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RESEARCH ARTICLE

Quantifying the spatiotemporal characteristics of ecosystem services and livelihoods in China's poverty-stricken counties

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Abstract Understanding the coupling relationship between ecosystem services and poverty livelihoods is a prerequisite for poverty eradication and ecological protection in China. In this paper, we intended to quantify the coupling relationship between ecosystem services and poverty livelihoods in 717 poverty-stricken counties in China. First, we identified distinct levels of ecosystem services and poverty respectively in the poverty-stricken areas based on the ecosystem services subsystem index and poverty livelihoods subsystem index. Then, we calculated the coupling degree and coupling coordination degree between the ecosystem services and the poverty livelihoods in China's poverty-stricken counties from 2000 to 2015. Finally, we analyzed the temporal and spatial evolution of the coupling between ecosystem services and poverty livelihoods. The results indicate that the ecosystem services showed a trend of first decreasing and then increasing, while the poverty level showed an increased trend. In addition, the coupling relationship between ecosystem services and poverty livelihoods in poverty-stricken counties was also improved from 2000 to 2015. However, the coupling degree value or coupling coordination degree values in some counties or contiguous impoverished areas showed a decreased trend, the coupling relationship between ecosystem services and poverty livelihoods in those counties or areas was higher conflict. Future more, the coupling relationship in China's poverty-stricken counties was mainly intermediate conflict and low conflict, which need to improve in the future. Thus, it is suggested that effective measures are required to lift ecosystem services out of the poverty trap and into sustainable livelihoods.

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1 Introduction

Ecosystem services are the ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems (Costanza et al., 1997; Daily, 1997; Costanza et al., 2017; Millennium Ecosystem Assessment (EMA), 2005), which include provisioning services, regulating services, cultural services and supporting services. A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living (Chambers and Conway, 1991). Ecosystem services are particularly vital for sustaining rural livelihoods for the billions of poor people of the world (Huq et al., 2020), while rural livelihood activities directly or indirectly affect the integrity and functional stability of the ecosystem structure (Auler et al., 2017). The linkages between ecosystem services and poverty livelihood are complex, dynamic, locally specific, and poorly understood. In the era of a global ecological crisis, exploring the interaction between the natural (e.g., ecosystems) and human (e.g., livelihood) systems is vital to attain a sustainable development.

Today, eliminating poverty is still a global challenge (Sen, 1999; Elvidge et al., 2009; Sumner, 2012; Shaffer, 2013). Through long-term poverty alleviation and development, poverty-stricken areas in China have been transformed from the overall poverty at the beginning of reform and opening up in 1978 to regional poverty (Heilig et al., 2006). The UN Millennium Development Goals Report 2015 shows that the number of citizens China has raised out of poverty accounts for 70 percent of the world's

total (The State Council Information Office, 2016). However, the fight remains tough as the country still has a large population living in remote mountainous areas, alpine mountain areas or deep mountain areas with fragile ecological environments. Thus, China's strategy for poverty alleviation has also changed from comprehensive poverty alleviation to targeted poverty alleviation (Li et al., 2016; Zhou et al., 2018b). Moreover, with China's attention to ecological and environmental protection, many regions are confronted with the contradiction of 'accelerating development' and 'ecological protection'. Therefore, how to achieve poverty alleviation while protecting the ecological environment is a matter of concern to the government and scholars. Increasing numbers of scientific studies stressed that the ecosystem services provide the possibility of improving livelihoods and reducing poverty (Daw et al., 2011; Fisher et al., 2014; Homewood and Schreckenberg, 2018; The Ecosystem Services for Poverty Alleviation (ESPA) program, 2018). Thus, only by fully understanding the interrelationship between ecosystem services and poverty livelihoods can we achieve poverty alleviation while protecting the ecological environment.

Existing research has hitherto greatly focused on the interaction between ecosystem services and poverty livelihoods. On the one hand, ecosystem services provide material for poverty livelihoods. For example, forest ecosystems provide poverty livelihoods with wood products and non-wood products, such as medicine, fodder, and mushrooms, which ensure the basic needs of poverty livelihoods and contributes to forest protection (Saha and Sundriyal, 2012; Kalaba et al., 2013). The crops provided by farmland ecosystems are the basis for maintaining poverty livelihoods (Zhang et al., 2008). Moreover, wetland ecosystems provide abundant water and fish resources, which make important contributions to the poverty livelihoods (Jogo and Hassan, 2010). On the other hand, the poverty livelihoods affect the structure of the ecosystem. Unreasonable farmland cultivation and overgrazing lead to changes in the physical structure and chemical composition of the soil and can affect the material cycle of the ecosystem (Quine and Walling, 1993; Ibáñez et al., 2007; Auler et al., 2017). At the same time, the destruction of ecological structures directly leads to changes in ecological functions. In addition, existing studies has also focused on the impact of external national policies and other factors on ecosystem services and poverty livelihoods. Li et al. (2018), forexample, analyzed the impact on livelihoods and ecosystem services of a major relocation and settlement program in China.

However, there are still gaps in the following two aspects of research on ecosystem services and poverty livelihoods. 1) The research on the response and coupling relationship between ecosystem services and poverty livelihood is insufficient. The existing research focuses more on the contribution of ecosystem services to the poverty livelihoods (Akwetaireho and Getzner, 2010; Robinson et al., 2019; Huq et al., 2020) or the impact of livelihood activities on ecosystem services (D'Amato et al., 2017; Cuni-Sanchez et al., 2019). However, few studies comprehensively consider the interrelationship between ecosystem services subsystem and poverty livelihood subsystem from the integrity perspective of a system. 2) The study of the temporal and spatial evolution of the coupling relationship between ecosystem services and poverty livelihoods is insufficient. In the temporal scale, the data sources of existing research mainly come from questionnaires or field surveys (D'Amato et al., 2017; Wang et al., 2017), making it difficult to accumulate long-term data and lack of long-term dynamic research. In the spatial scale, the existing studies mainly focus on the comparison between the experimental area and the control area (Kalaba et al., 2013), and there is an insufficient comparison between more areas. With the implementation of targeted poverty alleviation, it is imperative to quantify the temporal and spatial characteristics of ecosystem services and livelihoods and identify key locations where the differentiated poverty alleviation and environmental protection policies are needed to be implemented.

Recently, based on the concept of capacitive coupling and the capacity coupling coefficient model in physics (Illingworth, 1996) or the general systems theory (Meehan, 1969), researchers have constructed coupling models suitable for multiple system interactions. These models have been used to analyze the coupling relationship between urbanization and the ecological environment (Wang et al., 2014; Song et al., 2015; Zhao et al., 2016; Zhao et al., 2017), the coupling between industrialization and the urban environment (Zhen, 2015) and the production-living-ecology coupling in assessing land use multi-functionalization (Zhou et al., 2017). Meanwhile, with the support of geographic information systems (GIS), the spatial characteristics of the coupling degree have been able to be presented. Zhao et al. (2017) identified the spatial differentiation of the coupling relationship between urbanization and the eco-environment in countries globally. Ma et al. (2013) analyzed the spatial pattern of the coupling of regional economic development and environmental pollution in China. The application of these methods provides an important reference and support for this research.

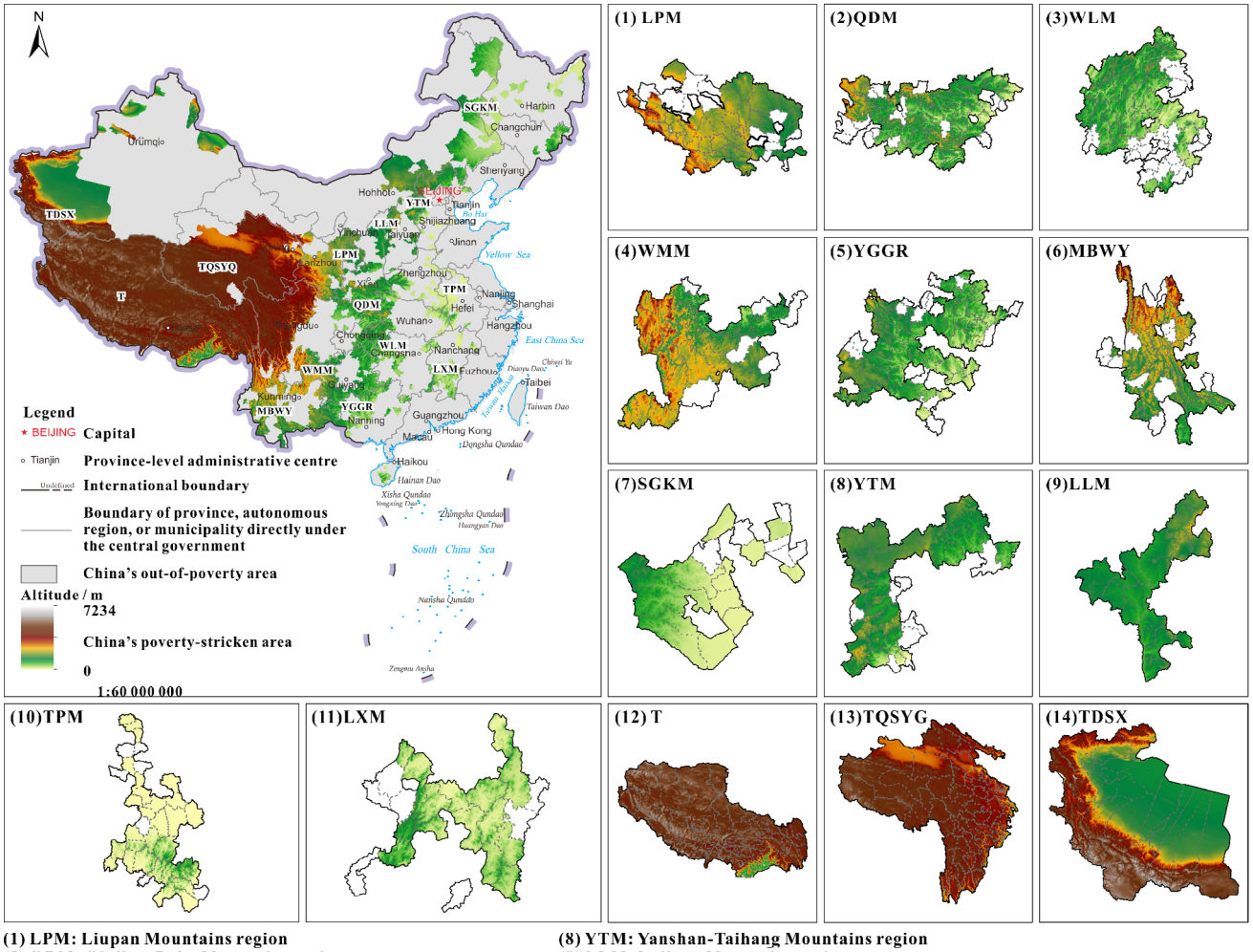
Against this background, this paper explores the following research questions: 1) How to quantify the coupling relationship between ecosystem services and livelihoods; 2) what are the spatio-temporal dynamic characteristics and trends of the coupling relationship between ecosystem services and livelihoods in China's poverty-stricken areas; 3) and how to determine whether there is a conflict between ecosystem services and livelihoods in China's poverty-stricken areas. To answer

these questions, first, we introduced the method of coupling analysis, which included the evaluation index system of ecosystem services and poverty livelihood and the formula for calculation of the coupling degree (CD) and the coupling coordination degree (CCD). Second, we analyzed the spatiotemporal characteristics of ecosystem services and poverty livelihoods in China's poverty-stricken areas from 2000 to 2015. Third, we also analyzed the spatiotemporal characteristics of CD and CCD as well as the trends of the CD and the CCD based on the long-term sequence characteristics from 2000 to 2015 in county scale and contiguous impoverished area scale. Finally, we analyzed the coupled characteristics (coupling relationships) between ecosystem services and poverty livelihoods and identified key counties or contiguous impoverished areas that beneficial for governments and local policy-makers to develop targeted poverty alleviation policies.

2 Materials and methods

2.1 Study area

The state council leading group office of poverty alleviation and development announced the list of key counties for national poverty alleviation and development work in 2012 (available at the State Council Leading Group Office of Poverty Alleviation and Development website), we selected these counties as well as the counties in Tibet Autonomous Region, Tibetan ethnic areas in Qinghai, Sichuan, Yunnan and Gansu provinces and Three districts of southern Xinjiang Uygur Autonomous Region, where China has clearly implemented special poverty alleviation policies, as cases study area. Owing to lack of data, 717 counties were studied in this article (Fig. 1). The study area, China's poverty-stricken counties (CPC), is



(1) LPM: Liupan Mountains region
(2) QDM: Qinling-Daba Mountains region
(3) WLM: Wuling Mountains region
(4) WMM: Wumeng Mountains region
(5) YGGR: Yunnan-Guizhou-Guangxi rock desertification region
(6) MBWY: Mountainous borderland of western Yunnan Province
(7) SGKM: South of Greater Khingan Mountains region
(8) YTM: Yanshan-Taihang Mountains region
(9) LLM: Lvliang Mountains region
(10) TPM: Ta-pieh Mountains region
(11) LXM: Luoxiao Mountains region
(12) T: Tibet Autonomous Region
(13) TQSYG: Tibetan ethnic areas in Qinghai, Sichuan, Yunnan and Gansu provinces
(14) TDSX: Three districts of southern Xinjiang Uygur Autonomous Region

Fig. 1 Spatial distribution of poverty-stricken counties of China.

situated between (73°40′E, 18°23′N) and (135°2′E, 51°25′N), which is adjacent to Fuyuan city (Helongjing Province) in the east, to Wuqia county (Xinjiang Uygur Autonomous Region) in the west, to Baoting Li and Miao Autonomous county (Hainan Province) in the south, and to Oroqen Autonomous Banner (Inner Mongolia Autonomous Region) in the north, involving 27 cities, 31 districts and 659 counties in 22 provinces. As can be seen from Fig. 1, the study area are mainly distributed in the 14 China's contiguous impoverished area, including Liupan Mountains region (LPM), Qinling-Daba Mountains region (QDM), Wuling Mountains region (WLM), Wumeng Mountains region (WMM), Yunnan-Guizhou-Guangxi rock desertification region (YGGR), Mountainous borderland of western Yunnan Province (MBWY), South of Greater Khingan Mountains region (SGKM), Yanshan-Taihang Mountains region (YTM), Lvliang Mountains region (LLM), Ta-pieh Mountains region (TPM), Luoxiao Mountains region (LXM), Tibet Autonomous Region (T), Tibetan ethnic areas in Qinghai, Sichuan, Yunnan and Gansu provinces (TQSYG) and Three districts of southern Xinjiang Uygur Autonomous Region (TDSX) (Liu et al., 2017; Chen and Ge, 2015; Ren et al.,2017). The poverty-stricken counties of China are concentrated in ecologically vulnerable areas with lagging economic conditions. The highest elevation of the CPC is 8385 m above sea level, and the average elevation is 2900 m above sea level. In accordance with up-to-date poverty standard of per capita net income (2300 yuan), China still has 43.35 million poverty people in 2016 (available at National Bureau of Statistics website).

