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The Base Value of the Ecological Compensation Standard in Transboundary River Basins: A Case Study of the Lancang–Mekong River Basin

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Abstract: The ecological compensation standard in transboundary river basins should be determined by the basin countries through negotiation on the basis of the base value of the ecological compensation standard. This paper calculated the base value range of the ecological compensation standard, determining the upper limit based on the spillover value of ecosystem services for the ecosystem-service-consuming country and the lower limit according to the cost of ecological protection for the ecosystem-service-supplying country. The final range was determined by integrating this with the willingness to pay and the actual effort in each basin country. Taking, for example, the Lancang–Mekong River basin, the results indicate that the spillover value of ecosystem services in Laos, China and Myanmar was positive and these three countries were ecosystem-service-supplying countries, while in Cambodia, Vietnam and Thailand it was negative and these three countries were ecosystem-service-consuming countries. Among the ecosystem-service-supplying countries, the cost of ecological protection of them was in descending order of Laos, China and Myanmar, which was related to their own level of economic development. Considering the adjustment coefficient for the payment of ecosystem service value and the cost-sharing coefficient of each basin country, the feasible range for the base value of the ecological compensation standard was determined to be $[2.47, 229.67] \times 10^8$ \$, which provided the basis for the negotiation on the determination of the ECS. In addition, implementation suggestions were proposed from three aspects: establishing a basin-information-sharing mechanism and platform, establishing an integrated management organization for transboundary river basins, and strengthening and improving the coordination and supervision model of ecological compensation.

Keywords: transboundary river basins; base value; ecological compensation standard; spillover value; cost; Lancang–Mekong River Basin

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Citation: Zhao, Y.; Li, F.; Chen, Y.; Chen, X.; Xu, X. The Base Value of the Ecological Compensation Standard in Transboundary River Basins: A Case Study of the Lancang–Mekong River Basin. *Water* **2023**, *15*, 2809. https://doi.org/10.3390/w15152809

Academic Editors: Peiyue Li and Jianhua Wu

Received: 5 June 2023
Revised: 27 July 2023
Accepted: 1 August 2023
Published: 3 August 2023

1. Introduction

Globally, there are 310 transboundary river basins (TBRBs) covering 150 countries and regions, and the basins cover 47.1% of the global land area, with about 52% of the global population living in TBRBs [1]. As the global shortage of freshwater resources intensifies and the population grows rapidly, the utilization and demand for water resources in TBRBs by basin countries (BCs) are increasing, leading to increasingly serious water resource problems such as water shortage [2], water environment pollution [3], and water ecology damage [4], and, thus, resulting in increasingly prominent conflicts among BCs. In the era of global integration, countries in the world are increasingly connected and dependent. It has gradually become a rational choice for BCs to solve contradictions and conflicts through cooperation. In TBRBs, due to the involvement of numerous BCs, each of which is an independent sovereign state, it is not possible to handle basin-related matters through mandatory means. Therefore, resolving the issues of ecological environment protection and benefit allocation in transboundary river basins through negotiation has become an effective means [5]. For example, the United States and Canada conducted full negotiations on the distribution of interests in the Columbia River, and finally signed an agreement in 1976 to clarify the rights and obligations of both parties, which became a successful case in the world to reasonably solve the distribution of interests in transboundary water resources [6]. Moreover, in the treatment of the allocation for the water resource in the Colorado River basin, the negotiation of various stakeholders played a key role in improving the water resource allocation model and resolving conflicts [7]. In addition, due to the mobility of water resources, TBRBs show a strong characteristic of basin integrity and form a water community with a shared future. This characteristic determines that each BC should prioritize the overall interests and promote sustainable development when dealing with ecological environmental protection issues in the basin.

Ecological compensation, as a means of environmental economic management, can effectively coordinate the relationship between resource exploitation and ecological environmental protection [8]. It can also effectively adjust the unequal distribution of benefits caused by resource exploitation and utilization, and alleviate the conflicts among BCs. It is an important means to propel the sustainable development of TBRBs forward. In the process of TBRB development, some BCs have ceded part of their own benefits in order to make the overall benefits of the TBRB maximum, and some BCs have enjoyed the overall benefits too much. In order to achieve sustainable development of TBRBs, beneficiary countries need to compensate the countries that transfer interests, thereby reducing conflicts and contradictions caused by uneven distribution of basin interests. For example, in the Elbe River basin, Germany compensated 9 million marks to the Czech Republic in 2000 for the construction of urban sewage treatment plants at the border of the Czech Republic and Germany to ensure the health and the stability of the water environment [9]; in the Lesotho highlands of Orange River, the upstream country, Lesotho, built dam facilities, and South Africa bore most of its construction costs to ensure that it could obtain water from upstream of Lesotho [10]; during the construction process of the Gabčíkovo-Nagymaros hydroelectric station in the Danube River, Hungary, undertook a portion of the engineering construction on the territory of Czechoslovakia to ensure equal sharing of costs and equal distribution of power-generation benefits [11]. These compensation measures have reduced the occurrence of conflicts and contradictions between different basin countries.

When carrying out ecological compensation activities, it is crucial to determine the ecological compensation standard (ECS) [8], which affects whether compensation activities can be effectively carried out. The quantity and magnitude of the ECS are influenced by factors such as the loss or gain of stakeholders, the international situation, national policy and so on. Because of the differences in the perspectives and main factors involved in different scholars' research, although there has been more research on the ECS, a unified standard or calculation method has not yet been formed. At present, scholars mostly determine the ECS from the perspective of investment and income [12]. The methods based on the investment perspective mainly include the cost of ecological protection (CEP) method [13,14], while the methods based on the income perspective mainly include the ecosystem service value (ESV) method [15,16] and the willingness to pay method [17,18]. The CEP method mainly includes the method of the direct cost and the opportunity cost [19]. When using the CEP method for calculation, the key lies in the selection of calculation indicators; that is, the coverage of the CEP. When using the ESV method, due to the large amount of the ESV and its tendency to be overestimated, there may be a significant deviation between the conclusions obtained and the actual situation [20]. When using this, scientific measurement can be made by deducting the consumption of ecosystem service value (CESV) by oneself. The willingness to pay method ensures the acceptance and recognition of compensation by relevant stakeholders through considering willingness to pay in the calculation of the ESV. However, during the investigation process, information asymmetry may occur, which may not match the actual willingness to pay [21]. Therefore, more objective methods need to be used to measure this.

In summary, scholars have generally recognized the importance of determining the ECS in TBRBs. Although the research methods are different, scholars are in agreement in the pursuit of fairness and rationality in the formulation of the ECS. However, currently, the determination of the ECS, both domestically and internationally, is based on one or several methods, with the author choosing the appropriate results or finding the mean or median as the ECS, lacking universality. In TBRBs, due to the involvement of numerous BCs, determining an ECS that can be accepted by all BCs should not be done solely through one method. In addition, each BC should be given sufficient negotiation autonomy to comprehensively determine the ECS in TBRBs, thereby improving the acceptability and feasibility of the ECS. In view of the role of various stakeholders in the ecological environment of TBRBs, the BC is taken as the basic research unit and can be subdivided into an ecosystem-service-supplying country (ESSC) and an ecosystem-service-consuming country (ESCC). During the negotiation, the ESSCs and the ESCCs are taken as two together, to conduct one-on-one negotiation, and the negotiation space of both sides should be determined first. The base value of the ECS in TBRBs is the theoretical value of the ECS formulated objectively and reasonably considering the input cost of the ESSC and the benefit degree of the ESCC, which can provide the basis for the negotiation among the BCs.

