A Specific Way to Evaluate Ecosystem Services Based on a Cost Model

Siran Lee, Chen Qi, Chunyan Wang

Business College of Southwest University, Chongqing, 402460

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Abstract: Land use projects will affect ecosystem services. Economic costs should include the negative effects of land use. And we should assess the environmental costs. We set up a cost model of environmental degradation. In the basic model, we mainly study the two main functions of the ecosystem. These functions are material supply services and air purification services (including dust retention value, water conservation and soil conservation, maintenance of soil fertility, etc),and we found the value of functional losses. We use the intermediate materials transformation method and the market value method to transform the cost of environmental degradation in land projects into monetary value, and then calculate the costs of environmental degradation through the corresponding products or service prices. Through comparative analysis, we further optimize the basic model, and finally stabilize the standard deviation with the actual case at $0.1 \leq 0.5$. In the optimization model, we put forward the indirect loss of ecological service function on the basis of the basic model, and add the loss of air pollution to human health and regional agricultural products. At the same time, we also take into account the changes in the soil over time so that our model is more accurate.

1. Introduction

Economic theories often ignore the impacts of their decisions on the biosphere, or assume that resources are unlimited [1]. However, it is not unlimited. Traditionally, many land use projects neglect the cost of the small-scale changes in land use, which do not take into account the impacts of ecosystem services or changes in ecosystem services [2]. At the same time, these cumulative factors directly affect biodiversity and lead to environmental degradation and environmental degradation cost [3]. Therefore, we should pay attention to these environmental costs .

2. Model Establishment and Solution

2.1 Model Establishment

2.1.1 Organic matter production

When the land is not developed and utilized, the ecosystem has the ability to produce organic matter.

The potential production of organic matter in this ecosystem is estimated as follows:

$$V_1 = P \times NPP \times A$$

$V_1$is potential yield of organic matter; P is the average price per unit of organic matter ($\mathrm{USD} \cdot \mathrm{kg}^{-1}$); NPP is net primary productivity per unit area ($\mathrm{kg} \cdot \mathrm{hm}^{-2}$); A is ecosystem area ($\mathrm{hm}^2$);

Net primary productivity = total primary productivity-autotrophic respiratory consumption.

2.1.2 Grain yield estimation

When ecosystems are not developed, they can provide food for humans if they are converted into arable land [4]. When the ecosystem is used for other purposes, the ecosystem is unable to produce the food needed by human beings, so the potential for food production of the ecosystem disappears and the potential for this part of the disappearance is our loss. We translate the potential production of an ecosystem into the average production price of food, which is calculated as follows:

$$V_2 = y \times P_f$$

$$P_f = \sum_{i=1}^{n} P_{f_i} a_i$$

V_2 is potential grain yield;y is total grain production in this ecosystem;P_f is the average price of food (USD· kg^{-1}). We take the weighted average of the prices of the main crops in the area,P_{f_i} is the price of the main crop,a_i is proportion of crop production; y is the total food production of this ecosystem (kg).

2.1.3 Fixation of CO_2

When ecosystems are not developed, natural forests purify the air and can absorb CO_2 in the air, according to the photosynthetic response equation:

$$CO_2(264kg) + H_2O(108kg) \longrightarrow C_6H_{12}O_6(108kg) + O_2(193kg) + \text{Polysaccharide}(163kg)$$

Then the value of fixed CO_2can be estimated by using afforestation cost method and carbon tax law:

$$V_3 = 1.63NPP \times P_{co_2} \times A$$

V_3 is the value of fixed CO_2;1.63 is the mass of CO_2 fixed for every 1 g of dry matter produced by the photosynthetic equation; NPP is net primary productivity per unit area ($kg \cdot km^{-2}$); P_{co_2} is the cost of fixed unit mass CO_2.

