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RESEARCH ARTICLE

Pattern changes of ecological product trade in countries along the Belt and Road

Wenpeng Du[1,2] · Huimin Yan[2,3] · Yanzhao Yang[2,3]

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Abstract

The Belt and Road Initiative (BRI) was designed to promote economic and trade cooperation between countries along the Belt and Road (B&R), specifically by building an international trade network. Ecological resources are the basis for human survival. Countries along the B&R transform ecological resources into ecological products by production activities. These products can then be used for trade, thereby driving the countries' economic development. This study uses net primary productivity (NPP) as a unified measure of ecological products, and explores the pattern changes of ecological product trade in countries along the B&R, from 2013 to 2019 (from the BRI proposal to the outbreak of COVID-19). The purpose of the study is to reveal the impact of the BRI on the trade of ecological products. The results show that (1) the trade scale of ecological products in the B&R region has changed significantly. The total volume of traded ecological products increased from 2071.74 to 2631.00 TgC. This represented an increase of about 26.99%, or 7.41% higher than the global average. (2) The spatial distribution pattern of ecological product trade did not change significantly in countries along the B&R. However, the gravity centers of the total and net trade volume of ecological products moved 120.74 km to the northeast and 392.98 km to the southeast, respectively. (3) The trade structure of ecological products in the B&R region, six sub-regions, and most countries remained relatively stable. Only the proportion of the livestock products trade in Mongolia and the proportion of the forest products trade in Bhutan have increased significantly. This finding suggests that the strength and breadth of the construction of unimpeded trade in countries along the B&R still need to further strengthened, in order to accelerate the realization of the vision of the Green Silk Road.

Keywords Ecological products; · International trade; · Change pattern; · Net primary productivity; · The Belt and Road

Introduction

The construction of an international trade network is the core link of the Belt and Road Initiative (BRI), which is also the basis and guarantee for promoting economic prosperity and regional cooperation among countries along the Belt and Road (B&R) (Liu et al. 2018; Song et al. 2018). In 2013, the cooperation initiative of the *Silk Road Economic Belt* and *21st-Century Maritime Silk Road* (referred to as the BRI) was first put forward. Since then, China has signed more than 200 cooperation documents related to jointly building the BRI with 151 countries and 32 international organizations[1]. Up to now, the BRI has officially been in the implementation stage, and the relevant construction (with the goal of unimpeded trade in countries along the B&R) has seen the initial effectiveness materialized. For example, the completion and pre-commissioning of the China-Laos Railway now

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✉ Huimin Yan
yanhm@igsnrr.ac.cn

Wenpeng Du
duwp@sicnu.edu.cn

Yanzhao Yang
yangyz@igsnrr.ac.cn

[1] Institute of Geography and Resources Science, Sichuan Normal University, Chengdu, Sichuan 610101, China

[2] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[3] University of Chinese Academy of Sciences, Beijing 100049, China

[1] Data sources: BELT AND ROAD PORTAL (https://www.yidaiyilu.gov.cn/xwzx/roll/77298.htm)

mark the interconnection of China, Laos, and Thailand[2]. Also, the trade index of the B&R increases each year[3], and the number of China's international routes increased by nearly 50% from 2015 to 2019 (He and Wang 2021).

Most of the countries along the B&R are developing countries; their residents' lifestyles and economic development are highly dependent on ecological resources (Chen et al. 2018). Relevant studies have shown that more than 20% of the GDP in this area comes from agriculture and the associated processing industries. In fact, more than 40% of the labor force is engaged in agricultural production in some countries along the B&R (Guo 2018). This implies that the primary production sector (represented by agriculture) continues to play a dominant role in the economic development of and workers' employment in countries along the B&R. International trade is conducive to the transfer of natural resources from low-efficiency sectors to high-efficiency sectors, which can promote economic development and reduce poverty in underdeveloped regions (Ricupero 2005; Santos-Paulino 2017; Thirlwall 2009). However, the outbreak of the financial crisis in 2008 led to de-globalization, causing the dividends received by developing countries from international trade to continue to decline (Kim et al. 2020; Madhok 2021). The vision that led to the BRI being proposed was the building of an inclusive and open global trade network, one that will help countries along the B&R to solve the problem of the weak development of their primary production sectors. This was to be achieved by transforming under-utilized ecological resources into ecological products used in trade (Le Goff and Singh 2013; Nguyen 2015).

The construction of the international trade network under the background of the BRI, and especially the impact of this network, is one of the key research fields in academia. Scholars are mostly concerned about the impact of trade network construction on the economic development of countries along the B&R (Cui and Song 2019; Tong and Yi 2019). This is followed by concerns regarding the role of trade network construction in promoting energy flows among countries along the B&R (Li et al. 2021; Shuai et al. 2020; Zhang et al. 2019a). In terms of ecological products, different scholars have explored the impact of trade network construction on the flow of food, crops, and timber (Gallo et al. 2017; Zhang et al. 2019b). However, at present, relatively little is understood about the comprehensive impact of trade network construction on the flow of ecological products; even less is known about the impact of the structure changes on the trade of ecological products.

Net primary productivity (NPP) is the amount of solar energy converted into biomass by vegetation photosynthesis in the terrestrial ecosystem. Essentially, NPP is the basic resource for sustaining human and heterotrophic organisms. Therefore, NPP is regarded as the basic material form in the quantitative assessment of ecological resources, and has become the indicator reflecting an ecosystem's productivity and ecological resource flow (Du et al. 2021; Haberl et al. 2012). The assessment framework of the human appropriation of net primary production (HANPP) can convert the ecological products used in production, life, and trade into ecological resources (unified measurement by NPP) (Erb et al. 2009; Haberl et al. 2014). In recent studies, the HANPP has been widely used to estimate the intensity of human activities consuming ecological resources (Du et al. 2021; Pan et al. 2022; Wackernagel et al. 2021). Therefore, the HANPP assessment framework provides the foundational algorithm for the uniform measurement of ecological product flow.

This study refers to the HANPP assessment framework to convert the trade volume of agricultural, forestry, and animal husbandry products into the consumption of ecological resources (NPP). From the scale, spatial pattern, and structure of ecological product trade, this study explores the pattern changes of such trade in countries along the B&R, from 2013 to 2019 (from the BRI proposal to the outbreak of COVID-19). This study aims to reveal the impact of the BRI on the trade pattern of ecological products in countries along the B&R, and also attempts to provide scientific support for the future optimization of the trade pattern of ecological products among countries along the B&R.

Data and methods

Data sources

The basic data used in this study are the trade volume of agricultural, forestry, and animal husbandry products in countries along the B&R (including import data and export data). The data are sourced from the database of the Food and Agriculture Organization of the United Nations (https://www.fao.org/faostat/en/#home). The trade data of agricultural products include 13 major categories: grains, grain products, beans, roots and tubers, nuts, vegetables, fruits, feed, sugar crops, sugar products, fiber products, oil crops, and vegetable oils. The trade data of forest products include nine major categories: round wood, sawn wood, wood-based panels, fiberboard, wood pulp, charcoal, paper and paper products, wood pellets, and wood chips, particles, and residues. The trade data of animal husbandry products include six major categories: beef, pork, poultry, other meat, eggs, and dairy products.

