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Identifying Nature–Community Nexuses for Sustainably Managing Social and Ecological Systems: A Case Study of the Qianjiangyuan National Park Pilot Area

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Abstract: Designing policies for the sustainable development of social-ecological systems with complex human–land relations requires integrated management and nexus thinking; China's national parks are typical social-ecological systems. Ecosystem services and community livelihood are two essential components of sustainable management in the nature–community nexus (NCN). This study focuses on the Qianjiangyuan National Park Pilot Area in eastern China. Following a systems approach and integrating qualitative (causal analysis and systems but dynamic methods) and quantitative (InVEST model, Spearman's correlation analysis, regression analysis, and multiple correspondence analysis) methods, we developed two causal mechanisms linking livelihood assets and ecosystem services, and verified them by exploring multi-dimensional linkages and revealing two types of NCNs. Results showed that the proportions of cropland and orchard areas have significant negative correlations with water and soil retention services, respectively, while forests significantly benefit both services. A positive NCN exists in areas where water and soil retention services perform well and the local community develops vibrantly with a considerable proportion of young, highly educated, or high-income (especially the income from secondary industries) residents. A negative NCN is seen in areas where the water and soil retention services values are low; a great many households do not have substantial income from secondary and tertiary industries, and few households have vast forest areas. These results can be used as scientific evidence for optimizing institutional arrangements and contributing to sustainable and harmonious development of national parks in China.

Keywords: social-ecological system; national park; nature-community nexus; system analysis; causal mechanism; ecosystem service; community livelihood

1. Introduction

There is a consensus in the scientific community that most areas in the world can be regarded as social-ecological systems [1] as human activities are intertwined with nature [2]. With the emergence of "people and nature" thinking in nature conservation, scholars and decision-makers are required to acknowledge the importance of the twoway, dynamic relationships between humans and nature for a sustainable and resilient future [3]. While the real world, with its wide range of stakeholders, is complex and "messy" [4], efficiently integrating diverse and interacting components is vital to making decisions and responding to the sustainability of social-ecological systems. Nexus thinking, presenting different and multi-dimensional complex relationships, such as water–food–energy [5], water–energy [6], energy–poverty–climate [7], water–economy [8], and ecosystem–water–food–energy [9], is important for an integrated analysis.

The local community, an inherent part of the social-ecological system [2], is one of the most crucial elements to be included in the analysis. The EU project OpenNESS (Operationalization of Ecosystem Services and Natural Capital)—which was created around the idea of ecosystem services (ES)—presented a conceptual nexus (ONEX) to map out the linkages between ESs and people on local scales, and to broaden local perspectives to cope with challenges of human wellbeing and sustainable ecosystem management [10]. Some other studies have also presented this nature–community nexus (NCN) from different perspectives, although the term "nexus" was not frequently used. Examples of NCN-related studies include identifying the preference for and importance of forest ESs, as perceived by local residents [11] with different social attributes (such as location, age, and educational level) [12], evaluating livelihood assets and their influence on natural resource dependence [13], and involving different stakeholders (especially local residents) in managing ESs in the complex ecosystem [14]. By building a collective view of the complex linkages between ecosystem services and human communities, it is expected that more institutional arrangements that promote human-nature harmony will be developed.

Ideally, sound institutions give consideration to both the scientificity and feasibility of a sustainable future. The "incentive compatibility" theory points out that a certain configuration of behavioral patterns should be compatible with the participants' 'natural inclinations' [15]. Aligning individual goals with social goals is an important issue in designing institutional systems and mechanisms, and the community's capabilities and motivations should be engaged in sustainable management plans [16]. With its dense population and fast-paced socio-economic development, China is a country with complex human–land relations [17]. Precisely identifying the focus of ecological conservation and social development strategies, and developing incentive-compatible institutional arrangements, is particularly important in this complex social context to balance the relationship between humanity and nature.

Although previous studies contributed to NCN analyses from different and inter-disciplinary perspectives, they seldom synthetically considered both ESs and livelihood improvement with a comprehensive, systems approach [18], and in integrated quantitative analysis, nor did they fully consider the feasibility and sustainability of institutional arrangements. More importantly, when varieties of studies were trying to present correlations among different factors of social-ecological systems, very few of them attempted to reveal the causal mechanisms [19] behind their observations; therefore, the conclusions were not adequate for better managing the resilience and sustainability of the systems. For example, varieties of quantitative calculations and scenario analyses [20–23] of ESs have focused on land use regulation to inform ecological restoration and ESs improvement policies, but paid little attention to the potential impacts of these policies on people's livelihoods. Many scholars tried to internalize externalities in the process of ecological conservation by optimizing the policies of ecological compensation or providing payment for ecosystem services [24–26], but did not consider the feedback of livelihood adjustment on ES improvement. The connection between local residents' social attributes and ESs, which may affect people's adaptability to new land use patterns and are important in triggering institutional change, and the causal chain linking people's livelihood assets and eco-conditions, has attracted little attention in policy development. With these issues to be addressed, methodologies for presenting refined and quantitative nexuses between nature and community are still being awaited [27].

This study referred to a systems approach, which is very important for understanding the non-linear dynamics and increased resilience of social-ecological systems [28]. By integrating qualitative and quantitative analysis methods, we not only tried to present multi-dimensional, complex relationships among ecological metrics and livelihood assets, which we defined as NCN, but also tried to explain why the nexus can exist and how it works. With causal mechanisms being revealed and tested with data analysis, we tried to contribute to the resilience and sustainability of social-ecological systems from a comprehensive perspective of natural and social science.

Considering that national parks in China are typical social ecological systems which have been of great importance in demonstrating ecological civilization and balancing natural conservation and social development, we applied the integrated approach and the nature–community nexus thinking in the Qiangjiangyuan National Park Pilot (hereinafter referred to as "the study area"), which is located in eastern China. The purpose of this study was to:

(1) Reveal causal mechanisms of how livelihood assets are linking to ecosystem services, and test the predicted mechanisms with data analysis.
(2) Synthetically and quantitatively explore the multi-dimensional linkage between community livelihood and ecosystem services (the NCN), and to classify the NCNs identified.
(3) Provide scientific evidence for optimizing institutional arrangements and contributing to the sustainable and harmonious development of social-ecological systems with new methodologies and new cases.

