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Effects of land use changes on values of ecosystem functions on coastal plain of South Hangzhou Bay Bank, China

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Land serves as carrier of various terrestrial ecosystems. The variation of ecosystem functions and its economic value composition are mainly caused by land use and land cover changes. Based on dynamic data of land use, this article applies the methods in the ecology and ecologic economics to analyze the economic value change of ecosystem functions on coastal plain of south Hangzhou bay bank, China. The results showed that there is a big difference among the ecological value per unit area in different ecosystems. The land use change led to the reduction of the total value of the ecosystem functions on the coastal plain of south Hangzhou bay bank, from 9.176 × 10^9 yuan RMB in 1987 to 8.989 × 10^9 yuan RMB in 2000, with a decrease of 1.861 × 10^8 yuan RMB, in which the value of ecosystem material product increased from 5.872 × 10^8 yuan RMB in 1987 to 1.011 × 10^9 yuan RMB in 2000, and the value of ecosystem services reduced from 8.588 × 10^9 yuan RMB in 1987 to 7.978 × 10^9 yuan RMB in 2000, and the increase of the value of ecosystem material product was smaller than the decrease of the value of ecosystem services. This variation was caused by the transformation of the ecosystem with higher total economic value and higher economic value of ecosystem services such as mudflat and forestland into other land uses with higher value of material products.

Key words: Land use change, ecosystem functions, economic value, coastal plain of south Hangzhou bay bank.

INTRODUCTION

Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems. Ecosystem material product (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly from ecosystem functions (Costanza et al., 1997). Ecosystem service refers to the life supporting products and services directly or indirectly obtained through the structures, processes and functions of the ecosystem. Since 1980s, a lot of research on ecosystem service and their economic values of various ecosystem types had been done by the ecologists all over the world (Konarska et al., 2002; Nu′.Nez et al., 2006, Woodward and Wui, 2001; Li and Zhang, 2003; Ouyang et al., 1999), and the research on the global ecosystem services and its economic value made by Costanza et al. (1997) is most representative. These researches have an irreplaceable role in evoking the public environmental awareness of ecosystem protection (Peng et al., 2005; Peters et al., 1989; Xie et al., 2001). Land use change aiming at the economic benefits may damage to the ecosystem functions, reduce the benefits that the ecosystem provides to the human being, and threaten the ecological foundation of the sustainable development (Bai and Chen, 2004). To strengthen the researches on the influence of human activities on the ecosystem functions, especially the influence of land use change on the ecosystem functions, will take advantage to understand the potential ecological crisis on human survival, utilize the land resources reasonably and promote sustainable development of socio-economic system.

The coastal plain of south Hangzhou bay bank in China is located in the northeast of Zhejiang province and outside the Qiantang River estuary. And its terrestrial coordinates are between 30°02′ and 30°24′ north latitude, 121°02′ and 121°42′ east longitude. This coastal plain

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belongs to the newly emerging Cixi city, which is the center of the gold triangle economic zone of Shanghai-Hangzhou-Ningbo. Its total land area is 1368.47 × 10^4 hm^2. It is one of the most developed coastal areas in east China. The coastal plain lies on the north edge of subtropics and has monsoon climate, with warm winter and cool summer, high light and temperature efficiency, sufficient rainfall.

MATERIALS AND METHODS

MATERIALS

Basic data adopted in the study are satellite images taken by Landsat TM on 18 h May, 1987 and Landsat ETM on 8th September 2000. The spatial resolutions of the images are 30 × 30. The relevant data includes the 1:50000 topographic maps, the present land-use maps in 1990, and the present land-use maps in 2000, etc.

The determination of the classification system for the land use directly related to the study results. According to the ecosystem characteristics in the study area and the practical requirement in the study, the land use classification system includes eight categories: construction land (CL), paddy fields (PF), dry land (DL), water body (WB), forestland (FL), fields for aquaculture (FA), salt field (SF) and mudflat (MF).

The images were radiation and geometric corrected using ENVI 4.2, and then supervised classification was used to classifying of land use types. Following classification, a number of post-classification operations were carried out to improving the appearance of the output thematic image (Darrel et al., 2001). The accuracy of sampling inspection for results from supervised classification showed that, Kappa index was respectively 0.87 in 1987 and 0.89 in 2000, both surpassing the requirement of the minimum acceptable accuracy 0.70 (Lucas et al., 1994).

