Postprint: Goal-Oriented Ecological Function Improvement Standards for Ecological Compensation of Hani Rice Terraces

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Abstract

Paddy field production exerts dual impacts on the ecological environment. To enable paddy field production to provide different combinations or higher levels of environmental services, compensation is required for farmers' income losses incurred by altering management practices. Using the Hani rice terrace system in Honghe Hani and Yi Autonomous Prefecture, Yunnan Province as a case study, and based on both the characteristics of paddy field ecosystems and the subjective economic decision-making traits of individual farmers, this paper investigates the spatial distribution of opportunity costs in supplying paddy ecosystem services from the perspective of farmers' microeconomic decision-making. From the viewpoint of regional macroeconomic behavior, it further examines the relationship between compensation standards and the ecological environmental benefits that farmers are willing to supply. Consequently, oriented toward improving paddy ecological functions and targeting incremental ecological environmental benefits, by coupling farmers' willingness to accept compensation with opportunity costs, the feasibility of determining dynamic compensation standards based on ecological function improvement requirements (incremental ecological benefits) is achieved. Calculations indicate that when the ecological function improvement target is set at an incremental ecosystem service value of 80.77×104 元 hm-2 a-1, the compensation standard should be 3000 yuan/hm2; when the target is set at an incremental value of 219.49×104 元 hm-2 a-1, the compensation standard should be 9000 yuan/hm2.

Full Text

Preamble

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Ecological Compensation Standard for the Hani Rice Terrace System: An Eco-Functional Improvement Target

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Abstract

Agricultural land not only provides food and fiber, which are crucial for human food security, but also supplies various non-market commodities for export or public use. However, paddy production also has numerous negative environmental impacts. To encourage farmers to adopt ecological or organic agriculture practices that provide greater ecosystem services, it is necessary to compensate them for losses incurred when altering their cultivation methods. Most current ecological compensation standards for paddy cultivation are calculated using separate factors—such as ecosystem conservation costs, ecosystem service values, or willingness to accept compensation—making it difficult to achieve consensus among all stakeholders and limiting operability due to neglected factors.

This study was conducted in the Hani Terrace System, designated as a Globally Important Agricultural Heritage System (GIAHS) in 2010 and a World Heritage Site in 2013. We calculated paddy ecological compensation standards based on the subjective decision-making characteristics of individual farmers and paddy ecosystem characteristics. Using the opportunity cost of ecosystem service supply, we aimed to determine the supply curve for ecosystem services.

First, through observation and sample testing, we compared differences in ecosystem service values supplied by two production modes: conventional mono-cropping (using chemical fertilizers and pesticides) and fish cultivation in rice fields (using half the amount of fertilizers and no pesticides). Second, from the perspective of individual farmers' microeconomic decision-making, we investigated the spatial distribution of opportunity costs for supplying paddy ecosystem services. Third, from the perspective of farmers' macroeconomic behaviors, we examined the relationship between compensation standards and the eco-environmental benefits farmers were willing to provide. Finally, we combined farmer willingness with the opportunity cost of ecosystem services to build an ecological restoration-oriented compensation standard for the paddy system.

Results indicated that the proportion of farmers converting their production mode increased with compensation payments. When compensation reached 3,000 yuan/hm^2, the conversion rate was 35.74%, the added value of ecosystem services was 80.77×10 yuan/hm^2, and required compensation funds were

91.04×10 yuan/a. When compensation was as high as 9,000 yuan/hm^2, almost all farmers (97.12%) were willing to convert; the added value of ecosystem services was 219.49×10 yuan/hm^2 and required compensation funds were 273.13×10 yuan/a.

Keywords: ecological compensation; ecosystem services; land resources; willingness to accept; opportunity cost; GIAHS

1. Introduction

China has begun implementing ecological compensation systems to protect ecological environments by adjusting the interests of ecological protectors and destroyers [1]. Dominated by the government, with fiscal transfers and subsidies as the main investment channels, and major ecological protection projects as the primary form, China has initially established an overall ecological compensation framework with governments at all levels as implementing bodies [2]. Progress has been achieved in forests [3], grasslands [4], wetlands [5], watersheds and water resources [6], mineral resource development [7], marine areas, and key ecological function zones [8]. However, China' s ecological compensation system construction remains in its early developmental stage, lacking a complete system and methodology for determining compensation subjects and regulatory measures [9]. Ecological compensation measures have not yet played their proper role in China' s agricultural sustainable development [10].