2. Materials and Methods

2.1. Study Area

The study area is located in the Yangtze River Delta region [29] (Figure 1), in the headwater region of the Qiantang River, northwest of Kaihua County of Quzhou City, Zhejiang Province. With a total area of 252 km^2, the study area covers 4 towns (Qixi, Hetian, Changhong, and Suzhuang) and 21 administrative villages, and supports a population of 9744 people [30]. It is an area with a mean annual total precipitation of ~2096 mm and an annual average temperature of 14–16 °C The precipitation distributed in March to July accounts for nearly 70% of the total yearly precipitation. It is a core area of central subtropical evergreen broad-leaved forest and is the "water tower" of Zhejiang. With an annual runoff depth of ~1222 mm and dense river network of about 1.58 $km \cdot km^{-2}$, the study area is critical in maintaining regulation services related to water resources. The high-quality water resources generated and provided at the water source benefit not only local residents but various stakeholders downstream in the entire Qiantang River basin.

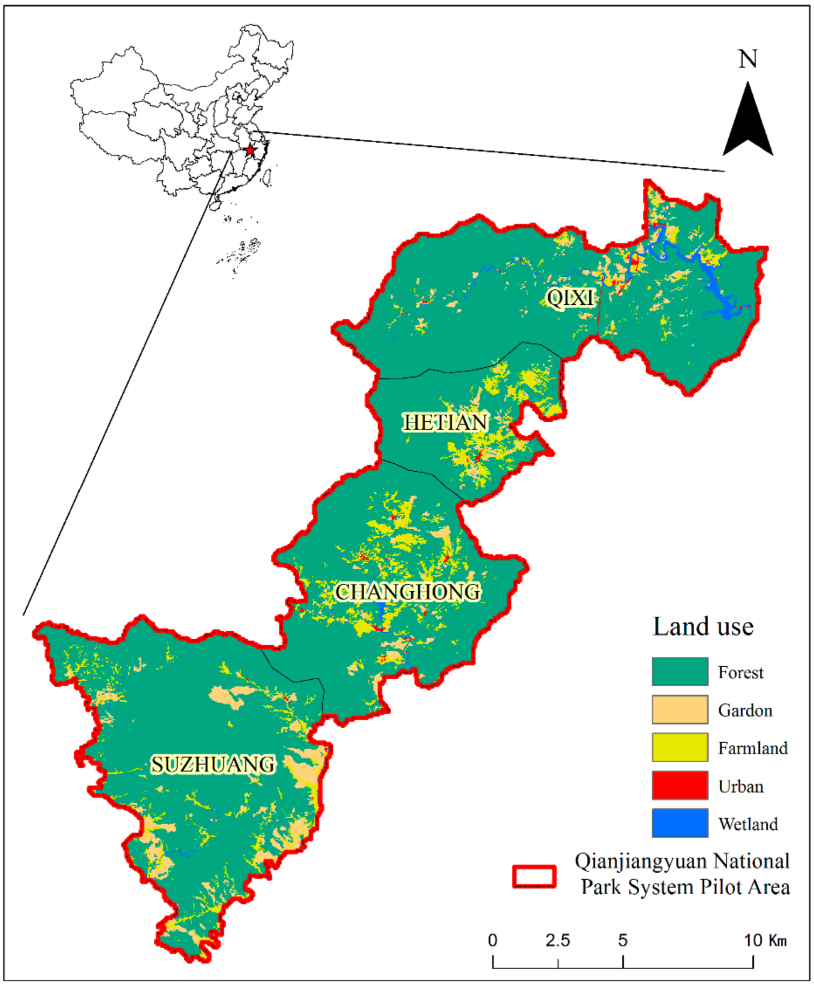


Figure 1. Location of Qianjiangyuan National Park System Pilot Area.

2.2. A Systems Analysis Approach and the Design of the Study Area as a Social-Ecological System

The systems approach framework advocates a four-step methodology to understand social-ecological system, which includes the design, formulation, appraisal, and output of the system [31]. At the system design step, in order to identify key metrics of both ecological and social sub-systems, we referred to previous studies related to the study area.

From the ecological perspective, we found much of previous literature has focused on forest ecosystems and biodiversity in the region [32–34] without fully considering the regulation services related to water resources, which are very important for this water source of the lower Qiantang River Basin. Normally, water quantity, quality, and turbidity are considered the key issues that need special attention in sustainable water resource management [35–37]. Meanwhile, during the social survey, we interviewed different stakeholders of the study area; for example, at the county and township level, government officials, village committee representatives, village resident representatives, etc., and noticed almost all of them care much about the water resource protection, which they think is closely related to their daily life. Therefore, we selected water retention, water purification, and soil retention [38,39] as the metrics of the eco-subsystem in our study.

From the social perspective, capital assets are the basis people draw on in pursuing livelihood strategies. Therefore, we referred to the UK Department for International Development's (DFID) sustainable livelihood analytical framework that defines five aspects of livelihood assets: human, social, physical, natural, and financial [13,40,41]. Considering that the purpose of this study was to provide a reference for institutional arrangements on land use optimization and ES improvement, social and physical assets will less be affected, or at least, residents' adaptabilities to new land use patterns/livelihood structures are less relevant to social and physical assets in this research context; these two types of assets were omitted in our analysis.

With those considerations, to explore how people are connecting with the water-related regulation services, and whether their livelihood structures promote or interfere with the condition of ESs, is one of the key issues in managing the study area as a social-ecological system. The steps of systems analysis will now be recounted.

2.3. Qualitative and Quantitative Analysis Methods: Causality Derivation and Hypothesis Testing

In the step of system appraisal, we applied series of quantitative analysis methods to test the hypothesis formulated in previous step.

2.3.1. System Formulation and Causality Derivation with Qualitative Analysis

Qualitative analysis methods were applied in the step of system formulation. We first developed a theory about NCN. It is generally assumed that natural conservation and social development contradict each other in the real world [42,43], and people are normally poor and ill-educated in well ecologically-protected areas. We argued that natural and social conditions can be parallel within a protected social-ecological system. To explain the theory, we referred the system dynamic and top-down process tracing [44] methods, and presented causal chain and causal mechanisms from the variables of residents' livelihood assets to ecosystem services. With the mechanisms having been presented, we derived two hypothesis (see the causal mechanisms in Section 3.1) which could be tested in the quantitative analysis.

