Journal of Zhejiang University SCIENCE B
ISSN 1673-1581 (Print); ISSN 1862-1783 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Science Letters:

A new quantitative model of ecological compensation based on ecosystem capital in Zhejiang Province, China*

Yan JIN[1,2,3], Jing-feng HUANG[†‡1,2,3], Dai-liang PENG[1,2]

(*[1]Institute of Agricultural Remote Sensing and Information Application; [3]Ministry of Education Key Laboratory of Environmental Remediation and Ecological Health, Zhejiang University, Hangzhou 310029, China*)

(*[2]Key Laboratory of Agricultural Remote Sensing and Information System of Zhejiang Province, Hangzhou 310029, China*)

[†]E-mail: hjf@zju.edu.cn

Received July 18, 2008; Revision accepted Nov. 11, 2008; Crosschecked Mar. 2, 2009

Abstract: Ecological compensation is becoming one of key and multidiscipline issues in the field of resources and environmental management. Considering the change relation between gross domestic product (GDP) and ecological capital (EC) based on remote sensing estimation, we construct a new quantitative estimate model for ecological compensation, using county as study unit, and determine standard value so as to evaluate ecological compensation from 2001 to 2004 in Zhejiang Province, China. Spatial differences of the ecological compensation were significant among all the counties or districts. This model fills up the gap in the field of quantitative evaluation of regional ecological compensation and provides a feasible way to reconcile the conflicts among benefits in the economic, social, and ecological sectors.

Key words: Payment for ecosystem services (PES), Gross domestic product (GDP), Ecological capital (EC), Geospatial distribution
doi:10.1631/jzus.B0820222 **Document code:** A **CLC number:** F062.2

INTRODUCTION

With the high-speed development of economy in China, the environmental pressure of resources doubles. As an important part and approach to the undertaking of regional ecological construction, ecological compensation is becoming one of the key and multi-discipline issues in the field of resources and environmental management (China Council for International Cooperation on Environment and Development, 2006). It is called ecological compensation or eco-compensation in China, which has payment for ecosystem services (PES) or payment for ecological benefit (PEB). A great number of researches about ecological compensation have been made both in China and other countries, most of which are focused on forests (Skärbäck, 2007; Murray and Abt, 2001; Sierra and Russmana, 2006), water (Becker, 1999; Wang and Ma, 2002; Zhang and Ruan, 2003; Qin and Qiu, 2005), and other systems. However, there are few researches on evaluating ecological compensation synthetically and quantitatively in large-scale areas.

In this paper, we construct a new quantitative estimate model for ecological compensation, analyze the correlation between gross domestic product (GDP) and ecological capital (EC) based on remote sensing and using county as study unit, and determine standard value so as to evaluate ecological compensation from 2001 to 2004 in Zhejiang Province, China. The results can be useful in regional economic and social development.

THEORY

Original data

1. Image data: MOD12Q1 (2001~2004) provided by the Data Center of the Earth Resources

‡ Corresponding author
* Project (No. 2006AA120101) supported by the Hi-Tech Research and Development Program (863) of China

Observation System, the United States Geology Survey.

2. Meteorological data: 63 stations acquired from Zhejiang Meteorological Administration, including daily mean precipitation, temperature, wind speed, the hours of sunlight, and relative humidity.

3. Digital elevation model (DEM) data with a scale of 1:250000 acquired from Institute of Agricultural Remote Sensing & Information Application, Zhejiang University, China.

4. Map of soil texture of Zhejiang Province with a scale of 1:250000 provided by Institute of Soil Science, Chinese Academy of Sciences.

5. Statistic data: the population and GDP of each county in Zhejiang Province from 2001 to 2004, provided by Zhejiang Provincial Bureau of Statistics (http://www.zj.stats.gov.cn/).

Estimation model of ecological capital

Within a region, *EC* (yuan/m^2) is dynamic and varies with time. It is the total value of all ecosystem services and natural resources of all ecosystems, and it varies with types, areas, and qualities of ecosystems (Costanza *et al*., 1997). Ecosystem services represent the benefits that living organisms derive from ecosystem functions that maintain the Earth's life support system. The gross value of regional *EC* can be expressed as:

$$EC=V_{POM}+V_{AGR}+V_{RNM}+V_{HWR}+V_{CSW}+V_{WT}, \quad (1)$$

where V_{POM}, V_{AGR}, V_{RNM}, V_{HWR}, V_{CSW}, and V_{WT} (yuan/m^2) are the values of production of raw materials, regulation of atmospheric gas, recycling of nutrient matters, holding water resources, conservation of soil and water resources, and waste treatment, respectively. These values can be calculated by Eqs.(2)~(8).