2.2 Data sources

The data set used in this paper is listed in Table 1 including statistical data and GIS data. 1) The statistical data of each poverty-stricken county was collected from the China Statistical Yearbook (2001–016), the Statistical Yearbook (2001–2016) of each province, and the China Rural Statistical Yearbook (2001–2016). 2) The GIS data include the Land Use/Cover Change (LUCC) data, DEM, Slop, soil data, climatic data (precipitation and temperature) and the vector data of China's county-level administrative boundaries. The raw climate data is from the meteorological station monitoring data, and we used ANUSPLIN software to calculate raster data of the precipitation and temperature (available at Australian National University website). All the spatial data sets were resampled to the same resolution of 1 km × 1 km.

Some counties' agricultural production statistics were missing, and we recalculated them with the data from the province and the ratio of different types of croplands in each county to the province. The CPC is distributed in mountain area (Fig. 1), the land use change is small every year. And the resolution of LUCC data is 1 km, the land use change in CPC are not obvious within 5 years. Thus, in this article, the land use data for all districts were replaced with LUCC data for China using the following exchanges: 2000 to 2002 data with 2000 LUCC data; 2003 to 2007 data with 2005 LUCC data; 2008 to 2012 data with 2010 LUCC data; and 2013 to 2015 data with 2015 LUCC data.

When some counties' agricultural production statistics were missing for a certain year, we recalculated them by a linear regression model based on the data from other years.

2.3 Method

2.3.1 Evaluation indexes

The index system for coupling evaluation of ecosystem services and poverty livelihoods was shown in Table 2 (Zhou et al., 2018a) with four-level structure: subsystem indicators, item level indicators, sub item level indicators and basic level indicators.

The evaluation indicator of the ecosystem services subsystem only considered the food and water supply

Table 1 List of data used in this paper

Category	Data	Year	Resolution	Data resource
Statistical Data	China Statistical Yearbook	2001–2016	/	National Bureau of Statistic
	Statistical Yearbook of Province	2001–2016	/	CNKI
	China Rural Statistical Yearbook	2001–2016	/	CNKI
GIS Data	Land Use/Cover Change data	2000, 2005, 2010, 2015	1 km	Chinese Academy of Sciences Resource and Environment Data Cloud Platform
	DEM	2000	90 m	National Earth System Science Data Sharing Infrastructure in China
	Slop	2000	90 m	Calculate from DEM
	Soil Data	2009	1 km	National Tibetan Plateau Data Center
	Precipitation data	2000–2015	/	National Meteorological Science Data Sharing Service Platform in China
	Temperature data	2000–2015	/	
	China's county-level administrative boundaries	2015	Vector	National Earth System Science Data Sharing Infrastructure in China

services in providing service. The reason for this choice is that providing services are the basis for maintaining the livelihood of poverty people, especially in CPC. The food and water supply services are important for improving rural livelihoods and reducing poverty. Taking data accessibility into consideration, we selected 31 indicators covering 6 item (i.e., crops, fruits, forest products, livestock products, aquatic products and water support) and 9 sub items (i.e., food crops, economic crops, fruits, wood, other wood products, meat, poultry eggs, aquatic products and water yield) for the ecosystem services evaluation subsystem. The annual water yield data were calculated by using the water yield module in the Integrated Valuation of Ecosystem Services and Trade-

Table 2 Evaluation indicator system on coupling between ecosystem services subsystem and poverty livelihood subsystem

Subsystem	Item	Sub item	Basic indicator	
Ecosystem services subsystem	Crops (E_1)	Food crops (E_{11})	E_{111}	Rice yield (t)
			E_{112}	Wheat yield (t)
			E_{113}	Corn yield (t)
			E_{114}	Beans yield (t)
			E_{115}	Potatoes yield (t)
		Economic crops (E_{12})	E_{121}	Peanut yield (t)
			E_{122}	Rapeseed yield (t)
			E_{123}	Cotton yield (t)
			E_{124}	Sugarcane yield (t)
			E_{125}	Sugar beet yield (t)
			E_{126}	Tobacco leaf yield (t)
			E_{127}	Tea leaf yield (t)
	Fruits (E_2)	Fruits (E_{21})	E_{211}	Apple yield (t)
			E_{212}	Citrus yield (t)
			E_{213}	Pears yield (t)
			E_{214}	Grapes yield (t)
			E_{215}	Bananas yield (t)
	Forest products (E_3)	Wood (E_{31})	E_{311}	Wood yield (t)
		Others wood products (E_{32})	E_{321}	Rubber yield (t)
			E_{322}	Turpentine yield (t)
			E_{323}	Lacquer yield (t)
			E_{324}	Tung seed yield (t)
			E_{325}	Camellia seed yield (t)
	Livestock products (E_4)	Meat (E_{41})	E_{411}	Pork yield (t)
			E_{412}	Beef yield (t)
			E_{413}	Mutton yield (t)
		Poultry eggs (E_{42})	E_{421}	Milk yield (t)
			E_{422}	Poultry eggs yield (t)
			E_{423}	Honey yield (t)
	Aquatic products (E_5)	Aquatic products (E_{51})	E_{511}	Fresh water products (t)
	Water support (E_6)	Water yield (E_{61})	E_{611}	Annual water yield($10^6 m^3 \cdot a^{-1}$)
Poverty livelihood subsystem	Financial capital (L_1)	Income level (L_{11})	L_{111}	Per rural residents net income (yuan)
			L_{112}	Per capital GDP (yuan/capital)
		Savings/borrowings (L_{12})	L_{121}	Urban and Rural Residents Savings Balance (Million yuan)
			L_{122}	Various loan balances of financial institutions (Million yuan)
	Nature capital (L_2)	Arable land level (L_{21})	L_{211}	Per capita cultivated area (m^3/people)
			L_{212}	Grain yield per unit area (t/hm^2)
		Water resources (L_{22})	L_{221}	Average annual rainfall (mm)
	Human capital (L_3)	Integrated labor (L_{31})	L_{311}	Rural population (Number)
			L_{312}	Agriculture, Forestry, Animal Husbandry and Fishery Practitioners (Number)
		Comprehensive education level (L_{32})	L_{321}	Secondary school students (Number)
			L_{322}	Primary school students (Number)
	Material capital (L_4)	Public facilities services (L_{41})	L_{411}	Number of hospital beds (Number)
	Social capital (L_5)	Social support level (L_{51})	L_{511}	Urbanization rate (%)
	Environment vulnerability (L_6)	Environmental/background vulnerability levels (L_{61})	L_{611}	Above 15° slope area ratio (%)

offs model (InVEST) (available at natural capital project website).

Based on a vulnerability analysis of the sustainable livelihood framework established by the Department for International Development (1999) and existing research (Yang et al., 2013; Berchoux et al., 2019; Kumar et al., 2019; Hu et al., 2020), we selected 14 indicators covering 6 item (i.e., financial capital, nature capital, human capital, material capital, social capital and environment vulnerability) and 9 sub item (income level, savings/borrowings, arable land level, water resources, integrated labor, comprehensive education level, public facilities services, social support level and environmental/background vulnerability levels) for the poverty livelihood subsystem.

2.3.2 Comprehensive assessment of subsystem efficacy

The comprehensive efficacy of the subsystem is the integration of the contribution of all indicators to its subsystem. We supposed that $e_1, e_2, ..., e_p$ represent the indexes of the ecosystem services system and that $l_1, l_2, ..., l_q$ represent the indexes of the poverty livelihood system; then, the comprehensive efficacy of the subsystem is achieved by the following equations:

$$U_e = \sum_{t=1}^{p} e_t' Z_t, \tag{1}$$

$$U_l = \sum_{k=1}^{q} l_k' Z_k, \tag{2}$$

where U_e and U_l are the integration value of the ecosystem services subsystem and the poverty livelihood subsystem, respectively. e_t' and l_k' are the standardized value of e_t and l_k respectively, which can be calculated by Min-max normalization method (Zhou et al., 2017; Yu et al., 2019). p and q are the number of indicators of each subsystem. Z_t and Z_k are the weight of e_t' and l_k', respectively.

The weight of each indicator was calculated by the analytic hierarchy process method (AHP) and the information entropy weight method (IEW) (Saaty, 1980 and 2003; Shemshadi et al., 2011; Zhang et al., 2018). The steps are as follows (Eqs. (3)–(6)):

$$R_{ij} = \frac{X_{ij}'}{\sum_{i=1}^{M} X_{ij}'}, \tag{3}$$

$$E_j = -\frac{1}{\ln M}\sum_{i=1}^{M}(R_{ij} \times \ln R_{ij}) \quad (0 \leqslant E_j \leqslant 1), \tag{4}$$

$$\omega_j = \frac{1 - E_j}{\sum_{j=1}^{N}(1 - E_j)}, \tag{5}$$

$$Z_j = \frac{\omega_j c_j}{\sum_{j=1}^{N} \omega_j c_j}, \tag{6}$$

where R_{ij} is the proportion of the jth indicator in county i, M is the number of counties, and N is the number of indicators. When $R_{ij} = 0$, which means zero probability yields zero information $R_{ij} \times \ln R_{ij} = 0$, E_j is the information entropy of the indicator. Where Z_j is the improved weight of jth indicator, ω_j is the weight by IEW of the jth indicator, and c_j is the weight by AHP of the jth indicator.

2.3.3 Calculation of CD

Coupling refers to a phenomenon in which two (or more than two) systems affect one another through various interactions. The coupling degree describes the degree to which systems or elements interact with each other. The CD is used to quantify the relationships between ecosystem services and poverty livelihoods and is given as follows (Li et al., 2012; Zhou et al., 2017; Liu et al. 2018):

$$C = \left(\frac{U_e \cdot U_l}{((U_e + U_l)/2)^2}\right)^{\frac{1}{2}}, \tag{7}$$

where U_e and U_l are the integration value of the ecosystem services subsystem and the poverty livelihood subsystem, respectively. C is the coupling degree between the ecosystem services subsystem and the poverty livelihoods subsystem. $C \in [0, 1]$; when $C = 1$, the coupling degree is the largest, and the systems or elements of the system have benign resonance; then, the system will tend to have a new orderly structure; when $C = 0$, the coupling degree is the smallest, and the systems or elements of the system will be uncorrelated; and then, the system will tend to have a disordered structure. The coupling degree is divided into 4 intervals based on the median segmentation method (Ma et al., 2013; Sun et al. 2019): when $C \in (0, 0.3]$, the ecosystem services subsystem and poverty livelihoods subsystem are in the low-level coupling state; when $C \in (0.3, 0.5]$, the ecosystem services subsystem and poverty livelihoods subsystem are in the rivalling state; when $C \in (0.5, 0.8]$, the ecosystem services subsystem and poverty livelihoods subsystem are in the gearing state; and when $C \in (0.8, 1)$, the ecosystem services subsystem and poverty livelihoods subsystem are in the high-level coupling state.

2.3.4 Calculation of CCD

CD can reflect the degree of coupling between ecosystem services and poverty livelihoods. However, in multiple regional comparison studies, the overall benefits of the

ecosystem services subsystem and the poverty livelihoods subsystem cannot be well reflected. To solve this problem, the CCD was calculated, which can reflect the level of harmony in the ecosystem services and poverty livelihoods coupling relationship and is given in the following formulas (Li et al., 2012; Zhou et al., 2017; Liu et al. 2018):

$$D = (C \cdot T)^{1/2}, \tag{8}$$

$$T = \delta U_e + \eta U_l, \tag{9}$$

where D represents the degree of coupling coordination, and $D \in (0, 1)$; C is the degree of coupling between ecosystem services and poverty livelihoods described above; T reflects the overall effect and level of ecosystem services and poverty livelihoods; δ and η are weights to be determined that represent the contribution of the ecosystem services subsystem and the poverty livelihoods subsystem, respectively. Because the ecosystem services are as equally important as the poverty livelihoods subsystem in China, the values of δ and η are equivalent, i.e., $\delta = \eta = 0.5$. The coupling coordination degree is also divided into 4 intervals by using the median segmentation method (Ma et al., 2013; Sun et al. 2019): when $D \in (0, 0.3]$, the ecosystem services subsystem and the poverty livelihoods subsystem are in a low coupling coordination; when $D \in (0.3, 0.5]$, the ecosystem services subsystem and the poverty livelihoods subsystem are in an intermediate coupling coordination; when $D \in (0.5, 0.8]$, the ecosystem services subsystem and the poverty livelihoods subsystem are in a high coupling coordination; and when $D \in (0.8, 1)$, the ecosystem services subsystem and the poverty livelihoods subsystem are in a higher coupling coordination.

3 Results

3.1 Spatiotemporal characteristics of ecosystem services and poverty livelihoods

According to the evaluation index system of the ecosystem services and the poverty livelihoods, we used the AHP and IEW method to assign index weights (details see the Supplementary material), and then calculated the integration value of the ecosystem services subsystem (U_e) and the poverty livelihood subsystem (U_l). Based on the integration values, the spatiotemporal characteristics of ecosystem services and poverty livelihoods were analyzed.