For human, natural, and financial capital, we selected six detailed indicators for data collection and analysis. Human capital has a variety of aspects, such as educational level, health, and labor force proportion [13]. Since health is hard to quantify in a social survey, and while age and educational level (Edu) may influence local communities' perceptions of ecosystem services [12], we focused on the age and educational level of the respondents for estimating human capital. Cropland and farmland are two major natural resources for residents, and thus, we used per-capita cropland area (PCA) and per-capita forest area (PFA) to reflect the natural capital. Annual per-capita income (API) and annual household income (AHI) were selected as the indicators of financial capital in this study. Meanwhile, we also collected income data from different industries for the nexus analysis.

2.3.2. System Appraisal and Linkage Analysis with Data Computing

(1) Investigating community livelihoods.

The information about livelihood capital was collected by a social investigation. We employed a stratified random sampling technique in a social survey to collect first-hand social data from June to July 2018. With the help of village leaders, we selected a few residents from the name list as interviewees from households with low, middle, and high-level incomes in the village.

We disseminated 225 questionnaires in total, and finally received 209 replies by the end of July 2018: 43 from Qixi, 31 from Hetian, 49 from Changhong, and 86 from Suzhuang. Of the 209 questionnaires received, 184 had complete information and were considered valid.

(2) Computing water-related regulation services.

We used the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model (https://naturalcapitalproject.stanford.edu) to compute the three water-related regulation ESs.

Water retention: Water retention refers to the ecosystem's function in intercepting and storing rainfall, regulating runoff, etc. [45]. The InVEST seasonal water yield (SWY) model was used to compute the water retention service. According to the SWY approach, runoff can be categorized as either quick or base flow. Base flow stays within a narrow range in the seasonal runoff variation, which can be used to determine the level of the water retention service [46]. The water balance principle [39], the core theoretical basis of SWY, is presented below.

$$BF = PRE - ET - QF, \tag{1}$$

where BF is baseflow (mm), which is an output variable of SWY model; PRE is annual precipitation (mm), which can be obtained through the meteorological observation data; ET is the annual actual evapotranspiration (mm) that can be calculated through SWY model; and QF is the quick flow (mm), which is an output variable of SWY model. Soil type, land use, and DEM data were needed as input variables to support the running of SWY model.

Water purification: Ecosystems intercept and reduce the concentrations of nutrients, such as nitrogen and phosphorus. We used the InVEST's nutrient delivery ratio (NDR) model to evaluate the water purification service. The nitrogen (N) export to streams is the key indicator in the evaluation, which can be presented as total nitrogen output per unit area of the ecosystem [47,48].

$$ALV_x = HSS_x \cdot pol_x. \tag{2}$$

ALV_x is the load value regulated by grid x ($t \cdot ha^{-1} \cdot yr^{-1}$), pol_x is the output coefficient of grid x, and HSS_x is the hydrological sensitivity score of grid x [49].

A limited number of studies have explored the parameters of water purification services in the study area. As part of the study area belongs to the Yangtze River Basin; we referred to the biophysical parameters used in evaluating the water purification service of the Yangtze River Basin [50]. Land use and precipitation data were needed to drive the NDR model.

Soil retention: Ecosystems can reduce soil erosion caused by precipitation through ecological structures and processes. Soil retention was defined as the difference between potential soil loss and actual soil loss during a year [51,52]. The InVEST sediment delivery ratio model, based on the universal soil loss equation (USLE) [53], can be applied to simulate soil erosion rates and to assess the soil retention service [21]. The estimation can be estimated as in Equation (3):

$$SR_x = SE_{potential\text{-}x} - SE_{actual\text{-}x} = R_x \cdot K_x \cdot LS_x \cdot C_{potential\text{-}x} \cdot P_{potential\text{-}x} - R_x \cdot K_x \cdot LS_x \cdot C_x \cdot P_x, \tag{3}$$

where SR_x is the soil rentention of grid x ($t \cdot ha^{-1} \cdot yr^{-1}$); $SE_{potential\text{-}x}$ is the potential soil erosion of grid x ($t \cdot ha^{-1} \cdot yr^{-1}$); $SE_{actual\text{-}x}$ is the actual soil erosion of grid x ($t \cdot ha^{-1} \cdot yr^{-1}$); R_x is the rainfall erosivity factor of grid x ($MJ \cdot mm \cdot h^{-1} \cdot ha^{-1} \cdot yr^{-1}$), which can be calculated by the daily precipitation data; K_x is the soil erodibility factor of grid x ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$), which can be calculated by soil data; LS_x is the slope and slope length factor of grid x (dimensionless variable), which can be output through SDR model; $C_{potential\text{-}x}$ and $P_{potential\text{-}x}$ are the potential vegetation cover factor and the management factor (dimensionless variable), whose values were 1 (no vegetation cover and no soil conservation management); C_x is the vegetation cover factor of grid x; and P_x is the management factor of grid x [49,54]. The values of C_x and P_x were defined in the biophysical file relevant to land use type.

The data gathered for water-related regulation services' computing included the following:

Land use: A land use map with a spatial resolution of 10 m that reflected land use in 2017 was provided by the Land Planning Bureau of Kaihua County, Zhejiang province. After reclassification, the land use types in the study area included forest, garden, cropland, urban land, and wetland.

Meteorological data: The National Meteorological Information Center of China (http://data.cma.cn/) and township automatic monitoring stations in Kaihua County jointly provided the meteorological data. The data were interpolated through the ArcGIS inverse distance weighting tool to produce the spatial precipitation data for the whole study area.

Soil data: The soil data used in this study was obtained from the Cold and Arid Science Data Center. It is a data product analyzed and processed from the data of the Second National Soil Survey by Beijing Normal University. This data stratifies the soil by soil depth; we used the data from layers

1–4 and weighed the average according to different soil thicknesses. The original data—reported in grams per kilogram—were converted into percentages.