Therefore, in order to promote the healthy and stable development of TBRBs, reduce interest disputes, and provide a theoretical basis for negotiation among various BCs; this paper attempted to design a feasible range of the base value of the ECS in TBRBs. Taking the BC as the research subject, the BC was divided into two main bodies: the ESCC and the ESSC. From the perspective of ecological beneficiaries, the upper limit of the base value of the ECS was determined on the basis of the spillover value of ecosystem services (SVES) of the ESCC. From the perspective of ecological protectors, the lower limit of the base value of the ECS was determined according to the CEP of the ESSC. The feasible range for the base value of the ECS in TBRBs was determined based on the actual water consumption and the willingness to pay of each BC. The general idea of this paper is shown in Figure 1.

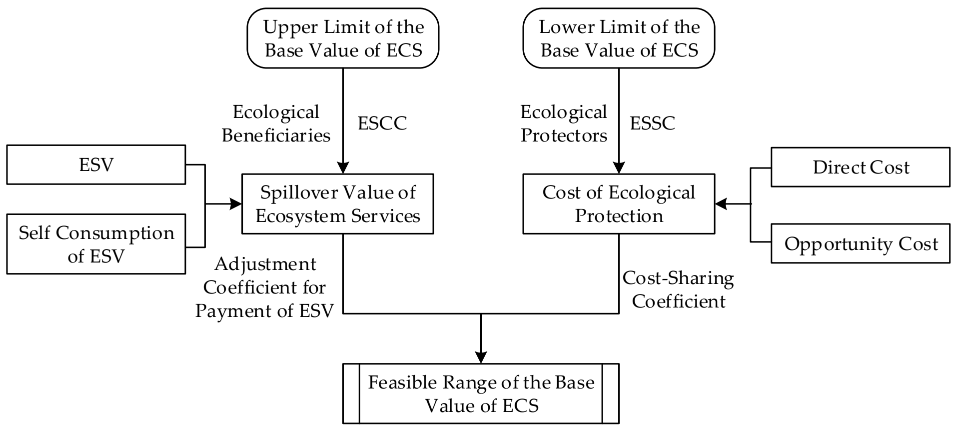

Figure 1. General idea of this paper.

2. Study Area and Data Resource

2.1. Study Area

The Lancang–Mekong River is the only transboundary river in Asia that connects six countries with one river. It originates in Qinghai, China and enters Vietnam through Myanmar, Laos, Thailand, and Cambodia [22]. The Lancang–Mekong River basin (LMRB) runs through the entire of southeast Asia and is linked to the economic and social development of various countries. The LMRB is rich in ecological resources, which are exploited and utilized by each BC based on its own development needs. However, due to the difference in economic development level, the exploitation and utilization degree and efficiency of basin resources are also different. In the process of resource utilization, the BCs have caused different degrees of impact on the basin's ecological environment. In addition, the differences in the willingness and ability of the basin's ecological protection result in the unbalanced relationship between the ecological environment and economic interests among the BCs. At present, although some transboundary cooperation has been carried out among Lancang–Mekong countries, interest conflicts in resource utilization and ecological protection occur from time-to-time. These conflicts pose a certain threat and challenge to the water security and long-term development of the LMRB. Therefore, ecological compensation can be used to solve this problem in the LMRB. The research area is shown in Figure 2 [23].

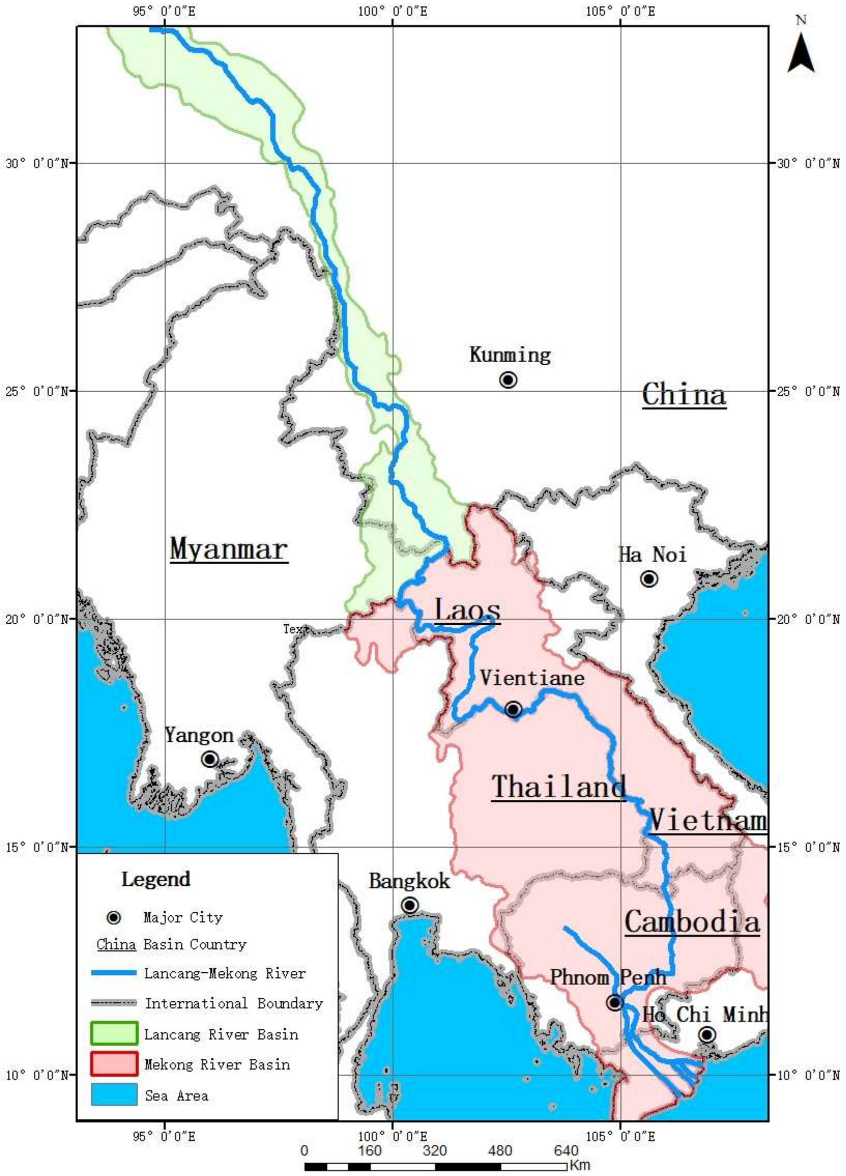

Figure 2. Geographical distribution of LMRB.