3.1.1 Spatiotemporal changes of ecosystem services

The integration values of the ecosystem services subsystem of CPC from 2000 to 2015 were calculated using Eq. (1). The mean integration values of the ecosystem services subsystem of CPC were shown in Table 3, and the overall trend of which were decreased first and then increased, with the range of values from 2000 to 2015 was 0.0343 to 0.0383. For further analyzed the changes in ecosystem services of CPC, the integration values of the ecosystem services subsystem (U_e) were divided into five levels by the equal interval method, with level 1 ($U_e \leqslant 0.04$), level 2 ($0.04 < U_e \leqslant 0.08$), level 3 ($0.08 < U_e \leqslant 0.12$), level 4 ($0.12 < U_e \leqslant 0.16$) and level 5 ($U_e > 0.16$), and the statistics on the number and proportion of counties at 5 levels as shown in Table 4. Approximately 90% counties with low integration values of the ecosystem services, and were divided into level 1 and level 2. The number of counties in level 1 and in level 5 all showed a trend of first increasing and then decreasing. Differently, the number of counties in level 4 showed a trend of first decreasing and then increasing. The number of counties in level 3 showed a decreased trend, while the number of counties in level 2 nearly unchanged.

Furthermore, the changes of the number of counties at 5 levels in different China's contiguous impoverished areas were also calculated. In Fig. 2, except TPM (Fig. 2(j)) and LXM (Fig. 2(k)), more than 50% counties in each contiguous impoverished area had an integration value of less than 0.04. The number of counties with an integration value less than 0.04 in LPM (Fig. 2(a)) and T (Fig. 2(l)) even accounted for more than 90%. The overall integration values of the ecosystem services in TPM (Fig. 2(j)) and LXM (Fig. 2(k)) were higher than that in other contiguous impoverished areas. Furthermore, the counties with an integration value greater than 0.16 were mainly appeared in QDM (Fig. 2(b)), WMM (Fig. 2(d)), YGGR (Fig. 2(e)), TPM (Fig. 2(j)), LXM (Fig. 2(k)), TQSYG (Fig. 2(m)) and other non-contiguous impoverished areas (Fig. 2(o)). During 2000 to 2015, the counties with an integration value less than 0.04 in LPM (Fig. 2(a)), WLM (Fig. 2(c)) and TPM (Fig. 2(j)) showed a decreased trend, while in the other contiguous impoverished areas had no obvious changes.

The spatial distribution of the integration values of the ecosystem services (Fig. 3) showed that the ecosystem services of the south-east region is generally higher than that of the north-west region. The largest integration values of the ecosystem services were mainly distributed in north-

Table 3 The mean of the integration value of the ecosystem services subsystem in China's poverty-stricken counties from 2000 to 2015

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mean	0.0383	0.0376	0.0353	0.0356	0.0386	0.0356	0.0343	0.0353	0.0382	0.0355	0.0362	0.0357	0.0370	0.0354	0.0378	0.0368

Table 4 The number and proportion of different integration value groups of the ecosystem services in China's poverty-stricken counties from 2000 to 2015

Year	Number					Proportion				
	(0, 0.04]	(0.04, 0.08]	(0.08, 0.12]	(0.12, 0.16]	(0.16, 1]	(0, 0.04]	(0.04, 0.08]	(0.08, 0.12]	(0.12, 0.16]	(0.16, 1]
2000	463	184	43	19	8	64.57%	25.66%	6.00%	2.65%	1.12%
2001	473	174	45	17	8	65.97%	24.27%	6.28%	2.37%	1.12%
2002	498	155	39	17	8	69.46%	21.62%	5.44%	2.37%	1.12%
2003	480	176	36	16	9	66.95%	24.55%	5.02%	2.23%	1.26%
2004	464	180	42	19	12	64.71%	25.10%	5.86%	2.65%	1.67%
2005	484	170	37	17	9	67.50%	23.71%	5.16%	2.37%	1.26%
2006	503	154	36	16	8	70.15%	21.48%	5.02%	2.23%	1.12%
2007	495	158	40	14	10	69.04%	22.04%	5.58%	1.95%	1.39%
2008	475	171	42	17	12	66.25%	23.85%	5.86%	2.37%	1.67%
2009	492	164	36	15	10	68.62%	22.87%	5.02%	2.09%	1.39%
2010	480	170	42	14	11	66.95%	23.71%	5.86%	1.95%	1.53%
2011	485	173	36	17	6	67.64%	24.13%	5.02%	2.37%	0.84%
2012	472	177	42	20	6	65.83%	24.69%	5.86%	2.79%	0.84%
2013	486	174	33	17	7	67.78%	24.27%	4.60%	2.37%	0.98%
2014	461	193	38	18	7	64.30%	26.92%	5.30%	2.51%	0.98%
2015	473	176	41	21	6	65.97%	24.55%	5.72%	2.93%	0.84%

eastern Inner Mongolia, YTM, TPM, YGGM and western Sichuan.

3.1.2 Spatiotemporal changes of poverty livelihoods

The integration values of the poverty livelihoods subsystem of CPC from 2000 to 2015 were calculated by using Eq. (2). And the mean integration values of the poverty livelihoods subsystem of CPC were shown in Table 5. Different from the trend of the mean integration values of the ecosystem services, the mean integration values of the poverty livelihood showed a trend of increasing, with the range of values from 2000 to 2015 was 0.0807 to 0.1387. This indicates that the poverty is gradually decreasing. What's more, the integration values of the poverty livelihood subsystem (U_l) were divided into five levels by the equal interval method, with extreme poverty ($U_l \leqslant 0.04$), poorer poverty ($0.04 < U_l \leqslant 0.08$), moderate poverty ($0.08 < U_l \leqslant 0.12$), general poverty ($0.12 < U_l \leqslant 0.16$) and mild poverty ($U_l > 0.16$), and the statistics on the number and proportion of counties at 5 poverty levels as shown in Table 6. Obviously, the number of extremely poverty counties was gradually decreasing from 424 (accounting for 59.14%) in 2000 to 109 (15.20%) in 2015, while the number of poorer poverty counties, moderate poverty counties, general poverty counties and the mild poverty counties were gradually increasing from 236 (32.91%) to 321 (44.77%), 53 (7.39%) to 178 (24.83%), 1 (0.14%) to 61 (8.51%) and 3 (0.42%) to 48 (6.69%), respectively.

Figure 4 shows the changes of the number of counties at 5 poverty levels in different China's contiguous impoverished areas scale. The percentage of the poverty level in each contiguous impoverished area was different (Fig. 4). The poverty level in T (Fig. 4(l)) was mainly extreme poverty and poorer poverty, the poverty level in TQSYG (Fig. 4(m)) was mainly poorer poverty, the poverty level in LPM (Fig. 4(a)), WMM (Fig. 4(d)), YGGR (Fig. 4(e)), MBWY (Fig. 4(f)), YTM (Fig. 4(h)), LLM (Fig. 4(i)) and TDSX (Fig. 4(n)) was mainly moderate poverty, the poverty level in QDM (Fig. 4(b)) and other non-contiguous impoverished areas (Fig. 4(o)) was mainly general poverty and mild poverty, and the poverty level in WLM (Fig. 4(c)), SGKM (Fig. 4(g)), TPM (Fig. 4(j)) and LXM (Fig. 4(o)) was mainly mild poverty. Furthermore, the extreme poverty level in LPM (Fig. 4(a)), QDM (Fig. 4(b)) and TQSYG (Fig. 4(m)) was gradually decreasing and exiting. Similarly, the poorer poverty level in WLM (Fig. 4(c)), YGGR (Fig. 4(e)), YTM (Fig. 4(h)), LLM (Fig. 4(i)), TPM (Fig. 4(j)) and LXM (Fig. 4(o)) was gradually decreasing and exiting, while the moderate poverty in TPM (Fig. 4(j)) and LXM (Fig. 4(o)) was also gradually decreasing and exiting. With the decreased of the extreme poverty counties, poorer poverty counties and moderate poverty counties, the proportion of general poverty or mild poverty increased.

As illustrated in Fig. 5, the overall poverty levels in CPC from 2000 to 2015 showed a ladder-like distribution, with

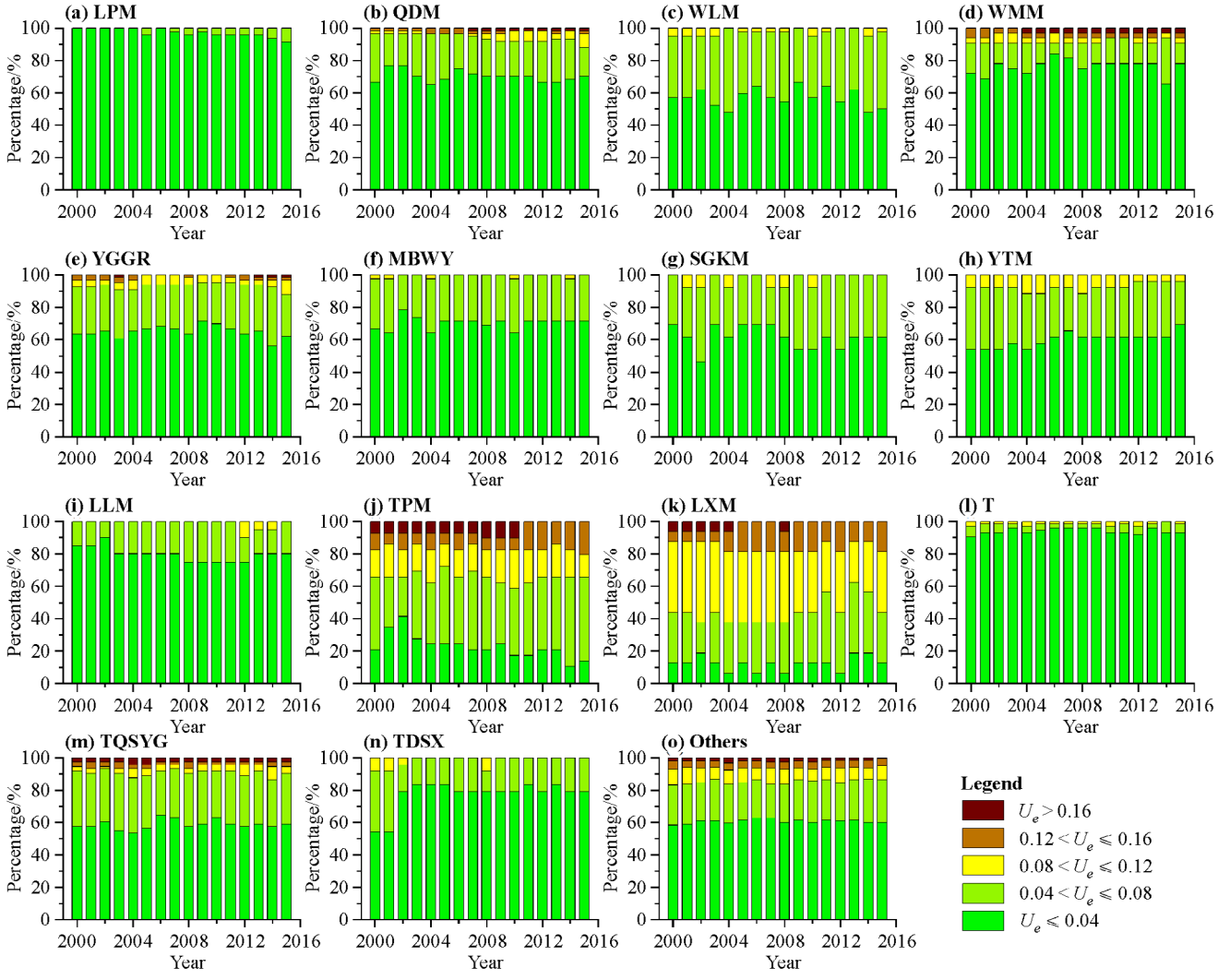


Fig. 2 Changes of the integration values of the ecosystem services at the contiguous impoverished area scale in China's poverty-stricken counties from 2000 to 2015.

Table 5 The mean of the integration value of the poverty livelihood subsystem in China's poverty-stricken counties from 2000 to 2015

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mean	0.0807	0.1203	0.1046	0.1025	0.1305	0.1262	0.1201	0.1366	0.125	0.1238	0.1227	0.1312	0.1385	0.1266	0.1243	0.1387

poverty worsening from the east region to the west region. The mild poverty counties were mainly distributed in Heilongjiang, Jilin, Anhui, Henan, Jiangxi, Hunan, Hubei provinces and Chongqing city. The extreme poverty and poorer counties were mainly distributed in Tibet, the Xinjiang Uygur Autonomous Region, the south of Qinghai Province and the west of Sichuan Province. Meanwhile, the counties in the central region with moderate poverty and general poverty, included the provinces of Inner Mongolia, Shanxi, Shaanxi, Ningxia, Guizhou, Yunnan and Guangxi. In addition, the extreme poverty and poorer poverty counties decreased from 2000 to 2015, while the general poverty or mild poverty increased. The significant changed areas were mainly Tibet, the south of Qinghai Province, the west of Sichuan Province, Chongqing, Yunnan and Guangxi.