2.3.3. System Output and Hypothesis Verification with Nexus Analysis

Spearman's correlation analysis (IBM SPSS Statistics ver. 18.0, IBM, New York, NY, USA) and regression analysis (JMP ver. 10.0.2., SAS, Cary, NC, USA) were applied to determine the linkages between the three types of livelihood assets and livelihood structure (Impact-1), and also between land use patterns and the three ESs (Impact-2) The effect of each variable was considered statistically significant at a confidence level of $p < 0.05$. Considering that the linkages between several factors are complex, we included factors with significant correlations into a multiple correspondence analysis (MCA) to present the social-ecological nexus.

Since the evaluation of ESs was conducted at the village level, while the community livelihood data were collected individually, we upscaled the livelihood data to match the units of ESs. We first grouped the value of each livelihood indicator. "Age" and "educational level" were grouped according to commonly used statistical methods [12]; "annual per-capita income" and "annual household income" were also grouped referring to related articles [12,13] with slight modifications to fit the actuality in the study area, while the other livelihood indicators (PCA and PFA) were grouped using a clustering method. According to the results of grouping, we selected groups with the highest and lowest values of each indicator for MCA analysis (e.g., the groups "young" and "senior" refer to the indicators of "age" valued the lowest and highest, respectively, while "EduH" and "EduL" refer to the indicators of "educational level" valued the highest and lowest, respectively). The livelihood data could then be recorded in terms of proportion of high-valued and low-valued groups in each village (e.g., the proportion of group "EduH" in village A).

Finally, since the actual value of ESs and the proportion data of livelihood groups were still too complicated for MCA analysis, we re-used the clustered method to simplify the data, presenting them in cluster numbers instead of actual values. Cluster "3" represents the highest actual value of ESs or proportion data of livelihood groups, while cluster "1" represents the lowest. The data, presented in terms of cluster numbers and recorded by village, were input into the SPSS Statistics software to process the MCA analysis.

3. Results

3.1. Causal Mechanisms Linking Livelihood Assets and Ecosystem Service

Based on the theory we put forward, that natural and social conditions can be parallel within a protected social-ecological system, and referring to the system dynamic models, we developed feedback loops between livelihood assets and water-related regulation services, as Figure 2 shows. There is a precondition for these loops, namely, the social-ecological system is a well-managed protected area, which means that only eco-friendly and traditional agroforestry industries are permitted and no illegal activities occur.

Following the system design step described above, the feedback loops started from human assets and ended with water-related regulation services. In the social sub-system, people with positive human assets (being young and highly educated, for instance) are more likely to have the ability to master new living skills in addition to traditional agroforestry activities. Consequently, they are less dependent on direct natural resource acquisition and may have less natural assets in use. The natural dependence will lead to two different results of people's income structure. Those who are highly depending on natural resources will have a relatively higher proportion of income from primary industries, while those who are relying less on nature will have higher incomes from secondary and tertiary industries. Normally, compared to primary industries, the secondary and tertiary industries will generate higher income as the financial assets for local residents, which will help to strengthen their belief and confidence in the new living skills. These factors constitute the three reinforcing loops as marked in the figure.

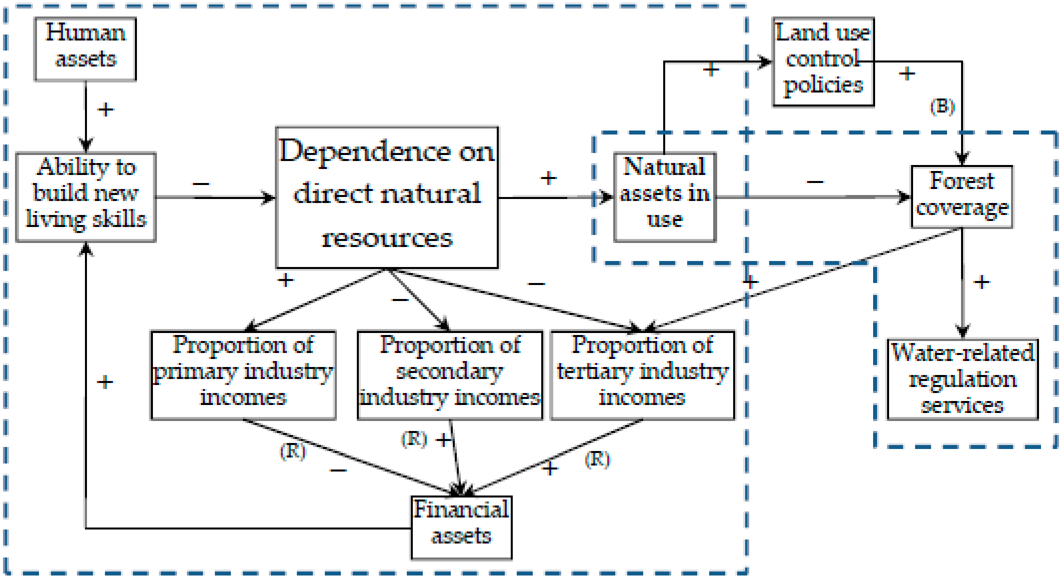


Figure 2. The feedback loops between livelihood assets and water-related regulation services.

The natural assets in use are the key in linking social and natural sub-systems; thus, we marked it with a boldface letter in the figure below. The less croplands and commercial forests people are using, the better the forest coverage and water-related regulation services that can be expected, which will further promote the tertiary industry development. However, the using natural assets cannot be increased unlimitedly. With land use control policies, there will be a balance loop to regulate the natural assets and guarantee the forest coverage.

The symbols of "+" and "−" represent positive and negative causality, respectively, while "R" and "B" refer to reinforcing and balancing feedback loops, respectively. The loop with an even number of negative causalities is the reinforcing causal circuit, which reinforces the causal trend derived. The loop with odd numbers of negative causalities is the balancing causal circuit, which stabilizes the system with a reverse force.

With the feedback loops presented above, two potential types of causal mechanism can be predicted. The positive mechanism can be described as people with positive human assets (being young or highly educated), high capacities to build new living skills, and who less dependent on direct natural resource acquisition. Therefore, they will have a higher proportion of income from secondary and tertiary industries and higher financial assets. Meanwhile, since less natural assets are being used, it is beneficial for forest coverage and water-related regulation services. The negative mechanism is just the opposite, which can be deduced from negative human assets (being a senior or poorly educated) to poor conditions of forest coverage and water-related regulation services.