2.2. Data Resource

The basic data involved in the determination of the base value of the ECS in the LMRB are mainly used to calculate the SVES and CEP of BCs. Considering the time development and data availability, this paper took 2019 as the research benchmark year. When confirming different land use types and areas of the BCs in the LMRB, the classification standards made by the Food and Agriculture Organization of the United Nations (FAO) and the Mekong

River Commission are adopted [24]. In this paper, land use in the LMRB was divided into seven types: farmland, grassland, forestland, water area, wetland, construction land and unused land. The land use data were sourced from the National Qinghai Tibet Plateau Scientific Data Center with a resolution of 10 m [25], and various land use areas were obtained through visual interpretation by ArcGIS. Specific data are shown in Table 1.

Table 1. Area of different land use types in LMRB. Unit: 10^4 km^2.

Category	Farmland	Grassland	Forestland	Water Area	Wetland	Construction Land	Unused Land
China	0.56	8.77	6.82	0.09	0.01	0.08	0.14
Myanmar	0.12	0.75	1.30	0.01	0.00	0.01	0.00
Laos	2.60	6.59	11.28	0.25	0.02	0.08	0.00
Thailand	11.32	3.36	3.44	0.27	0.08	0.52	0.00
Cambodia	6.89	1.35	6.45	0.77	0.75	0.11	0.00
Vietnam	2.01	1.07	2.01	0.07	0.00	0.08	0.00

The equivalent factor of the ESV was modified based on the Xie Gaudi Edition [26] and according to the actual land use situation in the LMRB. Among them, in the farmland ecosystem, the LMRB is mainly planted with rice, which has high value in food production and soil and water conservation [27]; in the forestland ecosystem, the LMRB mainly grows tropical rainforest with various values such as climate regulation and soil erosion prevention [28], and its NPP is relatively high [29,30]; in the construction land ecosystem, some construction land contains public green spaces, which have certain ESV such as environmental greening and soil conservation [31–33]. Taking the practical characteristics of the LMRB into account, the equivalent factor values for ecosystems of grassland, water area and unused land were determined on the basis of secondary classification of shrubland [34], water system, and bare land [31]. In addition, the precipitation in the LMRB is relatively abundant [35], and corresponding adjustments were made according to the adjustment rules of precipitation spatiotemporal adjustment factors [26,31]. The equivalent value per unit area in the LMRB determined in this paper is shown in Table 2.

Table 2. Ecosystem service equivalent value per unit area in LMRB.

Classification	Supply Service			Regulating Service				Support Service			Cultural Service
	FP	MP	WS	GR	CR	DE	HR	SC	NCM	BD	AL
Farmland	1.36	0.09	−0.88	1.11	0.57	0.17	8.16	1.30	0.19	0.21	0.09
Grassland	0.38	0.56	0.93	1.97	5.21	1.72	11.46	2.40	0.18	2.18	0.96
Forestland	0.42	0.96	1.48	3.15	9.43	2.80	20.62	3.84	0.29	3.49	1.54
Water Area	0.80	0.23	24.87	0.77	2.29	5.55	306.72	0.93	0.07	2.55	1.89
Wetland	0.51	0.50	7.77	1.90	3.60	3.60	72.69	2.31	0.18	7.87	4.73
Construction Land	0.01	0.03	0.41	0.75	2.01	0.97	5.08	0.92	0.07	0.89	0.69
Unused Land	0	0	0	0.02	0	0.10	0.09	0.02	0	0.02	0.01

Notes: FP: Food Production; MP: Material Production; WS: Water Supply; GR: Gas Regulation; CR: Climate Regulation; DE: Decontamination Environment; HR: Hydrologic Regulation; SC: Soil Conservation; NCM: Nutrients Cycle Maintenance; BD: Biological Diversity; AL: Aesthetics Landscape.

The output, price, planting area and agricultural output value of major food crops were from the FAO database [36]. The population, water resources and socio-economic data of the basin were from the Transboundary Waters Assessment Programme (TWAP) database [37], Transboundary Freshwater Dispute Database (TFDD) [38], Mekong River Commission [39], World Bank database [40] and the existing literature [32,41,42]. Among them, when calculating the direct cost of ecological protection, China uses data from the Yunnan Province (including Baoshan, Pu'er, Lincang, Xishuangbanna, Dali, Nujiang, and Diqing), sourced from the Yunnan Provincial Statistical Yearbook [43].

3. Materials and Methods

3.1. Upper Limit of the Base Value—SVES

3.1.1. Determination Ideas of the SVES

From the perspective of ecological beneficiaries, this paper determines the upper limit of the base value of the ECS according to the SVES of ESCCs. In this paper, the SVES is the surplus value, which is the remaining part after subtracting the ecological value used by residents for production and life based on the ESV of the basin. Therefore, the measurement of the SVES should contain two sections: the first is the measurement of the ESV, and the second is the measurement of the CESV by the BCs themselves. In the process of calculation, it is scientific and reasonable to use the SVES as the upper limit, taking into account the elimination of self-consumption based on the ESV. In the application of methods, it is comparable to obtain the SVES on the basis of the equivalent factor method, combining with the ecological footprint and ecological carrying capacity.

Based on the above analysis, a calculation model of the SVES in TBRBs is obtained, and it serves as the determination basis of the upper limit of the base value of the ECS in TBRBs. The specific calculation is shown in Equation (1).

$$\mathrm{SE_i} = \mathrm{FE_i} - \mathrm{CE_I} \tag{1}$$

where i = 1, 2, . . . , n is the BC; $\mathrm{SE_i}$ is the SVES in $\mathrm{BC_i}$($); $\mathrm{FE_i}$ is the ESV in $\mathrm{BC_i}$($); $\mathrm{CE_i}$ is the CESV in $\mathrm{BC_i}$($). When $\mathrm{SE_i} > 0$, it indicates that the CESV of $\mathrm{BC_i}$ is less than the ESV it owns, and its ESV status belongs to a surplus state. $\mathrm{BC_i}$ is the ESSC. When $\mathrm{SE_i} = 0$, it indicates that the CESV of $\mathrm{BC_i}$ is equal to the ESV it owns, and its ESV status is in an equilibrium state. $\mathrm{BC_i}$ is neither an ESSC nor an ESCC. When $\mathrm{SE_i} < 0$, it indicates that the CESV of $\mathrm{BC_i}$ is greater than the ESV it owns, and its ESV status belongs to a deficit state. $\mathrm{BC_i}$ is the ESCC.

