^4(Yuan/yr)	%	Rank	ESV_f 10^4(Yuan/yr)	%	Rank		
Gas regulation	27,857.8	10.0	6	29,217.7	10.0	6	26,768.5	10.5	6	6	↑
Climate regulation	32,574.2	11.7	4	33,325.4	11.4	4	27,004.8	10.6	5	5	↓
Water supply	63,572.3	22.9	1	67,057.6	23.0	1	58,321.9	22.9	1	1	–
Soil formation and retention	32,658.3	11.8	3	34,503.7	11.9	3	31,595.4	12.4	3	3	↑
Waste treatment	49,518.9	17.8	2	52,210.3	17.9	2	43,768.8	17.2	2	2	↓
Biodiversity protection	31,106.2	11.2	5	32,621.6	11.2	5	29,397.7	11.6	4	4	↑
Food	2077.6	0.7	9	2248.0	0.8	9	1814.9	0.7	9	9	–
Raw material	19,149.0	6.9	7	20,039.8	6.9	7	18,628.6	7.3	7	7	↑
Recreation and culture	19,083.8	6.9	8	19,917.8	6.8	8	17,165.8	6.7	8	8	↓
Total	27,7597.3	100	–	291,141.3	100	–	254,466.0	100	–	–	–

Table 7 – Percentage change in estimated total ecosystem service value and coefficient of sensitivity resulting from adjustment of ecosystem valuation coefficients (VC).

Change of value coefficient	1996		2000		2004	
	%	CS	%	CS	%	CS
Woodland VC±50%	24.63	0.49	23.63	0.47	24.72	0.49
Grassland VC±50%	0.05	0.00	0.00	0.00	0.01	0.00
Orchard VC±50%	5.44	0.11	6.67	0.13	7.71	0.15
Cropland VC±50%	0.84	0.02	0.88	0.02	0.62	0.01
Wetland VC±50%	7.03	0.14	6.39	0.13	3.99	0.08
Water body VC±50%	11.89	0.24	12.36	0.25	12.94	0.26
Unused land VC±50%	0.12	0.00	0.08	0.00	0.01	0.00
Build up VC±50%	0.00	0.00	0.00	0.00	0.00	0.00

ha per year were in the southeast, due to woodlands. Areas with low services level, less than 5000 Yuan per ha per year covered most of total area, expanding from the city center, are indicative of an urbanization trend.

3.4. *Ecosystem Sensitivity Analysis*

As shown in Table 7 the percentage change in estimated total ecosystem service value and the coefficient of sensitivity resulting from a 50% adjustment in the value of the coefficient, were calculated using formula (4).

In all cases, CS was far less than unity and often near zero, indicating that the total ecosystem services value estimated in this study area was relatively inelastic with respect to the value coefficients. CS for woodland, water body, wetland and orchard was relatively bigger. CS for woodland was the highest, about 0.5, because of the large area and high service value coefficient. Although the areas of water body and wetland were small, CS for these two land use categories was relatively large because of their high value coefficients. CS for water body increased from 0.24 in 1996 to 0.26 in 2004 while that for wetland decreased from 0.14 to 0.08. Compared with woodland, wetland and water body, ecosystem service level of orchard is lower. The CS for orchard was still relatively big, increasing from 0.11 to 0.15 from 1996 to 2004, because of its large area. The sensitivity analysis indicated that the estimation in this study area was robust in spite of uncertainties on the value coefficients.

3.5. *Discussion*

The method used to estimate ecosystem service value in this study was proposed by Costanza et al. (1997a,b), deriving ecosystem service value from multiplying the area of land use category and ecosystem value coefficient. However, as discussed in previous literature, the estimation results by this method are coarse with deviations and uncertainties due to the complex, dynamic and nonlinear ecosystems (Limburg et al., 2002; Turner et al., 2003), limitations of economic valuation (Costanza et al., 1997b), and problems of double counting and scales et al. (Konarska et al., 2002; Turner et al., 2003; Hein et al., 2006).

