Chin. Geogra. Sci. 2022 Vol. 32 No. 5 pp. 745−758
https://doi.org/10.1007/s11769-022-1298-9

Springer Science Press
www.springerlink.com/content/1002-0063

Spatio-temporal Pattern of Ecosystem Pressure in Countries Along the Belt and Road: Combining Remote Sensing Data and Statistical Data

DU Wenpeng[1, 2], YAN Huimin[1, 2], FENG Zhiming[1, 2], ZHANG Chao[1, 2], YANG Yanzhao[1, 2]

(1. *Institute of Geographic Sciences and Natural Resources Research*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*; 2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*)

Abstract: Building a Green Silk Road by integrating the Sustainable Development Goals (SDGs) is one of the Belt and Road Initiative (BRI) visions, but the BRI faces enormous challenge that is the conflict between economic development and ecological sustainability. Understanding the current scale and trend of the impact of human activities on the ecosystem is the preliminary work to ensure that human activities do not exceed the ecological carrying capacity under the BRI. This study evaluated the ecosystem pressure in countries along the Belt and Road (B&R) from 2000–2017 based on the supply-consumption balance relationship of ecological resources. Net primary productivity (NPP) is taken as the measure of ecological resources, and the supply level and consumption intensity of ecological resources is estimated based on remote sensing data and statistical data, respectively. Results show that thirteen countries with overconsumed ecological resources concentrated in the West Asia/Middle East. Although the intensity of the ecological resource consumption correlated with ecological resource endowments, the ecosystem pressure was determined by social development dependence on the ecological resources at the same ecological resource endowments level. Nearly 80% of countries along the B&R suffered from significantly increased ($P < 0.05$) ecosystem pressure during 2000–2017, since most of the countries along the B&R were developing countries, and their economic development was highly dependent on ecological resources. Some West Asia/Middle East countries successfully mitigated the ecosystem pressure by importing feed for livestock. Likewise, the Southeast Asian islands benefitted from the import of agricultural products. The results highlight that the BRI should reduce the dependence of social development demands on local ecological resources by international trade for ensuring the increasing ecosystem pressure trend within the ecological carrying capacity.

Keywords: Green Silk Road; ecosystem pressure; net primary productivity (NPP); ecological carrying capacity; remote sensing

Citation: DU Wenpeng, YAN Huimin, FENG Zhiming, ZHANG Chao, YANG Yanzhao, 2022. Spatio-temporal Pattern of Ecosystem Pressure in Countries Along the Belt and Road: Combining Remote Sensing Data and Statistical Data. *Chinese Geographical Science*, 32(5): 745−758. https://doi.org/10.1007/s11769-022-1298-9

1 Introduction

Population growth, economic development, and lifestyle change have increased natural resource consumption globally, escalating the threat to the earth system (Dasgupta and Ehrlich, 2013; Häyhä et al., 2016). Human activities have pushed four indicators of planetary boundaries beyond their safe operation thresholds, including land-system change, biogeochemical flows, biosphere integrity, and climate change (Steffen et al., 2015). In 2019, humans consumed natural resources corresponding to 1.75 Earth equivalents to meet their demand (https://www.overshootday.org/newsroom/past-earth-overshoot-days/), which is expected to increase to

Received date: 2021-11-15; accepted date: 2022-03-09
Foundation item: Under the auspices of the Strategic Priority Research Program of the Chinese Academy of Sciences (No. XDA20010202), Strategic Priority Research Program of the Chinese Academy of Sciences (No. XDA19040301)
Corresponding author: YAN Huimin. E-mail: yanhm@igsnrr.ac.cn
© Science Press, Northeast Institute of Geography and Agroecology, CAS and Springer-Verlag GmbH Germany, part of Springer Nature 2022

4.00 Earth equivalents by 2050 at the current growth rate of global population and consumption levels (O'Neill et al., 2018; United Nations, 2019).

Sustainable Development Goals (SDGs) were formally proposed in 2015 for achieving global sustainable development through environmental protection, economic development, and social inclusion and mitigating the threats posed by human activities to the earth system (United Nations, 2017). In 2015, China published *Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road*, in which the Belt and Road Initiative (BRI) was proposed (http://zhs.mofcom.gov.cn/article/xxfb/201503/20150300926644.shtml). The developing global shared vision of the BRI was accordant with the SDGs (Guterres, 2017). The potential conflict of the BRI vision with the goal of ecological sustainability is a matter of concern (Ascensão et al., 2018). This concern stems from the following two aspects: on the one hand, the countries along the Belt and Road (B&R) are located in a fragile eco-environment sensitive to climate change and a biodiversity hotspot (Newbold et al., 2016; Wu et al., 2019). The infrastructural development and fast-paced construction under the BRI might lead to biodiversity loss and threaten ecosystem stability (Lechner et al., 2018; Hughes, 2019). On the other hand, most of the countries along the B&R are developing economies. As a result, the residents' quality of life and economic development are highly dependent on ecological resources (Chen et al., 2018; Guo, 2018). With rapid population and economic growth, countries along the B&R will also witness unprecedented growth in the natural resource demand (Hillman, 2018; Liu et al., 2018a).

Due to the countries along the B&R have the dual characteristics of fragile eco-environment and high dependence on ecological resources for economic development, it is crucial to balance the relationship between achieving economic development and protecting the eco-environment under the construction of BRI (Chen et al., 2020). Although the Chinese government had resolved to build the Green Silk Road by integrating the concept of ecological civilization and sustainable development into the BRI, the industrial transformation and infrastructure upgrades will inevitably bring new pressure on the eco-environmen in the countries along the B&R. Therefore, understanding the impact of human activities on ecosystems in countries along the B&R is the preliminary to guide the coordinated development of socio-economic and eco-environment. Relevant studies have revealed that the eco-environmental impacts that the BRI would bring or have already brought, are mainly reflected in the biodiversity, carbon emissions, resource extraction, and environmental pollution, which involve the impact of new human activities on the ecosystem driven by the BRI (Lechner et al., 2018; Teo et al., 2019; Aung and Fischer, 2020; Rauf et al., 2020). However, the impact of the original human activities on the ecosystem has not been extensively studied, which is the key to determining the scale of the new human activities in the countries along the B&R.

The global eco-environmental sustainability standards formulated by the planetary boundary framework guarantee the realization of SDGs while providing a basic idea for measuring the sustainability of the earth system; that is, human activities can not exceed the safe operating space stipulated by the planetary boundary (Rockström et al., 2009; Steffen et al., 2015). Net primary productivity (NPP) is the amount of solar energy converted into biomass by vegetation photosynthesis in the terrestrial ecosystem. NPP is the basic material in which humans utilize ecological resources (Imhoff et al., 2004; Haberl et al., 2012). Running (2012) suggested that NPP, which integrates the planetary boundaries such as system change, biogeochemical flows, biodiversity loss, and freshwater use, should be regarded as the new planetary boundary. Human appropriation of net primary productivity (HANPP) is used to measure the consumption of ecological resources provided by human activities, more precisely agricultural production activities (Haberl et al., 2002; Haberl et al., 2014). The ecological resources consumed by agricultural production activities are the main driving factors behind the increased risk to the planetary boundaries (Campbell et al., 2017; Gerten et al., 2020). The pressure of human activities on the ecosystem can be quantitatively evaluated by comparing the relationship between NPP and consumed-NPP. Therefore, the impact of human activities on ecosystems can be described following the variation in ecosystem pressure, indicating whether the scale of human activities was within the ecological carrying capacity.

This study investigates 65 countries involved in the initial phase of the BRI using NPP as the basic measure of ecological resources. Based on the relationship

between supply (NPP supplied by the ecosystem) and consumption (consumption of NPP by human activities) of ecological resources, the ecological pressure index (*EPI*) of the countries along BRI during 2000–2017 was estimated. This study aims to evaluate the spatio-temporal patterns and its driving factor of ecosystem pressure in countries along the B&R. Moreover, it attempts to come up with probable strategies for BRI member countries to sustainably consume ecological resources while building the Green Silk Road.

2 Materials and Methods

2.1 Study area

This study follows the 65 countries in the *Joint Construction of Green Silk Roads: Social, Economic and Environmental Context* as the study area, and refers to the its zoning standard in the book and UNSD zoning standard (https://unstats.un.org/unsd/methodology/m49/) to divide the 65 countries into six regions (Fig. 1).

The B&R countries mainly located in the Eurasian continent and occupying nearly 50 million km^2. In 2017, the population of the B&R countries was approximately 4.665 billion people, accounting for 62% of the global population. The B&R countries were mainly developing countries, with the per capita GDP of approximately US$ 5200 in 2017, which was about half of the world average. The areas along the B&R are rich in ecosystem types, including forest, farmland, grassland, semi-desert/desert, and tundra. In recent years, the vegetation index has increased significantly during the vegetation growth seasons, and net primary productivity has generally increased in the B&R countries (Liu et al., 2019).