[2] Data sources: BELT AND ROAD PORTAL (https://www.yidaiyilu.gov.cn/xwzx/hwxw/257997.htm)

[3] Data sources: BELT AND ROAD PORTAL (https://www.yidaiyilu.gov.cn/jcsjpc.htm)

Table 1 The countries of the Belt and Road (B&R) and their zones

Region	Country name
China-Russia-Mongolia	China, Mongolia, Russian Federation
Southeast Asia	Vietnam, Laos, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Brunei Darussalam, Philippines, Myanmar, Timor-Leste
South Asia	India, Pakistan, Bangladesh, Afghanistan, Nepal, Bhutan, Sri Lanka, Maldives
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan
West Asia/Middle East	Turkey, Iran, Syria, Iraq, United Arab Emirates, Saudi Arabia, Qatar, Bahrain, Kuwait, Lebanon, Oman, Yemen, Jordan, Israel, Palestinian, Armenia, Georgia, Azerbaijan, Egypt
Central and Eastern Europe	Poland, Czechia, Slovakia, Hungary, Slovenia, Croatia, Romania, Bulgaria, Serbia, Montenegro, Macedonia, Bosnia Herzegovina, Albania, Estonia, Lithuania, Latvia, Ukraine, Belarus, Moldova

Study area

The spatial range of countries along the B&R has not yet been clearly defined. As the international influence of the BRI increases, the number of countries participating in the BRI construction is also increasing. This study mainly explores the pattern changes of ecological product trade in countries along the B&R, from the time the BRI was proposed.

When the BRI was initially proposed, the official media mentioned that the spatial range of the countries along the B&R was 65 countries (Liu 2019). These countries have been most deeply affected by the BRI, and for the longest time. Therefore, this study also selects the 65 countries as the study area, and refers to the zoning standards in the *Joint Construction of Green Silk Roads: Social, Economic and Environmental Context*. The list of countries along the B&R and their divisions are shown in Table 1.

Methods

Referring to the conversion ideas and parameters between physical consumption and carbon consumption in the HANPP assessment framework, the trade volume of agricultural, forestry, and animal husbandry products is uniformly converted into the trade volume of ecological resources (NPP) in countries along the B&R. This study reveals the changes in the trade scale and spatial pattern of ecological products in countries along the B&R from two perspectives, namely, the total trade volume and the net trade volume of ecological products. The total trade volume of ecological products refers to the sum of the import volume of ecological products and the export volume of ecological products. The net trade volume of ecological products refers to the difference between the import volume and export volume of ecological products. In addition, the change in the trade structure of ecological products is revealed from two perspectives: changes in the total trade structure of ecological products and the net trade structure of ecological products.

Estimation of the import/export volume of ecological products

(1) The import/export volume of agricultural products is obtained as follows: calculate the trade volume of ecological resources based on the physical trade volume of agricultural products.

$$IEP_A = \sum_{i=1}^{n} \frac{\left[I\_AGRI_i \times \delta_i \times (1 - Mc_i) \times (1 + HF_i) \times Fc\right]}{1 - WAS_i} \quad (1)$$

$$EEP_A = \sum_{i=1}^{n} \frac{\left[E\_AGRI_i \times \delta_i \times (1 - Mc_i) \times (1 + HF_i) \times Fc\right]}{1 - WAS_i} \quad (2)$$

where IEP_A represents the import volume of agricultural products, EEP_A represents the export volume of agricultural products (unit: gC), and *I_AGRI* and *E_AGRI* represent the physical volume of imports and exports of agricultural products (unit: g), respectively. Next, δ represents the conversion factor between agricultural products and crops, *Mc* represents the moisture content (Lobell et al. 2002; Souci et al. 2000; UNSD 2018; Zhou et al. 2018; Zhu et al. 2014), *HF* represents the harvest factor (Haberl et al. 2007; Peters et al. 2014; Rosillo-Calle et al. 2015; Zhou et al. 2018), and *WAS* represents the loss rate (Gustavsson et al. 2011). Finally, *Fc* represents the conversion coefficient between biomass and carbon content, with 0.45 gC/g being the international standard (Fan et al. 2008), and *i* represents the types of agricultural products.

(2) The import/export volume of forestry products is obtained as follows: calculate the trade volume of ecological resources based on the physical trade volume of forestry products.

$$IEP_F = \sum_{i=1}^{n} \frac{I\_FOR_i \times \sigma_i \times \rho \times Fc \times 10^6}{Ur \times (1 - Ba) \times \left(1 - WAS_i\right)} \quad (3)$$

$$EEP_F = \sum_{i=1}^{n} \frac{E\_FOR_i \times \sigma_i \times \rho \times Fc \times 10^6}{Ur \times (1 - Ba) \times \left(1 - WAS_i\right)} \quad (4)$$

where IEP_F represents the import volume of forestry products, EEP_F represents the export volume of forestry products (unit: gC), and *I_FOR* and *E_FOR* represent the physical volume of imports and exports of forestry products (unit: m^3 or t), respectively. Then, σ represents the conversion coefficients to round wood (Fonseca 2010); ρ represents the wood density, with 0.50 t/m^3 being used in this study (Winjum et al. 1998); *Fc* represents the conversion coefficient between biomass and carbon content, with 0.50 gC/g being the international standard (Dixon et al. 1994). Next, *WAS* represents the loss rate in the forestry product processing, with 37.5% being used in this study (Rosillo-Calle et al. 2015); *Ur* represents the effective utilization rate of forest resources (Haberl et al. 2007); *Ba* represents the bark coefficient, with 10% being used in this study (Haberl et al. 2007); and *i* represents the types of forestry products.

(3) The import/export volume of animal husbandry products is obtained as follows: calculate the trade volume of ecological resources based on the physical trade volume of animal husbandry products.

$$\mathrm{IEP_L}=\sum_{i=1}^{n}\frac{\left(I\_LIV_i\times FCR_i\times(1+HF)\times Fc\right)}{1-WAS_i} \quad (5)$$

$$\mathrm{EEP_L}=\sum_{i=1}^{n}\frac{\left(E\_LIV_i\times FCR_i\times(1+HF)\times Fc\right)}{1-WAS_i} \quad (6)$$

where IEP_L represents the import volume of animal husbandry products, EEP_L represents the export volume of animal husbandry products (unit: gC), and *I_LIV* and *E_LIV* represent the physical volume of imports and exports of animal husbandry products (unit: g), respectively. Then, *FCR* represents the feed conversion ratio (Clark et al. 2019; Imhoff et al. 2004; Quan et al. 2018; Zhou et al. 2018), *HF* represents the harvest factor (Haberl et al. 2007; Peters et al. 2014; Rosillo-Calle et al. 2015; Zhou et al. 2018), and *WAS* represents the loss rate (Gustavsson et al. 2011). Finally, *Fc* represents the conversion coefficient between biomass and carbon content, with 0.45 gC/g being the international standard (Fan et al. 2008), and *i* represents the types of animal husbandry products.

(4) The import/export volume of ecological products is the sum of the import/export volume of agricultural, forestry and animal husbandry products.

$$IEP = IEP_A + IEP_F + \mathrm{IEP_L} \quad (7)$$

$$EEP = EEP_A + EEP_F + \mathrm{EEP_L} \quad (8)$$

where *IEP* represents the import volume of ecological products (unit: gC), and *EEP* represents the export volume of ecological products (unit: gC).

Estimation of the total/net trade volume of ecological products

(1) The total trade volume of ecological products is the sum of the import volume of ecological products and the export volume of ecological products.

$$TEP = IEP + EEP \quad (9)$$

where *TEP* represents the total trade volume of ecological products (unit: gC).