METHODS

Material product (MP) value

The market price approach is used to calculate the material product value of the ecosystem, and the formula is as follows (Xue, 1997):

$$V_p = \sum_{i=1}^{n} (M_i \cdot P_i) \quad (1)$$

Where V_p is total economic value of the material product in the ecosystem, i is the type of material product in the ecosystem, M_i is the yield of the material product, and P_i is the price of the material product.

Value of gas and climate regulation (GCR)

The function of the vegetation in the ecosystem for regulating gas and climate is to fix CO_2 and release O_2. According to the chemical equation for the photosynthesis, the total amount of the CO_2 fixed and the O_2 released by the plants can be obtained. The primary productivity of various ecosystems can be obtained by sample testing the biomass of various plants and referring to the study results of FENG et al. (1999) and XU et al. (1998) and then the economic value of the gas and climate regulation from fixing CO_2 and releasing O_2 by the plants can be obtained by using the methods of carbon-tax rate and substitution of industrial oxygen price.

$$V_a = \sum_{i=1}^{n} [G_i \cdot (1.63 \cdot C + 1.19 \cdot O] \quad (2)$$

Where V_a is total economic value of the gas and climate regulation, i is the type of the vegetation in the ecosystem, G_i is the primary productivity of the vegetation, C and O is the carbon-tax rate and industrial oxygen price, respectively.

Value of soil and water conservation (SWC)

The ecosystem can largely reduce the direct scouring force to the surface soil caused by the rain and surface runoff via the actions such as plant interception, soil absorption and infiltration, etc. so as to effectively prevent the amount of soil erosion, decrease the loss of soil fertility and lighten the silting of river, lake and wetlands. The economic value of soil and water conservation can be calculated by formula (3)-(5) (Xiao et al., 2000):

$$V_c = \sum_{i=1}^{n} \left[P_i \cdot S_i \cdot (E_i - E'_i) / \alpha \right] \quad (3)$$

Where V_c is economic value of the prevention of soil erosion in the ecosystem; i is the soil type; S_i is the area of the soil; E_i is the erosion depth of the soil without vegetation covering; E'_i is the actual erosion depth of the soil; P_i is the economic value of unit area of the soil. α is the average cultivated soil depth, set to 0.5 m.

$$V_l = \sum_{i=1}^{n} (D_i \cdot C_{ij} \cdot P_j) \quad (4)$$

\Where V_l is economic value of the loss of soil fertility in the ecosystem; D_i is the amount of soil conversation; i is the soil type; C_{ij} is the content of organic, N, P, and K in the soil; P_j is the price of various fertilizer products.

$$V_n = A_c / \rho \cdot 24\% \cdot c \quad (5)$$

Where V_n is economic value for lightening the silting of river, lake and wetlands; A_c is the amount of soil conversation; ρ is the bulk density of soil (t/m^3); c is the reservoir engineering cost of per unit water, set to 0.67 yuan RMB/m^3.

Value of disturbance regulation (DR)

The function of disturbance regulation is the ecological capacitance, damping and integrity of ecosystem response to environmental fluctuations, represented by the storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure. The value of the disturbance regulation in the ecosystem can be calculated by the following method (Costanza et al., 1997):

$$V_d = \sum_{i=1}^{n} (A_i \cdot P_i) \quad (6)$$

Where V_d is total economic value of the disturbance regulation in the ecosystem; i is the ecosystem type; A_i is the area of the ecosystem; P_i is the economic value of the disturbance regulation function per unit area of the ecosystem.

Value of water regulation and supply (WRS)

The water regulation and supply is one of the important functions of the natural ecosystem, which is mainly represented by provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation and provisioning of water by watersheds, reservoirs and aquifers. The ecosystems that have the value of water regulation and supply in the study area mainly contains the forestland, artificial wetlands and mudflat. Their economic value can be calculated by the formulas (7)-(9) (Costanza et al., 1997):

$$V_f = (P - E) \cdot A \cdot w \quad (7)$$

Where V_f is economic value of the water regulation and supply in forestland; P is the average rainfall; E is the average evaporating capacity; A is the area of the forestland; w is the water price.

$$V_a = H \cdot A \cdot w \quad (8)$$

Where V_a is economic value of the water regulation and supply in artificial wetlands; H is the difference between the storage capacity of the artificial wetlands in the flood season of the wet year without affecting the normal growth of the crops and the storage capacity in the rainless season of the dry year (that is, maximum storage difference); A is the area of the artificial wetlands area; w is the water price.

$$V_m = A \cdot p \quad (9)$$

Where V_m is economic value of the water regulation and supply in mudflat; A is the area of the mudflat; p is the economic value of the water regulation and supply per unit area in mudflat.