As understanding of ecological and environmental issues continues to develop, the ecological functions of paddy fields have attracted widespread attention from scholars domestically and internationally [11]. Paddy production is not only an economic activity but also provides numerous functions including employment, maintenance of ethnic unity, and cultural heritage [12-13]. Particularly in economically underdeveloped regions with fragile ecological environments, paddy fields can protect vulnerable ecosystems while providing food production. However, under stimulation from food yield and economic profits, the abuse of pesticides and fertilizers has severely damaged paddy fields' capacity to purify wastewater, detoxify organic substances, and regulate pollution, while also creating non-point source pollution problems, destroying biodiversity, and triggering food safety issues [14]. In traditional areas, appropriate government compensation to farmers can incentivize adoption of environmentally friendly cultivation methods to fully realize the ecological and social functions of agricultural production [15].

Current paddy ecological compensation research remains at the case study level, with a considerable gap between theoretical discussion and practical application [16]. Most studies focus on compensation standard calculation methods: (1) based on input costs of environmentally friendly cultivation methods [17-18]; (2) based on farmers' willingness to accept compensation for adopting environmentally friendly methods, which reflects the cost of voluntarily providing quality ecosystem services [19-20]; or (3) based on ecological benefits generated by environmentally friendly cultivation methods, the most commonly used approach [21-22]. However, these calculation methods consider compensation standards based on single factors without coupling cost inputs with benefit outputs or linking compensation willingness with ecosystem service supply and consumption, making standards calculated from one perspective difficult for other parties to accept. Although effective incentive policies can enable paddy production to supply greater ecological and environmental benefits, the dual nature of paddy fields' environmental impacts and farmers' subjective economic decision-making characteristics make compensation standard determination particularly complex [23].

How to couple farmers' willingness to accept compensation with the opportunity cost of ecological environmental benefit supply to construct effective paddy ecological compensation standards constitutes the research focus of this paper.

2. Study Area

The Hani Rice Terrace System is primarily distributed in the Honghe Hani and Yi Autonomous Prefecture, Yunnan Province, China. This agricultural ecological structure has created a sustainable development model that has lasted for over 1,300 years in ecologically fragile, biodiversity-rich mountainous areas. The system was designated as a GIAHS site in 2010 and a World Heritage Site in 2013.

The Hani Rice Terrace System controls pest and disease occurrence through rice-fish farming while reducing agricultural non-point source pollution risks. However, the introduction of hybrid rice mono-cropping has led to increasing pesticide and fertilizer use year by year. Combined with low direct economic returns from rice production and the outflow of rural young labor, chemical fertilizer and pesticide application in the Hani Terrace area has damaged the local water and soil environment without significantly improving farmers' economic income [24]. Abandonment phenomena have gradually increased—on one hand, abandonment destroys the stable structure of terraces, while on the other hand, chemical inputs have not substantially increased farmers' economic returns. To restore environmentally friendly traditional rice-fish farming methods and compensate producers for losses from changing operational methods, this study examines ecological compensation standards that can incentivize paddy production to provide different combinations or higher levels of environmental services.

3. Data Sources

To quantitatively explore ecological compensation standards for farmers changing paddy production methods, this study selected Jiayin Township and Baohua Township in Honghe County, Honghe Hani and Yi Autonomous Prefecture, Yunnan Province as the research area. Since 2014, rice growth period experimental observations have been conducted in Jiayin Township, comparing two scenarios:

conventional chemical fertilizer/pesticide use versus halved fertilizer use with no pesticides.

A questionnaire survey was administered through face-to-face interviews in 8 villages. Using random cluster sampling, sample sizes for each village were determined based on the proportion of households. Each random cluster sample was controlled to 1/13 of the total sample. A total of 61 questionnaires were collected, with 61 valid questionnaires (100% of total). Surveyed households were predominantly male-headed, with middle-aged and elderly laborers as the main respondents—52.48% aged 41-60, 32.88% aged 61-80, and only 15.64% under 40. Annual household agricultural income was 77,794.5 yuan on average, with 86.7% of households earning 50,000 yuan or less. Off-farm work income accounted for over half of household income in 68.06% of cases. Details are shown in .