3.1.2. Determination of ESV

This paper calculates the total ESV of each BC using the equivalent factor method. When calculating, the main consideration is the land use area of various ecosystems, equivalent factor of various ecosystem service functions, and economic value corresponding to each equivalent factor. The specific calculation is shown in Equation (2).

$$\mathrm{FE_i} = \sum_{j=1}^{a}\sum_{p=1}^{b} \alpha_{jp}\cdot\beta_i\cdot \mathrm{A_i} \tag{2}$$

where j, $j = 1, 2, \cdots, a$ is different ecosystem types; p, $p = 1, 2, \cdots, b$ is different ecosystem service functions; α_{jp} is the equivalent factor value corresponding to the p-th ecosystem service function in the j-th ecosystem; β_i is the economic value ($/$\mathrm{hm^2}$) corresponding to the equivalent factor of BC i; $\mathrm{A_i}$ is the land use area ($\mathrm{hm^2}$) of various ecosystems in BC i; the other symbols are the same as above.

(1) Determination of equivalent factor value (α_{jp})

The determination of equivalent factor value α_{jp} is mainly based on the basic equivalent table revised by Xie Gaodi et al., in 2015 [26], and actual modifications are made based on the specific situation of the research basin. When making corrections, adjustments can be made based on net primary productivity (NPP), differences in precipitation, etc. [26].

(2) Determination of economic value corresponding to equivalent factors (β_i)

The economic value corresponding to each equivalent factor is the economic value generated by the national average grain production per hectare of farmland under natural conditions. In farmland ecosystems, food value is produced by natural factors and human factors, so it is difficult to accurately measure the specific amount of food value under the action of natural factors. Therefore, according to relevant research [44–46], the economic value corresponding to each equivalent factor is determined as 1/7 of the national average grain yield market value for that year. The economic value of grain crops is mainly determined by calculating the economic value generated by rice, wheat and corn, as shown in Equation (3).

$$\beta_i = \frac{1}{7}\sum_{m=1}^{3}\frac{Q_{im}\cdot P_{im}}{S_{im}} \tag{3}$$

where m, $m = 1, 2, 3$ represents rice, wheat and corn, respectively, in the farmland ecosystem; Q_{im} is the annual average yield (kt) of grain crop m in the farmland ecosystem of BC i; P_{im} is the average annual price (\$/kt) of grain crop m in the farmland ecosystem of BC i; S_{im} is the average annual planting area (hm^2) of grain crop m in the farmland ecosystem of BC i; the other symbols are the same as above.

3.1.3. Determination of CESV

This paper calculates the CESV according to the ecological consumption coefficient, which is the ratio of ecological consumption and ecological supply of each BC. After the ecological consumption coefficient is defined, the CESV can be obtained in consideration of the ESV. The specific calculation is shown in Equation (4).

$$CE_i = FE_i\cdot\theta_i \tag{4}$$

where θ_i is the ecological consumption coefficient of BC i; the other symbols are the same as above.

The specific calculation of θ_i is shown in Equation (5).

$$\theta_i = \frac{EC_i}{ES_i} \tag{5}$$

where EC_i is the ecological consumption of $BC_i(hm^2)$; ES_i is the ecological supply of BC_i (hm^2); the other symbols are the same as above.

(1) Determination of ecological consumption of each BC (EC_i)

The ecological consumption of each BC can be determined through the ecological footprint, which refers to the biological productive land area needed for the conversion of waste generated by product production and consumption during the development process [47]. It usually includes six types: farmland, grassland, forestland, waters, construction land and fossil energy land. The specific calculation of the ecological footprint is shown in Equations (6) and (7).

$$EC_i = N_i\cdot ec_i \tag{6}$$

$$ec_i = \sum_{k=1}^{6}\sum_{s=1}^{n} r_k\cdot\frac{C_{iks}}{GP_{ks}} \tag{7}$$

where N_i is the population of BC i; ec_i is the ecological footprint per capita of BC_i (hm^2/person); k, $k = 1, 2, 3, 4, 5, 6$ represents six land types: farmland, grassland, forestland, waters, construction land and fossil energy land; r_k is the equilibrium factor of various types of land; s, $s = 1, 2, \ldots, n$ represents the goods produced by various types of land; C_{iks} is the per capita output of the s-th commodity produced on the k-th land in the BC_i (kg/person); GP_{ks} is the global average production of commodity s produced by the k type of land (kg/hm^2); the other symbols are the same as above.

(2) Determination of ecological supply of each BC (ES_i)

The ecological supply of each BC can be determined by ecological carrying capacity, which refers to the total bioproductive area provided by a region [48]. It usually includes six land types: farmland, grassland, forestland, waters, construction land and fossil energy land. Generally speaking, when measuring ecological carrying capacity, 12% of the area needs to be subtracted for biodiversity conservation, in order to maintain regional sustainable development [16]. The specific calculation of ecological carrying capacity is shown in Equation (8).

$$ES_i = 1 - 12\% \sum_{k=1}^{6} A_{ik} \cdot r_k \cdot x_k \tag{8}$$

where A_{ik} is the utilization area (hm^2) of the k-th type of land in BC_i; x_k is the yield factor of each type of land; the other symbols are the same as above.

3.2. Lower Limit of the Base Value—CEP

3.2.1. Determination Ideas of CEP

From the perspective of ecological protector, the lower limit of the base value of the ECS is determined according to the CEP of ESSCs. The CEP in this paper refers to the total investment of each BC in the governance and protection of the ecological environment within the TBRB, as well as the loss caused by the development opportunity given up, including direct cost and opportunity cost [49]. The positive SVES exists in ESSCs, which has a positive effect on other regions, indicating that the ESSCs have paid a lot of funds and efforts to manage and maintain the ecological environment of the basin, and made certain sacrifices in their own economic development. Due to the systematic and holistic nature of TBRBs, ESCCs have excessively enjoyed the benefits of basins, posing a certain degree of threat and damage to the rights that ESSCs should have. According to the principles of fair and reasonable utilization as well as equal rights and responsibilities, from the perspective of sustainable development, it is reasonable for ESCCs, as beneficiaries, to compensate ESSCs to a certain extent for their efforts.

Therefore, the calculation of the CEP in a TBRB should contain two sections: the first is the calculation of direct cost of the CEP, and the second is the calculation of opportunity cost of the CEP. In the process of calculation, it should be fully combined with the characteristics of the basin and the collection of relevant data, so as to sort out and calculate the CEP invested by the ESSCs.

Based on the above analysis, a calculation model of the CEP in a TBRB is obtained, and it serves as the determination basis of the lower limit of the base value of the ECS in the TBRB. The specific calculation is shown in Equation (9).

$$PC_i = DPC_i + OPC_i \tag{9}$$

where i, $i = 1, 2, \cdots, n$ is the ESSCs; PC_i is the CEP of ESSCs ($); DPC_i is the direct cost for ecological protection of ESSCs ($); OPC_i is the opportunity cost for ecological protection of ESSCs ($).