Value of soil formation and nutrient cycle (SFNC)

The vegetation growth in the ecosystem plays an important role in the weathering of rock, the accumulation of organic material, and the formation of soil. Meanwhile, the ecosystem can also fix the N, P, K and other nutrient elements, which is very important for the nutrient cycle. The soil formation and nutrient cycling in the ecosystem can be calculated by the following formula (Costanza et al 1997):

$$V_s = \sum_{i=1}^{n} \left[A_i \cdot (P_i + P'_i) \right] \quad (10)$$

Where V_s is economic value of the soil formation and nutrient cycle in the ecosystem; i is the type of ecosystem; A_i is the area of the ecosystem; P_i is the economic value of the formation soil per unit area of the ecosystem; P'_i is the economic value of the nutrient cycle per unit area of the ecosystem.

Value of waste treatment (WT)

The value of waste treatment is mainly represented by the recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds. The ecosystems such as forest, river, lake, and mudflat, etc. have stronger waste treatment capability, and the economic value is calculated by the following formula (Costanza et al., 1997; Xie et al., 2001)

$$V_w = \sum_{i=1}^{n} (A_i \cdot P_i) \quad (11)$$

Where V_w is economic value of waste treatment in the ecosystem; i is the type of ecosystem; A_i is the area of the ecosystem; P_i is the economic value of the waste treatment per unit area of the ecosystem.

Value of biodiversity maintenance (BM)

The biodiversity maintenance in the ecosystem includes the values of the ecosystem in terms of pollination, biological control, refugia and genetic resources, which are movement of floral gametes, trophic-dynamic regulations of populations, habitat for resident and transient populations, sources of unique biological materials and products. Its economic value is calculated by the following formula (Costanza et al., 1997; Xie et al., 2001).

$$V_b = \sum_{i=1}^{n} (A_i \cdot P_{ij}) \quad (12)$$

Where V_b is economic value of the biodiversity maintenance; i is the type of ecosystem; A_i is the area of the ecosystem; P_{ij} is one of the biodiversity maintaining function in the ecosystem.

Value of recreation and cultural (RC)

The recreation function of the ecosystem means the function to provide opportunities for recreational activities for mankind, which is manifested mainly in providing the locations for eco-tourism, sports, fishing and other outdoor recreational activities. The cultural function of the ecosystem refers to the function to provide opportunities for non-commercial uses, which is manifested mainly in providing aesthetics, artistic, educational, spiritual, and scientific

Table 1. Changes of ecosystem functions value for each land cover category.

Land use type	Value of unit area (×10^{6}yuan RMB/km^2)	1987			2000			The change of area (km^2)	The change of value (×10 yuan RMB)
		Area (km^2)	Value(× 10^{6}yuan RMB)	Percentage of value (%)	Area (km^2)	Value(×10 ^{6}yuan RMB)	Percentage of value (%)		
CL	1.05	91.98	96.58	1.05	153.75	161.43	1.80	64.78	64.85
PF	3.17	131.96	418.31	4.56	119.75	380.12	4.23	-38.38	-38.19
DL	1.22	507.27	618.87	6.74	493.81	602.45	6.70	-61.77	-16.42
FL	8.17	151.21	1235.39	13.47	131.52	1076.52	11.96	-12.21	-158.87
WB	4.85	20.7	100.4	1.09	27.14	132.63	1.48	6.44	32.23
MF	15.1	434.43	6563.01	71.53	408.03	6446.87	71.72	-19.69	-116.14
FA	5.73	20.12	115.29	1.26	31.61	182.13	2.03	11.49	66.84
SF	2.57	10.8	27.76	0.30	2.86	7.35	0.08	-13.46	-20.41
Total Value	41.86	1368.47	9175.61	100	1368.47	8989.5	100	-62.8	-186.12

values of ecosystems. The economic value of the recreation and cultural functions of the ecosystem can be calculated by the following formula (Costanza et al., 1997; Xie et al., 2001)

$$V_r = \sum_{i=1}^{n} (A_i \cdot P_i) \qquad (13)$$

Where V_r is economic value of the recreation and cultural functions; i is the type of ecosystem; A_i is the area of the ecosystem; P_i is the economic value of the recreation and cultural functions per unit area in the ecosystem.