2.2 Basic idea

Ecological pressure index (*EPI*) is defined as the ratio of ecological resource consumption (*CNPP*) to ecological resource supply (*SNPP*). The *CNPP* is defined as the ecological resources consumed by agricultural production (farming, livestock, forestry), and the *SNPP* is defined as the ecological resources provided by the ecosystem for human.

The calculation of *CNPP* is based on the HANPP framework (Haberl et al., 2002; 2014). The HANPP consists of two parts: the ecological resources consumed by land use ($HANPP_{luc}$), the ecological resources consumed by agricultural activities and natural disasters ($HANPP_{harv}$). Considering that the $HANPP_{luc}$ is cumulant and most of the impacts are irreversible

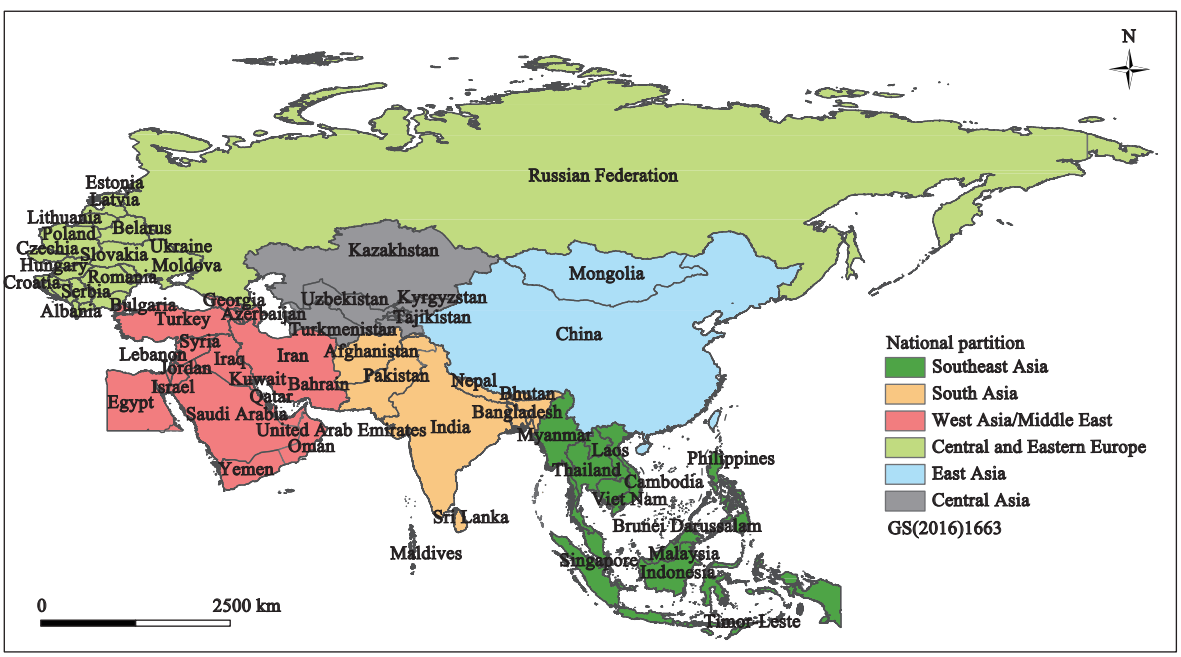

Fig. 1 Spatial range and zones of countries along the Belt and Road (B&R). Due to the limitations of the cartographic space, the name of six countries are not shown in the figure, including Bosnia and Herzegovina, Macedonia, Slovenia, Montenegro, Armenia, and Palestine, the same below

(Dupouey et al., 2002; Lawler et al., 2014) , and remote sensing inversion model of NPP has already been able to consider the impact of real land-use status (Xiao et al., 2004; Zhao et al., 2005), the *CNPP* does not contain $HANPP_{luc}$. Agricultural production is the main driving factor that leads to human activities to continuously close to the overload threshold of planetary boundary (Campbell et al., 2017; Gerten et al., 2020). Therefore, this article focuses on $HANPP_{harv}$ caused by agricultural production, the *CNPP* is used to represent the ecological resources consumed by agricultural production. Taking into account interannual fluctuation caused by natural factors such as climate (Imhoff and Bounoua, 2006), the multi-year mean of aboveground net primary productivity is regarded as the *SNPP*.

2.3 Data

The data used in this study included four aspects, as shown in Table 1.

2.4 Estimation the ecosystem pressure based on the supply-consumption relationship of ecological resource

2.4.1 Estimation of the ecological resource supply (SNPP)

(1) The aboveground biomass proportion coefficient (α) of different land-use types is obtained based on the CCI-LC data, combined with aboveground biomass ratio in total biomass of different vegetation types (Table S1) (Jackson et al., 1996; Mokany et al., 2006).

(2) *NPP* is calculated using the autotrophic respiratory ratio based on the gross primary productivity (*GPP*) (Zhang et al., 2017).

$$NPP = GPP \times (1 - Ra) \tag{1}$$

where, *NPP* represents the net primary productivity (unit: g C/m^2) and *Ra* represents the autotrophic respiratory ratio (Albrizio and Steduto, 2003).

(3) *NPP* and α are multiplied to obtain the aboveground *NPP*. The multi-year average of the ecological resource supply is used to reprsent the available ecological resources supply (*SNPP*) in this study to eliminate fluctuations caused by natural factors (Imhoff and Bounoua, 2006).

$$SNPP = \frac{\gamma^2 \times \sum_{i=1}^{n} (\alpha_i \times NPP_i)}{n} \tag{2}$$

where, *SNPP* represents the available ecological resource supply (unit: g C), α_i represents the aboveground biomass proportion coefficient for a given year *i*, and γ represents the spatial resolution (500 m).

2.4.2 Estimation of the ecological resource consumption (CNPP)

Ecological resources consumption (*CNPP*) refers to the quantity of ecological resources consumed in agricultural production activities, including farming, forestry, and livestock production.

(1) Ecological resources consumed in farming ($CNPP_{PA}$): the ecological resources consumed in farming production is calculated based on the crop yield.

$$CNPP_{PA} = \sum_{j=1}^{n} \left(YIE_j \times \left(1 - Mc_j\right) \times \left(1 + HF_j\right) \times Fc \right) \tag{3}$$

where, $CNPP_{PA}$ represents the framing production con-

Table 1 The types and sources of data used in this study

Name	Year	Resolution	Source	Note
Land-use/cover change, LUCC	2000–2017	300 m	European Space Agency, CCI-LC	Used to obtain spatial parameters of aboveground biomass proportion coefficient
Gross primary productivity, GPP	2000–2017	500 m	Scientific Data	Used to calculate the ecological resource supply
Agricultural yield and trade	2000–2017	National scale	Faostat Database	Used to calculate the ecological resources consumption
Population	2000–2017	National scale	World Bank Data	Used to analyze the drive factors of the ecological pressure change
Households and NPISHs final consumption expenditure	2000–2017	National scale	World Bank Data	Used to analyze the drive factors of the ecological pressure change
Agriculture, livestock and forestry, value added	2000–2017	National scale	World Bank Data	Used to analyze the drive factors of the ecological pressure change

Notes: (1) NPISHs: non-profit institutions serving households; (2) CCI-LC: Climate Change Initiative-Land Cover; (3) Source: European Space Agency (https://www.esa-landcover-cci.org/?q=node/164), Scientific Data (https://www.nature.com/articles/sdata2017165#MOESM171), Faostat Database (http://www.fao.org/faostat/en/#home/), and World Bank Data (https://data.worldbank.org/indicator)

sumption (unit: g C), *YIE* represents the crop yield (unit: g), *Mc* represents the moisture content (Table S2) (Lobell et al., 2002; Zhou et al., 2018), *HF* represents the harvest index (Table S3) (Haberl et al., 2007; Peters et al., 2014), *Fc* represents the conversion coefficient between biomass and carbon content with 0.45 g C/g being the international standard (Fan et al., 2008), and *j* represents the crop types.

(2) Ecological resources consumed in forestry ($CNPP_{PF}$): the ecological resources consumed in forestry is calculated based on timber harvesting.

$$CNPP_{PF} = \sum_{k=1}^{n} \frac{TIM_k \times T_k \times \rho \times Fc \times 10^6}{Ur \times (1 - Ba)} \quad (4)$$

where, $CNPP_{PF}$ represents the forestry production consumption (g C), *TIM* represents timber harvesting (m^3), ρ represents the wood density with 0.50 t/m^3 being used in this study (Winjum et al., 1998), *T* represents the conversion coefficients to Roundwood (Table S4) (Picos et al., 2010), *Fc* represents the conversion coefficient between biomass and carbon content with an international standard of 0.50 g C/g (Dixon et al., 1994), *Ur* represents the effective utilization rate of forest resources (see Table S5) (Haberl et al., 2007), *Ba* represents bark coefficient with 10% being used in this study (Haberl et al., 2007), and *k* represents the timber types.