3.2.2. Determination of Direct Cost for Ecological Protection in ESSCs

(1) Accounting Scope

The direct cost is the direct display of the funds invested by ESSCs in basin ecological environment protection work. Due to the differences in the actual situation of development and protection work in different basins, and the high demand for related data to determine the direct cost, there is no fixed standard for the accounting scope of direct cost. However, in general, for the sake of protecting the ecological environment of the basin and providing sustainable ESV, it is necessary for ESSCs to implement corresponding protection measures according to various land use types, including the construction of related protection projects and the management of related environmental problems. Thus, when assessing the accounting scope of direct cost for ecological protection in ESSCs, in this paper, it is divided into four categories: forestry and grassland construction cost (C_{Li}), water environment management and protection cost (C_{Wi}), wetland protection cost (C_{Si}) and biodiversity protection cost (C_{Di}). The accounting scope of direct cost for ecological protection in ESSCs is shown in Table 3.

Table 3. Accounting scope of direct cost for ecological protection in ESSCs.

Direct Cost	Index	Index Interpretation
Forestry and grassland construction cost (C_{Li})	Cost of forest protection	Investment in reducing deforestation, artificial afforestation, closed mountain afforestation etc.
	Cost of returning farmland to forest or grassland	Investment in returning sloping farmland to forests and grasslands, afforestation in barren mountains and wasteland etc.
	Cost of natural ecological protection	Investment in the construction and management of ecological function protection zones, ecological restoration, resource development supervision etc.
	Construction and management costs of nature reserves	Investment in infrastructure construction, daily maintenance, management operations etc.
Water environment management and protection cost (C_{Wi})	Cost of water conservancy project construction	Investment in the water facilities construction, operation and maintenance of water engineering etc.
	Cost of water pollution control	Investment in point and non-point source pollution etc.
	Cost of water quality monitoring	Investment in the construction and operation management of water quality monitoring stations, scientific research etc.
	Cost of saving water	Investment in water-saving projects, renovation and upgrading of water-saving facilities, innovation of technologies etc.
	Cost of soil and water conservation	Investment in regional comprehensive governance, related engineering construction etc.
Wetland protection cost (C_{Si})	Wetland protection cost	Investment in the construction of wetland protection areas, returning farmland to wetlands, restoring degraded wetlands etc.
Biodiversity protection cost (C_{Di})	Cost of plant and animal protection	Investment in the renovation and restoration of animal and plant habitats, as well as pilot projects in national parks

(2) Accounting Method

On the basis of the above analysis, the specific calculation of the direct cost for ecological protection in ESSCs is shown in Equation (10).

$$DPC_i = C_{Li} + C_{Wi} + C_{Si} + C_{Di} \tag{10}$$

where C_{Li} is the forestry and grassland construction cost of $ESSC_i$; C_{Wi} is the water environment management and protection cost of $ESSC_i$; C_{Si} is the wetland protection cost of $ESSC_i$; C_{Di} is the biodiversity protection cost of $ESSC_i$; the other symbols are the same as above.

3.2.3. Determination of Opportunity Cost for Ecological Protection in ESSCs

The opportunity cost is an indirect reflection of the development value sacrificed by ESSCs in ecological environment protection work in TBRBs. In order to maintain the overall healthy and long-term development of the basin environment, ESSCs have to restrict the exploitation and utilization of some natural resources; thus, losing the benefits obtained from utilizing these resources. When measuring the opportunity cost, it is difficult to obtain sufficient and accurate actual data as there is no unified measurement standard and method, and the TBRB situation is quite complex. As a consequence, this paper adopts the empirical comparison method to measure it [50]; that is, the difference between the economic development level of the ESSC and the neighboring region. The development opportunity cost lost by the ESSC due to ecological protection is calculated in detail as shown in Equations (11) and (12).

$$OPC_i = (G_s - G_i) \cdot N_i \cdot \sigma_i \tag{11}$$

$$\sigma_i = \frac{R_{Ai}}{R_{Ti}} \times 100\% \tag{12}$$

where G_s is the per capita disposable income ($/person) in the vicinity of $ESSC_i$; G_i is the per capita disposable income ($/person) in $ESSC_i$;·σ_i is the regulatory factor, that is, the proportion of the total agricultural product of the basin in the total basin product of $ESSC_i$; R_{Ai} is the total agricultural product of the basin in $ESSC_i$ ($); R_{Ti} is the total basin product of $ESSC_i$ ($); the other symbols are the same as above.

3.3. Determination of the Range for the Base Value of the ECS in TBRBs

On the basis of the analysis of Sections 3.1 and 3.2, this paper takes the SVES of ESCCs as the upper limit, and the CEP of ESSCs as the lower limit; thus, forming the selection range for the base value of the ECS in the TBRB. On this basis, it provides a basis for negotiation on the final value of the ECS between the ESSC and ESCC in the TBRB. Since the ESSCs and ESCCs are taken as two together to conduct one-to-one negotiation in this paper, the final range of the base value is shown in Equation (13).

$$\gamma \cdot \sum_{i=1}^{n} PC_i \leq S_0 \leq \sum_{i=1}^{n} l_i \cdot |SE_i| \tag{13}$$

where γ is the cost-sharing coefficient; S_0 is the base value of the ECS in the TBRB ($); l_i is the adjustment coefficient for payment of ESV for the BC i; the other symbols are the same as above.

The cost-sharing coefficient (γ) is mainly determined according to the utilization of water resources in the TBRB by ESSCs and ESCCs; that is, the CEP should be shared according to the proportion of the water consumption in ESCCs to the entire basin. The specific calculation of γ is shown in Equation (14).

$$\gamma = \frac{\sum_{i=1}^{n} W_{ci}}{\sum_{i=1}^{n} W_i} \tag{14}$$

where W_{ci} is the total water use (m^3) of basin water resources for the $ESCC_i$, including agricultural, industrial and domestic water use; W_i is the total water use (m^3) of basin water resources for the BC_i; the other symbols are the same as above.

The adjustment coefficient for payment of the ESV (l_i) is mainly determined according to the economic development level of each BC. Li Jinchang et al. proposed a method to get the value of willingness to pay on the basis of combining of the S-shaped Pearl growth curve model and the Engel coefficient [51], and applied it with significant results. Since then, many scholars have continuously used this model to get the adjustment coefficient for payment of the ESV [52], and its specific calculation is shown in Equation (15).

$$l_i = \frac{1}{1 + e^{-t_i}},\ t_i = \frac{1}{E_i^k} - 3 \tag{15}$$

where the image of l_i is called the Pearl Growth Curve, the range of which is from 0 to 1; E_i^k is the Engel coefficient for the year k of each BC; the other symbols are the same as above.

4. Results and Discussion

4.1. SVES of BCs in the LMRB

4.1.1. ESV of BCs in the LMRB

According to Equations (2) and (3), on the basis of clarifying the area of different land use types and the equivalent factor value in each BC, the ESV of each BC can be obtained by combining the economic value of main food crops. The specific calculation results are shown in Table 4.

Table 4. ESV of BCs in LMRB. Unit: 10^8 \$.