3.2 CD between ecosystem services and poverty livelihoods

3.2.1 Spatial distribution of CD

As shown in Fig. 6, the CD value between ecosystem services and poverty livelihoods in CPC from 2000 to

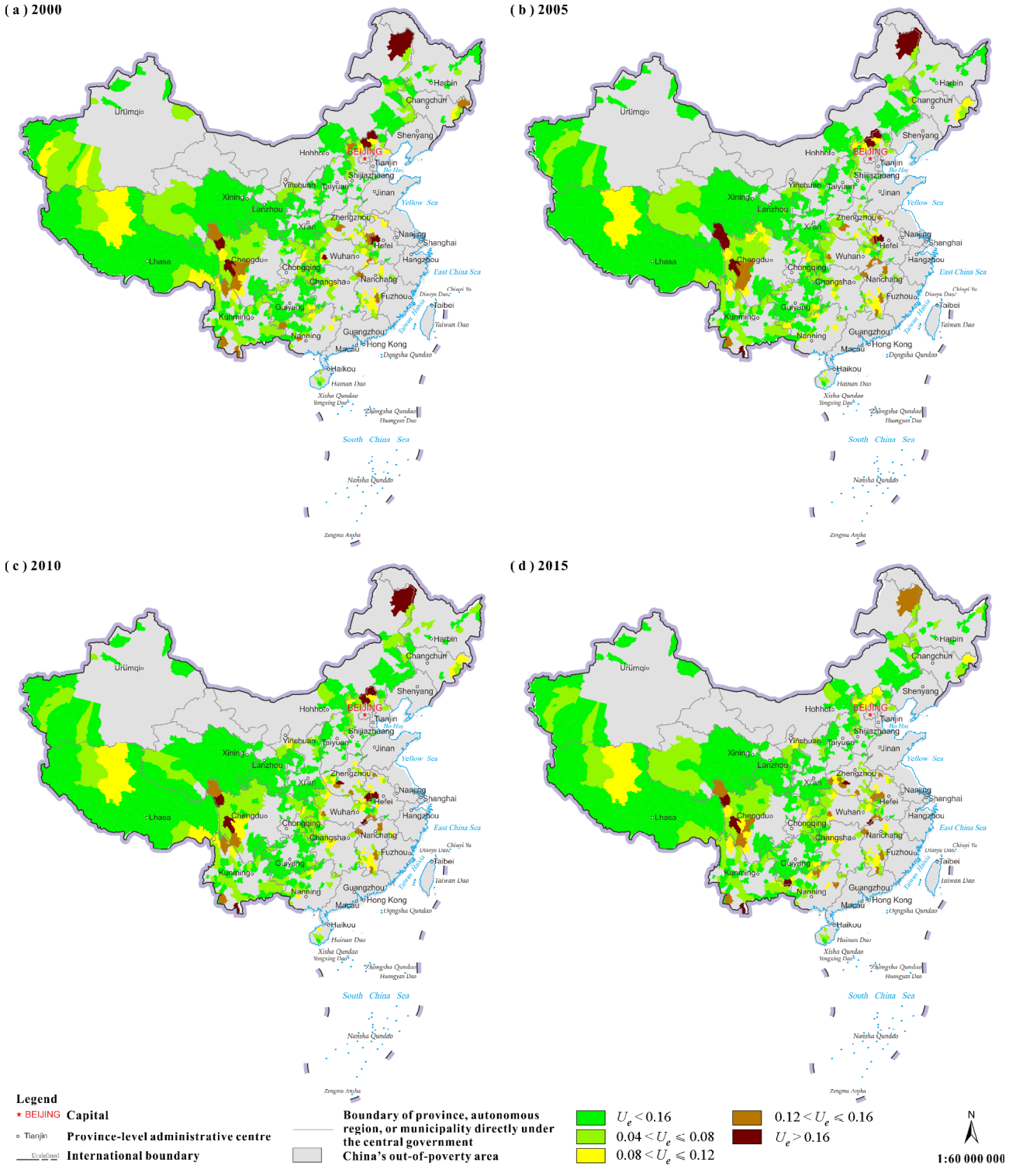


Fig. 3 Distribution pattern of the integration values of the ecosystem services subsystem in China's poverty-stricken counties from 2000 to 2015.

Table 6 The number and proportion of different integration value groups of the poverty livelihoods in China's poverty-stricken counties from 2000 to 2015

Year	Number					Proportion				
	Mild poverty	General poverty	Moderate poverty	Poorer poverty	Extreme poverty	Mild poverty	General poverty	Moderate poverty	Poorer poverty	Extreme poverty
2000	3	1	53	236	424	0.42%	0.14%	7.39%	32.91%	59.14%
2001	14	44	134	390	135	1.95%	6.14%	18.69%	54.39%	18.83%
2002	4	29	93	372	219	0.56%	4.04%	12.97%	51.88%	30.54%
2003	5	25	88	378	221	0.70%	3.49%	12.27%	52.72%	30.82%
2004	24	51	178	357	107	3.35%	7.11%	24.83%	49.79%	14.92%
2005	21	48	155	376	117	2.93%	6.69%	21.62%	52.44%	16.32%
2006	10	47	131	408	121	1.39%	6.56%	18.27%	56.90%	16.88%
2007	29	65	185	345	93	4.04%	9.07%	25.80%	48.12%	12.97%
2008	20	47	147	377	126	2.79%	6.56%	20.50%	52.58%	17.57%
2009	16	47	155	380	119	2.23%	6.56%	21.62%	53.00%	16.60%
2010	13	52	151	368	133	1.81%	7.25%	21.06%	51.32%	18.55%
2011	24	56	169	353	115	3.35%	7.81%	23.57%	49.23%	16.04%
2012	33	71	197	326	90	4.60%	9.90%	27.48%	45.47%	12.55%
2013	24	52	149	379	113	3.35%	7.25%	20.78%	52.86%	15.76%
2014	26	45	141	377	128	3.63%	6.28%	19.67%	52.58%	17.85%
2015	48	61	178	321	109	6.69%	8.51%	24.83%	44.77%	15.20%

2105 were between 0 and 1. In this paper, 717 counties were divided into 6 intervals based on the CD value to quantify the change in the CD from 2000 to 2015. From Fig. 6, we can see that the CD shows obvious spatial distribution and large variations during 2000 to 2015. There were only approximately 15% of the counties whose CD value is less than 0.5, while other approximately 85% of the counties whose CD value is greater than 0.5. The results of the CD indicate that the ecosystem services subsystem and the poverty livelihood subsystem were mainly in a gearing state or in a coordinated phase. In addition, the counties on the border between the Gansu and Qinghai provinces had the lowest CD, while the counties in Tibet, the south of Qinghai Province, the west of Sichuan Province, the Yunnan-Guizhou-Guangxi rock desertification region and the east China region had the highest CD. During 2000 to 2015, the number of counties with a CD of 0 to 0.3, 0.3 to 0.5 and 0.5 to 0.8 showed a trend of first increasing and then decreasing, while the counties whose CD were between 0.8 to 1 showed a trend of first decreasing and then increasing.

3.2.2 Trends of CD

Linear regression analysis with ordinary least squares and univariate nonlinear regression analysis were used to assess and quantify various change rates in the CD between ecosystem services and poverty livelihoods in CPC from 2000 to 2015. Figure 7 presents the distribution of 5 types of CD trend at county scale in CPC from 2000 to 2015. There were 85 counties whose CD trend increased parabolically (Type 1), accounting for 11.85% of all CPC. There were only 9 (1.26%) counties whose CD trend increased linearly (Type 2). Since there was no region with a trend of 0 in the strict sense, counties with a slope from −0.001 to 0.001 were divided into invariable regions. Thus, 98 counties whose CD were nearly unchangeable from 2000 to 2015 (Type 3), accounting for 13.67% of all CPC. Terribly, there were 525 counties (73.22%) whose CD showed a decreased trend. However, 466 (64.99%) of those counties whose CD showed a trend of first decreasing and then increasing (Type 4). Only 59 counties (8.23%) whose CD trend decreased linearly (Type 5). In addition, the counties with CD trend of type 1 or type 2 were mainly distributed in Tibet, Sichuan and Qinghai regions, while the counties with CD trend of type 5 were scattered distributed in various areas.

As a comparison, the CD trend at the contiguous impoverished area scale in CPC from 2000 to 2015 was shown in Fig. 8. The overall trend (Fig. 8(p)) of the CD presented a "U" curve change, decreased first and then increased. Except LXM (Fig. 8(k)), the CD trend of other 13 contiguous impoverished areas and non-contiguous impoverished area all showed a trend of first decreasing and then increasing. The CD trend in LXM (Fig. 8(k)) decreased linearly, however, the CD of LXM were larger than 0.85 from 2000 to 2015, representing a high-level coupling state. The TPM (Fig. 8(j)) was also at a high-level

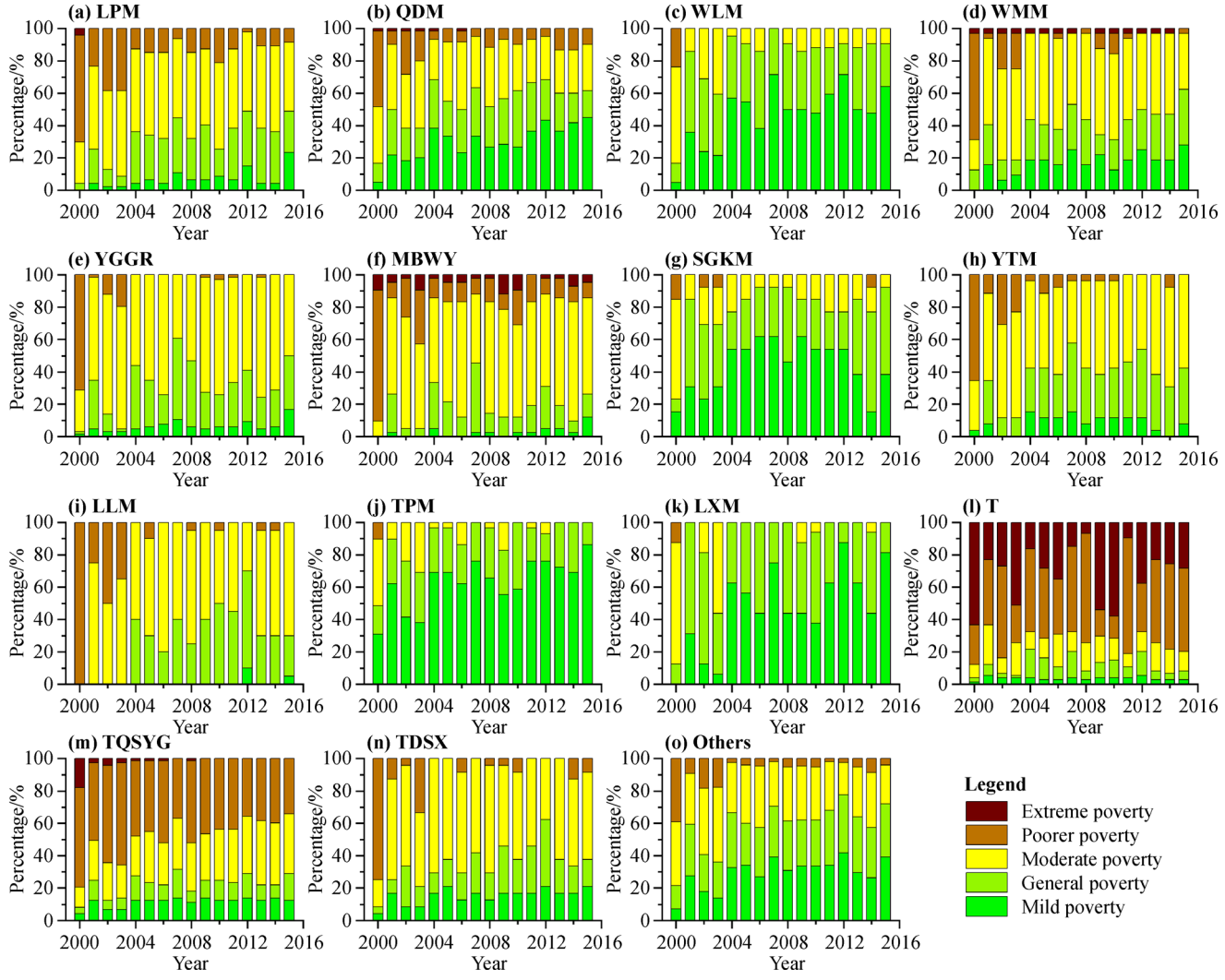


Fig. 4 Changes of poverty levels at the contiguous impoverished area scale in China's poverty-stricken counties from 2000 to 2015.

coupling state with the CD larger than 0.8. The LPM (Fig. 8(a)) and LLM (Fig. 8(i)) were at a gearing state for the CD between ecosystem services and poverty livelihoods was between 0.5 and 0.8 from 2000 to 2015. Furthermore, the CD values of QDM (Fig. 8(b)), WLM (Fig. 8(c)), WMM (Fig. 8(d)), YGGR (Fig. 8(e)), MBWY (Fig. 8(f)), SGKM (Fig. 8(g)), YTM (Fig. 8(h)), T (Fig. 8(l)), TQSYG (Fig. 8(m)), TDSX (Fig. 8(n)) and other non-contiguous impoverished area (Fig. 8(o)) from 2000 to 2015 were fluctuated around 0.8, which meant that the state was changed between gearing state and high-level coupling state.

3.3 CCD between ecosystem services and poverty livelihoods

3.3.1 Spatial distribution of CCD

As shown in Fig. 9, 717 counties were divided into 4 intervals based on the CCD value to quantify the change in the CCD from 2000 to 2015. From Fig. 9, we can see that the CCD shows obvious spatial distribution and the CCD values between ecosystem services and poverty livelihoods in CPC were all less than 0.5 from 2000 to 2015 (Except for one county in 2003). There were approximately 76% counties whose CCD values were between 0 and 0.3, and their ecosystem services subsystem and the poverty livelihood subsystem were in a low coupling coordination. While there were approximately 24% counties whose CCD values were between 0.3 and 0.5, and their ecosystem services subsystem and the poverty livelihood subsystem were in an intermediate coupling coordination (Fig. 9). In addition, the counties with low coupling coordination were mainly distributed in western China, while the counties with intermediate coupling were distributed in eastern China. According to the number of counties in different types (Fig. 9), the counties with a CCD of 0 to 0.3 showed a decreased trend, while the counties whose CCD were between 0.3 to 0.5 showed an increased trend.