(3) Ecological resources consumed in livestock production ($CNPP_{PS}$): the ecological resources consumed in livestock production is calculated based on the livestock quantity.

$$CNPP_{PS} = \sum_{x=1}^{n} (LIV_x \times GW_x \times GD_x \times Fc \times 1000) \quad (5)$$

where, $CNPP_{PS}$ represents the livestock production consumption (unit: g C), *LIV* represents the stockpiled livestock quantity or column livestock quantity (column = slaughter + export – import) (unit: head), *GW* represents the hay eaten by livestock every day (unit: kg DM/(head·d)) (Table S6) (Haberl et al., 2007; Herrero et al., 2013), *GD* represents the number of feeding days per year (unit: d/head) (Table S7) (Haberl et al., 2007; Herrero et al., 2013), *Fc* represents the conversion coefficient between biomass and carbon content with an international standard of 0.45 g C/g (Fan et al., 2008), *x* represents the livestock types.

(4) Ecological resources consumption (*CNPP*):

$$CNPP = CNPP_{PA} + CNPP_{PF} + CNPP_{PS} \quad (6)$$

2.4.3 Estimation of ecological pressure index (EPI)

The ecological pressure index (*EPI*) is calculated based on *CNPP* and *SNPP*.

$$EPI = \frac{CNPP}{SNPP} \quad (7)$$

The greater the *EPI*, the greater the ecosystem pressure exerted by human activities. $EPI < 1$ indicates that the ecological resources consumed by regional farming, forestry, and livestock production activities are within the available ecological resource supply (the ecosystem is in surplus). In contrast, $EPI > 1$ indicates that the ecological resources consumed by regional farming, forestry, and livestock production activities exceed the available ecological resource supply (the ecosystem is overloaded).

3 Results

3.1 Spatial pattern and driving factors of ecosystem pressure in countries along the B&R

In 2017, the ecological resources consumed (*CNPP*) by 80% (52) of the countries along the B&R in agricultural production activities were less than the available ecological resource supply (*SNPP*). In contrast, the *CNPP* of 13 countries exceeded the *SNPP*, of which nearly 70% were located in West Asia/Middle East (Fig. 2).

The ecological resource endowment was the leading factor behind differences in the ecosystem pressure among countries along the B&R. In 2017, the *EPI* and the per capita ecological resource occupancy showed a significant negative correlation ($R^2 = 0.3939$, $P < 0.05$; Fig. 3a). The West Asia/Middle East countries with desert ecosystems could use ecological resources less than 20 g C/m^2, becoming a concentrated area of the countries along the B&R with ecological overload (Fig. 2, Figs. S1, S2).

For countries with similar ecological resource endowments, the degree of dependence on ecological resources could also lead to differences in ecosystem pressure in countries along the B&R. In this study, six ecological resource endowment gradients were set up at the centre point of 0.50, 1.00, 3.00, 5.00, 8.00, and 10.00 Mg C/capita with 50% fluctuation. Except for the 0.50–1.50 Mg C/capita gradient (Fig. 3c), each gradient's *EPI* was significantly positively correlated with the per capita consumption of ecological resources in 2017 (Figs. 3b,

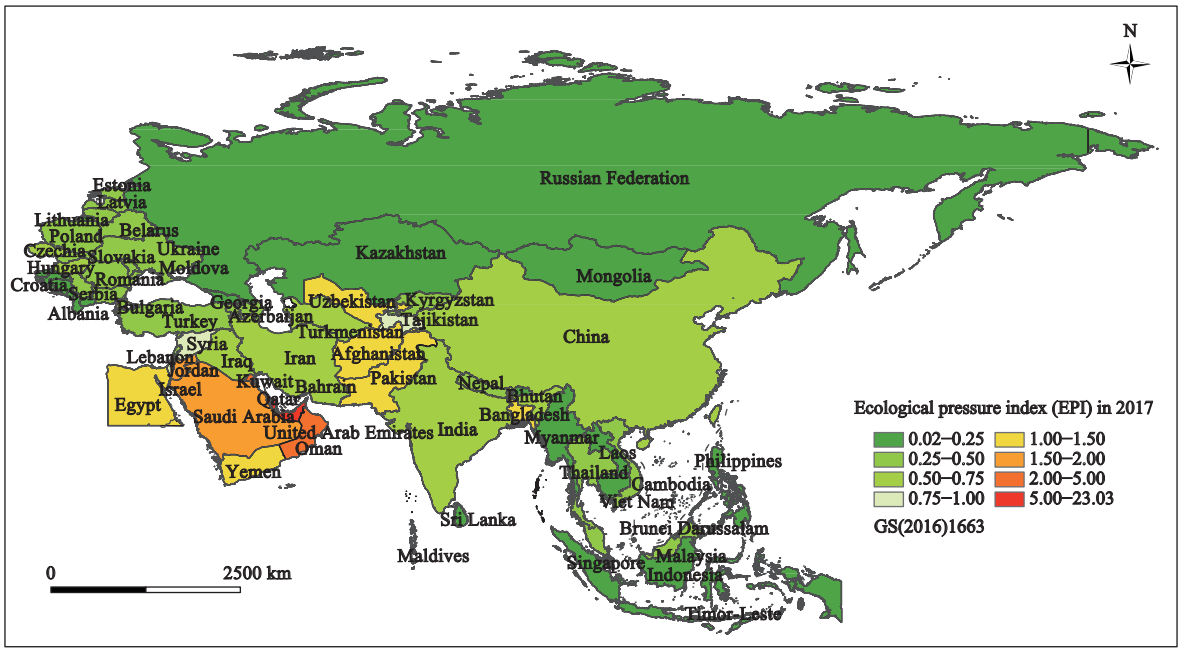

Fig. 2 The spatial distribution of ecosystem pressure of countries along the Belt and Road (B&R) in 2017

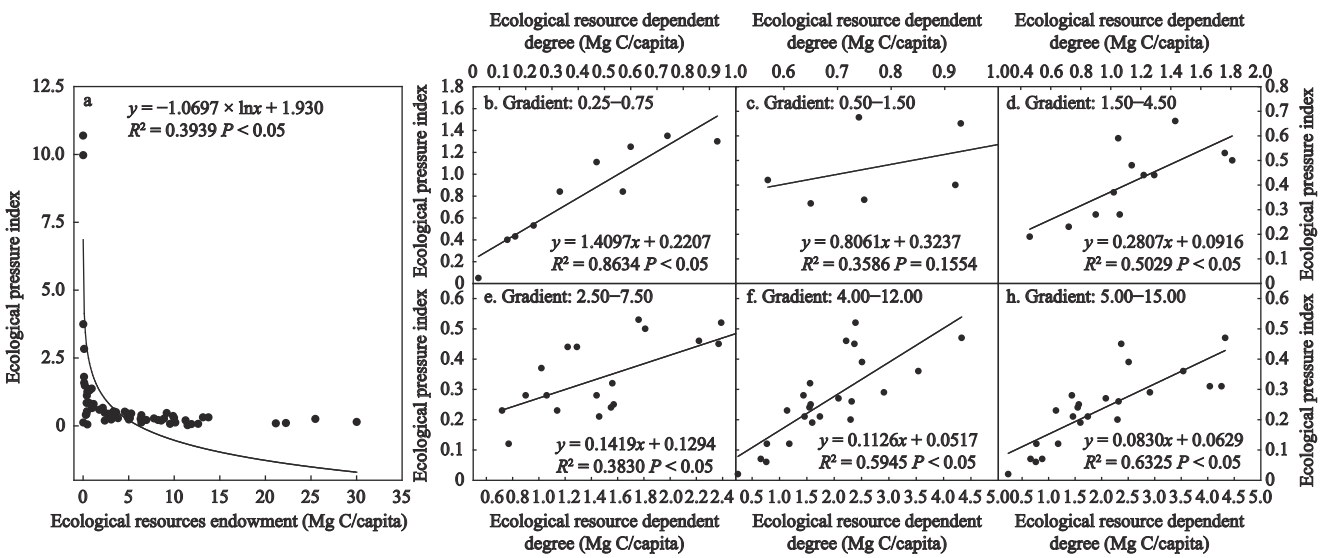

Fig. 3 Analysis of the driving factors of the spatial pattern of ecological pressure index (*EPI*) of the countries along the B&R in 2017 (a: the relationship between ecological resource endowment and *EPI*, b–g: the relationship between the dependence degree on ecological resource and *EPI* with different ecological resource endowment gradients)

3d–3g). Therefore, in countries with similar ecological resources, the higher the dependence of life and economic development demands on ecological resources, the greater is the ecosystem pressure.