To verify the predicted causal mechanisms, two groups of factors and their linkages, as marked in the blue dashed frames, were calculated through quantitative analysis (Figure 2).

3.2. Assessment of Key Elements of the Study Area as a Social-Ecological System

3.2.1. Livelihood Structure of Local Communities

(1). Livelihood assets.

Human assets of study area residents are listed in Table 1. More than half (51.09%) of the respondents fell in the 40–59 age group, and more than one-third (38.04%) were seniors. Meanwhile, 75% of the respondents had only been educated to the junior high school level or below. The PCA of community residents was stable with a small standard deviation (0.04), while the PFA had a much higher standard deviation (0.57).

Table 1. Human, natural, and financial capital of the communities in the study area.

Capital Category	Indicators	Rank	Percentage or Mean Value
Human capital	Age	Age-1: 18–39	10.87%
		Age-2: 40–59	51.09%
		Age-3: ≥60	38.04%
	Educational level	Edu-1: Primary and under	29.35%
		Edu-2: Junior high school	45.65%
		Edu-3: Senior high school	22.28%
		Edu-4: College and above	2.72%
Natural capital	Per-capita cropland area	/	0.66 ± 0.04 (mu)
	Per-capita forest area	/	5.16 ± 0.57 (mu)
Financial capital	Annual Household income	AHI-1: ≤10,000	5.43%
		AHI-2: 10,000–100,000	82.61%
		AHI-3: ≥100,000	11.96%
	Annual per-capita income	API-1: ≤5000	11.41%
		API-2: 5000–17,283	61.96%
		API-3: ≥17,283	26.63%

Financial capital differed significantly between households. Less than one third (26.63%) of the residents were living with an API higher than the average level of Kaihua County (17,283 CNY) [55], while there were still 11.41% whose API was lower than 5000 CNY. The vast majority of households (82.61%) had an AHI between 10,000 and 100,000 CNY.

(2). Resource utilization pattern reflected by industry structure.

The proportions of income from primary, secondary, and tertiary industries account for 20.72%, 2.07%, and 7.34% respectively. A large proportion (59.51%) of livelihood income is generated from working wages (Figure 3).

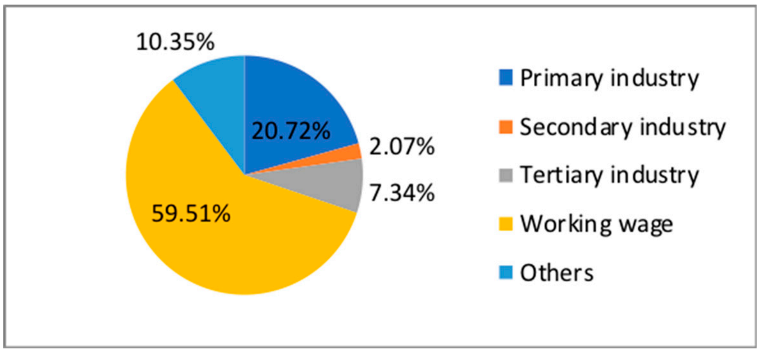


Figure 3. Livelihood structure of the communities in the study area.

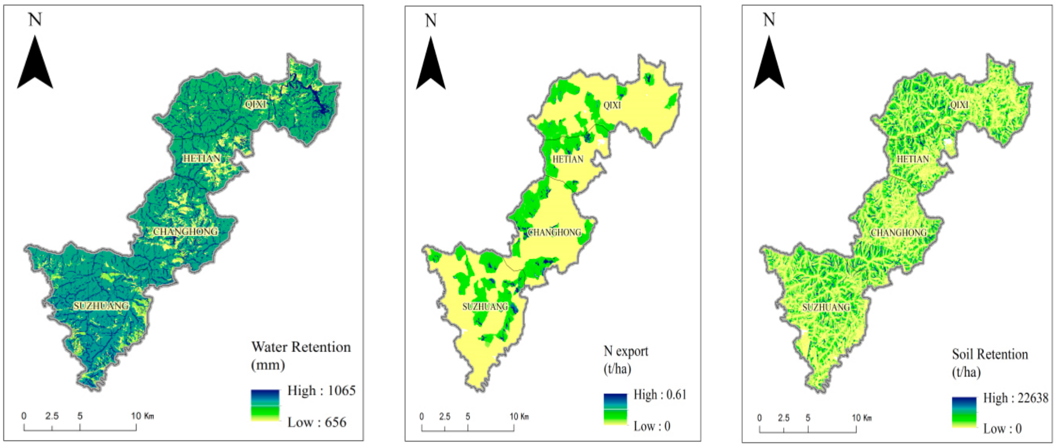
3.2.2. The Water-Related Regulation Services

With the support of the InVEST model, the three types of water-related regulation services have been listed in Table 2.

Table 2. Township-level mean value of water retention, water purification, and soil retention services in the study area.

Township	Water Retention (mm)	Water Purification (t/ha)	Soil Retention (t/ha)
Qixi	799.44	0.0052	98.98
Hetian	777.83	0.0097	96.52
Changhong	782.83	0.0099	89.90
Suzhuang	787.26	0.0086	86.23
Total	788.85	0.0080	92.24

As a water source of the Qiantang river basin, the study area performs well globally in regulating water resources. However, as expected, spatial differences exist for all three targeted ESs (Figure 4). As a pilot national park, the study area has a mission to preserve ecological integrity, which means that several parts of the region with relatively low ES values need to be restored under some enforcement.



(**a**) (**b**) (**c**)

Figure 4. Water retention service (**a**), water purification (N export) service (**b**), and soil retention service (**c**) in the study area.

3.3. Data-Based Linkage between Livelihood Structure and Water-Related Regulation Services

3.3.1. Influence of Livelihood Assets on Livelihood Structure of Residents

There are very few secondary industries in the study area. With limited data, we did not find a significant correlation between livelihood assets (except the AHI) and the proportion of income from secondary industries (PoSII).