2.1.4 O_2 release

The purification effect of ecosystem on air is also reflected in the ability of ecosystem to release O_2[5]. After the implementation of the land project, this part of the land no longer has the ability to release oxygen, and we can estimate the value of O_2 released by the forest through the industrial oxygen shadow price method:

$$V_4 = 1.19 \times NPP \times P_{o_2}$$

V_4 is the value of releasing O_2;1.19 is the mass (kg) released for O_2 per unit of dry matter produced by photosynthesis;P_{o_2} is the unit price of industrial oxygen (USD $\cdot$ kg^{-1}).

2.1.5 Absorption of SO_2

The ecosystem has the function of absorbing SO_2, and the land project makes this part of the land no longer have the function of absorbing SO_2, and we assume that this part of the SO_2 that should be absorbed is removed by means of industrial governance:

$$V_4 = q \times P_{SO_2}$$

q is the ecosystem SO_2 retention (kg); P_{SO_2} is to reduce the average unit governance cost of SO2. The price calculation for removing unit mass SO_2 is as follows:

$$2SO_2 + O_2 \xrightarrow{V_2O_5} 2SO_3$$

$$CaO + SO_3 \longrightarrow CaSO_4$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4$$

SO_2 (64g) of 1mol requires O_2(32g) of 0.5mol ,CaO(56g) of 1mol and Na_2CO_3(106g) of 1mol to eliminate .

$$P_{SO_2} = \frac{32}{64}P_{O_2} + \frac{56}{64}P_{CaO} + \frac{106}{64}P_{Na_2CO_3}$$

P_{o_2}refers to the unit price of industrial oxygen (USD $\cdot$ kg^{-1}),P_{CaO}refers to the unit price of calcium oxide (USD $\cdot$ kg^{-1}),$P_{Na_2CO_3}$ refers to the unit price of sodium carbonate (USD $\cdot$ kg^{-1}).

2.1.6 Stagnant dust value

The perfect forest ecosystem has the ecological function of retaining dust. After the implementation of the land project, the ecological benefits of this part no longer exist. We propose the following formula:

$$V_5 = k \times P_d$$

V_5 is the cost of removing SO_2 by industrial means;k is the amount of dust in an ecosystem per unit area (kg $\cdot$ hm^{-2}); P_d is the average cost of dust reduction (USD$\cdot$ kg^{-1}).

We calculate the dust retention per unit area of the ecosystem by studying the dust retention of the main plants in the ecosystem (the particle size is PM0.2-PM100, including the total suspended particulates).

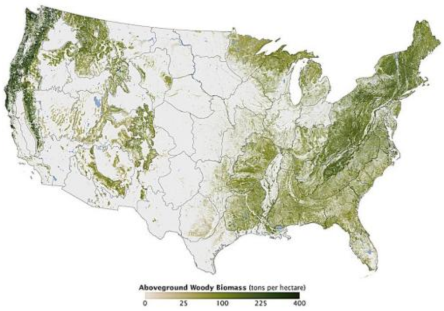

Figure1 Forestry Distribution Map (USA)

For the amount of dust retention, we mainly studied the amount of dust retention in forest land. Figure 1 is the forestry distribution map of the United States, from which we can see that the forestry of the United States is mainly concentrated in the East and West coasts, while the East and west coasts are also crowded areas, so it is necessary to assess ecosystem services in these areas.

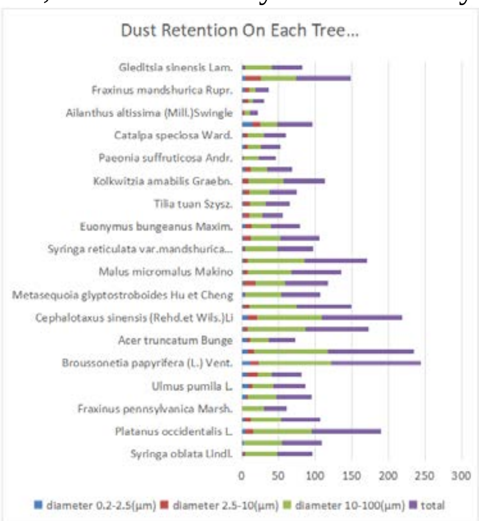

Figure2- Dust Retention On Each Tree Species(average)

In Figure 2, we list the dust retention of 35 tree species, and the retention of particles of various diameters by each tree species. We use the total amount of dust as an indicator of our amount of dust.