Land use is used as a proxy measure of ecosystem services. However, the biomes used as proxies for the land use categories are clearly not perfect matches in every case (Kreuter et al., 2001). In addition, the accuracy of the average value coefficients is in doubt because of ecosystem heterogeneity. For instance, the value coefficient of orchard which is derived from the average of forest and grassland is just an approximate estimation and need further validation, while that of build up is proposed to be zero, neglecting negative effectiveness of pollution (e.g. air pollution, water pollution, waste pollution et al.) which may produce a negative value. Multiplying “A” (area of land use category) and “VC” (ecosystem value coefficient) with uncertainties will therefore lead to a coarse “ESV” (ecosystem service values) with more uncertainty.

The spatial scale of measurement is also an important factor which should be taken into account in ecosystem service valuation. When land cover is used as a proxy for ecosystem service, the spatial scale at which the land cover is measured significantly influences measurements of both the ecosystem service extent and its valuation (Konarska et al., 2002). In this study, the estimation of ecosystem service value is based on land use data with the scale of 1:50,000. However, the total ecosystem service value and the changes may be quite different under different scales of measurement. For example, fine resolution data would produce results for individual trees rather than forest classes. Thus the ecosystem services value provided by forest would decrease. On the other hand, finer resolution data may also increase the extent of river, lakes, and wetland, which will significantly contribute to the increase of ecosystem services value. This indicates that the spatial context issue is highly complex, and the scale dependence of ecosystem service valuation should be addressed in future studies, particularly in urban areas where there are more spatial pattern fragments.

Our estimated total ecosystem services value of Shenzhen in 1996 was 2.9 billion Yuan, far less than 126.5 billion Yuan estimated by Peng et al. (2005). In Peng's study, the method of indirect market evaluation (e.g. avoid cost, replacement cost) was used to calculate the value coefficients corresponding to different service functions and land categories. Discrepancies in the results were mainly caused by using different value coefficients. According to our estimation, the value coefficient of climate regulation of woodland was about 2.6 thousand Yuan per ha per year, far less than 412.8 thousand Yuan per ha per year estimated by Peng. Our estimated value coefficient of water supply of woodland was about 3.1 thousand Yuan per ha per year, contrasting to 13 thousand Yuan per ha per year proposed by Peng. This indicates that more credible valuation techniques and accurate value coefficients are needed for ecosystem services valuation. Because methods used in this study have international recognition, these results can be compared to other international cities.

Although different valuation methods may lead to different estimation values, which will cause scientific critics and doubts on ecosystem service valuation, it is important to realize that accurate coefficients are often less critical for time series than cross-sectional analysis because coefficients tend to affect estimates of directional change less than estimates of the magnitude of ecosystem values at specific points in time. This study is primarily concerned with changes in ecosystem services over time, and the scope of our project precluded us from deriving area-specific ecosystem value coefficients

(Kreuter et al., 2001). In addition, sensitivity analysis indicated that the total ecosystem services value estimated in this study area were relatively inelastic with respect to the value coefficients and our estimate was robust in some extent in spite of uncertainties in the value coefficients. By calculating the ecosystem services value in 1996 and 2004 and analyzing any changes across this time period, uncertainties and errors could thus be reduced or offset.

The economic growth often seems to be in conflict with ecological protection. From 1996 to 2004, GDP increased by 260.3%, with an average growth rate of 17.4% per year, while ecosystem services value decreased by 8.3%, with an average decline rate of 1.1% per year. The total ecosystem services value of Shenzhen was only about 2.9% of GDP in 1996, which even declined to 0.74% in 2004. According to Costanza et al.'s (1997a,b), the global ecosystem services value was about 1.8 times of the global GNP. Based on Costanza et al (1997a,b), Chen and Zhang (2000) estimated Chinese ecosystem services value to be 1.73 times of Chinese GDP in 1994 (The value supplied by terrestrial ecosystem services was 1.25 times of GDP.). This means that the level of ecosystem service values in Shenzhen is extremely under the global and national average. Since GDP per unit area in Shenzhen is much higher than the national average (The average GDP per area in Shenzhen was 85 million Yuan per square kilometer while the national average was 0.93 million Yuan per square kilometer in 2000), it seems reasonable that the ecosystem service value is much lower than GDP in Shenzhen.