Although Spearman's correlation analysis did not reveal a correlation between age and the proportion of income from primary industries (PoPII), the linear regression analysis showed that age has a significant, positive effect on PoPII ($p < 0.01$) and a negative effect on the proportion of income from tertiary industries (PoTII) ($p < 0.01$). Educational level had a significant negative and positive influence on PoPII ($p < 0.01$ in Spearman's correlation analysis and $p < 0.05$ linear regression analysis) and PoTII ($p < 0.001$ in both Spearman's correlation and linear regression analysis) respectively.

Table 3. Factors of livelihood assets identified from Spearman's correlation and linear regression for income from primary industries (PoPII), income from secondary industries (PoSII), and income from tertiary industries (PoTII).

Livelihood Assets		PoPII		PoSII		PoTII	
		Correlation	Regression	Correlation	Regression	Correlation	Regression
Human capital	Age	/	**	/	/	−0.267 ***	**
	Edu	−0.190 **	*	/	/	0.311 ***	***
Natural capital	PCA (mu)	−0.375 ***	***	/	/	/	/
	PFA (mu)	−0.205 **	*	/	/	/	/
Financial capital	AHI	−0.390 ***	***	/	**	/	/
	API	−0.364 ***	**	/	/	/	**

Note: Coefficients are marked with *, **, and *** at the significance levels of $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Correlation and regression in this table are the results of Spearman's correlation and linear regression analysis, respectively.

The PCA turned out to have a positive influence on PoPII ($p < 0.001$ in both Spearman's correlation analysis and linear regression analysis), but no significant effect on PoTII. Similarly, the PFA had a positive correlation with PoPII ($p < 0.01$ in Spearman's correlation analysis, and $p < 0.05$ linear regression analysis), but no significant effect on PoTII. According to Spearman's correlation analysis, both the API and AHI are factors that affect PoPII ($p < 0.001$). In the linear regression analysis, in addition to influencing PoPII, API was a significant positive factor for PoTII ($p < 0.01$), while AHI affected PoSII ($p < 0.01$) (Table 3).

3.3.2. Influence of Land Use on the Water-Related Regulation Services (I-2)

As Table 4 indicates, we did not find a significant correlation between the water purification service and land use types. Both Spearman's correlation analysis and linear regression analysis revealed that cropland areas have a significant negative correlation with the water retention service ($p < 0.001$); orchard areas have a significant negative correlation with the soil retention service ($p < 0.05$), and forested areas are significantly beneficial for both water retention ($p < 0.05$) and soil retention services ($p < 0.001$ in Spearman's correlation analysis and $p < 0.01$ in the linear regression analysis).

Table 4. Land use factors identified from Spearman's correlation and linear regression analyses for three water-related regulation services.

Area Proportion	WatRet		WatPur		SoiRet	
	Correlation	Regression	Correlation	Regression	Correlation	Regression
Cropland	−0.757 ***	***	/	/	/	/
Orchard	/	/	/	/	−0.455 *	*
Urbanland	/	/	/	/	/	/
Forest	0.475 *	*	/	/	0.719 ***	**
Wetland	/	/	/	/	/	/

Note: WatRet = water retention, WatPur = water purification, SoiRet = soil Retention. Coefficients are marked with *, **, and *** at the significance levels of $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Correlation and regression in this table are the results of Spearman's correlation and linear regression analysis, respectively.

3.4. *Nature-Community Nexus in Terms of ESs and Community Livelihoods*

The significantly linked factors we identified included age, educational level, PCA, PFA, API, and AHI for livelihood assets; PoPII, PoSII, and PoTII for livelihood structure; and water retention service and soil retention service for ESs. Combining all those factors together, we conducted MCA to reflect the NCN (Figure 5).

From left to right, the first axis of the MCA (29.87% of the variance) revealed an increase in soil retention service, the proportion of residents who were young or highly educated, and also the proportion of households with low PoPII, high PoSII, or high PoTII. It also showed a decrease in the proportion of seniors and poorly educated residents, and the proportion of households with high PCA and low AHI, API, or PoSII.

From bottom to top, the second axis of the MCA (25.06% of the variance) showed an increase in two of the ESs (water retention and soil retention). Meanwhile, the proportion of households with low API, high PoPII, or PoSII also increased from bottom to up. The proportion of households with low PoSII decreased.

Although the relations among the above-mentioned factors are complex, we identified two major types of NCNs from the MCA biplot. The first type can be termed a positive NCN. From the circle in quadrant 1, we can see that the highest value of both water and soil retention services appears in areas where young residents and households with high API, AHI, and PoSII account for a considerable proportion of the population. On the other hand, low water and soil retention services are bundled in areas where a large proportion of households do not have visible economic incomes from secondary and tertiary industries, and very few of the residents live in a high PFA or generate a relatively high secondary industry income, as shown in quadrant 3. We call this type of nexus a negative NCN.

The linkages among livelihood assets and water-related regulation services analyzed in previous section and the two types of NCNs revealed through the MCA method finally tested and verified the causal mechanisms we predicted.