Descriptive statistics of the household survey

4. Research Methods

The fundamental approach of this paper is to derive the ecosystem service supply curve based on the opportunity cost of ecosystem service supply. From one perspective, we examine the relationship between compensation standards and farmers' willingness to provide ecological environmental benefits from the microeconomic decision-making viewpoint of individual farmers, and investigate the spatial distribution of opportunity costs for paddy ecosystem service supply. From another perspective, we examine farmers' macroeconomic behaviors.

4.1 Assumptions and Premises

We assume each paddy plot can adopt two production methods: conventional mono-cropping using chemical fertilizers and pesticides, and rice-fish cultivation using half fertilizer amount and no pesticides. The current production method has an initial ecosystem service supply. To increase ecosystem service supply, farmers must make decisions to reduce fertilizer and pesticide use for maximum economic benefit. When farmers receive no additional incentives, they will not adopt the new method. Financial incentives must be provided to convert farmers to the new method. For simplicity, we assume this conversion cost is zero.

If production method b generates e units of ecosystem service supply per hectare of paddy field annually, and farmers' paddy production decisions are based on maximizing expected returns, they will choose method b if its expected value $v(p,s,b)$ is higher than that of method a. Here, p represents product price, s represents different plots, and z represents land use methods.

4.2 Value of Newly Added Paddy Ecosystem Services

Ecosystem service value represents a quantitative monetary evaluation of ecosystem services. This study first used established physical and monetary valuation methods [25-26] to obtain physical quantity data through plot observations and sampling tests under the two production modes. Second, different ecological economics methods were applied to assess paddy ecosystem functions and their values.

Evaluation indicators were selected based on the actual conditions of Hani terraces and paddy ecological compensation needs, including: CO and O exchange processes between paddy ecosystems and the atmosphere; nutrient maintenance; pest and disease control through rice-fish farming; water regulation; tourism value; and negative impacts of water pollution (N, P).

The value of newly added ecosystem services per unit paddy area after switching from method a to b is calculated as:

$$e = ES = ESV_{Ib_j} - ESV_{Ia_j}$$

where ESV_{Ia_j} and ESV_{Ib_j} represent per-unit-area ecosystem service values provided under production methods a and b respectively, and j represents ecosystem service types.

4.3 Opportunity Cost of Paddy Ecosystem Service Supply

If the spatial distribution probability density function (/p) is known, and no other economic incentives exist, farmers will adopt production method b when compensation p_e is paid annually. Under an ecological compensation policy, p_e is defined as the price per unit of ecosystem service provided—farmers receive p_e for each additional unit of ecosystem service supplied.

When farmers adopt method b, per-unit-area expected returns become:

$$v(p, s, b) + e \cdot p_e$$

where $v(p, s, b)$ is direct revenue from method b, and $e \cdot p_e$ is compensation for ecosystem service provision [27].

The proportion of paddy fields adopting method b is r. The opportunity cost per unit ecosystem service for farmers is /e. At compensation price p_e, farmers will choose method b if /e < p_e. Based on the density function (/e), the proportion of land converting from method a to b is:

$$r(p_e) = \int_0^{p_e} \varphi(\omega/e)\, d(\omega/e)$$

4.4 Ecological Restoration Target-Oriented Paddy Ecological Compensation Standards

If total paddy area in the study region is H, total ecosystem services without compensation is $S_0 = r_0 \times H \times e$. With ecological compensation incentives, newly added ecosystem service supply is:

$$S(p_e) = r(p_e) \times H \times e$$

Total ecosystem service supply becomes:

$$S_{total}(p_e) = S_0 + S(p_e)$$

The process of deriving ecological compensation standards through the spatial distribution of ecosystem service supply opportunity costs is illustrated in [Figure 1: see original paper]. The left curve shows the opportunity cost spatial distribution, with the vertical axis representing farmers' opportunity cost per unit ecosystem service (/e) and the horizontal axis its density function (/e). The right curve shows the ecosystem service supply curve, a function of unit ecosystem service price, with the horizontal axis representing newly added ecosystem service supply *S*. The supply curve intersects the horizontal axis at the initial equilibrium point *S_0*. As compensation standards increase, the proportion of paddy fields under the new production method increases, with ecosystem service supply approaching the vertical asymptote at maximum ecological service quantity $H \cdot e$.