$$V_{POM}=NPP\times R_{POM}, \quad (2)$$

$$V_{AGR}=NPP\times(1.62\times R_{CO_2}+1.2\times R_{O_2}), \quad (3)$$

$$V_{RNM}=NPP\times(r_{1N}\times r_{2N}\times R_N+r_{1P}\times r_{2P}\times R_P+r_{1K}\times r_{2K}\times R_K), \quad (4)$$

$$V_{HWR}=P_{mean}\times r_{1w}\times r_{2w}\times R_w, \quad (5)$$

$$V_{CSW}=V_{RLA}+V_{LS}+V_{PSF}, \quad (6)$$

$$V_{WT}=V_{SO_2}\times V_{dust}, \quad (7)$$

where net primary production (*NPP*, g C/(m^2·a)) is the mass of raw materials produced per year , and R_{POM} (yuan/g C) is the price of producing organic matter. R_{O_2} and R_{CO_2} (yuan/g C) are the prices of producing O_2 and CO_2 using industrial methods. r_{1N} is the distributive ratio of nitrogen in organic matter in corresponding ecosystem, r_{2N} is the ratio of pure nitrogen converted to nitrogenous fertilizer, and R_N (yuan/g C) is the average price of nitrogenous fertilizer. The valuations of P and K are just as that of N. P_{mean} (mm) is monthly precipitation, r_{1w} is the ratio between runoff precipitation and total precipitation, r_{2w} is the value ratio of decreasing runoff compared with bare land, and R_w is the price of building reservoir. V_{RLA}, V_{LS}, and V_{PSF} (yuan/g) are the values of reducing the land abandonment, lightening sedimentation, and protecting soil fertility; V_{SO_2} and V_{dust} (yuan/g) are the values of removing SO_2 and dust.

NPP means the estimated using an improved light utilization efficiency model (Sun and Zhu, 2000), and can be modeled using the following formula:

$$NPP=\varepsilon_{max}\times f_1(T)\times f_2(\beta)\times PAR\times FPAR-RC, \quad (8)$$

where *PAR* (MJ/m^2) is photosynthetical active radiation, ε_{max} is the maximum efficiency of *PAR*, $f_1(T)$ and $f_2(\beta)$ account for the effects of air temperature and soil moisture on assimilation, and *FPAR* is the fraction of *PAR* absorbed by plant canopy, which can be determined by the normalized difference vegetation index (NDVI). *RC* (g C/(m^2·month)) is the monthly amount of respirated carbon (Sellers *et al*., 1994).

Analysis of EC and GDP

We chose six representative counties (districts) (i.e., Hangzhou, Ningbo, Yiwu, Changxing, Taishun, and Longquan) based on economic condition in order to analyze the relationship between county ecosystem and economy. The average annual EC and GDP per area or per capita in these regions from 2001 to 2004 were shown in Table 1.

The average values of county-level EC and GDP varied significantly in these regions both per area and per capita. The differences of EC and GDP per area varied much more significantly among the six regions than those per capita. EC/GDP ratio indicated that the

Table 1 Statistic values of GDP and EC from 2001 to 2004 in the six various representative regions in Zhejiang Province, China

County name	Area (km^2)	GDP		EC		EC/GDP
		Per area (yuan/m^2)	Per capita ($\times 10^3$ yuan)	Per area (yuan/m^2)	Per capita ($\times 10^3$ yuan)	
Hangzhou	683	149.70	52.51	1.65	0.58	0.01
Ningbo	1033	72.26	57.17	1.91	1.51	0.03
Yiwu	1103	16.16	26.19	1.96	3.18	0.12
Changxing	1428	7.21	16.61	1.85	4.26	0.26
Taishun	1762	0.89	8.35	4.53	42.48	5.09
Longquan	3059	0.75	8.35	3.43	38.08	4.56

GDP: gross demostic product; EC: ecological capital

ecological status and economical status were comparative: if the ratio ≥1, this region held certain ecological capacitance, while the ratio <l indicates that the regional ecological capacitance declined and that the ecological stress exceeded the respective biocapacity (Pan *et al.*, 2004). In other words, the counties supporting most ecosystem services were all poor regions or underdeveloped areas. There was a huge horizontal financial gap between economically developed counties and underdeveloped areas, and the gap increased with the passage of time.