(2) The net trade volume of ecological products is the difference between the import volume and export volume of ecological products.

$$NEP = IEP - EEP \quad (10)$$

where *NEP* represents the net trade volume of ecological products (unit: gC). According to the net trade volume of ecological products, countries can be divided into the two categories of net importers of ecological products ($NEP > 0$) and net exporters of ecological products ($NEP < 0$).

Results and analysis

Changes in trade scale of ecological products

From 2013 to 2019, the total trade volume of ecological products in the B&R region increased from 2071.74 to 2631.00 TgC (an increase of about 26.99%). The net trade volume of ecological products increased from 255.58 to 402.64 TgC (an increase of about 57.54%) (Fig. 1a). From the perspective of the import and export volume of ecological products, the contribution rate of the increase in ecological product imports to the change in the total trade volume of ecological products was about 63.15%; the contribution rate of the increase in ecological product exports was about 36.85% (Fig. 1b). From the regional perspective, the contribution rate of the total trade increment of ecological products in China-Russia-Mongolia was about 37.86%, and the contribution rates of Southeast Asia and Central and Eastern Europe were similar, at 21.52% and 21.38%, respectively. The contribution rates of West Asia/Middle East, South Asia, and Central Asia were all less than 10%, among which the contribution rate of Central Asia was only 1.90% (Fig. 1c).

From 2013 to 2019, the total trade volume of ecological products increased in most countries (60) along the B&R; those increases were mostly between 0 and 50%. The total trade volume of ecological products in Bhutan,

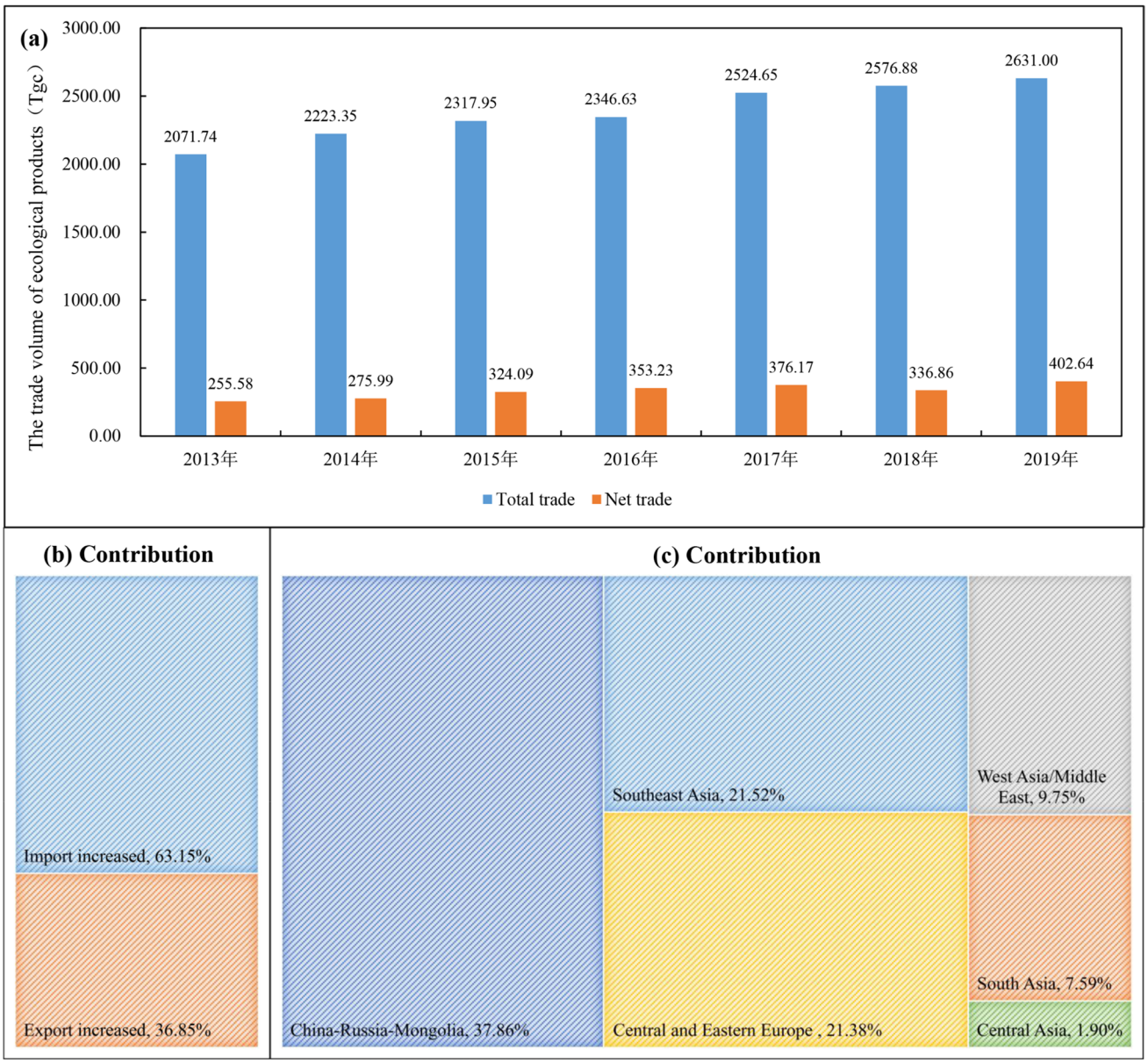

Fig. 1 Changes in the total trade and net trade volume of ecological products in the B&R, and analysis of the contribution to changes in the total trade volume of ecological products (2013–2019)

Nepal, Cambodia, Mongolia, and Laos increased by more than 100% (Fig. 2a). In terms of sub-regions, the increases of the total trade volume of ecological products in West Asia/Middle East, South Asia, and Southeast Asia were 15.88%, 19.05%, and 22.44%, respectively. These increases were lower than the average level of the whole B&R region (26.99%). Oppositely, the increases of the total trade volume of ecological products in Central Asia, China-Russia-Mongolia, and Central and Eastern Europe were 27.22%, 35.35%, and 36.11%, respectively, increases which were higher than the average level of the whole B&R region (26.99%) (Fig. 2a). The ratio of the numbers of countries whose net trade volume of ecological products were increasing or decreasing was 4:1 in the B&R. Separately, the spatial distribution had no obvious regularity. Countries whose net trade volume increased in the range of from 0 to 25% were the most concentrated, accounting for about one-third of the B&R countries (Fig. 2b). In terms of sub-regions, the net trade volume of ecological products in Central Asia and Southeast Asia showed negative growth, with decreases of 39.03% and 5.49%, respectively, while other regions showed positive growth. The net trade volume of ecological products in South Asia increased by 198.17%, a figure which was much higher than that of other regions (Fig. 2b).