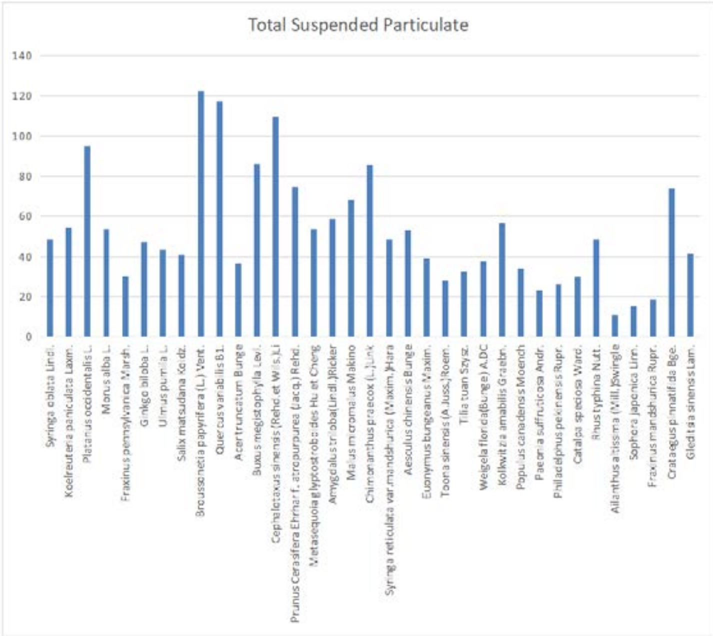

Figure3 Total Suspended Particulate

Figure 3 is a histogram of the total dust retention of each tree species with that of the tree species, from which we can see that there are obvious differences in the dust retention of the tree species, so we use the method of intra-group links for cluster analysis by SPSS software. The dust retention capacity of the studied tree species was divided into low (0 ~20), medium (20 ~ 60), upper middle (60 ~ 90) and high (above 90).

According to the results of the division, the mean value of dust retention at each level is calculated.

Table1 Mean Value of Each Levels Dust Retention

Levels	Low	Medium	Above Medium	High
Mean Value	14.85615	77.70002	111.0418	114.0418

2.1.7 Water conservation

A good ecosystem has the function of conserving water. when the land is used, the soil no longer has the function of conserving water. we calculate the loss of this part of the water source as the cost:

$$V_6 = A \times W \times P_w$$

V_6 is ecological value of dust retention; A is the area of the ecosystem (km^2); W is the amount of water conservation in the ecosystem, that is, precipitation (mm);ρis the density of rain water;P_w is the price of water resources (USD· m^{-3}).

2.1.8 Soil conservation

When the ecosystem is not used, a good ecosystem can maintain the soil and reduce soil loss. Soil loss can cause loss of soil accumulation, and we translate this part of the loss into the cost of restoring the soil to its original state:

$$\mathrm{V}_7 = G \times P_G$$

V_7 is ecological value of Water Conservation;G is to maintain the total amount of soil (m^{-3}),P_G is the cost of excavating and transporting earthwork per unit volume (USD· m^{-3}).

2.1.9 Maintain soil fertility

Soil erosion also reduces the productivity of the ecosystem, mainly as the number of chemical elements in the soil that provide fertility to the ecosystem is reduced. we have selected three chemical elements that regulate plant growth, namely, nitrogen and phosphorus, potassium. We translate the reduced fertility of this ecosystem into the market value of corresponding types and quality fertilizers. The benefit of forest fertilizer conservation only calculates the loss of three main mineral nutrients, nitrogen, phosphorus and potassium. we converted the contents of P ,N and K into the contents of ammonium bicarbonate, calcium superphosphate and potassium sulfate to calculate the loss value:

$$E_1 = G \times n \times P_N$$

$$E_2 = G \times p \times P_P$$

$$E_3 = G \times k \times P_K$$

G is to maintain the total amount of soil n, p, k are the average percentage of soil N, P, K in the constant ecosystem; P_N, P_P, P_K are the fertilizer prices of N, P, K, respectively, we use the following formula to calculate:

$$P_N = \frac{79}{14} \times P_{\mathrm{NH_4}HCO_3}$$

$$P_P = \frac{234}{31} \times P_{\mathrm{CaP_2}H_4O_8}$$

$$P_K = \frac{174}{39} \times P_{\mathrm{K_2}SO_4}$$

$P_{\mathrm{NH_4}HCO_3}, P_{\mathrm{CaP_2}H_4O_8}, P_{\mathrm{K_2}SO_4}$ denote are $\mathrm{NH_4}HCO_3$,$\mathrm{CaP_2}H_4O_8$, $\mathrm{K_2}SO_4$ unit mass price when their purity is close to 100% (USD· kg^{-1}) .

Finally,we add up the costs caused by all the factors to get the total cost of the initial model:

$$\mathrm{P}_{total} = \sum_{i=1}^{7} V_i + \sum_{i=8}^{10} E_i$$

2.2 Model Solution

We validate our model with some examples. The water conservation, the soil reinforcement and fertility maintenance and the carbon-fixing and oxygen-releasing of the ecosystem were mainly validated in our model.

2.2.1 Water Conservation

As for Water Conservation, our formula represent as:

$$V_6 = A \times W \times P_w$$

In each case, the area of the ecosystem is determined, the amount of water (precipitation) of the ecosystem should be known, and the unit storage cost can be obtained from the hydrological data center.

2.2.2 Soil reinforcement and fertility maintenance

As for soil reinforcement and fertility maintenance, we referred to the soil models of InVest. After comparing with the examples, we found that there is a disparity which can not ignore. So we do the error analysis, then we realized that disparity was caused by the total soil conservation(G) , next we fixed the formula.

2.2.3 Carbon-fixing and Oxygen-releasing

We directly used the corresponding formula in our model to calculate the amount of carbon fixation and oxygen release, the we added them together to compare with the data in examples.

Result

1) The standard deviation of economic benefits between the water conservation in our model and the water conservation in examples is less than 0.8 thousand dollars.

2) The standard deviation of economic benefits of the soil reinforcement and fertility

maintenance in two sides is less than 1 thousand dollars.

3) The standard deviation of economic benefits of the carbon-fixing and oxygen-releasing is less than 0.5 million dollars.

Fixed formula

In Soil Reinforcement and Fertility Maintenance, we fixed the formula of the total soil conservation (G), and now the formula represent as:

$$G = S \times (N-F)$$

S stands for the area of the ecosystem(hm^2),N represent the erosion modulus of farmland($t/km^2.a$) and the F stands for the erosion modulus of woodland($t/km^2.a$).

3. Establishment and Solution of the Improved Model

Our optimization model considers large-scale land use projects, and takes a single city as the research object to study the ecosystem.

Aiming at air pollution, the following two aspects of losses will be caused.

3.1 Human Health Loss

The human capital method is used to calculate the loss of human capital caused by ecological environment pollution, which is transformed into the sum of the output value created by labor force and medical expenses during this period.

Air pollution can cause damage to human health, manifested in the rising incidence of chronic diseases and even premature death. The losses caused by air pollution to human society include the loss of patients'work, the loss of caregivers' missed work, and the loss of medical expenses. We use human capital to account for this part of the loss:

$$V_8 = \left[p \times \sum_{i=1}^{k} T_i \left(L_i - L_{0i}\right) + \sum_{i=1}^{k} Y_i \left(L_i - L_{0i}\right) + p \times \sum_{i=1}^{k} H_i \left(L_i - L_{0i}\right) \right] \times M$$

In the formula above, S represents the loss of human health caused by air pollution. p stands for per capita wage level. T_i represents the loss of working time(y) per capita for patients with type i diseases, L_i and L_{0i} are respectively expressed as the incidence of class I diseases in polluted and clean areas. Y_i denotes the average medical expenses of patients with type i diseases, H_i denotes the average time of missed work of nurses with type i diseases, and M denotes the regional population in the polluted areas.