3.2 Temporal pattern and driving factors of ecosystem pressure in countries along the B&R

From 2000 to 2017, the interannual change rate of the *EPI* was positive value in 90% (59) of the countries countries along the B&R, in which 51 countries showed a significant increase in the ecosystem pressure (Fig. 4; Fig. S3). The interannual change rate of the *EPI* of countries with significant increase is between 0.03%–8.69%, there were five countries with the interannual change rate of the *EPI* exceed 5%, namely Qatar and Bahrain in West Asia/Middle East, Uzbekistan, Kazakhstan and

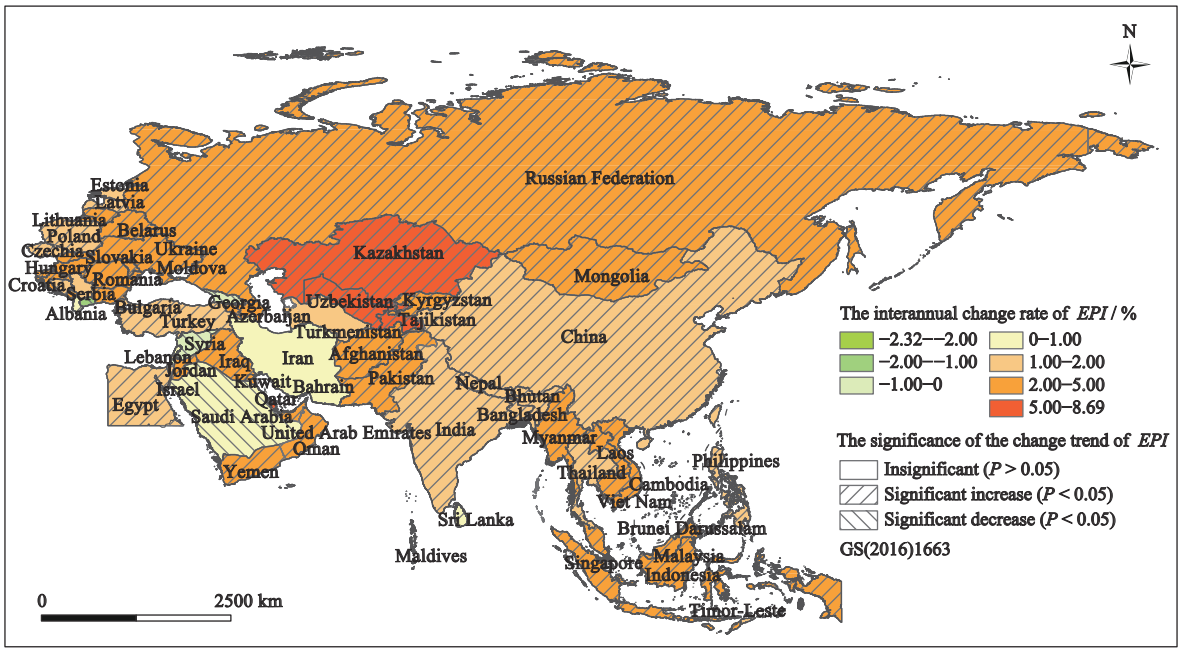

Fig. 4 The average inter-annual change rate of the ecological pressure index (*EPI*) from 2000–2017 in countries along the B&R

Tajikistan in Central Asia (Fig. 4). Among the countries along the B&R, only six countries were negative value of the interannual change rate of *EPI*, in which five countries showed a significant decrease in the ecosystem pressure, namely Maldives, Macedonia, Syria, Georgia and Palestinian (Fig. 4; Fig. S3).

Through regression analysis of the interannual change rate of *EPI* with population, the Households and NPISHs final consumption expenditure and agriculture production value, there was no significant correlation between the interannual change rate of *EPI* and that of population (R^2 = 0.0128, P = 0.46, Fig. 5a). The results also showed a significant positive correlation between the interannual change rate of *EPI* and that of final consumption expenditure (R^2 = 0.1122, P < 0.05, Fig. 5b), also between the interannual change rate of *EPI* and that of agriculture production value (R^2 = 0.2549, P < 0.05, Fig. 5c). Although the correlation between the interannual change rate of *EPI* and that of agriculture production value was higher than the correlation between the interannual change rate of *EPI* and that of final consumption expenditure, there was only a weak correlation between the interannual change rate of *EPI* and that of agriculture production value.

Since most countries along the B&R were developing countries, economic development was highly dependent on ecological resources. Moreover, due to the relatively backward agricultural technology, the primary processing industries using ecological resources as raw material were an essential factor driving their economic

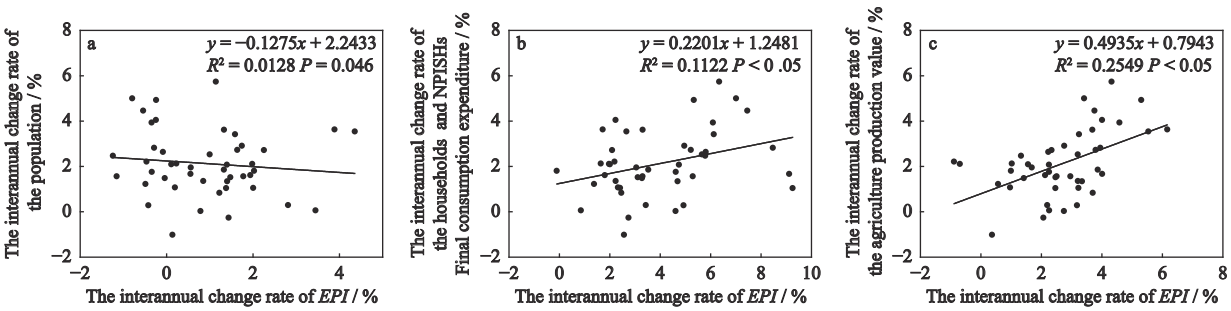

Fig. 5 Analysis of the driving factors of the interannual change rate of *EPI* of the countries along the B&R (a: the interannual change rate of *EPI* vs. that of the population, b: the interannual change rate of *EPI* vs. that of the Households and NPISHs final consumption expenditure, c: the interannual change rate of *EPI* vs. that of the agriculture production value. Due to the limitation of data availability, only the driving factors for the EPI chang of 45 countries were analyzed)

development. Therefore, the impact of changes in the consumption level on the changes in ecosystem pressure is much higher than the impact of population changes in countries along the B&R. Therefore, compared with population and consumption levels, changes in agricultural production value were more closely related to changes in ecosystem pressure.

4 Discussion

4.1 Reasons for the weak correlation between *EPI* changes with its driving factors

Studies on a global scale have shown that population growth and the improvement of consumption levels led to the continuous increase of human utilization of ecological resources, further increasing the ecosystem pressure (Bennett and Balvanera, 2007; Röös et al., 2017). However, from the interannual change rate perspective, this study shows that there is no significant correlation between the interannual change rate of *EPI* and that of population, and there is weak correlation between the interannual change rate of *EPI* and that of final consumption expenditure in the countries along the B&R (Figs. 5a, 5b). There may be two reasons for the different regulation between the national scale along the B&R with the global scale:

(1) International trade increasingly differenciated the geographical production space from the corresponding consumption space of ecological resources (Liu et al., 2015; Liu et al., 2018b; Wiedmann and Lenzen, 2018). As a result, the ecosystem pressure due to the demand for ecological resources by the growth of population and consumption levels in one region could be transferred to other regions through trade (Syrbe et al., 2012; Serna-Chavez et al., 2014). For example, Singapore and Brunei Darussalam mainly relied on imported ecological resources to meet the living demands of residents (D'Odorico et al., 2014; Singapore Food Agency, 2020), changes in population and consumption levels will not have a real impact on the local ecosystem.

(2) Previous studies have shown that the increase in the population of African countries is the main factor leading to the increase in ecological resources demand, while the improvement of consumption levels in Asian countries is the main factor leading to the increase in ecological resources demand (Running, 2012). Especially for some Central and Eastern European countries along the B&R, the population has shown negative growth, but the increase in consumption level still makes the demand for ecological resources increase (Krausmann et al., 2008; Liu et al., 2018b). Therefore, the impact of changes in the consumption level on the changes in ecosystem pressure is much higher than the impact of population changes in countries along the B&R.