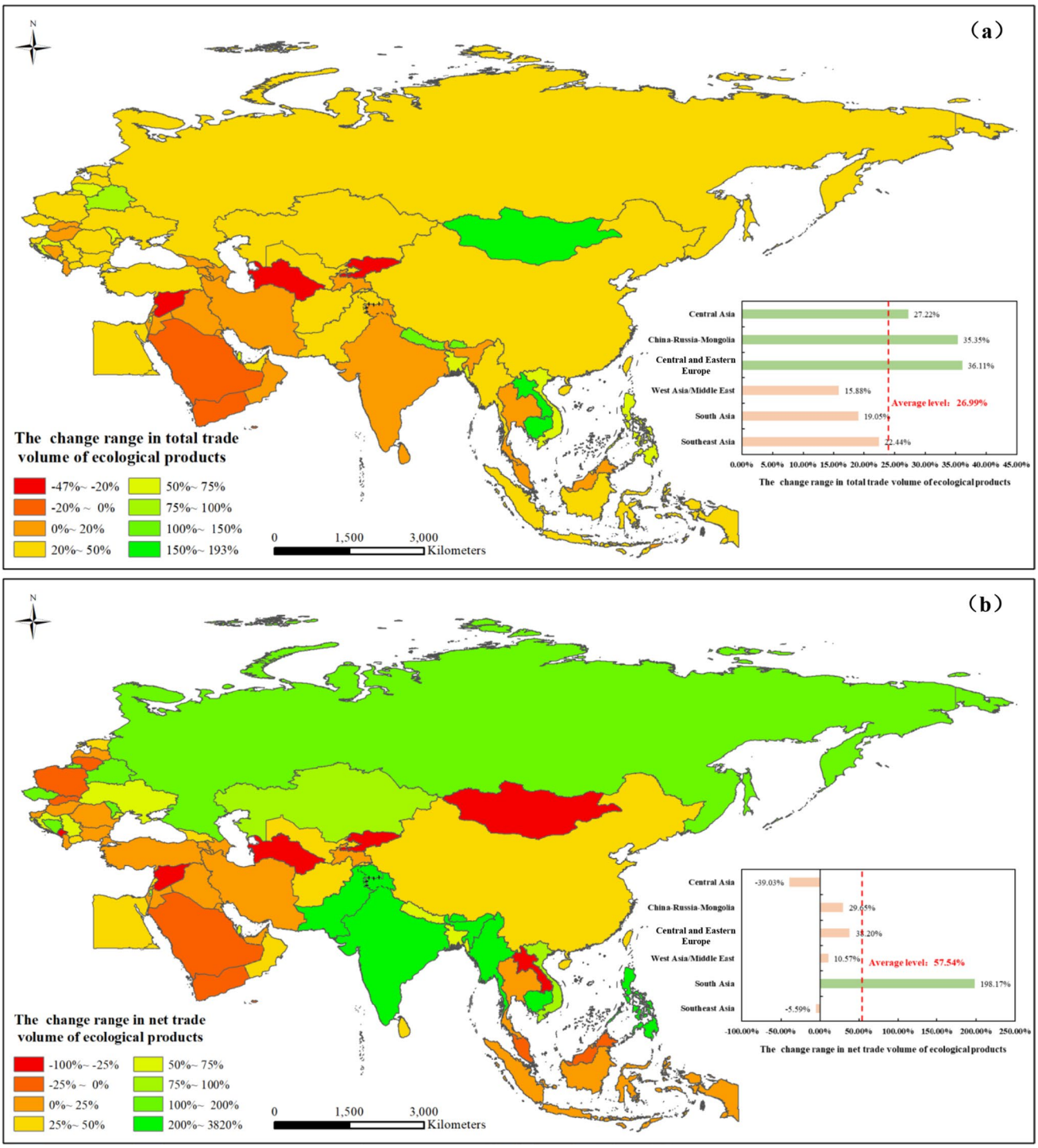

Fig. 2 Changes in the total trade and net trade volume of ecological products in countries and six sub-regions along the B&R (2013–2019) (**a** total trade volume, **b** net trade volume)

Changes in the spatial pattern of ecological product trade

From 2013 to 2019, the spatial distribution pattern of both the total trade volume and net trade volume of ecological products in the countries along the B&R did not change significantly (Fig. 3; Table 2). Based on the spatial distribution pattern of the total trade volume of ecological products in the countries along the B&R, the total trade volume of ecological products in China accounted for more than 20% of the whole B&R

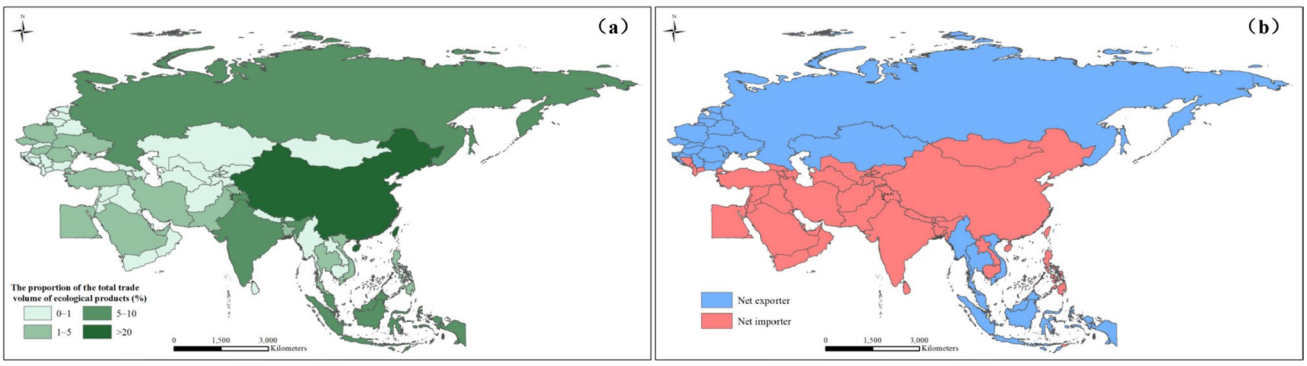

Fig. 3 Spatial distribution of ecological products in countries along the B&R in 2019 (**a** the ratio of ecological products total trade volume, **b** net importers/exporters of ecological products)

Table 2 Hierarchical statistical table of spatial pattern of total trade and net trade volume of ecological products in countries along the B&R

	2013	2014	2015	2016	2017	2018	2019
Share of total trade volume							
0~1%	Maldives, Brunei Darussalam, Timor-Leste, Bhutan, Mongolia, Montenegro, Albania, Armenia, Macedonia, Palestinian, Turkmenistan, Bahrain, Kyrgyzstan, Georgia, Moldova, Cambodia, Qatar, Laos, Nepal, Tajikistan, Bosnia Herzegovina, Azerbaijan, Afghanistan, Lebanon, Kuwait, Oman, Syria, Sri Lanka, Estonia, Serbia, Croatia, Jordan, Myanmar, Uzbekistan, Slovenia, Yemen, Iraq, Lithuania, Israel, Belarus, Slovakia, Latvia, Bulgaria, Kazakhstan	+Singapore	-	-	-	−Kazakhstan	+Kazakhstan
1~5%	Singapore, Bangladesh, Hungary, Philippines, Pakistan, Czechia, Romania, United Arab Emirates, Iran, Saudi Arabia, Egypt, Poland, Vietnam, Turkey, Ukraine, Thailand	−Singapore	-	-	-	+Kazakhstan	−Kazakhstan
5~10%	Russian Federation, Malaysia, India, Indonesia	-	-	-	-	-	-
>20%	China	-	-	-	-	-	-
Net exporter/net importer							
Net exporter	Indonesia, Malaysia, Ukraine, Russian Federation, Thailand, Romania, Bulgaria, Hungary, Latvia, Belarus, Kazakhstan, Poland, Czechia, Lithuania, Slovakia, Serbia, Estonia, Croatia, Laos, India, Myanmar, Moldova, Cambodia	−India − Cambodia +Slovenia +Vietnam	—Myanmar	-	-	-	+ Myanmar—Laos
Net importer	Bhutan, Timor-Leste, Slovenia, Montenegro, Maldives, Brunei Darussalam, Mongolia, Bosnia Herzegovina, Palestinian, Macedonia, Vietnam, Albania, Armenia, Bahrain, Philippines, Georgia, Turkmenistan, Kyrgyzstan, Qatar, Nepal, Pakistan, Oman, Tajikistan, Sri Lanka, Lebanon, Kuwait, Azerbaijan, Jordan, Afghanistan, Syria, Uzbekistan, Yemen, Singapore, Israel, Iraq, United Arab Emirates, Bangladesh, Turkey, Iran, Saudi Arabia, Egypt, China	+India + Cambodia – Slovenia −Vietnam	+Myanmar	-	-	-	—Myanmar + Laos

"-" indicates that the list of countries is unchanged from the last year; "—country name" indicates that the number of countries decreased, compared with the last year; and "+country name" indicates that the number of countries increased, compared with the last year.