Category	Farmland	Grassland	Forestland	Water Area	Wetland	Construction Land	Unused Land	Total
China	6.30	221.59	296.17	28.94	0.93	0.91	0.03	554.87
Myanmar	1.32	18.53	55.02	1.83	0.00 *	0.09	0.00	76.79
Laos	37.03	211.84	622.67	97.76	2.18	1.13	0.00	972.61
Thailand	115.08	77.27	135.77	75.90	7.11	5.05	0.00	416.18
Cambodia	144.05	63.89	523.12	451.80	134.83	2.19	0.00	1319.88
Vietnam	42.66	51.27	165.79	40.56	0.26	1.66	0.00	302.20
Total	346.44	644.39	1798.54	696.79	145.31	11.03	0.03	3642.53

Note: The actual value of 0.00 * is 0.00257359.

The Table 4 indicated that the overall ESV in the LMRB was 3642.53 × 10^8 \$. From the perspective of BCs, Cambodia had the highest ESV, which was 1319.88 × 10^8 \$, accounting for 36.23% of the total basin. It was followed by Laos, China, Thailand, Vietnam and Myanmar, which accounted for 26.70%, 15.23%, 11.43%, 8.30% and 2.11%, respectively. The ESV in Myanmar was the lowest in the basin: only 76.79 × 10^8 \$. In terms of land use type, the ESV of forestland was the highest in the entire ESV of each BC, among which Myanmar and Laos accounted for 71.65% and 64.02%. The proportion of construction land and unused land was the lowest. Except China, there was no unused land in the other five countries. The proportion of ESV of different land use types in the LMRB is shown in Figure 3.

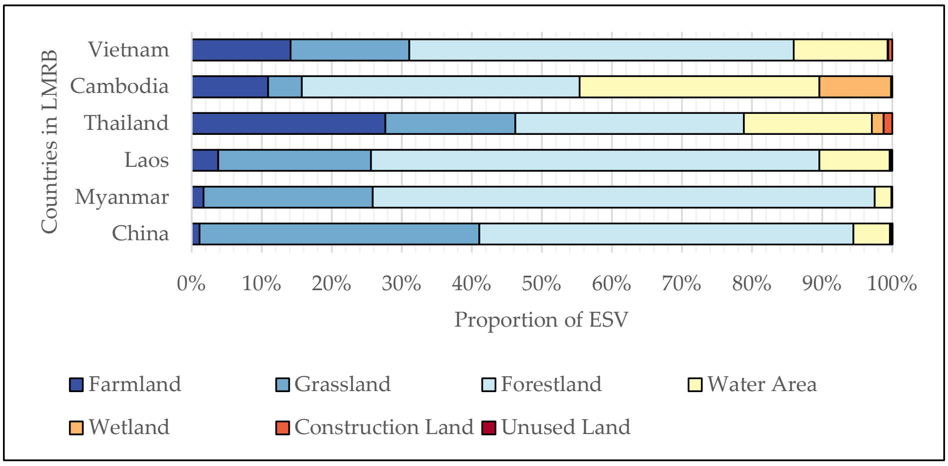

Figure 3. The proportion of ESV of different land use types in LMRB.

4.1.2. CESV of BCs in the LMRB

According to Equations (5)–(8), the ecological consumption coefficient of each BC can be obtained by combining the equilibrium factor and yield factor of various land types, based on clarifying the population of each BC, the area of different land use types, and the main production commodity yield of each land type. Among them, the equilibrium factors for farmland, grassland, forestland, water area, construction land and land for energy and fuel are 2.10, 0.47, 1.33, 0.36, 2.18 and 1.35, respectively [32]. The yield factors are 1.65, 0.20, 0.91, 0.99, 1.65 and 0, respectively [32]. The specific calculation results are as shown in Table 5.

According to Table 5, the ecological consumption coefficient of China, Myanmar and Laos was less than 1, and that of Thailand, Cambodia and Vietnam was greater than 1, indicating that the ecological supply of China, Myanmar and Laos exceeded the ecological consumption, while the ecological consumption of Thailand, Cambodia and Vietnam exceeded the ecological supply. The ecological consumption coefficient of Thailand reached 1.6, which was higher than that of Cambodia and Vietnam. In terms of geographical location, China, Myanmar and Laos lie in the upstream and middle stream of the LMRB, while

Thailand, Cambodia and Vietnam lie in the downstream. The ecological consumption level in the downstream was significantly higher than that in the upstream and middle stream.

Table 5. Ecological consumption coefficient of BCs in LMRB.

Category	Ecological Footprint (10^4 hm^2)	Ecological Carrying Capacity (10^4 hm^2)	Ecological Consumption Coefficient
China	1328.70	1641.66	0.81
Myanmar	115.13	184.41	0.62
Laos	1425.80	2083.29	0.68
Thailand	6430.64	4017.26	1.60
Cambodia	2172.48	2022.20	1.07
Vietnam	1148.37	864.20	1.33

From the perspective of ecological footprint, Thailand was the highest, which was 6430.64×10^4 hm^2, accounting for about 50.95% of the whole basin, and the rest were Cambodia, Laos, China, Vietnam and Myanmar, in turn. From the perspective of ecological carrying capacity, Thailand still was the highest, which was 4017.26×10^4 hm^2, accounting for 37.15% of the whole basin, and the rest were Laos, Cambodia, China, Vietnam and Myanmar, in turn. From a geographical location point of view, both aspects generally showed a trend of gradual growth from the up-reaches to the low-reaches of the basin, which was closely affected by the geographical distribution, basin area, economic conditions, natural resource endowment conditions and other factors of the BCs.

According to Equation (4), combined with the ESV shown in Table 4 and the ecological consumption coefficient shown in Table 5, the CESV of each BC can be obtained. Specifically, the CESV of China, Myanmar, Laos, Thailand, Cambodia and Vietnam was 449.09×10^8 \$, 47.94×10^8 \$, 665.65×10^8 \$, 666.20×10^8 \$, 1417.96×10^8 \$ and 401.57×10^8 \$, respectively.

4.1.3. SVES of BCs in the LMRB

According to Equation (1), the SVES of each BC in the LMRB can be obtained by combining the ESV of each BC and its own CESV. Specifically, the SVES in China, Myanmar, Laos, Thailand, Cambodia and Vietnam was 105.78×10^8 \$, 28.85×10^8 \$, 306.96×10^8 \$, -250.02×10^8 \$, -98.08×10^8 \$ and -99.37×10^8 \$, respectively.

The results indicated that the SVES in China, Myanmar and Laos was positive, resulting in positive ecological spillover, indicating that these three countries could offer ESV to other BCs after deducting their own CESV. They were ESSCs and should receive compensation. The SVES in Thailand, Cambodia and Vietnam was negative, showing that they had excessively consumed the ESV and destroyed the balance of nature of the river basin in the process of development. They were ESCCs and should compensate.