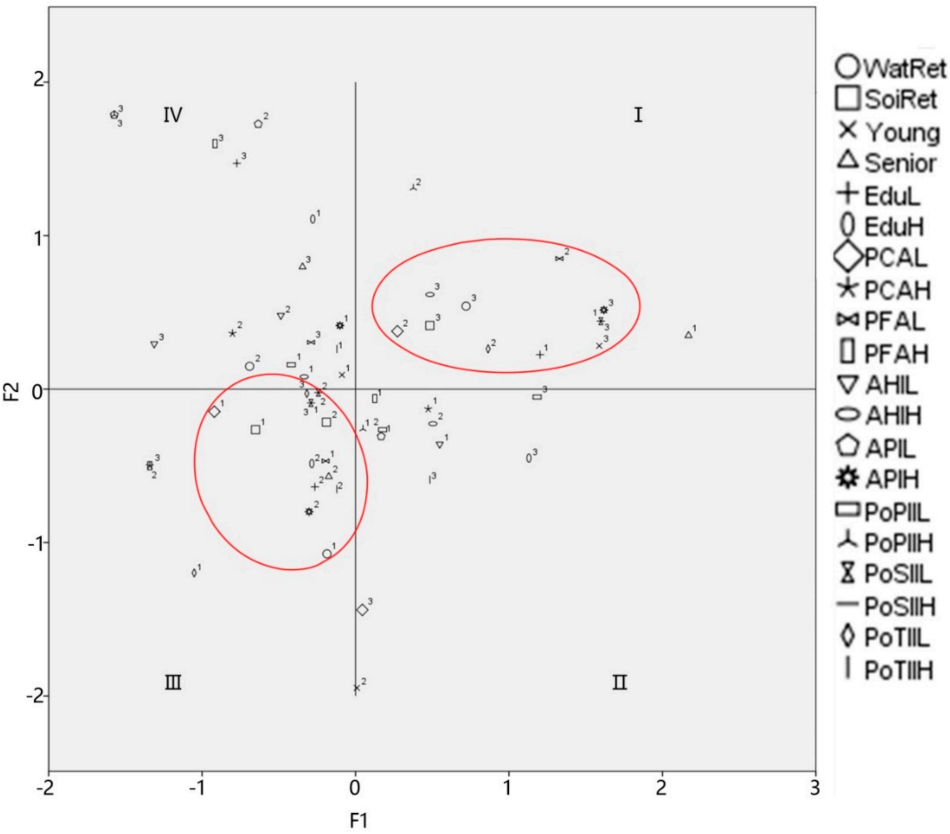


Figure 5. Multiple correspondence analysis biplot.

4. Discussion

4.1. An Interdisciplinary Perspective and Qualitative-Quantitative Combined Methods to Understand the Complexity of the Social-Ecological System and Support Its Sustainability

Social-ecological system is a complex system with intertwined human–nature relations. As a populous country, China attaches great importance to the establishment of ecological civilization and takes national parks, the typical social-ecological systems, as the priority areas in balancing natural conservation and social development. A sound management of a complex social-ecological system needs to integrate various disciplines [31]. This study is an attempt to integrate qualitative and quantitative analysis methods, trying to contribute resilience and sustainability of social-ecological system from a comprehensive perspective of natural and social science.

Systems analysis is considered to be an effective approach to combining several disciplines, understanding the complexity, and developing co-beneficial policies [18]. Following analytical steps recommended by a systems approach framework [31], we identified key elements to be studied and set the study's objective in the system design step. To understand how people are connecting with the water-related regulation services, and whether their livelihood structures promote or interfere with the condition of ESs, we referred to the system dynamic theory [56] in the system formulation step. With the feedback loops within the social-ecological system being presented (Figure 2), we predicted causal mechanisms linking livelihood assets and ecosystem services.

To verify the predicted mechanisms, we applied several quantitative analysis approaches in the system appraisal step. The InVEST model, which is widely used in ecosystem service evaluations, Spearman's correlation, and regression analysis methods, were combined in our study to explore the linkages among two groups of factors, as pointed out in previous step.

At the final step of our study, we adopted multiple correspondence analysis (MCA), a method to identify the pattern of relationships of several categorical dependent variables [57]. The output of the systems analysis, two types of nature-community nexuses (NCN), were revealed in the MCA analysis (Figure 5), to be similar to the causal mechanisms we predicted, which verified the hypotheses we proposed at the very beginning of this study.

Previous studies proposed solutions for better managing social-ecological systems from either social or natural science dimensions, but very few of them paid attention to comprehensively analyzing the system by integrating qualitative theoretical mechanism analysis and quantitative data validation, and therefore, many of them failed to clearly reveal the linkage between ESs and community livelihoods. Given that the livelihood structure can reflect whether and to what extent people depend on direct acquisition of natural resources (e.g., cropland and forest management), or on other means of ecosystem services (e.g., eco-tourism), we introduced intermediate variables of livelihood structures/land use patterns to connect ecological and social sub-systems in our study, and developed causal mechanisms and tested them with data.

With a combined perspective of social and natural science, as well as integrated analysis methods, our study not only presented the results of multiple correlations among intertwined factors within the system, but also explained the causal mechanisms behind them. We believe such an attempt of interdisciplinary research can make the result more convincing and better support policy making process for managing the resilience and sustainability of a complex social-ecological system.

4.2. A Parallel Trend between Natural and Social Conditions Revealed by the Positive and Negative NCNs

Starting from a hypothetical theory that natural and social conditions can be parallel within a protected social-ecological system, we revealed two causal mechanisms by presenting feedback loops, and explained that positive human assets are beneficial for maintaining or improving water-related regulation services, while negative human assets may lead to opposite results. By collecting varieties of data about the social and ecological sub-systems, synthesizing the influence of land use on water-related regulation services (Table 4), and the linkage between people's social attributes and resources utilization (Table 3), we tested the hypothesis and causal mechanisms, and presented data-based multi-dimensional linkages among them, which we called the NCN (nature–community nexus).

The results of this study show that people with low incomes and educational levels tend to be less involved in secondary and tertiary industries (eco-tourism for instance) (Table 3), indicating that they are more dependent on direct resource provisions or material production. On the other hand, residents with high incomes in our study area were more likely to have a higher income proportion from secondary industries (Table 3), and be less dependent on the direct utilization of natural resources. This is a reality in many areas wherein villages with higher dependence on agricultural activity are on average poorer than other. However, by taking the negative causal mechanism and negative NCN into consideration, we were trying to show a new perspective to view this issue. As we mentioned, it is generally assumed that natural conservation and social development contradict each other, but it may be different in a protected area. With a precondition that the system is well-managed and only eco-friendly and traditional agroforestry industries are permitted, young, highly educated, and rich people may try to seek new, promising living skills, while those who are highly depending on direct acquisition of natural resources can still rely on traditional agroforestry industries. This makes poorer areas in a protected area more sensitive to loss ecosystem services. Actually, previous studies had already drawn a similar conclusion that the dependence of rural poor on local ecosystems for livelihood has the potential to accelerate the loss of ecosystem services [58]. Our study further proved it with the causal mechanism and NCN analysis, and tested whether natural and social conditions could be parallel in a protected area.