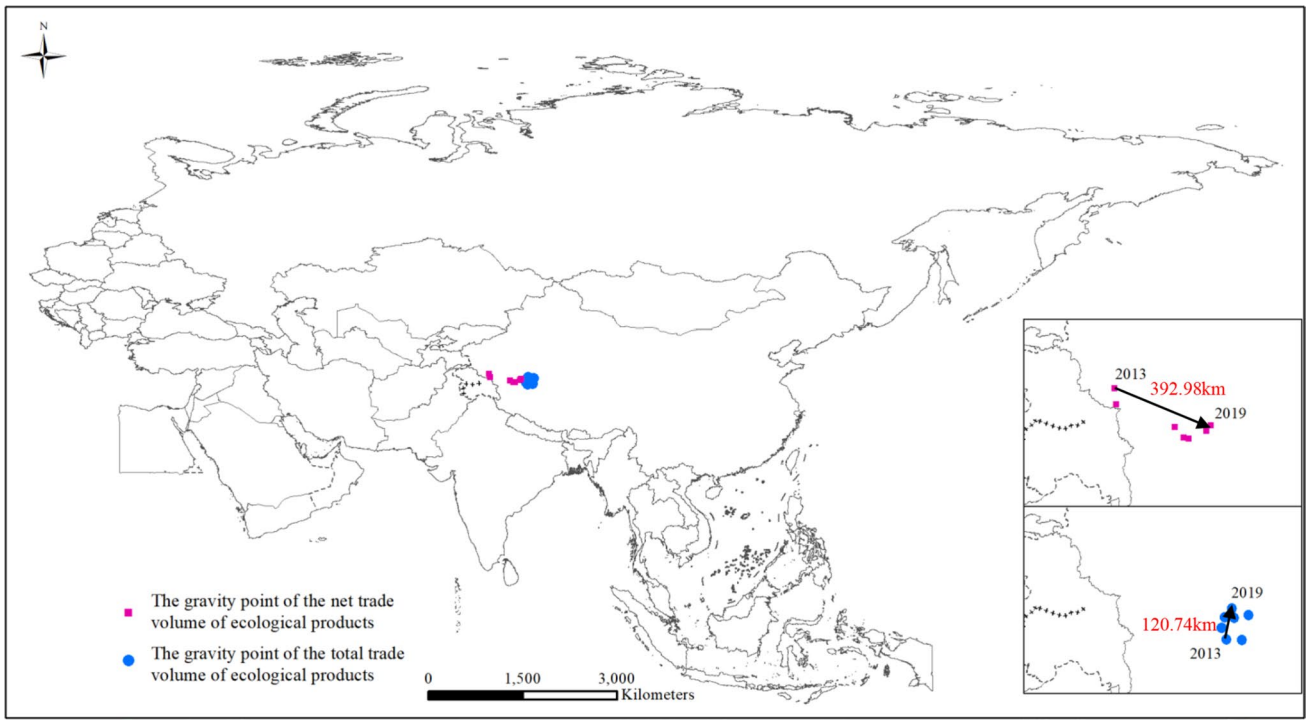

Fig. 4 Spatial distribution of gravity points of the total trade and net trade volume of ecological products in countries along the B&R (2013–2019)

region, which was more than twice that of other countries. The total trade volume of ecological products for nearly 70% of the countries along the B&R accounted for no more than 1% of the whole B&R region (Fig. 3a). Only Singapore and Kazakhstan changed in the classification of the proportion of total trade volume of ecological products, while the classification in other countries was unchanged from 2013 to 2019 (Table 2). Based on the spatial distribution pattern of the net importers/exporters of ecological products, the net exporters of ecological products were mainly distributed in Central and Eastern Europe and Southeast Asia, while the net importers of ecological products were distributed in all sub-regions (Fig. 3b). From 2013 to 2019, the net trade status in India, Cambodia, Slovenia, Laos, Vietnam, and Myanmar changed. Among them, India, Cambodia, and Laos changed from being net exporters to being net importers of ecological products, while Slovenia and Vietnam changed from being net importers to being next exporters. Myanmar changed from being a net exporter of ecological products to being a net importer and then back to being a net exporter (Table 2).

According to the spatial distribution of the gravity center of the total trade volume and net trade volume, the gravity center was always in China from 2013 to 2019. However, the gravity centers of the total and net trade volume of ecological products moved 120.74 km to the northeast and 392.98 km to the southeast, respectively. Compared with the change of the gravity center of the total trade volume of ecological products, the changes of the gravity center of the net trade volume of ecological products were more obvious (Fig. 4). Combining with Fig. 2, the direct reason of the move of the gravity center of ecological product trade volume can be analyzed. The growth rate of the total trade volume in the three northern regions (China-Russia-Mongolia, Central and Eastern Europe, Central Asia) was greater than that in the three southern regions (West Asia/Middle East, South Asia, Southeast Asia), so the gravity center of the total trade volume moves to the northeast, and the growth rate of the net trade in South Asia was much higher than that of other regions, so the gravity center of the net trade volume moves to the southeast.

Changes in the trade structure of ecological products

From the perspective of total trade volume of ecological products

From 2013 to 2019, the trade structure of ecological products remained relatively stable in the whole B&R region, with the ratio of agricultural, forestry, and animal husbandry products at about 6:3:1 (Fig. 5a). Differences existed in the trade structure of ecological products among the sub-regions along the B&R, but in most of the regions, agricultural products had the highest proportion