RESULTS AND DISCUSSION

The ecological value per unit area in different ecosystems

There is a big difference among the ecological value per unit area in different ecosystems of the study area (Table 1). The descending alphabetic sort order of the ecological value is mudflat, forestland, fields for aquaculture, water body, paddy fields, salt field, dry land and construction land. Mudflat and forestland have a big variety of ecosystem service functions and every service function has a relatively high economic value. So, they have a great economic value in per unit area. Fields for aquaculture is operated in an intensive pattern, and it produces many material products (aquatic products), it also has a relatively high economic value. With the functions of gas and climate regulation, water regulation and supply, waste treatment, recreation and cultural, water body has a relatively great economic value in per unit area. On the contrary, paddy fields, salt field, dry land and construction land have a relatively low economic value in per unit area. Just in view of the service value of ecosystems, the descending alphabetic sort order should be mudflat, forestland, dry land, paddy fields, water body, fields for aquaculture, salt field and construction land. Therefore, mudflat and forestland are ecosystems that need special protection in terms of ecosystem conservation.

The change of total value of ecosystem functions

The total economic value of the ecosystem functions on the coastal plain of south Hangzhou bay bank reduced significantly from 1987 to 2000 (Table 1). Compared with the year 1987, the total economic value of the ecosystem functions in the year 2000 reduced by 1.8612 × 10^8 yuan RMB, which is 20.28% of the total economic value of the ecosystem service functions in 1987. Although the increase of fields for aquaculture, construction land, and water body contributed an increase of 1.6392 × 10^9 yuan RMB to the ecosystem functions value, the reduction of forestland, mudflat, paddy fields, salt field, and dry land resulted in a loss of over 3.4624 × 10^9 yuan RMB in the ecosystem functions value, which far surpasses the increased value. The average annual decrease in the ecosystem functions value reached 1.430 × 10^7 yuan RMB during past 13 years.

The change of ecological functions value of different ecosystem

Based on the analyze of the variations of ecosystem functions value of different ecosystem (Table 1), it can be seen that the value of the mudflat is dominant in the ecological function value constitution of the ecosystem on the coastal plain of south Hangzhou bay bank, which occupied 71.53 and 71.72% of the total value in the year 1987 and 2000, respectively. The mudflat area reduced by about 20 km^2 from the year 1987 to the year 2000 because of the reclamations, which is 4.6% of mudflat area in the year 1987; and the ecological function value reduced by 1.161 × 10^8 yuan RMB, which is 1.8% of the value of mudflat ecosystem in the year 1987. Because the formation of *Spartina alterniflora* ecosystem on

Table 2. Value variations in the constitution of ecosystem functions.

Service function of ecosystem	1987			2000			1987-2000	
	ESV ($\times 10^6$yuan RMB)	Percentage of value (%)	sorting order	ESV ($\times 10^6$ yuan RMB)	Percentage of value (%)	sorting order	The change ($\times 10^6$ yuan RMB)	
MP	587.23	6.40	6	1011.31	11.25	3	424.08	
GCR	607.22	6.62	5	493.97	5.49	7	-113.25	-610.19
SWC	801.39	8.73	3	698.13	7.77	5	-103.26	
DR	2666.99	29.07	2	2482.03	27.61	2	-184.96	
WRS	2911.99	31.74	1	2775.35	30.87	1	-136.64	
SFNC	118.38	1.29	19	110.49	1.23	19	-7.89	
WT	751.43	8.19	4	726.19	8.08	4	-25.24	
BM	187.49	2.04	8	177.55	1.98	8	-9.94	
RC	543.49	5.92	7	514.48	5.72	6	-29.01	
Total value	9175.61	100	-	8989.50	100	-	-186.11	