In real life, Thailand, Cambodia and Vietnam lie in the middle and lower reaches and have relatively high levels of utilization of basin resources, consuming a large amount of water and ecological resources in their respective development processes. This also explains why these three countries are ESCCs. Thailand mainly diverts the Mekong River for agricultural irrigation and daily life. The area of Thailand in the LMRB accounts for nearly 1/4 of the entire basin. It has formulated multiple Mekong River diversion plans, introducing massive water resources into the country for self-use, which has seriously affected downstream water use [42]. Cambodia is a typical agricultural country, with more than 85% of its land area located in the LMRB. Meanwhile, 60% of the water supply of Tonlé Sap in Cambodia comes from the Mekong River. Its economic development has a high demand for river water resources [41]. The lower Mekong Delta is home to high-quality rice from around the world, with Cambodia accounting for about 1/5 of the area and the remaining area belonging to Vietnam. Here, 90% of Vietnam's exported rice grows. Therefore, it needs a large amount of irrigation and ecological water [53]. China and Laos, which lay in the upstream, have put much energy and resources into basin ecological environment protection and water conservancy engineering construction, which can reduce the losses caused by special water conditions in downstream countries during drought periods and floods. For instance, in 2016, China implemented emergency water replenishment for the downstream of the Mekong River through sluice opening, which effectively relieved the drought in Vietnam [54]. Laos has built dams upstream to alleviate water scarcity and flood disasters in downstream countries during dry periods [32]. As a result, in the light of the principle of beneficiary compensates, it is fair for the ESCCs to compensate the ESSCs.

4.2. CEP of BCs in the LMRB

According to the analysis in Section 4.1.3, China, Myanmar and Laos were the ESSCs. Therefore, the CEPs of these three countries need to be calculated to determine the lower limit of the base value of ESV in LMRB. According to Equations (9)–(12), combined with the direct and opportunity cost in China (Yunnan Province), Myanmar and Laos, the CEP of ESSCs in LMRB can be obtained. The specific results are shown in Table 6.

Table 6. CEP of BCs in LMRB. Unit: 10^4 \$.

Category	Direct Cost	Opportunity Cost	CEP
China	4954.40	4155.27	9109.67
Myanmar	216.73	1062.93	1279.66
Laos	2148.06	15,839.28	17,987.34
Total	7319.19	21,057.48	28,376.67

As seen from Table 6, the entire CEP of ESSCs in the LMRB was 28,376.67 $\times$ 10^4 \$, in which the direct cost was 7319.19 $\times$ 10^4 \$, accounting for 25.79% of the total cost. The opportunity cost was 21,057.48 $\times$ 10^4 \$, accounting for 74.21% of the total cost. From the perspective of BCs, China had the highest direct cost, accounting for 67.69% of the total direct cost, while Laos had the highest opportunity cost, accounting for 75.22% of the total opportunity cost.

The CEP of ESSCs in the LMRB is closely related to its own level of economic development. The higher the level of economic development, the higher the awareness and ability of ecological protection, and the more funds can be directly invested in ecological protection for the basin. Myanmar and Laos, due to their relatively backward economy and small population size, are unable to fully undertake the obligations of resource development and ecological environment protection, resulting in significantly smaller direct cost investments. Although Myanmar lies in the upstream of the LMRB, only about 2% of the basin coverage area is within Myanmar's borders. Therefore, Myanmar has low enthusiasm for water resource development in the LMRB, and focuses more on forest environmental protection in the basin [4], resulting in higher opportunity costs. Most of Laos' national territory is located in the LMRB. The water production of the LMRB in Laos accounts for 35% of the total basin volume, ranking first among the six countries in the basin [42]. Although Laos has great potential for hydropower development, its utilization level is relatively low, resulting in higher opportunity costs. China has the highest level of economic development among the three countries, a strong enthusiasm for ecological protection, and has invested the most in costs. For example, China actively carries out the construction of Sanjiangyuan National Park to improve the water conservation and grassland coverage of the Lancang River; it actively promotes the construction of Potatso National Park; and constantly improves the value of forest ecosystem services. In addition, because of the fact that China's utilization of water resources in the LMRB is mainly based on hydropower and shipping, which are classified as non-consumable water, the actual consumption of water in China is relatively low [22]. So the opportunity cost is also high.

4.3. Range for the Base Value of the ECS in the LMRB

Combined with the analysis in Section 3.3 and the judgment above, the SVES in Thailand, Cambodia and Vietnam was taken as the upper limit, and the CEP in China, Myanmar and Laos was taken as the lower limit, when determining the feasible range for the base value of the ECS in the LMRB. The final confirmation of the range was combined with the cost-sharing coefficient and adjustment coefficient for payment of the ESV.

When determining the cost-sharing coefficient, it is necessary to consider the proportion of water resource consumption in Thailand, Cambodia and Vietnam in the total basin water consumption. The water resources utilization of countries in the LMRB is shown in Table 7. When determining the adjustment coefficient for payment of the ESV, it is necessary to consider the Engel coefficients of Thailand, Cambodia and Vietnam. According to statistics from the US Department of Agriculture's Bureau of Economic Research, they are 0.276, 0.446 and 0.411, respectively.

Table 7. Water resources utilization of countries in LMRB. Unit: 10^8 m^3.

Category	Agricultural Water	Industrial Water	Domestic Water	Total
China	21.43	2.15	4.10	27.68
Myanmar	1.36	0.03	0.10	1.49
Laos	39.44	0.20	2.39	42.03
Thailand	98.09	1.40	11.23	110.72
Cambodia	89.54	0.20	5.20	94.94
Vietnam	259.14	1.22	5.45	265.81
Total	509.00	5.20	28.47	542.67

To sum up, according to Equations (13)–(15), the range for the base value of the ECS in the LMRB can be obtained, as shown in Table 8.

Table 8. Range for the base value of ECS in LMRB.

	Upper Limit of the Base Value				Lower Limit of the Base Value			
	SVES	**ACP**	**APV**	**Total**		**CEP**	**CSC**	**Total**
Thailand	250.02	0.65	162.51	229.67	China	0.91	0.87	2.47
Cambodia	98.08	0.32	31.39		Myanmar	0.13		
Vietnam	99.37	0.36	35.77		Laos	1.80		
Range for the base value of ECS in LMRB: [2.47, 229.67] $\times 10^8$ $								

Notes: ACP: adjustment coefficient for payment of ESV; APV: actual payment value; CSC: cost-sharing coefficient.

As seen from Table 8, the feasible range for the base value of the ECS in the LMRB was [2.47, 229.67] $\times 10^8$ $ considering the actual development level of each BC, the willingness to pay and the actual water consumption. That is to say, the theoretical space for the negotiation between the ESSCs and ESCCs in the LMRB on the ECS was [2.47, 229.67] $\times 10^8$ $, within which the two sides can conduct full negotiation in order to work out a fair and reasonable scheme for the ECS in the LMRB.

The ECS based on the SVES in the LMRB may exceed the actual tolerance range of ESCCs, as the ESV is huge and difficult to estimate, and often several times the economic value. The research method in this paper provided a way of thinking. However, the ECS was still influenced by factors such as the geographical location of each BC and the acquisition of relevant data, which can only be used as the theoretical upper limit of the ECS. The ECS based on the CEP is in accordance with the ecological environment governance and protection costs and opportunity costs of ESSCs. Influenced by factors such as economic and social development level, people's living standards, and government policies, coupled with high requirements for data accuracy, it was easy to be underestimated during accounting and can only be used as the theoretical lower limit of the ECS. Therefore, the final ECS must be fully negotiated and determined by each BC.