During the 30 years since establishment, Shenzhen has made great progress in economic development. The ecosystem service level however is relatively low compared to the economic level. Ecosystem service value was less than 1% of GDP in Shenzhen in 2004 with a declining tendency. With Shenzhen, sustainable development is critical. A compromise between economic development and ecological protection must therefore be addressed. It is suggested that a reasonable land use plan should be made with emphasis on protecting wetland, water body and woodland which have high ecosystem service value, so as to maintain a balance between economic development and ecosystem health in the future.

Despite some methodological shortcomings, ecosystem service valuation has the potential to inform policy decisions by highlighting the benefits of sustainable ecosystem management. Comparisons with findings obtained in other cities may also help us to understand the reliability of ecosystem service valuation. Wu et al. (2006) applied the coefficients proposed by Xie et al. to estimate the ecosystem service value in Wuhan City (29°58′ N to 31°22′ N, 113°41′ E to 115°05′ E). The total ecosystem service value of Wuhan decreased from 4.58 billion Yuan to 4.56 billion Yuan, while GDP per capita increased from 10.97 thousand Yuan to 19.56 thousand Yuan during 1996 to 2001. Yu et al. (2005) used another set of coefficients derived from the index of net primary productivity to estimate the ecosystem services value in Huzhou City (30°22′ N to 31°11′ N, 119°14′ E to 120°29′ E). The estimated results showed that the total ecosystem services value of Huzhou decreased from 19.48 billion Yuan to 17.36 billion Yuan, while GDP per capita increased from 15.03 thousand Yuan to 19.10 thousand Yuan during 1996 to 2001. Although the ecological and economical characteristics and the techniques of evaluation varied, their estimated results consistently showed that ecosystem services and functions tend to decline under current patterns of urban economic development. Future planning should therefore put more stress on environmental protection and nature conservation.

Our investigation provided a case study of ecosystem service valuation in urban areas. Compared with natural ecosystems, ecosystems in urban areas are much more complex. While many previous studies focused on natural ecosystems, future studies on ecosystem service valuation should pay more attention to ecosystems in urban areas where intensive interactions between human and ecosystems take place. This will make the techniques of valuation more useful to guide future human activity.

4. Conclusions

By analyzing and discussing the changes of ecosystem service value based on land use in Shenzhen from 1996 to 2004, we finally came to the conclusions as follows: (1) the total ecosystem services value of Shenzhen was about 2776.0 million Yuan in 1996, 2911.4 million Yuan in 2000 and 2544.7 million Yuan in 2004. The net decline in ecosystem service value was about 231.3 million Yuan from 1996 to 2004, which was mainly caused by the decreasing areas of woodland and wetland. Woodland produced most of the ecosystem services value, about 50% of the total value. The combined ecosystem service value of woodland, wetland, water body and orchard was over 90% of the total value, indicating that these land use categories play important roles in ecosystem services. (2) Water supply and waste treatment were the top two ecological functions with high service value, contributing about 40% of the total services value. The overall rank for each ecosystem function based on their contributions to overall value of ecosystem services was from high to low, as follows, water supply, waste treatment, soil formation and retention, biodiversity protection, climate regulation, gas regulation, raw material, recreation and culture, and food production. (3) Areas with high services level were mainly located in the southwest coast, due to wetland (mangroves), and southeast part (due to woodlands), while those with low services level expanded from the city center.

Land use can be used as a proxy measure of ecosystem services through matching the land use categories with equivalent biomass and ecosystem service valuation can then be easily and conducted based on land use data. The accuracy and reliability of the estimated results are mainly determined by the accuracy of value coefficients. Therefore, it is necessary to extract more accurate value coefficients in future research. On the other hand, absolutely accurate coefficients are often less critical for time series than cross-sectional analyses because coefficients tend to affect estimates of directional change less than estimates of the magnitude of ecosystem values at specific points in time. In other words, uncertainties and errors could be reduced or offset by calculating the ecosystem service value at different temporal scales and then analyzing the changes over time.

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