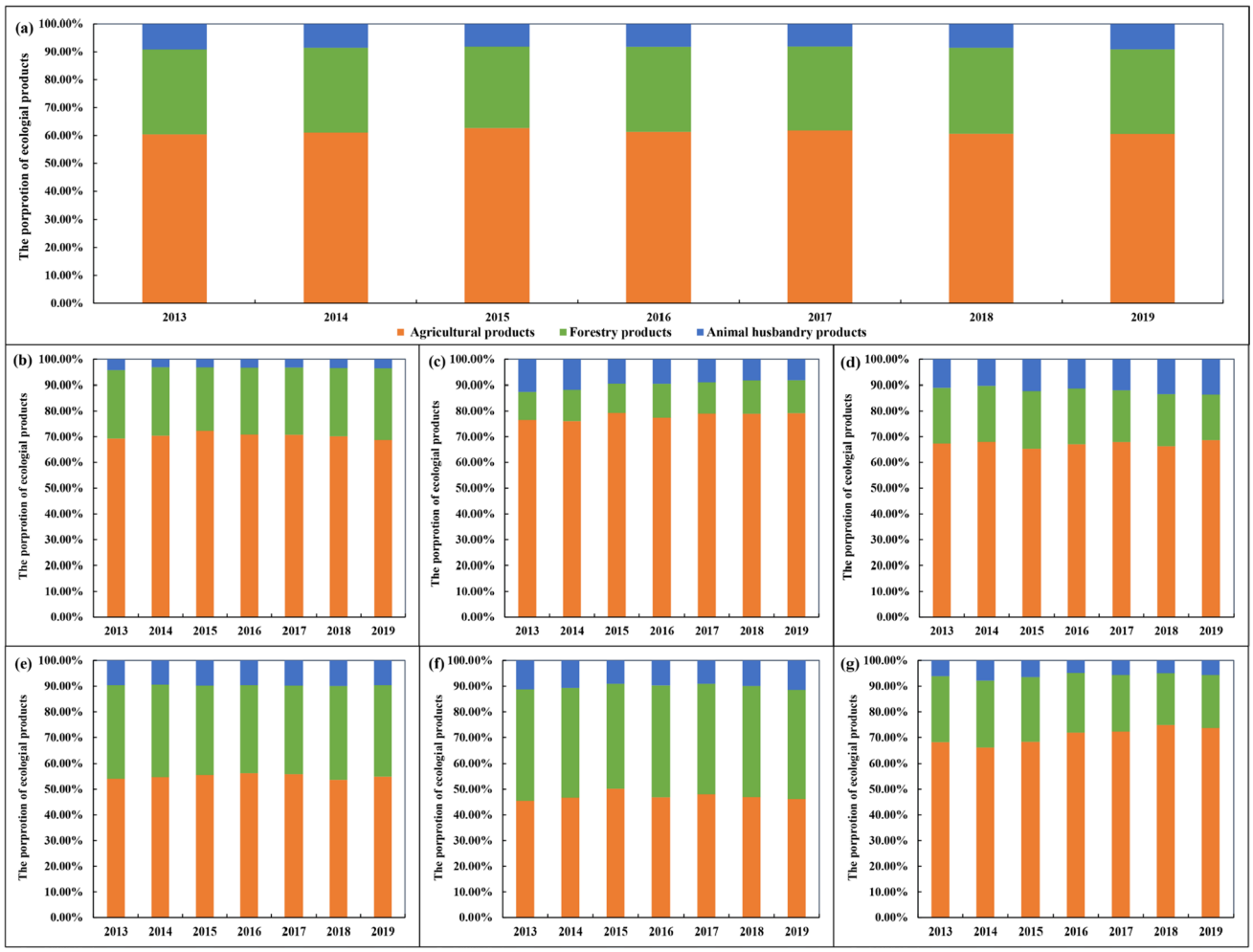

Fig. 5 Structure of total trade volume of ecological products in the region and sub-region of the B&R (2013–2019) (**a** whole region, **b** Southeast Asia, **c** South Asia, **d** West Asia/Middle East, **e** Central and Eastern Europe, **f** China-Russia-Mongolia, **g** Central Asia)

of the total trade volume. For example, the proportions of the total trade volume of agricultural, forestry, and animal husbandry products in Southeast Asia, South Asia, West Asia/Middle East, and Central and Eastern Europe remained at the levels of 7:2.5:0.5, 8:1:1, 7:2:1, and 5.5:3.5:1, respectively (Fig. 5b, c, d, e). The total trade volume of agricultural products and forestry products in China-Russia-Mongolia accounted for an equal share, with each accounting for 4.5 shares; animal husbandry products accounted for one share (Fig. 5f). The trade structure of ecological products in Central Asia did change; specifically, the proportion of agricultural, forestry, and animal husbandry products changed from 7:2.5:0.5 in 2013 to 7.5:2:0.5 in 2019 (Fig. 5g).

Compared with 2013, the trade structure of ecological products in most countries along the B&R had not changed significantly in 2019 (Fig. 6). For example, (1) the trade volume of agricultural products accounted for more than 40% of the total, and was mainly concentrated at the level of 40–80% in most countries. (2) The trade volume of forestry products accounted for less than 50% of the total, and was mainly concentrated at the level of 0–30% in most countries. (3) The trade volume of animal husbandry products accounted for less than 30% of the total, and was mainly concentrated at the level of 0–20% in most countries.

From 2013 to 2019, the trade structure of ecological products in Mongolia, Bhutan, and the five Central Asian countries had changed significantly (Fig. 6). The proportion of animal husbandry products in the total trade volume in Mongolia increased from 14.21 to 46.40%; the proportion of forestry products in the total trade volume in Bhutan increased from 8.12 to 68.68%. The proportion of the trade volume of agricultural products changed from more than 50% of the total to more than 60% in all Central Asian countries, and the proportion in each country increased.

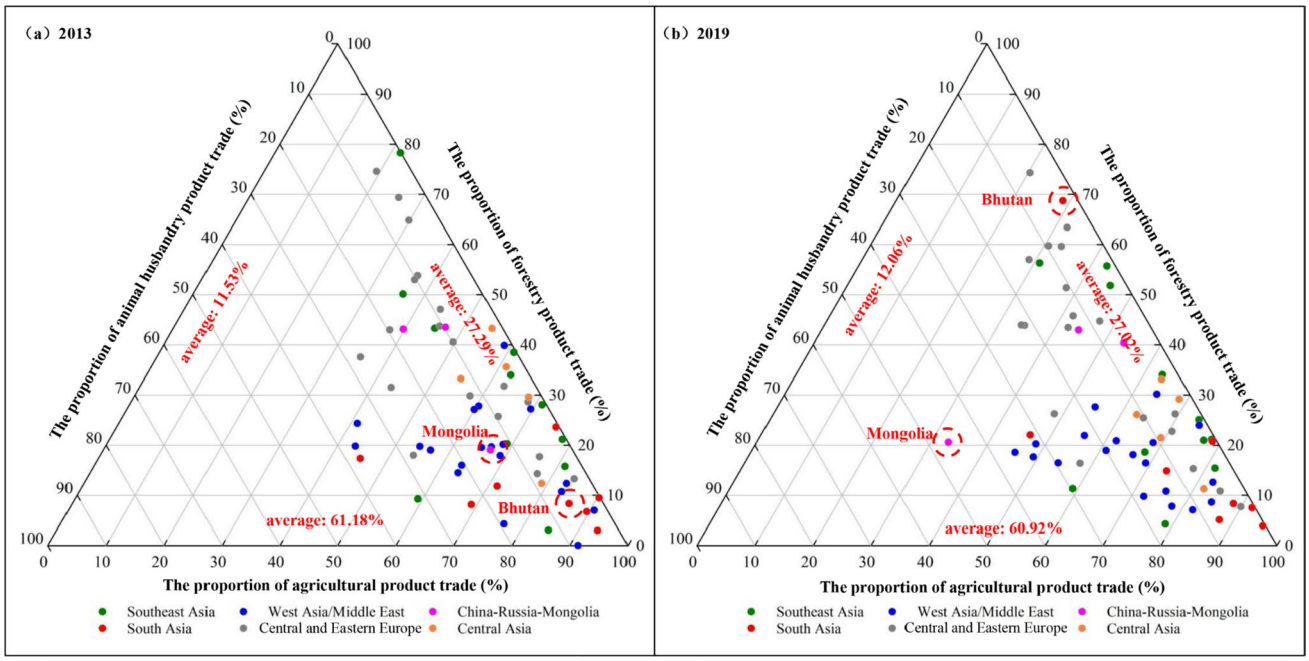

Fig. 6 The structure of total trade volume of ecological products in countries along the B&R (**a** in 2013, **b** in 2019)

From the perspective of net trade volume of ecological products

Compared with 2013, there were no obvious change in the trade structure of ecological products in the whole B&R region and six sub-regions in 2019. The agricultural products, forestry products, and animal husbandry products of the whole B&R region were in net import, and the trade structure of ecological products in West Asia/Middle East and China-Russia-Mongolia was the same as that of the B&R whole region (Fig. 7a, d, f). In contrast, the three types of ecological products in Central and Eastern Europe were all in net export (Fig. 7e). Southeast Asia was in net export of agricultural and forestry products, while animal husbandry products was in net import (Fig. 7b); South Asia was in net import of agricultural and forestry products, while animal husbandry products were in net export (Fig. 7c); Central Asia was in net export of agricultural products, while forestry and animal husbandry products were in net import (Fig. 7f).