In addition to the results above, the two NCNs revealed in our study have other similarities and continuity with previous studies. In ONEX, it is emphasized that both "objective" (e.g., basic material needs) and "subjective" (e.g., positive emotions) dimensions should be embraced to include human well-being in nexus thinking [10]. Some scholars tried to reveal local residents' awareness and perception of ESs [11], with results showing people with low incomes and low educational levels prefer provisioning services related to material production (e.g., timber, paddy, and water), while people with high educational levels tend to prefer provisioning and cultural services (e.g., eco-tourism) [12]. Our study not only explored 'objective' linkages between human society and ESs by analyzing the impacts of livelihood assets on livelihood structure, and the land use patterns on ESs values, but also included residents' human assets (age and education) into the nexus analysis, which provided a perspective with "subjective" thinking for follow-up studies on residents' capabilities and motivations to change their livelihood structures for ESs' improvements. In this sense, this study reaffirmed the idea of ONEX. Besides, in terms of DFID's sustainable livelihood framework, previous studies tried to reveal the natural resource dependence of different individuals with different livelihood assets [13]. While most of them mainly paid attention to direct utilization of natural resources or specifically to primary industries, our study explored different people's livelihood strategies in primary, secondary, and tertiary industries, and included all the three types of industries in nexus thinking to present an intricate and more comprehensive ES-livelihood inter-linkage.

4.3. Community-Friendly Land Use Regulation Directions and Sustainable Development Strategies Enlightened by ES-Livelihood Linkages and NCNs

Among all the land use types, we found that croplands ($p < 0.001$) and orchards ($p < 0.05$) have the most significant negative correlation with water and soil retention service, and forests have strong positive linkages with both water ($p < 0.05$) and soil retention ($p < 0.001$) in the study area (Table 4). This result can be explained by factors related to surface runoff coefficient factors [59] and terrain (gradient, aspect, and slope length) [60,61]. The correlation between soil retention and orchards is stronger than that for cropland. One possible explanation for this is that the soil retention is not only influenced by land use types, but is also affected by gradient, slope, etc., just as the Equation (3) indicated [60,61]. The orchards have better vegetation cover than croplands, but they are mainly located in mountains and hills in the study area, which makes it more vulnerable to soil erosion.

A traditional and common idea in ecosystem management is to change land use/land cover; namely, to restore croplands or orchards to forests to improve ESs [21,47,62,63]. However, the long-term environmental sustainability and resilience of social-ecological systems depends not only on top-down landscape regulations, but also active grassroots community engagement [16,64]. According to "incentive compatibility" theory, conservation objectives should be accepted by the local population to sustain ESs [16].

To achieve specific conservation objectives, paying local residents for their efforts in providing ecosystem services or land use, likely to secure that service—which is known as payment for an ecosystem service—is widely used by governments or users of services around the world to internalize an externality [65]. However, based on the ES–human livelihood linkage analysis in our study, not only payment but diversified development assistance measures should be combined with community-friendly land use regulation policies. For example, if the lands of residents who are highly dependent on agriculture or forestry and who are less likely to change their livelihood strategies have been restored, long-term support policies should be developed to ensure their wellbeing rather than one-off compensation for the land acquisition. For those who are capable of shifting from a primary industry to a secondary or tertiary industry, industry transformation-supporting policies, such as technical assistance and job offers, can be applied to avoid high fee-payments and to motivate behavioral changes. In other words, in a social-ecological system with close human-land relations, conservation objectives (improving the state of ESs, for instance) are not the only principles in preparing for a sustainable future;

diversified livelihood assistance polices should be developed by fully considering local residents' social attributes and livelihood structures.

In the study area, high annual household income is associated with good water and soil retention services, which is an incentive compatible with developing conservation and development strategies at this point. According to the "incentive compatibility" theory and the NCNs revealed, other factors—such as ES conditions, industry structures, educational levels, and living environments for young generations—should be comprehensively considered in the future to develop integrated management strategies for better supporting sustainability of the social-ecological system. Here are some preliminary implications for NCN-based sustainable development strategies. (1) In areas where ES values are low compared to other values, the local residents' income proportions from secondary and tertiary industries should be improved when ecological restoration is implemented. (2) For areas with high ES values, the focus of the governance strategy should maintain these conditions. Policies that aim to create living environments for young generations, increase income, optimize industry structures, promote education, and reduce the proportion of poorly educated residents will be helpful in maintaining a positive and mutually beneficial link between humans and nature.

5. Conclusions

Nexus thinking is necessary for the integrated management of social-ecological systems with complex human–land relations. Following a systems approach and integrating qualitative and quantitative analysis, we tentatively developed two causal mechanisms linking livelihood assets and ecosystem services, and verified them by exploring multi-dimensional linkages and revealing the nature–community nexus (NCN). The NCN in this study was specified as the nexus between water-related regulation services and community livelihood assets in the Qianjiangyuan National Park Pilot Area.

Incorporating diverse ecological and social components together, we found that: (1) The local residents—a significant proportion of whom are living with non-optimal livelihood assets (e.g., being poorly educated, low-income, or senile)—depend on primary industries much more than other industries, except for the wage-earners; (2) the study area performs well globally in regulating water resources, but spatial differences exist and ecological restoration is required to improve the ecological integrity; (3) significant correlations exist between livelihood assets and livelihood structure, and between the land use pattern and water-related regulation services. Excessive dependence on primary industries may threaten water and soil retention services, since the proportions of cropland and orchard areas are negatively correlated with the two services; and (4) two types of multi-dimensional linkages among the water-related regulation services, people's livelihood structures, and livelihood assets, namely, the NCNs, have been found in this study. The first type of NCN—which we call positive NCN—refers to the fact that water and soil retention services performed well, and the local community developed vibrantly with a considerable proportion of young, highly educated, or high-income residents. The negative NCN is the exact opposite.

With the two types of NCN identified, further institutional arrangements could benefit from integrated scientific evidence. For example, the proportion of local residents' incomes from secondary and tertiary industries should improve when ecological restoration for higher ES values is implemented; creating a living environment for young generations, increasing income, optimizing industry structures, and improving education are expected to be effective in maintaining a positive and mutually beneficial inter-linkage between humans and nature.

With the comprehensive perspective of social and natural sciences and integrated analysis methods, we tried to present both the results of multiple correlations among intertwined factors and the causal mechanisms behind them. Such an interdisciplinary study can be used to better support policy making process for managing the resilience and sustainability of a complex social-ecological system.

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