3.2 Indirect Loss of Agricultural Production

The indirect losses of agricultural production are mainly caused by the negative effects of sulphur dioxide and acid rain on crops, resulting in the loss of crop production. Our paper chooses the main crops in cities as accounting items and refers to the reaction function of acid rain and sulfur dioxide in the laboratory to reduce the output of agricultural products. The following is the regression equation of the reaction function of vegetables, wheat, cotton and soybean expressed by experts such as Hongfa Cao.

Vegetables: $Q_1 = 19.40 - 13.02X_1 + 1.83X_2$

Wheat: $Q_2 = 17.84 - 7.41X_1 + 1.04X_2$

Cotton: $Q_3 = 22.15 - 8.84X_1 + 1.62X_2$

Soybean: $Q_4 = 30.57 - 13.24X_1 + 1.92X_2$

$Q_i$is the output of agricultural products, X_1 is the concentration of SO_2, X_2 is the pH of acid rain.

Comparing with the crop yields of non-polluted (SO_2=0, pH=5.6), we concluded that the reduction rate R_i of class I agricultural products under atmospheric pollution environment is as follows:

$$R_i = \frac{Q_{U_i} - Q_{C_i}}{Q_{U_i}}$$

Q_{U_i} is the output of agricultural products per unit area without pollution, and Q_{C_i} is the output of agricultural products per unit area under pollution.

We combining the two formulas to calculate indirect loss cost:

$$V_9 = \sum_{i=1}^{s} Q_i R_i$$

$$\mathrm{P}_{total}{}^{*} = \sum_{i=1}^{7} V_i + \sum_{i=8}^{10} E_i + S + \sum_{i=1}^{s} Q_i R_i$$

3.3 Time Model

Because time plays a role in many parameters of our model, we select the sensitive factors for time comparison. Finally, we decided to study the relationship between the percentage of nitrogen, phosphorus, potassium and soil content and time. After consulting the literature and searching for relevant data, we made the following table:

Table 2 Changes of Nitrogen, Phosphorus and Potassium in two kinds forest soils

	Nitrogen(N)	Phosphorus(P)	Potassium (K)
Evergreen broad-leaved forest	-0.12%	-0.04%	-0.20%
Chinese fir forest	-0.10%	-0.04%	-0.28%

As shown in the table, we have made statistics on evergreen broad-leaved forest and Chinese fir forest, and we can see that the trend of three elements in different forest soils (without human intervention) decreases with time. The data in the cell represent the annual change rate of the corresponding element content (percentage) in the forest soil, so it can be used to predict the percentage of the element content in the forest soil after the change rate.

4. Conclusions

We translate the costs of environmental degradation into the loss of human health and agricultural products caused by environmental degradation, and then add it to our model. Our model can describe the cost loss of environmental degradation.

References

[1] Daily GC, Polasky S, Goldstein J, et al. Ecosystem services in decision making: Time to deliver[J]. Frontiers in Ecology and the Environment. 2009(4): 256-258.

[2] Plummer ML. Assessing benefit transfer for the valuation of ecosystem services [J]. Frontiers in Ecology and the Environment. 2009(8): 145-147.

[3] Lavorel S, Grigulis K. How fundamental plant functional trait relationships scale up to trade offs and synergies in ecosystem services[J]. Journal of Ecology. 2012(8): 136-139.

[4] LI Weijie, Wang Tingmei, Wang Guiping, Chen Xun. Study on the dynamic change of eco—footprints in Guizhou karst areas[J]. 2010(6): 78-81.

[5] Li Mo, Ma Zeyu, Xu Yansen, Sun Fengbin, Lun Xiaoxiu, Liu Xuhui, Chen Jungang, Yu Xinxiao. Assessing the capacity of plant species to accumulate particulate matter in Beijing, China[J]. 2015, 27(10): 278-280.