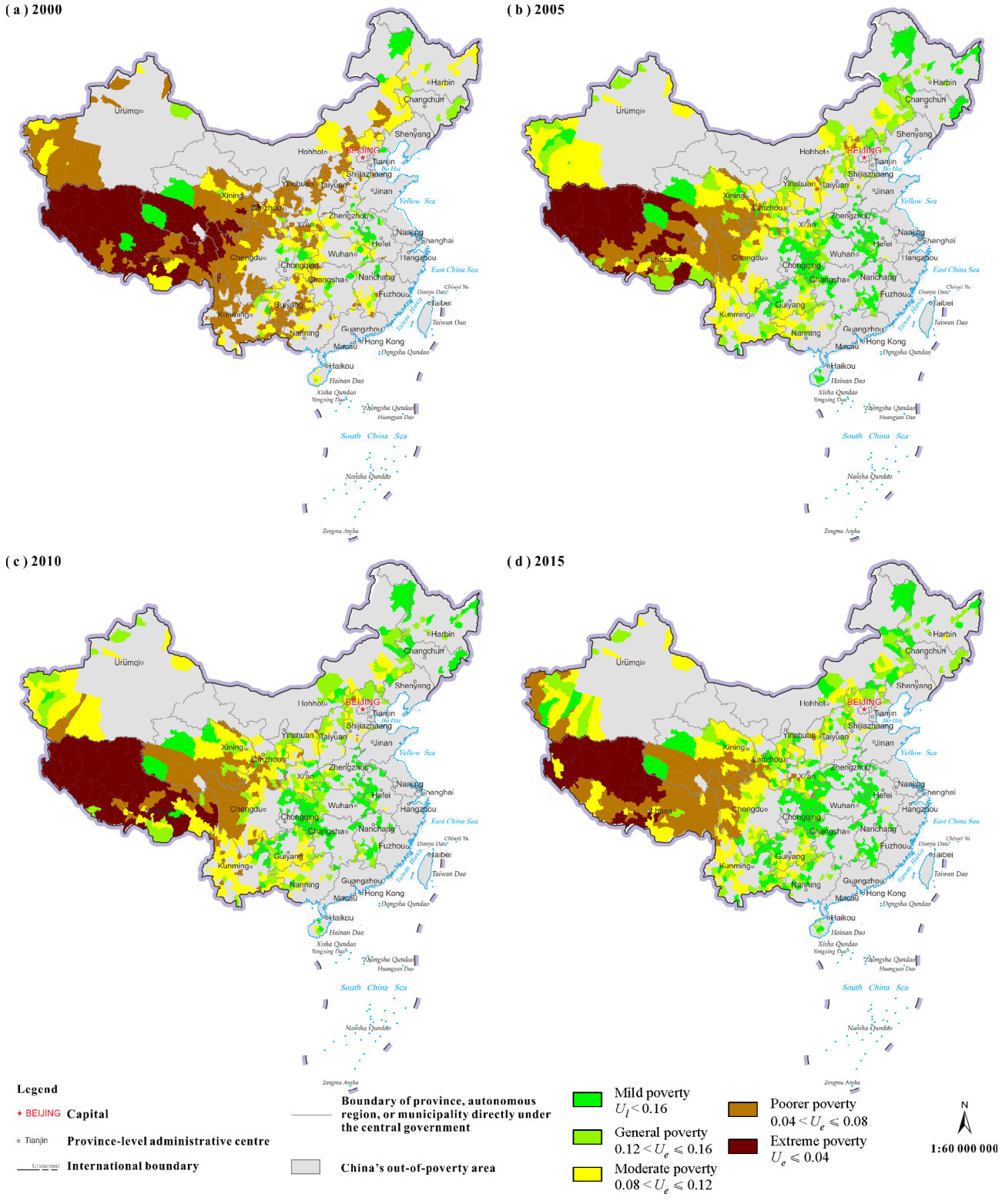


Fig. 5 Distribution pattern of poverty level in China's poverty-stricken counties from 2000 to 2015.

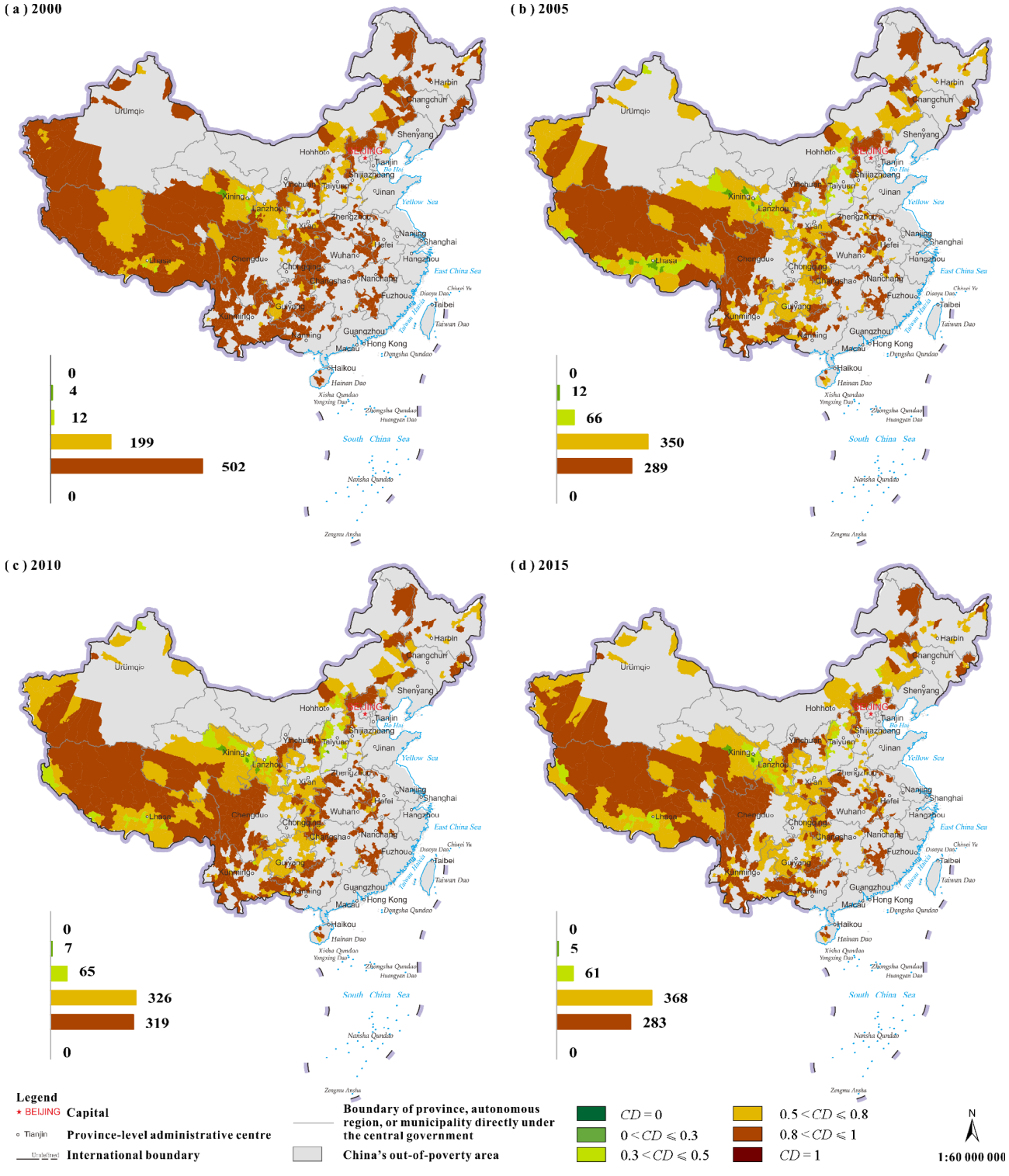


Fig. 6 Spatial distribution of CD between ecosystem services and poverty livelihoods in China's poverty-stricken counties from 2000 to 2015.

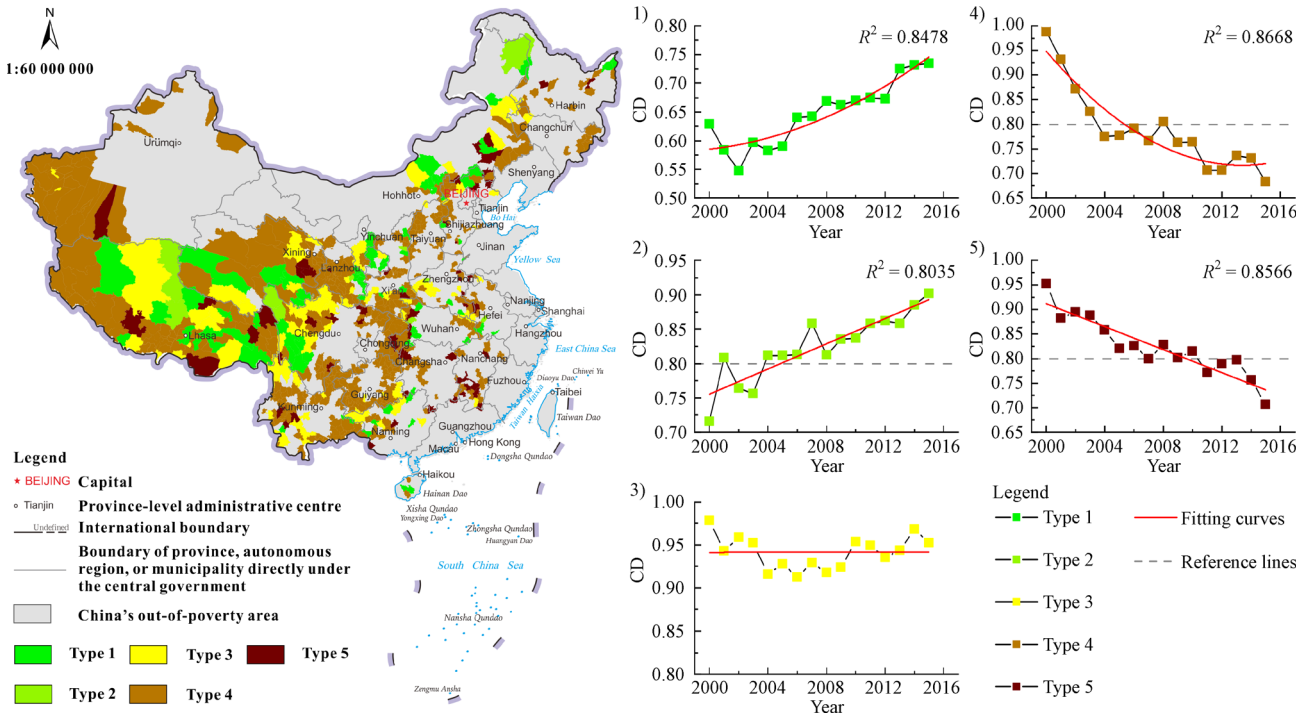


Fig. 7 The CD trend of the ecosystem services and the poverty livelihoods in China's poverty-stricken counties from 2000 to 2015.

3.3.2 Trends of CCD

Linear regression analysis and univariate nonlinear regression analysis were also used to assess and quantify various change rates in the CCD between ecosystem services and poverty livelihoods in CPC from 2000 to 2015. The distribution of 6 types of CCD trend at county scale in CPC from 2000 to 2015 was shown in Fig. 10. There were 349 counties whose CCD trend increased, accounting for 48.68% of all CPC. Among these counties, there were 155 counties (accounting for 21.62%) whose CCD showed a trend of first increasing and then decreasing (Type 1), 81 counties (11.30%) whose CCD showed a trend of first decreasing and then increasing (Type 2) and 113 counties (15.76%) whose CCD trend increased linearly (Type 3). It is worth noting that there were 329 counties whose CCD were nearly unchangeable from 2000 to 2015 (Type 4), accounting for 45.88% of all CPC. There were only 20 counties (2.79%) whose CCD showed a decreased trend with the CCD values increased first and then decreased (Type 5). While there were 19 counties (2.65%) whose CCD showed a decreased trend with the CCD values decreased first and then increased (Type 6). In addition, the counties with CCD trend of type 5 or type 6 were mainly distributed in Tibet, Xinjiang, Hebei, Inner Mongolia, Anhui, Jilin and Heilongjiang regions, while the counties with CCD trend of other types were scattered distributed in various areas.

The CCD trend at the contiguous impoverished area scale in CPC from 2000 to 2015 was shown in Fig. 11. The overall trend (Fig. 11(p)) of the CCD increased linearly with the CCD between 0.21 and 0.25. The CCD trend in LPM (Fig. 11(a)), QDM (Fig. 11(b)), WLM (Fig. 11(c)), WMM (Fig. 11(d)), YGGR (Fig. 11(e)), LLM (Fig. 11(i)), TPM (Fig. 11(j)) and TQSYG (Fig. 11(m)) were also showed an increased linearly. Among these 8 areas, except for the TPM (Fig. 11(j)), the other 7 areas with the CCD were all less than 0.3. There were five areas whose CCD showed an increased trend with CCD values increased first and then decreased, including MBWY (Fig. 11(f)), SGKM (Fig. 11(g)), YTM (Fig. 11(h)), LXM (Fig. 11(k)) and other non-contiguous impoverished area (Fig. 11(o)). Among these 5 areas, except for the LXM (Fig. 11(k)), the other 4 areas with the CCD were all less than 0.3. In contrast, the CCD in T (Fig. 11(l)) and TDSX (Fig. 11(n)) showed a trend of first decreasing and then increasing, and the CCD value was less than 0.3. The result of CCD indicated that the ecosystem services subsystem and the poverty livelihoods subsystem in TPM (Fig. 11(j)) and LXM (Fig. 11(k)) were in an intermediate coupling coordination, while in other areas were in a low coupling coordination.