mudflat after 1987 has higher ecological service value than the bare flat, in some extent it counteracts the reduction of the ecosystem service value caused by the decrease of the bare flat area. Furthermore, the forestland has considerably high ecological service value, and the reduction of the forestland area resulted in a loss of 1589 $\times 10^8$ yuan RMB in the ecological value. The reduction is the highest in all the ecosystems, so that its proportion in the total value reduced from 13.47% in 1987 to 11.96% in 2000. The reduction of the dry land and paddy fields areas led to a 1.642 $\times 10^7$ yuan RMB reduction and a 3.819 $\times 10^7$ yuan RMB reduction, respectively. The water body and fields for aquaculture increased by 6.44 and 11.49 km^2 from the year 1987 to 2000, and their ecological value respectively increased by 3.223 $\times 10^7$ yuan RMB and 6.684 $\times 10^7$ yuan RMB. The salt field area reduced by 13.46 km^2 in the past 13 years, and its ecological value reduced by 2.041 $\times 10^7$ yuan RMB. The increase of the construction land contributed a 6.485 $\times 10^7$ yuan RMB increase to the ecological value.

Value variations in the constitution of ecological functions

The total economic value of the ecosystem functions can be reduced to material product value and ecological service value. The net output of the material products in the ecosystem in the study area was 1.01131 $\times 10^9$ yuan RMB in year 2000. Compared with the 5.8723 $\times 10^8$ yuan RMB in year 1987, it increased by 4.2408 $\times 10^8$ yuan RMB, being 72.22% of the net output in year 1987 (Table 2). At the same time, compared with the year 1987, the ecological service value in the year 2000 reduced by 6.1019 $\times 10^8$ Yuan RMB, and the reduction is 1.44 times of the increase of material product value in the year 2000. It can be concluded that, the increase of the material product value in the study area is accompanied with an even faster and bigger decrease of the ecological service value.

From the proportion of the various ecological function values in the total value (Table 2), gas and climate regulation, water regulation and supply, and disturbance regulation function contributed the most to the total value of the ecosystem function, which reached 60.81 and 58.48% respectively in the year 1987 and 2000. The soil formation and nutrient cycle and biodiversity maintaining function contributed the least to the total value, which occupied only 3.33 and 3.21% respectively in the year 1987 and 2000. The contribution of the other five functions to the total value lies between the above two. Furthermore, on the influence of land use changes, the order for the contribution of the value of each ecological function to the total value changes. The order for the contribution of the material product and recreation and cultural functions to the total value increased, and the contribution of the soil and water conservation and gas and climate regulation functions to the total value decreased.

Causes of the decline in total economic value of ecosystem functions

The decline of total economic value of ecosystem functions was caused by the land use change in the study area. In the past 13 years, the agricultural restruc-turing, priority has been shifted from traditional agriculture with low economical value such as paddy and cotton production to the all-round development of modern agriculture with high economical value such as fruits and vegetables. With the seashore accretion of south Hangzhou bay bank, reclamation of mudflat is a main way to carry out the dynamic balance on the total amount of cultivated land in study area, and a lot of mudflat was used as fields for aquaculture. The adjustments of agri-culture structure increases the material output of land greatly. Moreover, the agricultural modernization, espe-cially the construction of Cixi agricultural science and technology Park, greatly enhances the added value of material products in the agricultural ecosystems.

Mudflat and forestland are the ecological systems which have highest economic value of service functions in per unit area (Table 1). The conversion of mudflat and forestland to other land use inevitably results in the loss of services value of ecosystem though it increases the value of material output. For example, mudflat is used for cultivation or aquaculture, the material product is greatly increased, but mudflat's ecological functions of waste treatment, gas and climate regulation, disturbance regulation and biodiversity maintenance will be reduced or eliminated. The reduction of economic value of service functions outruns that of the increase of material products.

Conclusions

The ecosystem functions value has close relationship with the development tendency of socio-economic system. The land use change directly affects the economic value of ecosystem functions. From 1987 to 2000, the total economic value of the ecological functions in coastal plain of south Hangzhou Bay bank obviously declined. The value of material product grew greatly and service value declined a lot. Consequently, the sharp increase of the value of material products in the ecosystems is based on sacrificing a part of ecological functions. In other word, the mudflat, forestland and other ecosystems that have high total value and service value are adapted for material product value. In the long run, the land use change will have an adverse effect on the regional social-economic system development and will influence the sustainable development of the mankind.

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