Althoug 56 countries with a significant increase or decrease of ecosystem pressure from 2000–2017, some countries depicted obvious turning points. According to the differences in the changing trends of ecosystem pressure before and after the turning point, these countries can be divided into three categories:

(1) Bahrain and Qatar: first fluctuated and the increased (the turning point was 2009) (Figs. 6a, 6b). The increase in livestock production was the leading factor driving the increase of ecosystem pressure (Figs. 7a, 7b). Before the financial crisis in 2008, oil and gas exploitation was the pillar of Bahrain and Qatar, characterized by the phenomenon of 'Dutch disease' (Apergis et al., 2014). Affected by the financial crisis, Bahrain and Qatar began to develop livestock based on imported agricultural products to balance the national industrial structure (Mansfeld and Winckler, 2008), causing a rapid increase in the ecological resources consumed by the production activities.

(2) Mongolia, Estonia and Albania: first decreased and then increased (Figs. 6c, 6d, 6e). Affected by extreme climate disasters, large-scale livestock deaths occurred in Mongolia during 2000–2002 and 2009–2010 (Rao et al., 2015), causing a continuous decline in livestock production and consumption from 2000–2004. The scale of livestock production began to recover in 2004 and then dropped sharply during 2009–2010. The change of ecosystem pressure in Estonia and Albania was mainly caused by the political instability and systemic agricultural reforms initiated by the collapse of the former Soviet Union (Pisanelli et al., 2010; Csaki and Jambor, 2019; Jürgenson and Rasva, 2020).

(3) Maldives, Georgia, Saudi Arabia and Syria: first increased and then decreased (Figs. 6f–6i). In all the four countries, the transition caused by the decline of farming production intensity, occurred around 2005 (Figs. 7c–7f). According to the World Bank and Faostat

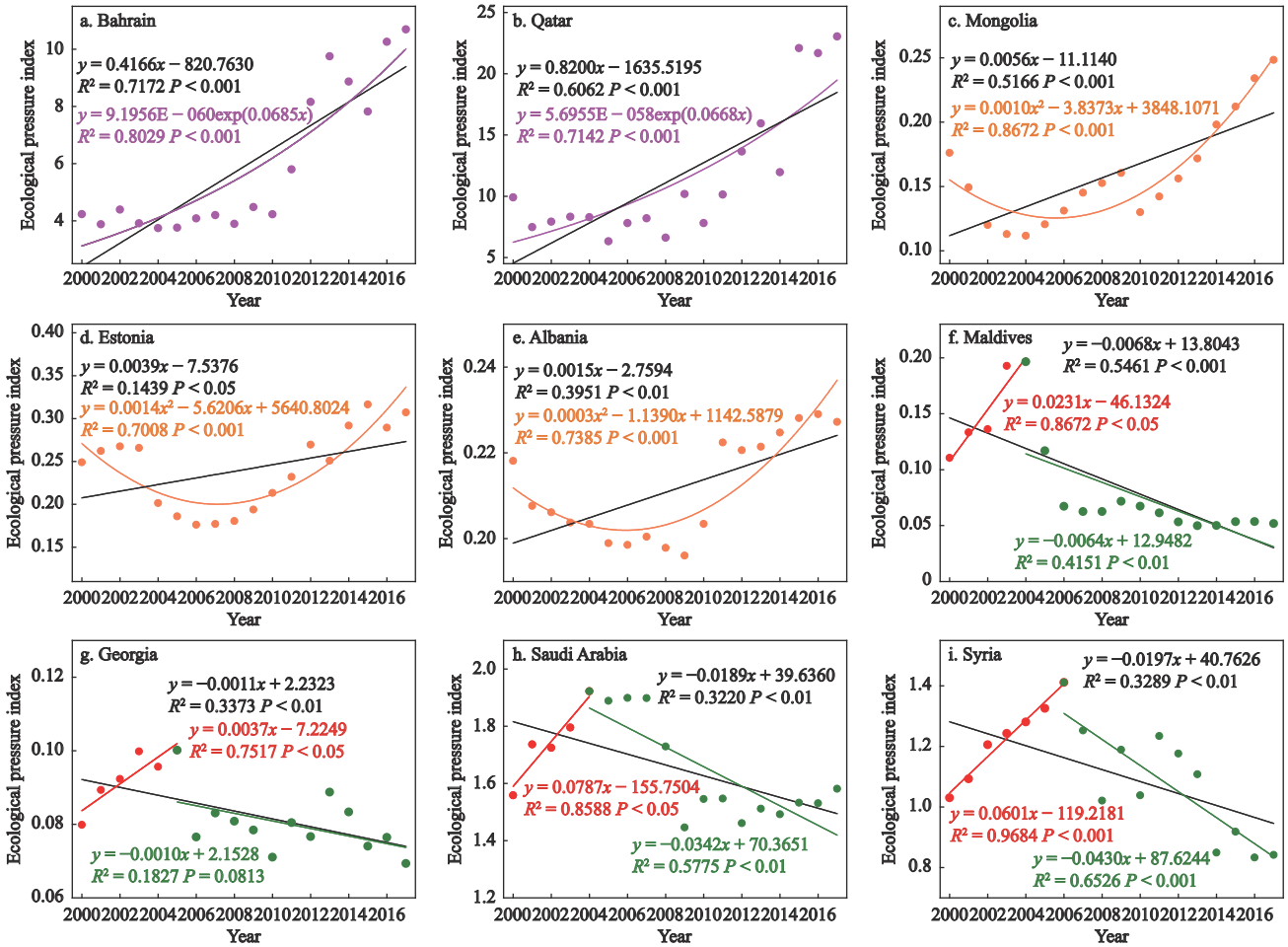

Fig. 6 The change trend of the *EPI* in countries with existed turning point of ecosystem pressure from 2000 to 2017 (a–b: first fluctuated and the increased, c–e: first decreased and then increased, f–i: first increased and then decreased. The change trend of the *EPI* of all countries of B&R see in Fig. S3)

Database, tourism played a significant role in Maldives' economic development. As a result of tourism development in recent years, a large fraction of the agricultural population has switched to the service sector, leading to a decrease in the agricultural production intensity in the Maldives. The land system reforms resulted in the sharp decrease of the cultivated land area, increasingly prominent restriction of water resources on irrigated agriculture, and the frequent occurrence of national political instability and wars, which were the main driving factors behind the change of ecosystem pressure from increasing to decreasing in Georgia, Saudi Arabia, and Syria, respectively (Rocchi et al., 2013; Multsch et al., 2017; Chowdhury et al., 2019; Mohamed et al., 2020).

The change trends and its reasons of ecosystem pressure in above-mentioned counties show that the industrial structure adjustment, natural disasters, political instability and war can affect the intensity of human activities on the development of ecological resources, thereby changing the change trend of ecosystem pressure. This means that these factors weaken the linear impact of changes in population and consumption levels on changes in ecosystem pressure.

4.2 Possible approaches to alleviate the local ecosystem pressure

As mentioned above, international trade enables regions to meet the ecological resource demands brought about by the increase in population and consumption levels through imports, thereby reducing local ecosystem pressure. Similarly, the flow of ecological resources between agricultural production sectors can also provide an opportunity to alleviate regional ecosystem pressure. Modern livestock has steadily shifted from

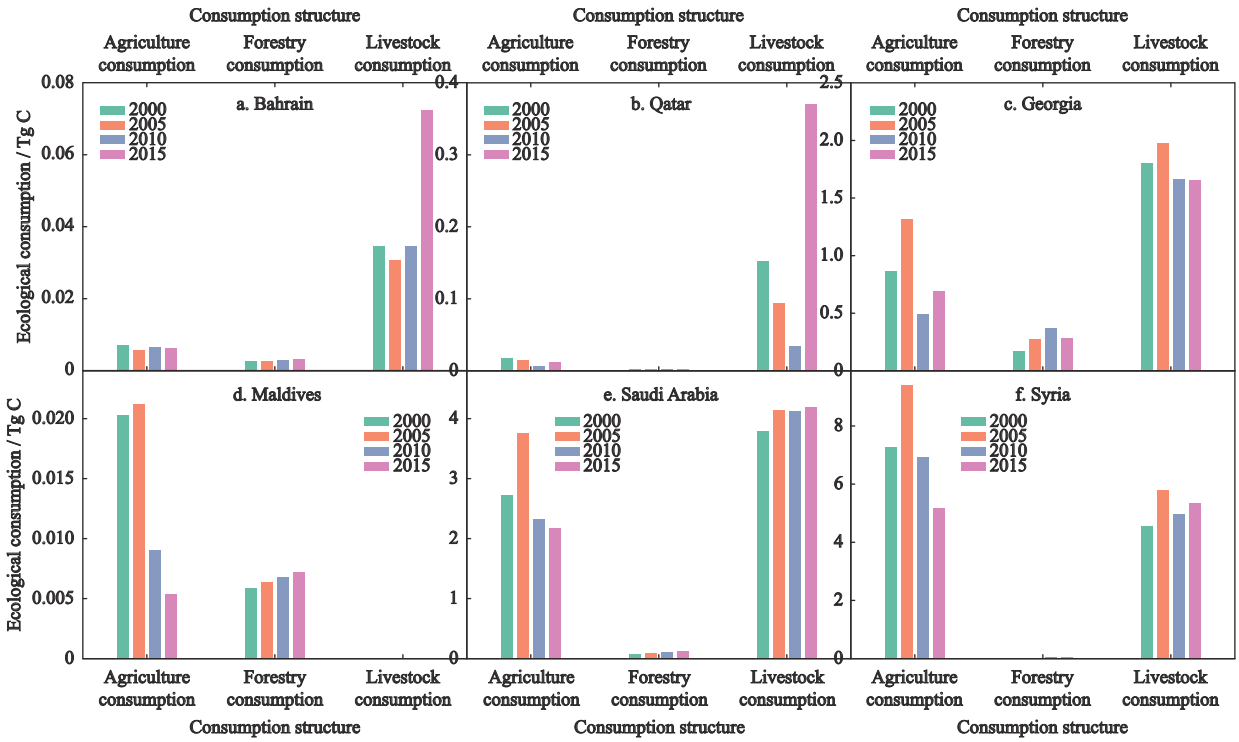

Fig. 7 The amount of ecological resources consumed in farming, forestry, and livestock activities of partial countries in Fig. 6 in 2000, 2005, 2010, 2015