3.4 Coupled characteristics of ecosystem services and poverty livelihoods

The coupling characteristic may divide into 7 types based on the combination of CD and CCD, as shown in Table 7. There were 6 coupling characteristics in this paper, namely higher conflict (low CD and low CCD), high conflict

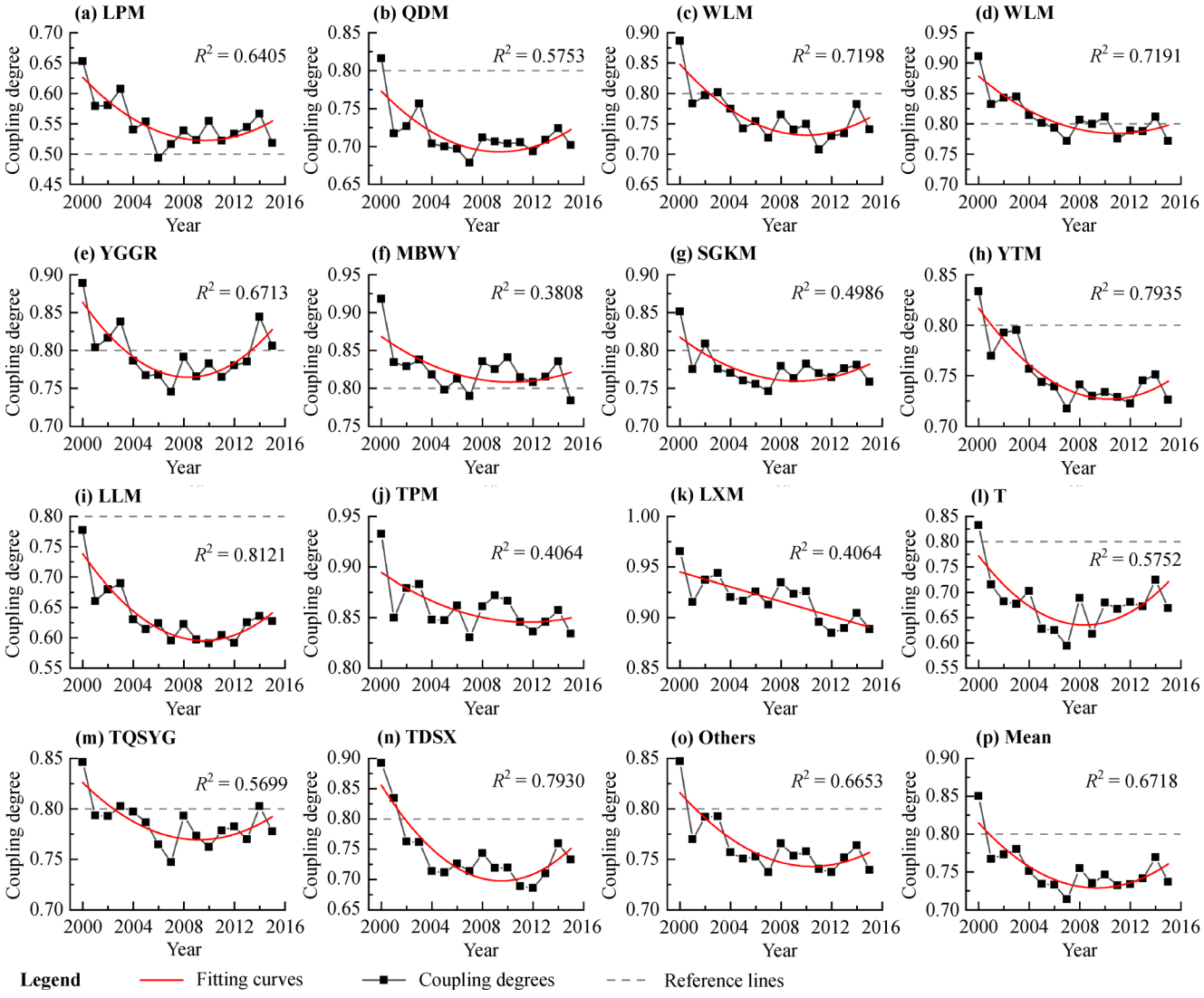


Fig. 8 The CD curve between the ecosystem services and the poverty livelihoods at the contiguous impoverished area scale in China's poverty-stricken counties from 2000 to 2015.

(intermediate CD and low CCD), intermediate conflict (high CD and low CCD), low conflict (high CD and intermediate CCD, higher CD and low CCD), low balance (higher CD and intermediate CCD), intermediate balance (higher CD and high CCD), respectively.

The number of counties by 6 coupling characteristics from 2000 to 2015 was shown in Table 8. The result indicated that the counties with intermediate conflict and low conflict were more than 70%, while the counties with low balance were less than 18% (Table 8). However, the conflict between ecosystem services and poverty livelihoods was gradually improving. The number of counties with higher conflict, high conflict, and intermediate conflict showed a trend of first increasing and then decreasing, the number of counties with low conflict showed a trend of first decreasing and then increasing, and the number of counties with low balance showed an increased trend from 2000 to 2015.

The number of counties by 6 coupling characteristics from 2000 to 2015 in contiguous impoverished areas were shown in Fig. 12. The coupling characteristics of ecosystem services and poverty livelihoods in each contiguous impoverished area was obviously differences. The coupling characteristics of counties in LPM (Fig. 12 (a)), WLM (Fig. 12(c)) and YGGR (Fig. 12(e)) were mainly intermediate conflict. The coupling characteristics of counties in QDM (Fig. 12(b)), SGKM (Fig. 12 (g)), YTM (Fig. 12(h)), LLM (Fig. 12(i)) and TQSYG (Fig. 12(m)) were mainly low conflict and intermediate conflict. The coupling characteristics of counties in YMM (Fig. 12(d)) and LXM (Fig. 12(k)) were mainly low balance and intermediate conflict. The coupling character-

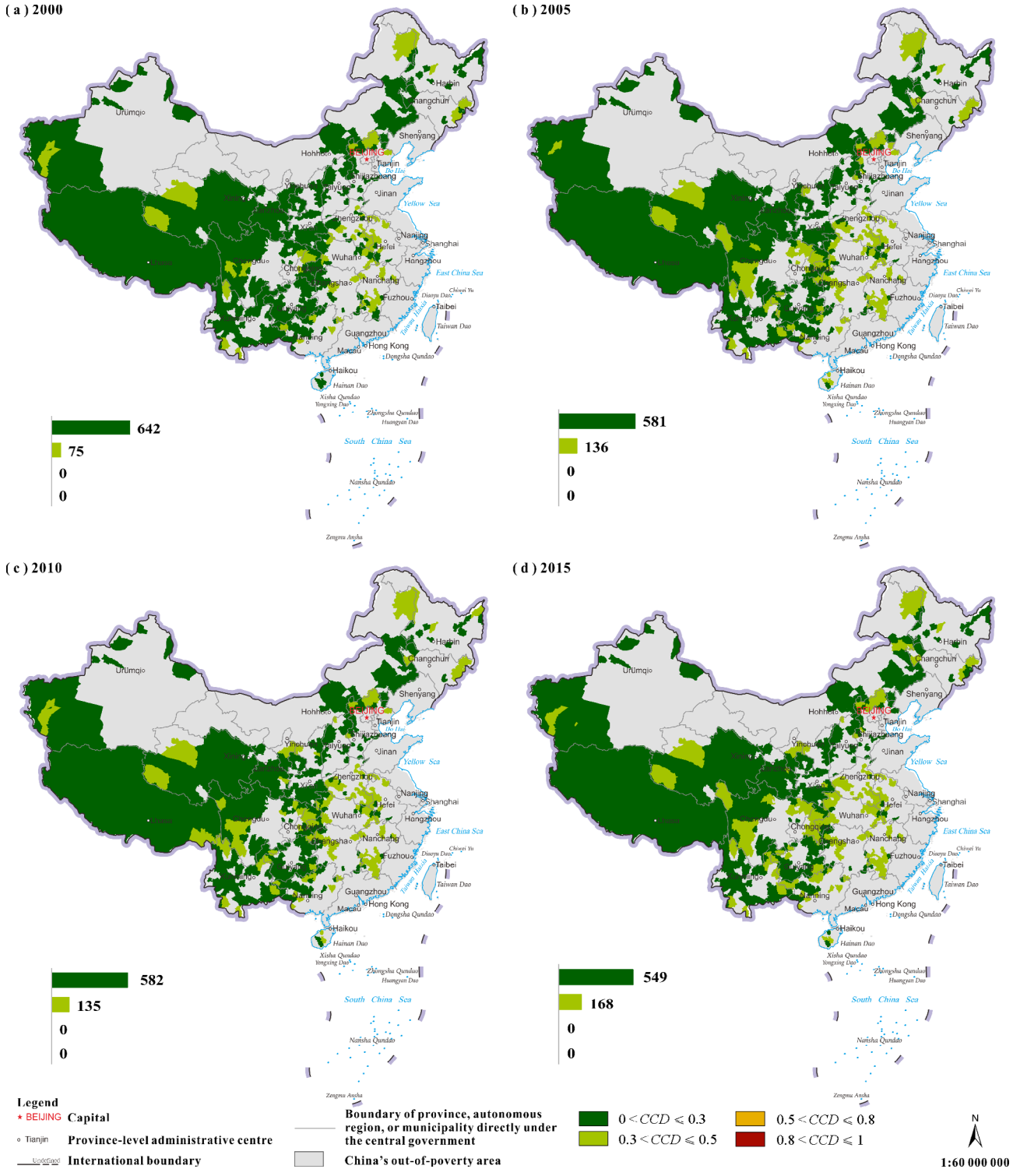


Fig. 9 Spatial distribution of CCD between ecosystem services and poverty livelihoods in China's poverty-stricken counties from 2000 to 2015.

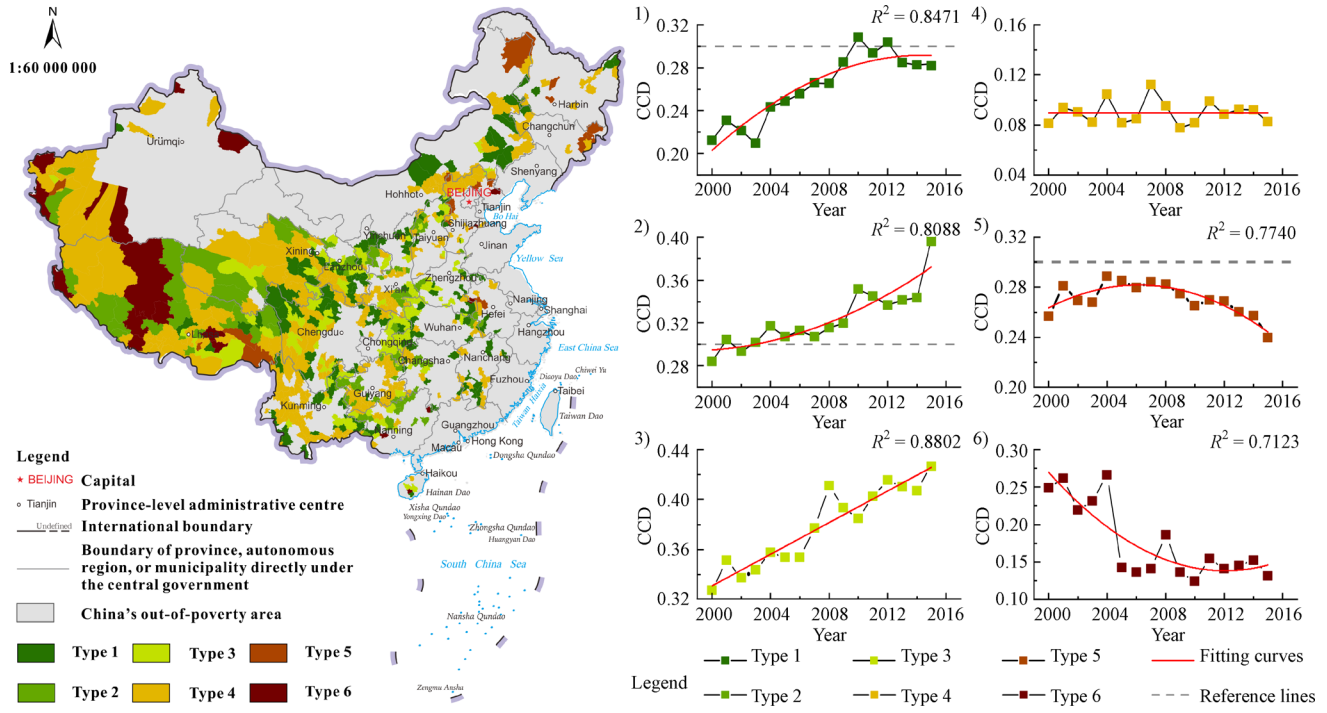


Fig. 10 The CCD trend of the ecosystem services and the poverty livelihoods in China's poverty-stricken counties from 2000 to 2015.

istics of counties in T (Fig. 12(l)) and TDSX (Fig. 12(n)) were mainly low conflict. The contiguous impoverished area with the best coupling characteristics is MBWY (Fig. 12(f)), which is mainly dominated by low balance. There were five types of coupling characteristics in TPM (Fig. 12(j)) and other non-contiguous impoverished areas (Fig. 12(o)), the different between them was the proportion of counties with higher conflict in other non-contiguous impoverished areas (Fig. 12(o)) was more less than that in TPM (Fig. 12(j)).

The spatial distribution of coupled characteristics of ecosystem services and poverty livelihoods in China from 2000 to 2015 are shown in Fig. 13. The counties with higher conflict and high conflict were mainly distributed in the Qinghai Province, Gansu Province, Shanxi Province and Xigaze region of Tibet. The counties with intermediate conflict were mainly distributed in the Heilongjiang Province, eastern Inter Mongolia, northeastern Qinghai Province, southern Shaanxi Province, southern Gansu Province, southern Xinjiang Uygur Autonomous Region, Guizhou Province and southern Tibet Autonomous Region. The counties with low conflict were mainly distributed in the central and northern Tibet, the southern Qinghai Province, southern Xinjiang Uygur Autonomous Region, and the northwestern Sichuan Province. The counties with a low balance were mainly distributed in the southwest of Sichuan, the junction of the Guangxi, Guizhou and Yunnan provinces, as well as the regions of Hubei, Anhui, Jiangxi, Hainan, northeastern Hebei and northeastern Inner Mongolia.

4 Discussion

4.1 Selection of ecosystem services and livelihoods indicators

The selection of evaluation indicators follows the principles of indicator diversity and data availability. In this paper, the evaluation factors of the ecosystem services subsystem were selected from the perspective of providing service, and the factors of livelihood subsystem were selected from five aspects: financial capital, nature capital, human capital, material capital, social capital and environment vulnerability.