Compared with 2013, the trade structure of ecological products in 50 countries along the B&R has not changed in 2019. Among the 15 countries whose trade structure of ecological products has changed, 10 countries have changed towards the increasing net import, and 5 countries have changed towards the increasing net export (Fig. 8a, b). By 2019, more than half of the countries (33) were in net import of the three types of ecological products, mainly concentrated in West Asia/Middle East. Only three countries were in net export of the three types of ecological products, namely, Thailand, Latvia, and Ukraine (Fig. 8b).

Discussion

The growth rate of the total trade volume of ecological products along the B&R was higher than the global average during the study period. From 2013 to 2019, the growth rate of ecological product trade along the B&R was 7.41% higher than that of the global average level. In fact, the growth rate in the B&R was higher than the global annual growth rate in other years, except 2016 (Fig. 9). This finding shows that the proposed BRI and the implementation of unimpeded trade have promoted trade interoperability among countries along the B&R, effectively alleviating the de-globalization of international trade.

If the relevant data of the BRI implementation and previous studies are combined to analyze the changes in the trade scale and structure of ecological product in countries along the B&R, the results can reflect the positive impact of the construction of the global trade network under BRI.

(1) The BRI proposal has led to a sharp increase in the number of China-Europe railway express trains (from 80 trains in 2013 to 8,225 trains in 2019[4]), which in turn has accelerated the trade between China and Europe. Due to the impact of the China-Europe Railway Express, the growth rate of the total trade volume of ecological products in China-Russia-Mongolia and

[4] Data sources: BELT AND ROAD PORTAL (https://www.yidaiyilu.gov.cn/xwzx/gnxw/223960.htm)

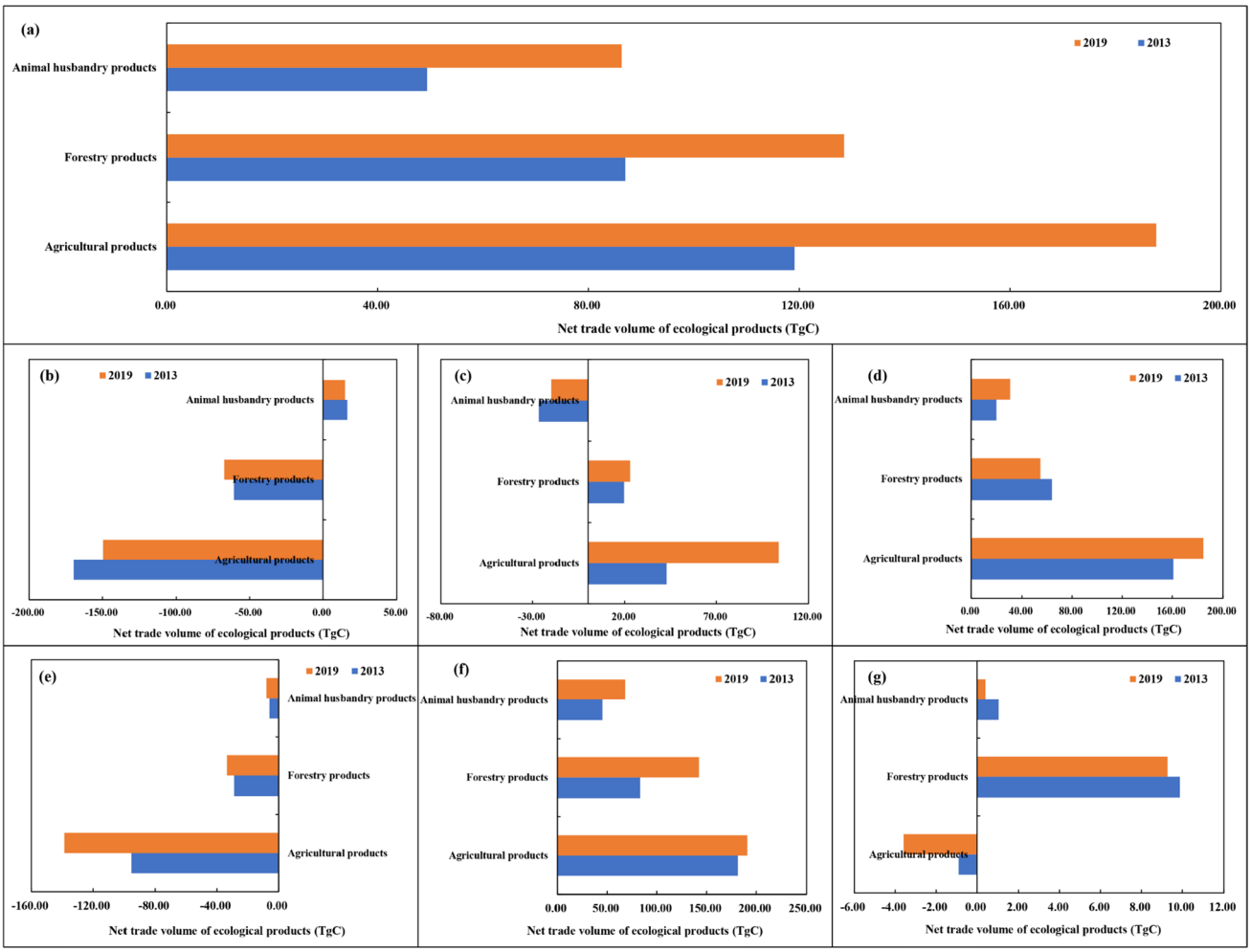

Fig. 7 Structure of net trade volume of ecological products in the region and sub-region of the B&R (2013–2019) (**a** whole region, **b** Southeast Asia, **c** South Asia, **d** West Asia/Middle East, **e** Central and Eastern Europe, **f** China-Russia-Mongolia, **g** Central Asia)

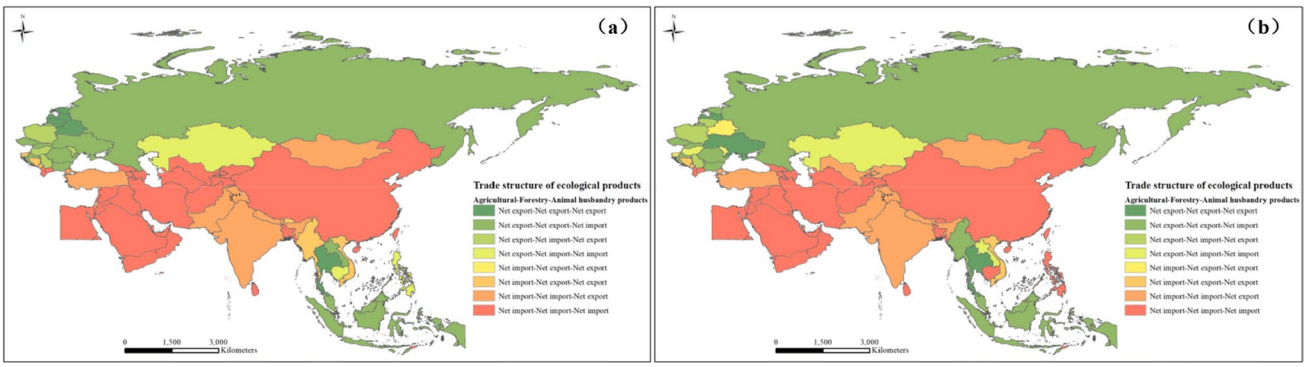

Fig. 8 The structure of net trade volume of ecological products in countries along the B&R (**a** in 2013, **b** in 2019)

Central and Eastern Europe was much higher than other regions from 2013 to 2019 (Fig. 2a).