Estimate model of ecological compensation

Considering the financial system and the feasibility of implementing eco-compensation in Zhejiang Province, we chose county administration district as analysis unit in this study. According to the base year of 2001, we defined *PES* (yuan) as the county total value of ecological compensation. The formula of *PES* can be expressed as:

$$PES=\gamma\times PES_{\mathrm{p}}+(1-\gamma)\times PES_{\mathrm{a}}, \tag{9}$$

where PES_{p} is the county total value of ecological compensation according to the population; PES_{a} is the county total value of ecological compensation according to the region area. γ is the parameter characterizing the weights of PES_{p} and PES_{a}. In this study, we chose γ as 0.5, and the weight of population and area could be studied more specifically in the further research.

Because of the different population densities in different regions, PES_{p} can be calculated as:

$$\begin{aligned}PES_{\mathrm{p}(i,j)}=&\left[\left(\frac{EC_{i,j+1}-GDP_{i,j+1}}{TP_{i,j+1}}-\frac{EC_{i,j}-GDP_{i,j}}{TP_{i,j}}\right)\right.\\&-\left(\left(\sum_{i=1}^{n}EC_{i,j+1}-\sum_{i=1}^{n}GDP_{i,j+1}\right)\Big/\sum_{i=1}^{n}TP_{i,j+1}\right.\\&\left.\left.-\left(\sum_{i=1}^{n}EC_{i,j}-\sum_{i=1}^{n}GDP_{i,j}\right)\Big/\sum_{i=1}^{n}TP_{i,j}\right)\right]\cdot TP_{j+1},\end{aligned} \tag{10}$$

where $EC_{i,j}$ is the EC of the *i*th county in the *j*th year (*j*=2001, 2002, or 2003); $GDP_{i,j}$ is the GDP of the *i*th county in the *j*th year; $TP_{i,j}$ is the total population of the *i*th county in the *j*th year. $PES_{i,j}$ is the county total value of ecological compensation of the *i*th county from the *j*th year to the (*j*+1)th year.

Considering the area of every county administration districts, PES_{a} can be calculated as:

$$PES_{\mathrm{a}(i,j)}=\left[(EC_{i,j+1}-GDP_{i,j+1})-(EC_{i,j}-GDP_{i,j})\right]-\frac{S_i\left[\left(\sum_{i=1}^{n}EC_{i,j+1}-\sum_{i=1}^{n}GDP_{i,j+1}\right)-\left(\sum_{i=1}^{n}EC_{i,j}-\sum_{i=1}^{n}GDP_{i,j}\right)\right]}{\sum_{i=1}^{n}S_i}, \tag{11}$$

where S_i (km^2) is the area of the *i*th county (district).

RESULTS

The spatial distribution of the county (district) total PES of Zhejiang Province is shown in Fig.1. Spatial differences of PES were significant among all the counties or districts. The county PESs in the northeast and southeast of Zhejiang Province were negative, while they were positive in west and southwest regions. The lowest values (<−4.0 billion yuan) were found in municipal districts like Hangzhou, Xiaoshan, Ningbo, and so on. The rather low values (i.e., −4.0 to 0 billion yuan) were found in the north and east regions. The positive values were found in most of counties especially in the western Zhejiang.

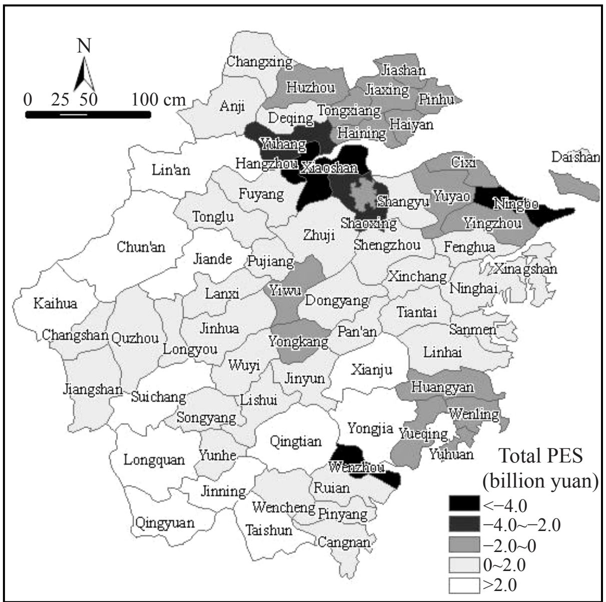

Fig.1 Spatial distribution of the average annual county PES from 2001 to 2004 in Zhejiang Province, China