The food and water supply services are important for improving rural livelihoods and reducing poverty. In this paper, 31 evaluation indicators were selected to construct the ecosystem services index subsystem. The food crops (E_{11}) and economic crops (E_{12}) provided from farmland ecosystem are the basis for maintaining the livelihood of farmers (Huq et al., 2020). The livestock products including meat (E_{41}) and poultry eggs (E_{42}) provided from grassland ecosystem are the basis for maintaining the livelihood of herdsmen. The poverty-stricken areas were mainly distributed in mountain area with rich forest, the wood products (E_{31}, E_{32}) and fruits (E_{21}) were also an important support for farmers to maintain their livelihoods (Reed et al., 2017). Water resources are indispensable for human survival, the water yield (E_{61}) was selected. In poverty-stricken areas rich in water resources, people can also obtain aquatic products (E_{51}) from wetland ecosystem

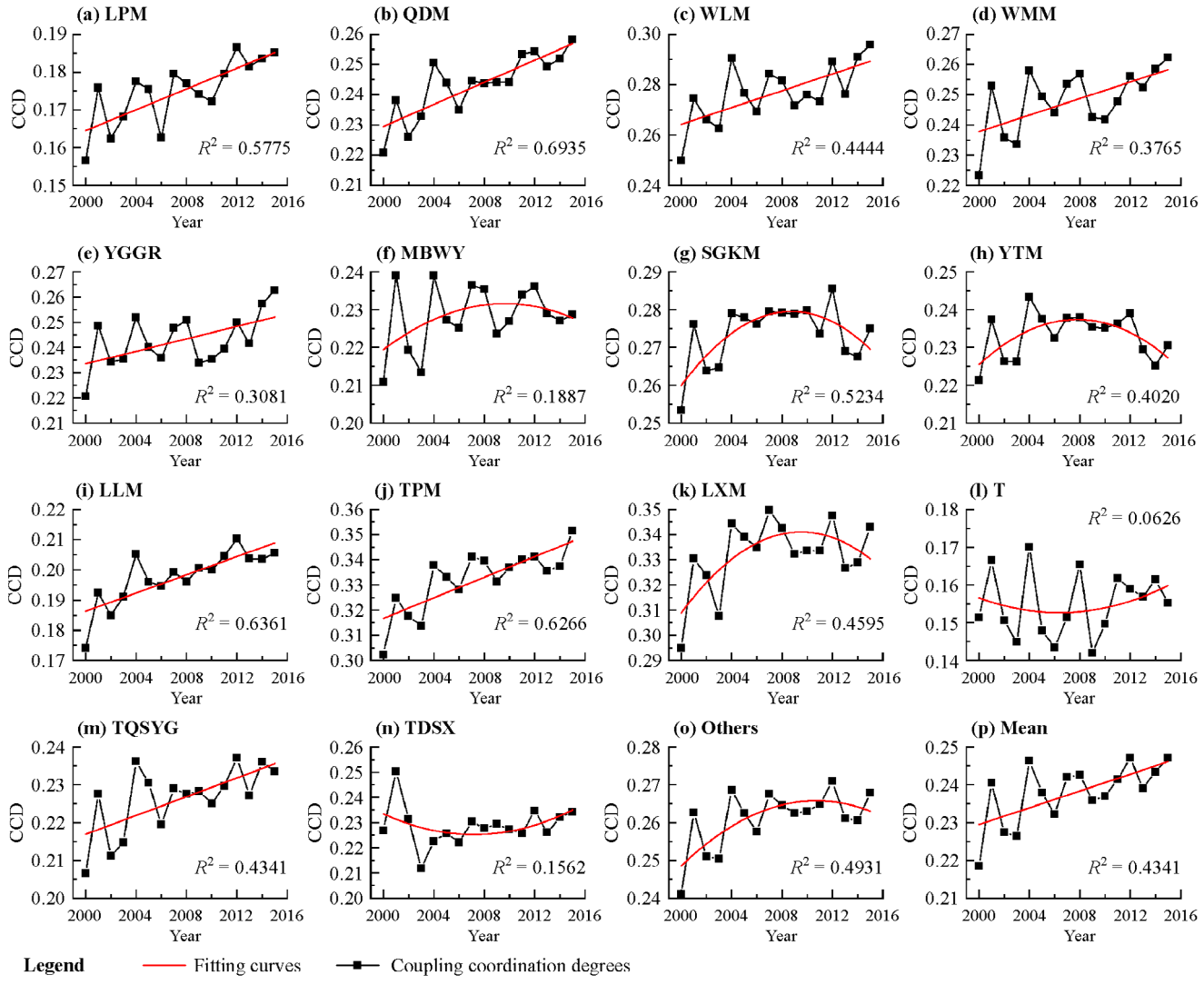


Fig. 11 The CCD curve between the ecosystem services and the poverty livelihoods at the contiguous impoverished area scale in China's poverty-stricken counties from 2000 to 2015.

Table 7 Coupling characteristics of different pairs between ecosystem services and poverty livelihoods

		CD			
		[0, 0.3] low	(0.3, 0.5] intermediate	(0.5, 0.8] high	(0.8, 1] higher
CCD	(0, 0.3) low	**Higher Conflict**	**High Conflict**	**Intermediate Conflict**	**Low Conflict**
	(0.3, 0.5) intermediate	High Conflict	Intermediate Conflict	**Low Conflict**	**Low Balance**
	(0.5, 0.8) high	Intermediate Conflict	Low Conflict	Low Balance	**Intermediate Balance**
	(0.8,1) higher	Low Conflict	Low Balance	Intermediate Balance	High Balance

to improve their livelihoods.

The disadvantage of the natural environment has limited the development potential of the poverty-stricken areas. In this paper, we selected 3 evaluation indicators including per capita cultivated area (L_{211}), grain yield per unit area (L_{212}), and average annual precipitation (L_{221}) to construct the evaluation poverty livelihoods index subsystem. The livelihoods of poverty-stricken counties in China are mainly based on agriculture and animal husbandry. For farmers, the quality of cultivated land directly leads to the harvest of crops. In the case of the same quality of cultivated land, the difference in weather conditions also affects the harvest of crops (Gregory et al., 2009; Xiong et al., 2007). A stable harvest allows residents to sell

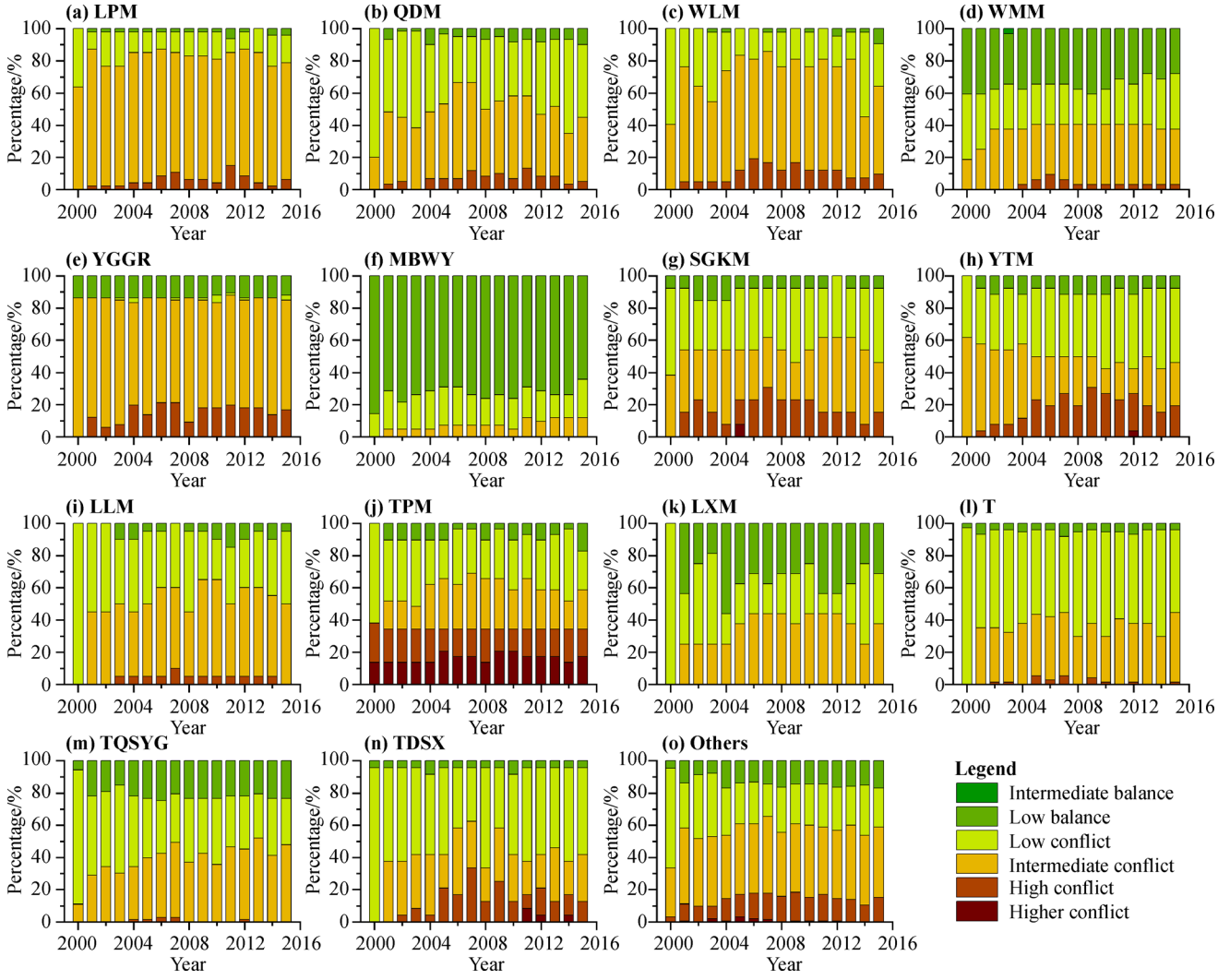


Fig. 12 Changes of coupled characteristics between ecosystem services and poverty livelihoods at the contiguous impoverished area scale in China's poverty-stricken counties from 2000 to 2015.

surplus food and increase income on the basis of meeting their own needs. Similarly, for herdsmen, the quality of cultivated land directly affects the quality of pasture, and the climatic condition is also the main factor that restricts the development of animal husbandry (Parton et al., 1995; Tao et al., 2015).

Poor terrain conditions limit the development of the poverty-stricken areas. The poverty-stricken areas in China are mainly distributed in high-altitude areas with an average elevation of 4000 m, with steep slopes and a fragile ecological environment (Fig. 1). We selected an index of slope area ratio above 15° (L_{611}) to evaluate poverty. Due to the limitation of the terrain, infrastructure construction such as roads in high-altitude areas is lagging, which has disadvantages for the exchange of information between regions. The market cannot be opened, investment funds cannot enter, and the residents of poverty-stricken areas are basically living in a self-sufficient way. Moreover, geological disasters such as landslides and mudslides also frequently occur in high altitudes, especially in southwest China. The poverty-stricken areas have experienced disaster more times than the poverty alleviation areas (Gong and Zhang, 2007; Zhou et al., 2014).

The levels of labor education and income are also important factors that restrict the development of poverty areas. We selected 8 evaluation indicators to evaluate poverty livelihood: rural residents net income (L_{111}), per capital GDP (L_{112}), urban and rural residents savings balance (L_{121}), various loan balances of financial institutions (L_{122}), rural population (L_{311}), agriculture, forestry, animal husbandry and fishery practitioners (L_{312}), secondary school students (L_{321}), and primary school students (L_{322}). Compared with the eastern regions of China, the education faculty and the educational infrastructure of the western regions are relatively weak, the geographical location is relatively remote, and the geographical environment is relatively closed. As a result, the level of education of the poverty-stricken areas in the west is

Table 8 The number and proportion of different coupling characteristics in China's poverty-stricken counties from 2000 to 2015

Year	Number						Proportion					
	Higher conflict	High conflict	Intermediate conflict	Low conflict	Low balance	Intermediate balance	Higher conflict	High conflict	Intermediate conflict	Low conflict	Low balance	Intermediate balance
2000	4	12	197	431	73	0	0.56%	1.67%	27.48%	60.11%	10.18%	0.00%
2001	5	38	321	240	113	0	0.70%	5.30%	44.77%	33.47%	15.76%	0.00%
2002	4	38	307	269	99	0	0.56%	5.30%	42.82%	37.52%	13.81%	0.00%
2003	7	34	297	286	92	1	0.98%	4.74%	41.42%	39.89%	12.83%	0.14%
2004	5	56	306	224	126	0	0.70%	7.81%	42.68%	31.24%	17.57%	0.00%
2005	12	66	321	211	107	0	1.67%	9.21%	44.77%	29.43%	14.92%	0.00%
2006	8	79	327	198	105	0	1.12%	11.02%	45.61%	27.62%	14.64%	0.00%
2007	7	92	333	174	111	0	0.98%	12.83%	46.44%	24.27%	15.48%	0.00%
2008	4	62	305	227	119	0	0.56%	8.65%	42.54%	31.66%	16.60%	0.00%
2009	7	81	313	205	111	0	0.98%	11.30%	43.65%	28.59%	15.48%	0.00%
2010	7	65	308	220	117	0	0.98%	9.07%	42.96%	30.68%	16.32%	0.00%
2011	8	75	321	202	111	0	1.12%	10.46%	44.77%	28.17%	15.48%	0.00%
2012	8	68	311	210	120	0	1.12%	9.48%	43.38%	29.29%	16.74%	0.00%
2013	5	60	340	203	109	0	0.70%	8.37%	47.42%	28.31%	15.20%	0.00%
2014	5	47	289	265	111	0	0.70%	6.56%	40.31%	36.96%	15.48%	0.00%
2015	5	61	317	217	117	0	0.70%	8.51%	44.21%	30.26%	16.32%	0.00%

relatively behind, the cultural quality of laborers is relatively low, the labor structure is irrational, and the income level is low.

The social environment also restricts the development of the poverty-stricken areas. To evaluate poverty livelihood, we selected the indicators of number of hospital beds (L_{411}) and urbanization rate (L_{511}). Incomplete infrastructure facilities and insufficiently connected markets have made it impossible to improve the quality of life of people who live in poverty-stricken areas. A relatively poor social environment restricts the development of the poverty-stricken areas. We should strengthen the social support level and increase the infrastructure services level gradually, which will have an advantage of developing the poverty-stricken areas, speeding up the progress of poverty eradication, and gradually realizing urbanization (Wang, 2010). Infrastructure includes the construction of roads, the construction of hospitals and so on. The connectivity of roads can open a relatively closed market in the poverty-stricken areas, enabling the poor areas to receive more rapid external information, while the construction of hospitals can protect the residents' physical health and improve the residents' quality of life.

4.2 Coupling analysis between ecosystem services and the poverty livelihood in the CPC

The framework of coupling between the ecosystem services subsystem and the poverty livelihood subsystem is depicted in Fig. 14, which included ecosystem, livelihood and human well-being modules. Ecosystem services improve people's livelihoods, including the following forms of capital: physical, financial, natural, human, and social. Each type of capital interacts with each other and works together to form a livelihood. The stable ecosystem services are conducive to improve livelihoods, which may reduce or prevent poverty. With livelihood improvement, people will move above the national poverty line, which means poverty alleviation. The most direct embodiment of poverty alleviation is that people's living environment is better, the society is more stable and harmonious, people's basic lives improved in essence, people's health is guaranteed, educational resources are realized and human well-being is further increased (Fisher et al., 2014).

