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Study on the coupling coordinated development of ecological environment and industrial economy in the Russian Far East Federal District

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Under the background of the international development trend, the Russian Far East Federal District has become the open frontier area of the comprehensive strategic cooperation between China and Russia, which possesses great research value. Focusing on the Russian Far East Federal District as the study object, this paper constructs the ecological environment evaluation system and the industrial economic evaluation system. Combined with the comprehensive weighting method of the entropy weighting method and coefficient variation weighting method, this paper quantitatively calculates the ecological environment levels and the industrial economy levels in the Russian Far East Federal District from 2017 to 2023. Based on the coupling coordination model, this paper quantitatively analyzes the degree, characteristics and dynamic evolution of the coupling coordinated development of the ecological environment levels and the industrial economy levels in the Russian Far East Federal District from 2017 to 2023. The results show that from 2017 to 2023, in the Russian Far East Federal District, 1) In the ecological environment system, the ecological environment levels generally show the trend of first rising and then declining, showing the pattern characteristics of "High West, Low East" and "High South, Low North". 2) In the industrial economic system, the industrial economic levels generally show the increasing trend, showing the pattern characteristics of "High Core, Low Northeast and Low Southwest". 3) The coupling coordinated development degree of industrial economy and ecological environment shows the increasing trend, but it is still in the basic coordinated stage in general, which is characterized by the unbalanced pattern of "High Northwest, High Southeast, Low Northeast and Low Southwest". Finally, the proposals for the coordinated development of the ecological environment and industrial economy are proposed in the Russian Far East Federal District.

KEYWORDS

ecological environment, industrial economy, coupling coordination degree, spatial and temporal pattern, Russian Far East Federal District

1 Introduction

The 2016 《Outline of the China-Mongolia-Russia Economic Corridor》 has greatly broadened the cooperation development space among China, Mongolia and Russia (Huang, 2016; Liu, 2015). In 2023, the heads of China and Russia signed two joint statements, marking that the China-Russia comprehensive strategic partnership has reached the historic high moving forward levels in a new era. The Russian Far East Federal District, which is adjacent to Northeast China, is not only the important part of the China-Mongolia-Russia Economic Corridor construction (Lu et al., 2017), but also the open frontier area for China-Russia comprehensive strategic cooperation.

At present, the researches on the ecological environment and industrial economy of the Russian Far East Federal District mainly focus on the following two aspects: 1) The discussion of ecological environment problems: Zhuravel (2016) proposed an efficient operation plan for the coordinated development of the mining industry and the ecological environment in the view of the current situation of coal mining in the southern part of Yakutia in Russian Far East Federal District. Zhou (2008) and Koshkin and Yevdoshenko, (2019) believed that air and water pollution was affected by emissions from large industrial enterprises and domestic waste in Russian Far East Federal District. Li (2015) studied that urban construction was affected by the saline soil areas and the high salinity groundwater in the cold areas. According to the "follow-up survey method". Chu et al. (2022) studied the urbanization development level, eco-environment development level, and their coupling coordinated development degree in Russian Far East Federal District. Fan (2009) concluded that the use of forest land resources was mostly extensive in the Russian Far East Federal District. He believed that forestry cooperation was very promising in the Russian Far East and Northeast China. Bityukova (2011) held that the severity of air pollution depended on the degree of specialization of the industrial sector in the Russian Far East Federal District. Bityukova and Safronov, (2015) used the index of human environmental impact intensity to rate the ecological conditions of the Russian Far East Federal District in terms of air and water pollution, solid waste quantity, thermal pollution and radiation pollution, etc. Chu et al. (2021) measured the development levels of urbanization and ecological environment, exploring the degree of coordinated development between urbanization and ecological environment in the Russian Far East Federal District. 2) The research on the industrial economy development: Chi Chuang, (2008) believed that the industrial resource development was affected by the transportation conditions in the Russian Far East Federal District. The road network density was low and unevenly distributed, there was a lack of a good policy environment, and the price of transportation services was high in the Russian Far East Federal District. Zhou et al. (2017) analyzed that although the Russian Far East Federal District had the oil and gas resources potential, abundant gold and silver production, there were still unfavorable factors such as the poor transportation infrastructure and the insufficient labor condition. Wang (2016) analyzed that the industrial development of the Russian Far East had gone through the stages of the collapse and stagnation of the Soviet Union, the establishment of advanced development zones and free ports, and the population migration of the Far East Federal District. Liu (2005) believed that the current stage of industrial economic development was mainly affected by the project development funds and the economic market competitiveness in the Far East Federal District. Yang (2002) believed that China and Russia were neighbors and they had friendly relations. The industrial development cooperation between Russian Far East and Northeast China would solve the dilemma of industrial development investment, science and technology, and labor circumstances in the Far East Federal District. Glazyrina et al. (2013) conducted a study on the long-term benefits of cross-border cooperation between China and Russia based on the efficiency of mineral and raw material development in the Russian Far East Federal District. Mazitova (2022) reviewed the estimates of foreign trade indicators of the Russian Far East Federal District during the COVID-19 pandemic in 2020–2021. Yang et al. (2019) comprehensively evaluated the economic development levels of Northeast China and the Far East and Baikal regions of Russia, analyzing the compatibility of the above-mentioned regions in multiple aspects. Feng (2014) and Gao (2014) found that the economic urbanization levels had been increasing rapidly relying on industrialization in the Russian Far East Federal District.