[Figure 1: see original paper] Methodology

5. Results

5.1 Value of Newly Added Paddy Ecosystem Services

Using different ecological economics methods to evaluate paddy ecosystem functions and values under the two production modes (conventional chemical use vs. halved fertilizer with no pesticides), we obtained per-unit-area ecosystem service values. The newly added ecosystem service value e per unit area is shown in .

The eco-service value of Hani Rice Terrace (yuan/hm² · a)

5.2 Opportunity Cost of Paddy Ecosystem Service Supply

Original data on rice-fish farming income differences were obtained through questionnaire surveys. Statistical software calculated the mean and standard deviation of annual income differences as 7,779.45 and 2,959.5 yuan/hm², respectively. For individual farmers, behavioral decisions are based on personal opportunity costs, which vary across individuals. Under large sample sizes, individual opportunity costs follow a normal distribution.

Using Matlab 7.6.0 for test analysis, the opportunity cost /e of paddy ecosystem service value follows a normal distribution with mean 0.40 and standard deviation 1.04. The opportunity cost density function was plotted to derive the paddy ecosystem service supply curve [Figure 2: see original paper].

[Figure 2: see original paper] Spatial distribution of opportunity cost of eco-services value

5.3 Ecological Restoration Target-Oriented Paddy Ecological Compensation Standards

Based on survey results of farmers' willingness to accept direct subsidies under the two scenarios (conventional chemical use vs. halved fertilizer with no pesticides), we constructed the relationship between compensation standards and farmers' willingness to convert production methods. Combining this with the newly added ecosystem service value *e* per unit area after conversion, we constructed the compensation standard and newly added ecosystem service supply curve [Figure 3: see original paper].

[Figure 3: see original paper] The supply curve of eco-services

Without ecological compensation, only 14.86% of paddy fields in the 8 surveyed villages used production method *b*, involving no newly added ecosystem services. To increase ecosystem service supply, ecological compensation is required. When the ecological function improvement target is set at newly added ecosystem services of 80.77×10 yuan/hm^2, the compensation standard should be 7,779.45 yuan/hm^2, with 35.74% of farmers willing to convert, requiring total compensation funds of 91.04×10 yuan. When the target is 219.49×10 yuan/hm^2, the compensation standard should be 9,000 yuan/hm^2, with 97.12% willing to convert, requiring 273.13×10 yuan .

The eco-service supply under different prices

6. Summary and Discussion

As understanding of ecological and environmental issues continues to develop, the ecological functions of paddy fields have received widespread attention. Providing farmers with economic incentives through ecological compensation to adopt environmentally friendly cultivation methods, thereby enabling paddy ecosystems to supply higher-level ecosystem services, represents an effective measure for solving paddy ecological and environmental problems [19]. Determining ecological compensation standards is a key issue in constructing ecological compensation mechanisms.

This study, taking Jiayin and Baohua townships in Honghe County, Yunnan Province as the research area, derived ecosystem service supply curves based on the opportunity cost of ecosystem service supply. From the microeconomic decision-making perspective of individual farmers, we explored the spatial distribution of opportunity costs for paddy ecosystem service supply. From the regional macroeconomic behavior perspective, we examined the relationship between compensation standards and farmers' willingness to provide ecological environmental benefits. Thus, targeting newly added paddy ecological environmental benefits, we combined farmers' willingness to accept with opportunity costs to realize dynamic compensation standard determination based on ecological restoration targets and added ecological benefits.

Our methodology couples natural and human processes in ecological compensation mechanism construction. However, due to research needs, we simplified the natural process of paddy ecosystem service supply by using standard plot measurements to represent regional average conditions, though actual ecosystem services exhibit spatial heterogeneity. Under China' s current socio-economic development context, ecological compensation funds are often limited. To maximize compensation efficiency, spatial selection of compensation objects that could provide higher ecosystem service values is necessary to determine the most effective compensation scope.

Ecological compensation, as an effective fiscal incentive mechanism, can prompt ecosystem service providers to change land use methods, altering their livelihood strategies and welfare conditions. However, providers are not purely rational economic agents in reality, and their subjective willingness to change land use is often influenced by age, education level, risk aversion, and other factors. When considering farmers' micro-level decision-making processes, we simplified by assuming rationality without accounting for these differences. These factors affecting compensation standards require further in-depth research.

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Note: Figure translations are in progress. See original paper for figures.