Due to the particularity of TBRBs, the current practice of ecological compensation in TBRBs mainly relies on negotiated compensation between two countries. For example, Canada agreed to build three reservoirs on the upstream of the Columbia River to regulate the runoff, so as to meet the flood control requirements in the lower reaches of America. And, America paid Canada for the construction of reservoirs and shared the benefits of power generation [55]. However, theoretical research on ecological compensation in TBRBs pays more attention to the theoretical framework of compensation mechanisms, and there is less research on the setting of the ECS. Yu Jiawen et al. explored the ECS for the Mekong River Basin through the ESV method, and obtained the actual compensation amounts that Thailand, Vietnam and Cambodia need to pay separately as the ecological compensation objects [32]. The base value of the ECS discussed in this paper is a range of intervals, and from the perspective of the overall basin. The compensation subjects and objects are discussed as two entities. In this paper, the setting of the base value of the ECS offers quantitative support for the development of the ecological compensation activities in TBRBs. Meanwhile, it provides a theoretical basis for the negotiation among BCs, which helps to clarify the ecological protection responsibilities of the BCs, reduces the occurrence of basin disputes, and promotes the sustainable development of TBRBs. In terms of the final ECS for TBRBs and the amount of compensation each BC should bear and accept, respectively, this paper believes that the final decision can be made by the BCs themselves through full negotiation according to the actual economic and social development of each BC, combined with their benefit degree, ability to pay, fund use efficiency and other aspects. In terms of specific compensation methods, this paper believes that various methods such as financial compensation, ecological financing, water rights trading, political coordination, unimpeded trade, technical support and industrial assistance can be adopted through negotiation by various BCs to promote the long-term movement of ecological compensation activities.

5. Conclusions

For the reason of reducing the conflicts caused by the inharmonious relationship between resource exploitation and ecological environmental protection of BCs, and realize the sustainable development of TBRBs, this paper divided BCs into ESSCs and ESCCs in view of the overall basin. The paper took them as two together to conduct one-to-one negotiation on setting the ECS of the basin, and discussed the basis of the two parties' negotiation—the base value of ECS. Firstly, a calculation model for the SVES of BCs in TBRB was constructed. The equivalent factor method was used to estimate the ESV of each BC, and the CESV of each BC was measured by the ecological consumption coefficient. On this basis, the SVES of each BC was obtained. The upper limit of the base value of the ECS was determined based on the SVES in ESCCs. Secondly, a calculation model of the CEP in the TBRB was constructed, and the lower limit of the base value of the ECS was determined according to the CEP in ESSCs. Finally, the feasible range for the base value of the ECS in the TBRB was determined by combining the adjustment coefficient for payment of the ESV and cost-sharing coefficient of each BC.

This paper took the LMRB as an example to conduct a case study, and the main conclusions were as follows.

(1) The SVES in LMRB was Laos, China, Myanmar, Cambodia, Vietnam and Thailand, in descending order. Among them, Laos, China and Myanmar had positive SVES, and they were ESSCs. Cambodia, Vietnam and Thailand had negative SVES, and they were ESCCs.
(2) The CEP of ESSCs in the LMRB was in descending order of Laos, China and Myanmar. Among them, China had the highest direct cost and Laos had the highest opportunity cost. The CEP of ESSCs in the LMRB is closely related to its own level of economic development. The higher the level of economic development, the higher the awareness

and ability of ecological protection, and the more funds can be directly invested in ecological protection for the basin.

(3) Based on the adjustment coefficient for payment of the ESV and the cost-sharing coefficient of each BC, the feasible range for the base value of the ECS in the LMRB was determined to be [2.47, 229.67] $\times 10^8$ \$, which provided the basis for the negotiation between the ESSCs and the ESCCs on the determination of the ECS.

Ecological compensation for TBRBs is a complex activity involving many stakeholders. In the specific implementation process, it involves various influencing factors and prerequisites such as communication and cooperation between various BCs, selection and operation of negotiation platforms, fair and effective determination of the ECS, and so on. Consequently, in the practical application of compensation, there is a relatively large difficulty in coordination. To successfully achieve the goal of ecological compensation in TBRBs, it is necessary to fully leverage the negotiation autonomy of each BC, and establish and improve a guarantee mechanism for conducting ecological compensation activities in the TBRB. Firstly, establish a basin-information-sharing mechanism and platform to regularly share information related to ecological resources, such as water and forest resources in the basin; secondly, establish an integrated management organization for the TBRB, and jointly formulate rules for ecological environment protection and ecological compensation activities, especially for the formulation of rules of procedure in special situations; thirdly, strengthen and improve the coordination and supervision model of ecological compensation in the TBRB, establish a platform for basin coordination and supervision, standardize the cooperation and coordination procedures and improve the regulatory system of ecological compensation.

However, because of the difficulty in obtaining basin information and related data, this paper still has certain limitations and can be further explored in future research. Firstly, the variability and development trend of the ESV in each BC can be considered, and exploration can be conducted from the perspective of value increment; secondly, when modifying parameters such as equivalent factor values, differential corrections can be made based on the individual situation of each BC; thirdly, when setting the base value of the ECS, the impact of cross-sectional water quality monitoring data on the determination of the ECS can be further explored. In the future, BCs need to strengthen the concept of integrated development, adhere to interest sharing and mutually beneficial cooperation, establish an information-sharing mechanism, and assist in the long-term development of the basin.

Author Contributions: Conceptualization, Y.Z.; methodology, Y.Z. and F.L.; software, F.L. and X.C.; validation, Y.Z. and X.C.; formal analysis, Y.Z. and X.X.; investigation, Y.C.; resources, F.L. and Y.C.; data curation, X.C. and X.X.; writing—original draft preparation, Y.Z. and F.L.; writing—review and editing, Y.C., X.C. and X.X.; funding acquisition, Y.C. and X.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Major Projects of National Social Science Fund of the People's Republic of China (Project No. 17ZDA064), General Projects of the National Social Science Fund of the People's Republic of China (Project No. 21BGL289), Anhui Provincial Education Department Humanities Key Fund (No. SK2021A0652), Tongling College Talent Fund (2021tlxyr15).

Data Availability Statement: The data supporting the findings of this paper are available from the corresponding author upon reasonable request.

Acknowledgments: We thank all the members of the Major Projects of National Social Science Fund of the People's Republic of China (Project No. 17ZDA064), as well as the editors and reviewers for their valuable comments and suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

TBRB	Transboundary river basins
BC	Basin country
ECS	Ecological compensation standard
CEP	Cost of ecological protection
ESV	Ecosystem service value
CSEV	Consumption of ecosystem service value
ESSC	Ecosystem service supplying country
ESCC	Ecosystem service consuming country
SVES	Spillover value of ecosystem services
NPP	Net primary productivity
LMRB	Lancang-Mekong River Basin

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