grazing to food-feed crops. As a result, it is common for ecological resources to flow from the agricultural system to the livestock system (Palmer, 2014; Van Zanten et al., 2016). About 40% of the global arable land is used to produce feed for livestock development (Mottet et al., 2017). Roughly 58% of the biomass available for direct human use is also used for livestock production (Pelletier and Tyedmers, 2010).

In 2017, more than 50% of the ecological resources consumed by livestock production in 28 countries along the B&R came from agricultural products (agricultural products, feed, and residues). Compared with year 2000, the dependence of livestock on agricultural products increased in more than two-thirds of the countries along the B&R in 2017 (Fig. 8). Countries with scarce ecological resources, such as Saudi Arabia, Kuwait, and Lebanon, located in West Asia/Middle East, relied entirely on agricultural products for livestock production. Sri Lanka, Malaysia, Indonesia, and Thailand, located in South Asia and Southeast Asia, are dominated by farmland and forest ecosystems. Although these countries had sufficient ecological resources, grassland resources were so scarce that livestock production depended entirely on agricultural production (Fig. 8, Fig. S1, Fig. S2).

Livestock production based on agricultural products could alleviate the ecosystem pressure of countries along the B&R. In particular, for countries with ecological overload, the ecosystem pressure reduced at a rate greater than 10%, even more than 50% in United Arab Emirates, Kuwait, and Saudi Arabia (Figs. 9a, 9b). In 2017, Afghanistan, Bangladesh, Egypt, Jordan, Kuwait, Saudi Arabia developed livestock using agricultural products to reduce the consumption of ecological resources, due to which their ecosystems were in surplus (Fig. 9b).

A comparison of agricultural products used for livestock and farming production consumption in ecologically overloaded countries showed a higher development of the former than the latter in 2017, Jordan, Saudi Arabia, Oman, Kuwait, United Arab Emirates, implying that imported agricultural products supported the development of domestic livestock in these countries. Moreover, compared with 2000, the dependence on external ecological resources increased (Figs. 9c, 9d). To a certain extent, this phenomenon indicated that the impact of the ecological resources endowment on the ecosystem pressure was weakening in countries with ecological overload.

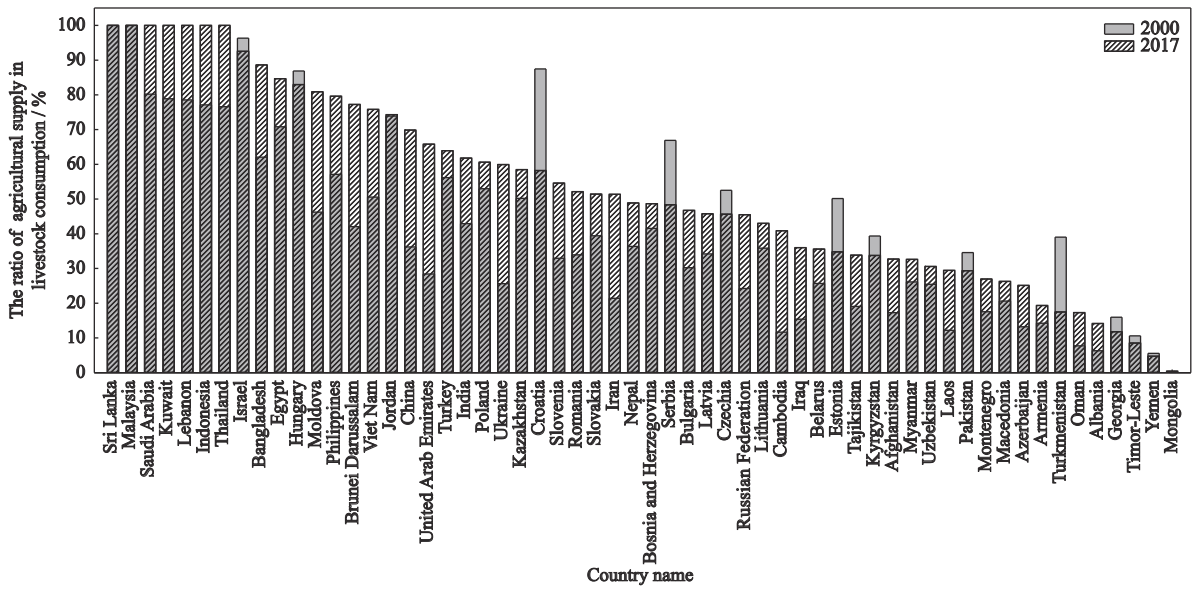

Fig. 8 The proportion of agricultural production in the livestock production consumption in countries along the B&R in 2000 and 2017 (due to the lack of relevant data in the Maldives, Palestine, Qatar, Bahrain, Syria, Singapore, and Bhutan, only relevant information of 58 countries along the B&R is plotted)

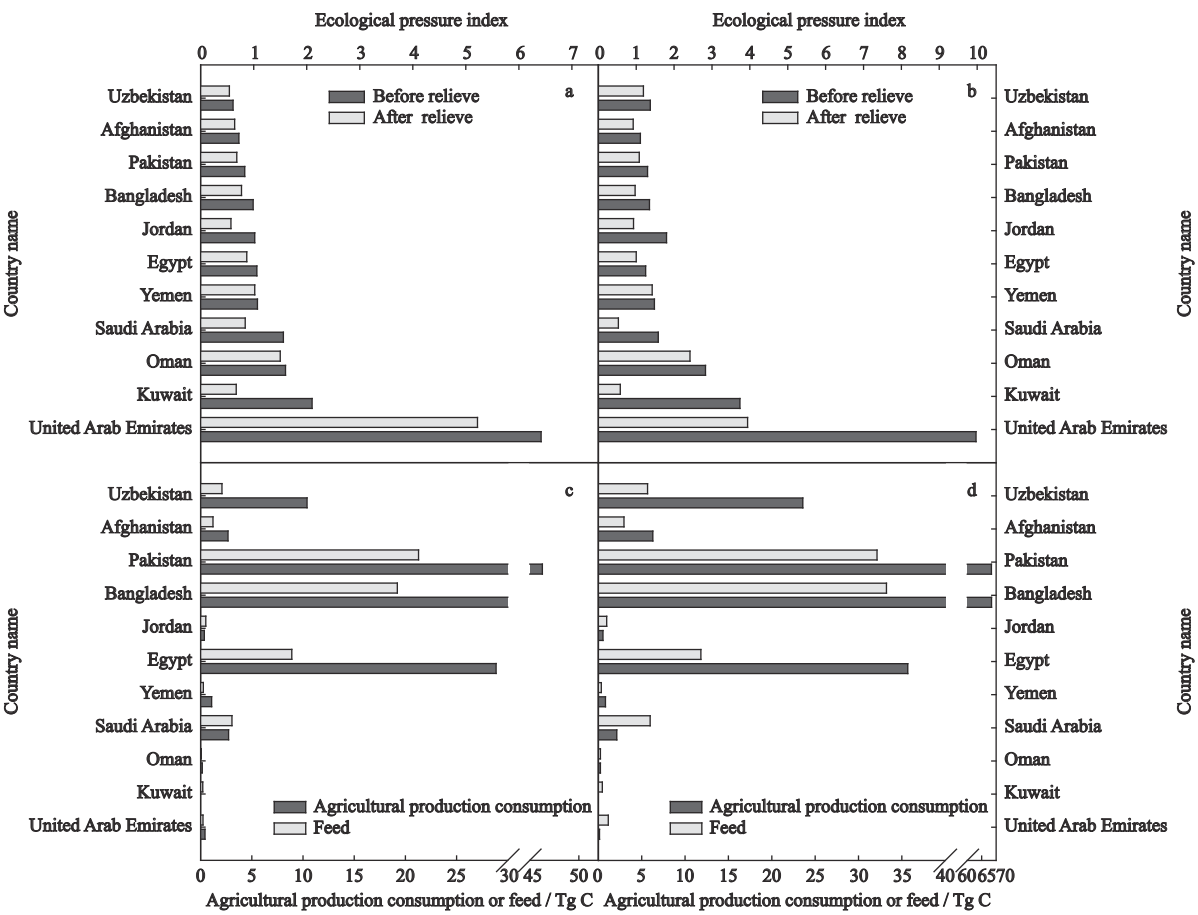

Fig. 9 Allievation of ecological pressure due to agricultural feeding livestock (a: 2000, b: 2017), as well as the relationship between agricultural products used in livestock and farming production consumption in ecologically overloaded countries (c: 2000, d: 2017)