(2) From 2013 to 2019, the growth rate of the net trade volume of ecological products in South Asia was much higher than other regions (Fig. 2b). Relevant studies have shown that underdeveloped countries (represented by Bangladesh and India) have used more ecological resources for export, in order to support economic

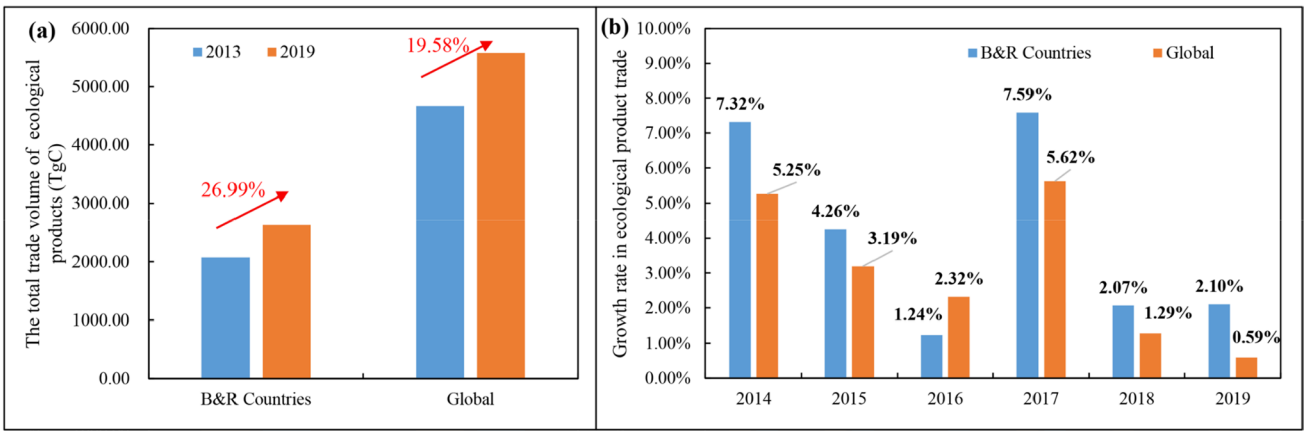

Fig. 9 Comparison of the growth rate of the total trade of ecological products between the B&R region and the world (**a** in six years, **b** by year)

development. In 2013, this practice led to the sacrifice of the well-being of residents (Yan et al. 2022). The substantial increase in the net trade volume of ecological products in South Asia showed that the BRI implementation has played a positive role in changing this previously unreasonable economic and trade model.

(3) The *New Silk Road Economic Belt* was first proposed in Kazakhstan, and the Central Asian countries were also the first to participate in the construction of the Green Channel, which is used for agricultural products. The Green Channel reduces the loss rate in the agricultural product trade by shortening the customs clearance time[5]. From 2013 to 2019, the proportion of trade volume of agricultural products in Central Asian countries generally increased (Fig. 6), thus reflecting the effectiveness of the Green Channel's construction in promoting trade exchanges between Central Asian countries and other countries along the B&R.

(4) The per capita ecological resources of Bhutan and Mongolia rank first and second, respectively, among the countries along the B&R (Yan et al. 2022). In terms of ecosystem types, in Bhutan, ecological resources are dominated by forestry resources; in Mongolia, ecological resources are dominated by grassland resources (Du et al. 2022). From 2013 to 2019, the proportion of the trade volumes of animal husbandry products in Mongolia and forestry products in Bhutan both increased significantly (Fig. 6). This finding indicates that the BRI was able to help transform regional ecological resource advantages into economic development advantages, and could also promote the economic development of countries with good ecological resource endowments.

Conclusions and future prospects

The construction of a global trade network is the key content of the BRI; ecological product trade is also an important component of the international trade between countries along the B&R. This article takes the net primary productivity (NPP) as a unified measure of ecological products, and explores the pattern changes of ecological product trade in countries along the B&R, from 2013 to 2019, from the three aspects of trade scale, pattern, and structure of ecological product. The results show the following:

(1) The total trade volume of ecological products in the B&R region increased by about 26.99%, which was 7.41% higher than the global average level. The net trade volume of ecological products also increased by about 57.54%. The growth rate of the total trade volume of ecological products in China-Russia-Mongolia and Central and Eastern Europe was higher than other regions, and the growth rate of the net trade volume of ecological products in South Asia was much higher than other regions.

(2) The spatial distribution pattern of ecological product trade did not change significantly in countries along the B&R, but the gravity centers of the total and net trade volume of ecological products moved 120.74 km to the northeast and 392.98 km to the southeast, respectively.

(3) The trade structure of ecological products remained relatively stable in the whole B&R region, with the ratio of agricultural, forestry, and animal husbandry products, respectively, at about 6:3:1, and the agricultural, forestry, and animal husbandry products all be in net import. Differences existed in the trade structure of ecological products among the sub-regions along the B&R, but the trade structure was not obvious changed in most regions. The proportions of the total trade vol-

[5] Data sources: BELT AND ROAD PORTAL (https://www.yidaiyilu.gov.cn/ldzd/dejgfld/wjxz/86708.htm)

ume of animal husbandry products in Mongolia and forestry products in Bhutan increased significantly, and the proportion of the total trade volume of agricultural products in the five Central Asian countries all increased slightly.

The results of this study reflect that the construction of the international trade network has had a significant impact on the trade scale of ecological products in all B&R regions (as well as the trade structure of ecological products in some countries) since the BRI was put forward. However, the spatial distribution pattern of ecological product trade has not changed substantially in countries along the B&R, and the trade structure of ecological products has not changed significantly at the whole-region and sub-region levels. This implies that, at this stage, there are differences in the participation or the effect of countries along the B&R in the implementation of unimpeded trade. In the future, it will still be necessary to strengthen the strength and breadth of the construction of unimpeded trade in countries along the B&R. The realization of the Green Silk Road should also be accelerated through the establishment of an inclusive and open international trade network.

The outbreak of COVID-19 is another event that affects global trade after the BRI. Due to the limitation of data, this article only explores the change pattern of ecological product trade from the BRI proposal to the outbreak of COVID-19. In the future, our team will focus on exploring whether the resilience of the ecological product trade network of the B&R countries has been enhanced under the dual background of the BRI and the outbreak of COVID-19, and further clarifying the impact of the BRI on the trade pattern of ecological products in countries along the B&R.

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Data Availability The basic data are sourced from the database of the Food and Agriculture Organization of the United Nations (https://www.fao.org/faostat/en/#home).

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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