DISCUSSION

Majority of the important ecological function regions are coincident with the underdeveloped areas. For example, as the ecological barrier of Zhejiang Province, the southwestern counties are the underdeveloped areas. In an ecological viewpoint, these counties could obtain ecological compensation from other developed counties or municipal districts for required ecosystem services. In an economical viewpoint, they undertake more important mission to protect ecological environment than the economic developed areas like Hangzhou bay areas or coastal areas. What is more, as the river head of eight water systems in Zhejiang Province, they need to support the lower areas with clean water, which means resource-dependent industrial sectors (serious pollution industrial sectors) are limited in these regions. Generally speaking, PES can solve the problems and adjust the benefit distribution of ecosystem and economy between the relevant stakeholders. At the same time, it is necessary to reduce the income gap between the towns and the country, in order to boost the harmonious development of region, protect the resource and environment, realize the continuable development, and enhance the international competition.

CONCLUSION

This model fills up the gap in the field of quantitative evaluation of regional ecological compensation based on ecological capital, and provides a feasible way to reconcile the conflicts among benefits in the economic, social, and ecological sectors. This study could be also considered as a supplement or necessary improvement to the research of existing ecological capital, as further theoretical research of ecological capital transfers in the conditions of different social economic development levels or different regional development. Considering the financial system and the feasibility of implementing eco-compensation, PES was evaluated in a unified administrative region. This model has universal properties, which can be applied in all scales of study area even in the world. It will help increase not only the governmental macro-regulating level, but also public consciousness of protecting environment.

References

Becker, N., 1999. A comparative analysis of water price support versus drought compensation scheme. *Agricultural Economics*, **21**(1):81-92. [doi:10.1016/S0169-5150(99)00019-5]

China Council for International Cooperation on Environment and Development, 2006. Eco-compensation Mechanism and Policies in China. http://www.cciced.org/2008-03/04/content_11547986.htm

Costanza, R., d'Arge, R., Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., *et al*., 1997. The value of the world's ecosystem services and natural capital. *Nature*, **387**(6630):253-260. [doi:10.1038/387253a0]

Murray, B.C., Abt, R.C., 2001. Estimating price compensation requirements for eco-certified forestry. *Ecological Economics*, **36**(1):149-163. [doi:10.1016/S0921-8009(00)00224-X]

Pan, Y.Z., Shi, P.J., Zhu, W.Q., 2004. Measurement of ecological capital of Chinese terrestrial ecosystem based on remote sensing. *Science in China*, *Series D: Earth Sciences*, **34**(4):375-384 (in Chinese).

Qin, L.J., Qiu, H., 2005. Study on water resources compensation in Songliao River Basin. *Journal of Natural Resources*, **20**(1):14-20 (in Chinese).

Sellers, P.J., Tucker, C.J., Collatz, G.J., Los, S.O., Justice, C.O., Dazlich, D.A., Randall, D.A., 1994. A global 1° by 1° NDVI data set for climate studies. Part 2: the generation of global fields of terrestrial biophysical parameters from the NDVI. *International Journal of Remote Sensing*, **15**(17):3519-3545. [doi:10.1080/01431169408954343]

Sierra, R., Russmana, E., 2006. On the efficiency of environmental service payments: a forest conservation assessment in the Osa Peninsula, Costa Rica. *Ecological Economics*, **59**(1):131-141. [doi:10.1016/j.ecolecon.2005.10.010]

Skärbäck, E., 2007. Urban forests as compensation measures for infrastructure development. *Urban Forestry & Urban Greening*, **6**(4):279-285. [doi:10.1016/j.ufug.2007.05.006]

Sun, R., Zhu, Q.J., 2000. Distribution and seasonal change of net primary productivity in China from April, 1992 to March, 1993. *Acta Geographica Sinica*, **55**(1):36-45 (in Chinese).

Wang, J.L., Ma, W.M., 2002. Study of valley ecology compensation question. *Journal of Soil Water Conservation*, **16**(6):82-83, 150 (in Chinese).

Zhang, C.L., Ruan, B.Q., 2003. The economy analysis on water resources restoration and compensation. *Water Conservancy Science and Technology and Economy*, **9**(1):3-5 (in Chinese).