5 Conclusions

Countries along the B&R will be the hot spots of global population growth and rapid economic development in the future. It is vital to understand the status and trends of human activities on ecosystems in countries along the B&R for achieving ecosystem sustainability in building the Green Silk Road. This study revealed the spatio-temporal patterns and its causes of ecosystem pressure in countries along the B&R from 2000 to 2017 through the supply-consumption balance relationship of ecological resources.

The characteristics of ecological resource endowments were the main factors behind the differences in ecosystem pressure in countries along the B&R. Moreover, for countries with similar ecological resource endowments, the ecosystem pressure increased with the dependence of social development demands on ecological resources. In 2017, 80% of the countries along the B&R had a surplus ecosystem, while the countries in West Asia/Middle East had a overloaded ecosystem. From 2000 to 2017, nearly 80% of countries along the B&R suffered from significantly increased ecosystem pressure and the interannual change rate of the ecosystem pressure of those countries was between 0.03%–8.69%. Due to the impact of international trade, industrial structure adjustment, natural disasters, and political instability, the change rates of population growth and consumption level were not closely relate to the corresponding change rate of ecological pressure in the B&R countries.

It is worth noting that international trade leads to the nonlinear response of ecosystem pressure to population and consumption levels, which implies that countries along the Belt and Road with ecological overload can transfer and alleviate local ecosystem pressure through international trade. For example, Singapore and Brunei Darussalam have maintained a good ecological environment while meeting domestic demand for ecological resources by import. Meanwhile, this study also shows that modern livestock pattern (livestock production based on agricultural products) could alleviate the ecosystem pressure of countries along the B&R. Especially for countries in West Asia/Middle East (such as Saudi Arabia, Kuwait and Jordan), the livestock production relied on imported feed has turned their ecosystems from an overloaded state to a surplus state.

Appendix

Tables S1–S7 and Figs. S1–S3 could be found in the corresponding article at http://egeoscien.neigae.ac.cn/article/2022/5.

References

Albrizio R, Steduto P, 2003. Photosynthesis, respiration and conservative carbon use efficiency of four field grown crops. *Agricultural and Forest Meteorology*, 116(1–2): 19–36. doi: 10.1016/S0168-1923(02)00252-6

Apergis N, El-Montasser G, Sekyere E et al., 2014. Dutch disease effect of oil rents on agriculture value added in Middle East and North African (MENA) countries. *Energy Economics*, 45: 485–490. doi: 10.1016/j.eneco.2014.07.025

Ascensão F, Fahrig L, Clevenger A P et al., 2018. Environmental challenges for the Belt and Road Initiative. *Nature Sustainability*, 1(5): 206–209. doi: 10.1038/s41893-018-0059-3

Aung T S, Fischer T B, 2020. Quality of environmental impact assessment systems and economic growth in countries participating in the belt and road initiatives. *Impact Assessment and Project Appraisal*, 38(6): 502–520. doi: 10.1080/14615517.2020.1818520

Bennett E M, Balvanera P, 2007. The future of production systems in a globalized world. *Frontiers in Ecology and the Environment*, 5(4): 191–198. doi: 10.1890/1540-9295(2007)5[191:tfopsi]2.0.co;2

Campbell B M, Beare D J, Bennett E M et al., 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society*, 22(4): 8. doi: 10.5751/es-09595-220408

Chen Di, Yu Qiangyi, Hu Qiong et al., 2018. Cultivated land change in the Belt and Road Initiative region. *Journal of Geographical Sciences*, 28(11): 1580–1594. doi: 10.1007/s11442-018-1530-9

Chen Y, Liu S B, Wu H Q et al., 2020. How can belt and road countries contribute to glocal low-carbon development. *Journal of Cleaner Production*, 256: 120717. doi: 10.1016/j.jclepro.2020.120717

Chowdhury S, Kabir F, Chowdhury I R et al., 2019. Importing and exporting agricultural crop products: an assessment of Virtual Water Flow (VWF) in Saudi Arabia. *Arabian Journal for Science and Engineering*, 44(5): 4911–4920. doi: 10.1007/s13369-018-3627-y

Csaki C, Jambor A, 2019. Convergence or divergence: transition in agriculture of Central and Eastern Europe and commonwealth of independent states revisited. *Agricultural Economics*, 65(4): 160–174. doi: 10.17221/195/2018-agricecon

Dasgupta P S, Ehrlich P R, 2013. Pervasive externalities at the population, consumption, and environment Nexus. *Science*, 340(6130): 324–328. doi: 10.1126/science.1224664

Dixon R K, Solomon A M, Brown S et al., 1994. Carbon pools

and flux of global forest ecosystems. *Science*, 263(5144): 185–190. doi: 10.1126/science.263.5144.185

D'Odorico P, Carr J A, Laio F et al., 2014. Feeding humanity through global food trade. *Earth's Future*, 2(9): 458–469. doi: 10.1002/2014ef000250

Dupouey J L, Dambrine E, Laffite J D et al., 2002. Irreversible impact of past land use on forest soils and biodiversity. *Ecology*, 83(11): 2978–2984. doi: 10.1890/0012-9658(2002)083[2978:IIOPLU]2.0.CO;2

Fan J W, Zhong H P, Harris W et al., 2008. Carbon storage in the grasslands of China based on field measurements of above and belowground biomass. *Climatic Change*, 86(3–4): 375–396. doi: 10.1007/s10584-007-9316-6

Gerten D, Heck V, Jägermeyr J et al., 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, 3(3): 200–208. doi: 10.1038/s41893-019-0465-1

Guo H D, 2018. Steps to the digital Silk Road. *Nature*, 554(7690): 25–27. doi: 10.1038/d41586-018-01303-y

Guterres A, 2017. *Remarks at the Opening of the Belt and Road Forum*. https://www.un.org/sg/en/content/sg/speeches/2017-05-14/secretary-general's-belt-and-road-forum-remarks

Haberl H, Krausmann F, Erb K H et al., 2002. Human appropriation of net primary production. *Science*, 296(5575): 1968–1969. doi: 10.1126/science.296.5575.1968

Haberl H, Erb K H, Krausmann F et al., 2007. Quantifying and mapping the human appropriation of net primary production in Earth's terrestrial ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, 104(31): 12942–12947. doi: 10.1073/pnas.0704243104

Haberl H, Steinberger J K, Plutzar C et al., 2012. Natural and socioeconomic determinants of the embodied human appropriation of net primary production and its relation to other resource use indicators. *Ecological Indicators*, 23: 222–231. doi: 10.1016/j.ecolind.2012.03.027

Haberl H, Erb K H, Krausmann F, 2014. Human appropri-ation of net primary production: patterns, trends, and planetary boundaries. *Annual Review of Environment and Resources*, 39: 363–391. doi: 10.1146/annurev-environ-121912-094620

Häyhä T, Lucas P L, van Vuuren D P et al., 2016. From Planetary Boundaries to national fair shares of the global safe operating space: how can the scales be bridged. *Global Environmental Change*, 40: 60–72. doi: 10.1016/j.gloenvcha.2016.06.008

Herrero M, Havlík P, Valin H et al., 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America*, 110(52): 20888–20893. doi: 10.1073/pnas.1308149110

Hillman J, 2018. *How Big is the Belt and Road*? Hong Kong: Hong Kong Trade Development Council. http://beltandroad.hktdc.com/en/node/15086

Hughes A C, 2019. Understanding and minimizing environmental impacts of the Belt and Road Initiative. *Conservation Biology*, 33(4): 883–894. doi: 10.1111/cobi.13317

Imhoff M L, Bounoua L, Ricketts T et al., 2004. Global patterns in human consumption of net primary production. *Nature*, 429(6994): 870–873. doi: 10.1038/nature02619