However, poverty and ecological degradation often occur at the same time and affect each other in poverty-stricken areas. If the response is not timely or the method is inappropriate, a vicious circle of poverty-ecological degradation-poverty will be formed (Khan and Khan, 2009). How to understand the mechanism and process behind this phenomenon is the prerequisite for eliminating poverty and protecting the ecology. The key is to scientifically understand the coupling relationship between poverty livelihoods and ecosystem services. At present, managers mainly protect and regulate the stability of ecosystems through the implementation of laws and policies, which affects livelihoods and ecosystem services (Wang et al., 2017). People's livelihoods will be impacted by current policy changes. In the application process,

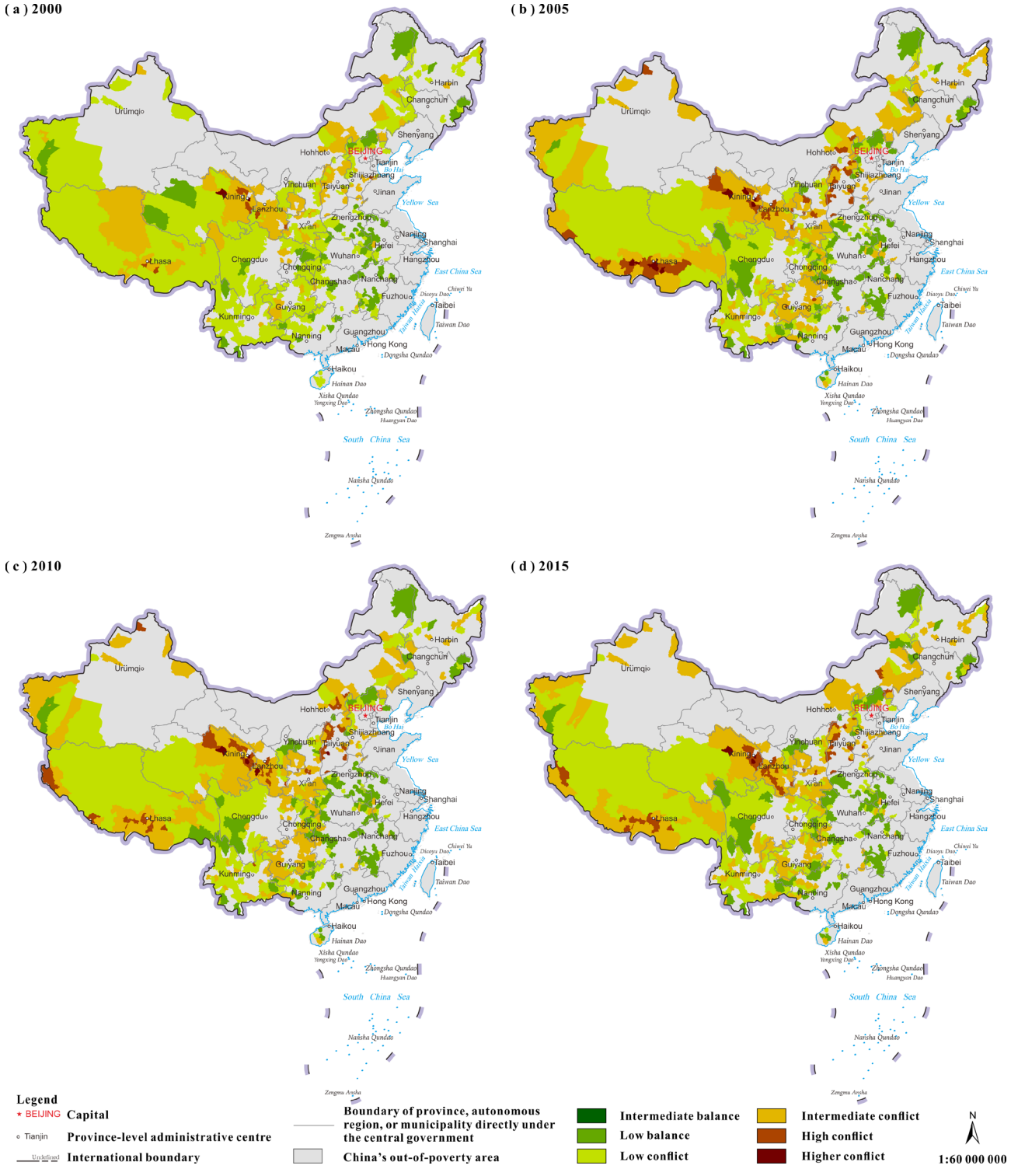


Fig. 13 Spatial distribution of coupled patterns between ecosystem services and poverty livelihoods in China's poverty-stricken counties from 2000 to 2015.

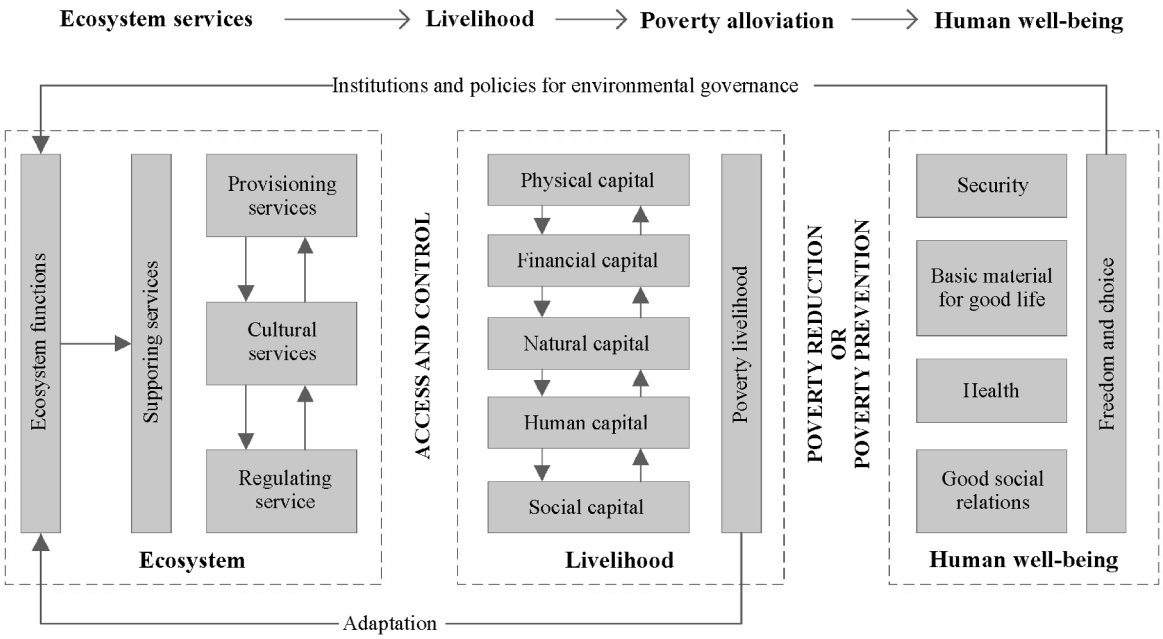


Fig. 14 The conceptual framework of coupling between the ecosystem services subsystem and poverty livelihood subsystem. Based on D'Amato et al. (2017) and Fisher et al. (2014).

human activities directly affect the stability of ecosystem structures and functions (Ai et al., 2020; Zhang et al., 2020). At the same time, the products and services provided by the ecosystem will change, thereby affecting livelihoods. The interact relationships between ecosystem services and poverty livelihoods can be quantified by CD value, and whether there is a contradiction between ecosystem services and livelihoods can be judged by CCD value. The harmonious relationship between the ecosystem services and livelihoods is the key to the poverty-stricken area in the future. To achieve this goal, there is still a long way to go in the future, for the coupling relationship between ecosystem services and poverty livelihoods in poverty-stricken area was mainly conflict.

4.3 Sustainable proposal for ecosystem services and the poverty livelihood

In our study, the mean integration values of both the ecosystem services and the poverty livelihoods will continue to increase according to the fitting trends based on historical data (Table 3 and Table 5). The spatial characteristics of ecosystem services and the poverty livelihoods were significant different (Figs. 3 and 5), especially in different China's contiguous impoverished areas (Figs. 2 and 4). From the spatial distribution of CD (Fig. 6), there were approximately 85% of the counties whose CD value is greater than 0.5. This observation indicates that the ecosystem services and the poverty livelihood are interrelated and interact in poverty-stricken areas and that the potential for maintaining a stable ecosystem to improve livelihoods is enormous. However, the CCDs of almost all 717 poverty counties are all less than 0.5 (Fig. 9). This finding implies that the development between different counties is uncoordinated. Furthermore, less than 18% poverty-stricken counties have a balanced development of ecosystem services and poverty livelihoods, while the other counties are in conflict (Table 8). The results indicate that the conflict between the regional development and the environmental protection in the poverty-stricken areas is very serious. China must make more efforts to eliminate the current conflict.

In recent years, with the Chinese government's attention on ecological issues, China has introduced several policies and regulations concerning ecological protection, such as the Sloping Land Conversion Program, the Natural Forest Conservation Program, the Three-North (for northwest China, north China, and northeast China) Forest Shelterbelt Program, the Relocation and Settlement Program, the Major National Ecological Function Zones, Major Function Oriented Zoning, and National Park. These programmes aim to improve livelihood options and alleviate poverty while reducing natural disaster risk by restoring forest, grassland and wetland (Li et al., 2018; Ouyang et al., 2016). However, the implementation of these policies and regulations temporarily broke the balance between the ecosystem services subsystem and poverty livelihood subsystems. These two subsystems must be restored from the changes resulting from the policies, and the system will be unstable until a new balance is found, as shown in Fig. 8(p), the mean of CD presented a "U" curve change, decreased first and then increased. Overall,

China's national conservation policies contributed significantly in improving the coupling coordination relationship between ecosystem services and poverty livelihood, as shown in Fig. 11(p), the mean of CCD showed an increasing trend.

In addition, from a spatial partition management perspective, different contiguous impoverished areas should optimize and improve national policies to better match the status of the region, or specifically develop policies should apply to the development of the region. The changes of CD (Fig. 8), CCD (Fig. 11) and the coupling relationship (Fig. 12) between ecosystem services subsystem and the poverty livelihoods subsystem in contiguous impoverished areas were different, the results indicate that the areas with a decreasing CD or CCD trend should learn from good policies used in other areas with an increasing CD or CCD trend.

At the same time, different county policies cannot be ignored. The counties with decreased CD trend values (59 counties, accounting for 8.23%) distributed in different contiguous impoverished areas (Fig. 7), as well as the counties with decreased CCD trend (20 counties, accounting for 2.79%) (Fig. 10). The relevant policies or laws should be implemented immediately in those counties to prevent further deterioration of the coupling relationship between ecosystem services subsystem and the poverty livelihoods subsystem.

From these discoveries, we can deduce that with the further implementation of national, regional, and county policies, the CCD value between the ecosystem services subsystem and the poverty livelihoods subsystem in CPC will continue to increase, while the CD value will be maintained in a high coupling range. The relationship between the ecosystem services subsystem and the poverty livelihoods subsystem in CPC will be more harmonious, with stable regional ecosystems, higher ecosystem services, and improved livelihoods.

4.4 Limitations and future research direction

In this paper, the coupling relationship between ecosystem services and poverty livelihoods has been evaluated in each poverty county. It's difficult to collect the data on the same evaluation indicators in different counties. It also requires data for 16 consecutive years (from 2000 to 2015), which further complicates our earlier data collection. Although we used GIS data or recalculated some data by mathematical methods to replace some missing data, data for many evaluation indicators were still not available. Therefore, when constructing the evaluation index system, many indicators were eliminated or replaced. In addition, we only consider the provisioning services, for the provisioning services provide food, fruits, energy, and water resources, which can protect people's subsistence and directly relate to poverty livelihoods. However, the regulating services provide a stable living environment for people through climate and hydrological regulation. The cultural services provide culture and appreciation value, enrich the human spirit, and maintain good social relations. The support service is to maintain the nutrient cycle of the earth's living environment through ecological, physical and chemical processes and to provide guarantees for the provisioning, regulating and cultural services (Millennium Ecosystem Assessment (EMA), 2005). In future studies, all four ecosystem services should be considered in the construction of coupling evaluation index system of ecosystem services and poverty livelihoods coupling.

In this paper, we analyzed the dynamic coupling relationship and spatiotemporal characteristics of ecosystem services and livelihoods, and determined whether there are conflicts between current ecosystem services and livelihoods. The effective measures are required for counties with conflict coupling relationship. Based on our research, the next step will be to identify the main driving factors, put forward a method of conflict resolution, and finally resolve the conflict. However, driver factors analysis needs more field survey research data to support. The workload of the investigation is very large, which needs a lot of human and financial support. Therefore, our next research needs the cooperation of the government and the support of special projects.

5 Conclusions

Based on the index system of ecosystem services and poverty livelihoods, we quantified the coupling relationship between ecosystem services and poverty livelihoods by calculating CD value and CCD value in CPC from 2000 to 2015. Then, we explored the spatio-temporal trends of the coupling relationship. The zoning of CD and CCD values in CPC were obvious. In county scale, the CD between ecosystem services and the poverty livelihood in 717 counties were mainly in a gearing state or in a coordinated phase with the CD value large than 0.5, but the CD between ecosystem services and the poverty livelihood were mainly in a low coupling coordination with CCD value less than 0.3. During 2000 to 2015, the interaction between ecosystem services and the poverty livelihood was gradually decreasing with 525 counties (73.22%) whose CD showed a decreased trend, however, the level of harmony in the ecosystem services and poverty livelihoods coupling relationship was gradually increasing, there were 349 counties whose CCD trend increased. In contiguous impoverished area scale, the overall trend of the CD presented a "U" curve change, decreased first and then increased. But for Luoxiao Mountains region with a decreased trend from 2000 to 2015. The trend of the CCD in 14 contiguous impoverished area was all increased. We also determined whether there is a conflict between ecosystem services and livelihoods. The results indicated that the coupling relationship between ecosystem services

and poverty livelihoods in CPC was mainly conflict, for the counties mainly with high CD value and low CCD value. However, the coupling relationship between ecosystem services and poverty livelihoods was gradually improving. Our findings may provide a reference for government and policy makers to formulate different policies for better implementing the targeted poverty alleviation policies in different poverty areas.

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