Imhoff M L, Bounoua L, 2006. Exploring global patterns of net primary production carbon supply and demand using satellite observations and statistical data. *Journal of Geophysical Research*, 111(D22): D22S12. doi: 10.1029/2006jd007377

Jackson R B, Canadell J, Ehleringer J R et al., 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia*, 108(3): 389–411. doi: 10.1007/bf00333714

Jürgenson E, Rasva M, 2020. The changing structure and concentration of agricultural land holdings in Estonia and possible threat for rural areas. *Land*, 9(2): 41. doi: 10.3390/land9020041

Krausmann F, Fischer-Kowalski M, Schandl H et al., 2008. The global sociometabolic transition: past and present metabolic profiles and their future trajectories. *Journal of Industrial Ecology*, 12(5–6): 637–656. doi: 10.1111/j.1530-9290.2008.00065.x

Lawler J J, Lewis D J, Nelson E et al., 2014. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, 111(20): 7492–7497. doi: 10.1073/pnas.1405557111

Lechner A M, Chan F K S, Campos-Arceiz A, 2018. Biodiversity conservation should be a core value of China's Belt and Road Initiative. *Nature Ecology & Evolution*, 2(3): 408–409. doi: 10.1038/s41559-017-0452-8

Liu J G, Mooney H, Hull V et al., 2015. Systems integration for global sustainability. *Science*, 347(6225): 1258832. doi: 10.1126/science.1258832

Liu H, Fang C, Miao Y et al., 2018a. Spatio-temporal evolution of population and urbanization in the countries along the Belt and Road 1950 –2050. *Journal of Geographical Sciences*, 28(7): 919–936. doi: 10.1007/s11442-018-1513-x

Liu J G, Hull V, Godfray H C J et al., 2018b. Nexus approaches to global sustainable development. *Nature Sustainability*, 1(9): 466–476. doi: 10.1038/s41893-018-0135-8

Liu W D. 2019. *Joint Construction of Green Silk Roads*: *Social, Economic and Environmental Context*. Beijing: The Commercial Press.

Lobell D B, Hicke J A, Asner G P et al., 2002. Satellite estimates of productivity and light use efficiency in United States agriculture, 1982–98. *Global Change Biology*, 8(8): 722–735. doi: 10.1046/j.1365-2486.2002.00503.x

Mansfeld Y, Winckler O, 2008. The role of the tourism industry in transforming a *Rentier* to a long-term viable economy: the case of Bahrain. *Current Issues in Tourism*, 11(3): 237–267. doi: 10.1080/13683500802140307

Mohamed M A, Anders J, Schneider C, 2020. Monitoring of changes in land use/land cover in Syria from 2010 to 2018 using multitemporal Landsat imagery and GIS. *Land*, 9(7): 226. doi: 10.3390/land9070226

Mokany K, Raison R J, Prokushkin A S, 2006. Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology*, 12(1): 84–96. doi: 10.1111/j.1365-2486.2005.001043.x

Mottet A, de Haan C, Falcucci A et al., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14: 1–8. doi: 10.1016/j.gfs.2017.

01.001

Multsch S, Alquwaizany A S, Alharbi O A et al., 2017. Water-saving strategies for irrigation agriculture in Saudi Arabia. *International Journal of Water Resources Development*, 33(2): 292–309. doi: 10.1080/07900627.2016.1168286

Newbold T, Hudson L N, Arnell A P et al., 2016. Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science*, 353(6296): 288–291. doi: 10.1126/science.aaf2201

O'Neill D W, Fanning A L, Lamb W F et al., 2018. A good life for all within planetary boundaries. *Nature Sustainability*, 1(2): 88–95. doi: 10.1038/s41893-018-0021-4

Palmer L, 2014. A new climate for grazing livestock. *Nature Climate Change*, 4(5): 321–323. doi: 10.1038/nclimate2215

Pelletier N, Tyedmers P, 2010. Forecasting potential global environmental costs of livestock production 2000–2050. *Proceedings of the National Academy of Sciences of the United States of America*, 107(43): 18371–18374. doi: 10.1073/pnas.1004659107

Peters C J, Picardy J A, Darrouzet-Nardi A et al., 2014. Feed conversions, ration compositions, and land use efficiencies of major livestock products in US agricultural systems. *Agricultural Systems*, 130: 35–43. doi: 10.1016/j.agsy.2014.06.005

Picos J, Fonseca M, Clark D et al., 2010. *Forest Product Conversion Factors for the Unece Region*. Geneva Timber and Forest Discussion Paper 49, Geneva: United Nations. Geneva Timber and Forest Discussion Paper.

Pisanelli A, Bregasi M, Jupe A et al., 2010. Research priorities and opportunities within the forestry and agroforestry sectors in Albania. *iForest Biogeosciences and Forestry*, 3(5): 113–117. doi: 10.3832/ifor0534-003

Rao M P, Davi N K, D'Arrigo R D et al., 2015. Dzuds, droughts, and livestock mortality in Mongolia. *Environmental Research Letters*, 10(7): 074012. doi: 10.1088/1748-9326/10/7/074012

Rauf A, Liu X X, Amin W et al., 2020. Does sustainable growth, energy consumption and environment challenges matter for Belt and Road Initiative feat? A novel empirical investigation. *Journal of Cleaner Production*, 262: 121344. doi: 10.1016/j.jclepro.2020.121344

Rocchi B, Romano D, Hamza R, 2013. Agriculture reform and food crisis in Syria: impacts on poverty and inequality. *Food Policy*, 43: 190–203. doi: 10.1016/j.foodpol.2013.09.009

Rockström J, Steffen W, Noone K et al., 2009. Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14(2): 32. doi: 10.5751/es-03180-140232

Röös E, Bajželj B, Smith P et al., 2017. Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change*, 47: 1–12. doi: 10.1016/j.gloenvcha.2017.09.001

Running S W, 2012. A measurable planetary boundary for the biosphere. *Science*, 337(6101): 1458–1459. doi: 10.1126/science.1227620

Serna-Chavez H M, Schulp C J E, van Bodegom P M et al., 2014. A quantitative framework for assessing spatial flows of ecosystem services. *Ecological Indicators*, 39: 24–33. doi: 10.1016/j.ecolind.2013.11.024

Singapore Food Agency, 2020. Singapore's Modern Farms Series.https://www.sfa.gov.sg/food-for-thought/tags?tag=singapores-modern-farm-series&page=1

Steffen W, Richardson K, Rockström J et al., 2015. Planetary boundaries: guiding human development on a changing planet. *Science*, 347(6223): 1259855. doi: 10.1126/science.1259855

Syrbe R U, Walz U, 2012. Spatial indicators for the assessment of ecosystem services: providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators*, 21: 80–88. doi: 10.1016/j.ecolind.2012.02.013

Teo H C, Lechner A M, Walton G W et al., 2019. Environmental impacts of infrastructure development under the belt and road initiative. *Environments*, 6(6): 72. doi: 10.3390/environments6060072

United Nations, 2017. *Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development Report No. A/RES/71/313*. https://undocs.org/en/A/RES/71/313

United Nations, 2019. *World Population Prospects* 2019. https://www.un.org/development/desa/pd/content/publications

Van Zanten H H E, Meerburg B G, Bikker P et al., 2016. Opinion paper: the role of livestock in a sustainable diet: a land-use perspective. *Animal*, 10(4): 547–549. doi: 10.1017/s1751731115002694

Wiedmann T, Lenzen M, 2018. Environmental and social footprints of international trade. *Nature Geoscience*, 11(5): 314–321. doi: 10.1038/s41561-018-0113-9

Wu S, Liu L, Liu Y et al., 2019. The Belt and Road: geographical pattern and regional risks. *Journal of Geographical Sciences*, 29(4): 483–495. doi: 10.1007/s11442-019-1611-4

Winjum J K, Brown S, Schlamadinger B, 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. *Forest Science*, 44(2): 272–284. doi: 10.1093/forestscience/44.2.272

Xiao X M, Hollinger D, Aber J et al., 2004. Satellite-based modeling of gross primary production in an evergreen needleleaf forest. *Remote Sensing of Environment*, 89(4): 519–534. doi: 10.1016/j.rse.2003.11.008

Zhang Y, Xiao X M, Wu X C et al., 2017. A global moderate resolution dataset of gross primary production of vegetation for 2000–2016. *Scientific Data*, 4: 170165. doi: 10.1038/sdata.2017.165

Zhao M S, Heinsch F A, Nemani R R et al., 2005. Improvements of the MODIS terrestrial gross and net primary production global data set. *Remote Sensing of Environment*, 95(2): 164–176. doi: 10.1016/j.rse.2004.12.011

Zhou C B, Elshkaki A, Graedel T E, 2018. Global human appropriation of net primary production and associated resource decoupling: 2010–2050. *Environmental Science & Technology*, 52(3): 1208–1215. doi: 10.1021/acs.est.7b04665