Current researches focus on the internal contradictions of a single system on the ecological environment or industrial economy, lacking the overall deconstruction of the interaction mechanism between the two systems of ecological environment and industrial economy in the Russian Far East Federal District. In addition, the research methods are mainly concentrated on the qualitative descriptions or local case analyses, with few establishing the scientific and quantitative comprehensive evaluation systems of the ecological environment and industrial economy in the Russian Far East Federal District. What's more, the research data mainly focus on the static sectional data, making it difficult to reveal the spatio-temporal dynamic evolution characteristics of the ecological environment and industrial economy in the Russian Far East Federal District. Based on these, taking the 11 federal subjects of the Russian Far East as the research objects, this paper selects eight ecological environment indicators from the three dimensions of Pressure, State and Response, and 10 industrial economic indicators from the three dimensions of Potential, Scale and Structure to construct the ecological environment systems and industrial economy systems in the Russian Far East Federal District. Then, it uses the entropy weighting and coefficient of variation weighting to comprehensively determine the weights of ecological environment indicators and industrial economic indicators, measuring the ecological environment development levels and industrial economic development levels of the 11 federal subjects in the Russian Far East Federal District from 2017 to 2023. Next, it uses the coupling coordination degree model to quantitatively analyze the dynamic evolution characteristics of the coupling and coordinated development of the ecological environment levels and industrial economic levels of the 11 federal subjects in the Russian Far East Federal District from 2017 to 2023. It could make up for the shortcomings of previous studies that focused on a single system of ecological environment or industrial economy in the Russian Far East Federal District. Finally it puts forward the suggestions for the coordinated development of the ecological environment and industrial economy in the Russian Far

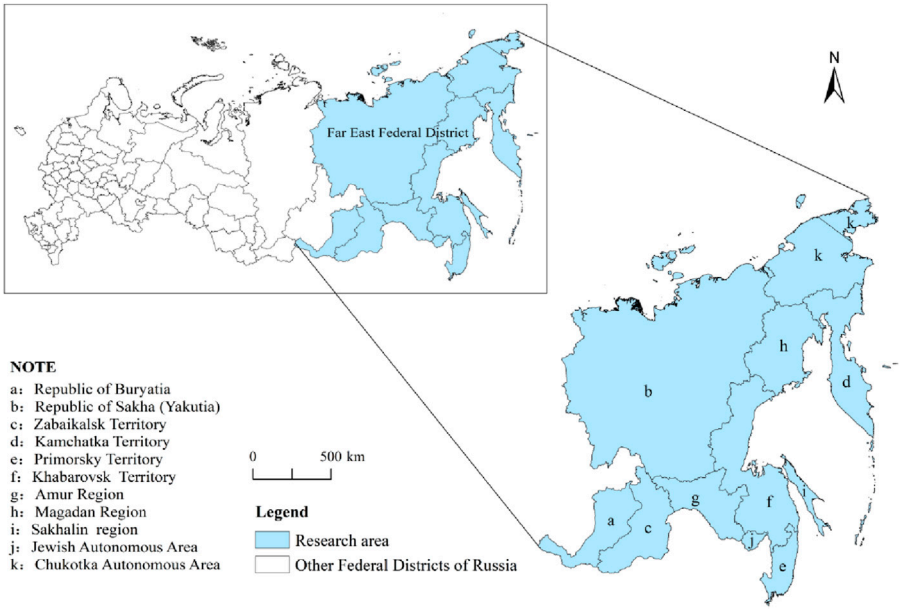

FIGURE 1
Sketch map of the study area.

East Federal District. It could compensate for the defect of not establishing the scientific quantitative evaluation system of ecological environment and industrial economy in the Russian Far East Federal District. It could also make up for the deficiency of only conducting qualitative descriptions and static researches of ecological environment and industrial economy in the Russian Far East Federal District in the previous studies. Thus, in the theory, this study could enrich the geo-economics contents and systems. In the practice, it could provide the references for the sustainable development of the Russian Far East Federal District and the cross-border cooperation between China and Russia.

2 Materials and methods

2.1 Study area and data sources

2.1.1 Study area

The Russian Far East Federal District is located in the eastern part of Russia (Figure 1), with a vast territory of 6,942,900 square kilometers, accounting for 41% of the total areas of Russia (Saniev and Sun, 2013). It consists of 11 federal subjects, namely, the Republic of Buryatia, Republic of Sakha (Yakutia), Zabaikalsk Territory, Kamchatka Territory, Primorsky Territory, Khabarovsk Territory, Amur Region, Magadan Region, Sakhalin Region, Jewish Autonomous Area, and Chukotka Autonomous Area. On one hand, the Russian Far East Federal District has abundant natural resources, with the forest coverage rate of more than 56%, and the timber production accounting for about 29% of Russia's timber industry. On the other hand, it has rich industrial resources, with large reserves of oil, natural gas, coal, precious metals and non-ferrous metal minerals, of which gold, silver, copper, tin, uranium and others exceed half of Russia's total reserves (Chai and Zhou, 2017).

2.1.2 Data sources

The data of indicators related to ecological environment and industrial economy come from 2018-2022 published on the official website of the Russian Federal Statistical Service "https://www.gks.ru/". 《РеГионы России. СоциальноэкономическиеПоказатели》 (Socio-economic indicators of Russian regions) and 《Российски йстатистическийежеГодник》 (Regional Statistical Yearbook of Russia).

2.2 Research methods

2.2.1 Indicator system

"Coupling" is a physical concept that refers to the phenomenon in which two (or more) systems affect each other through various interactions, and the degree of coupling is a measure of this synergy in the two (or more) systems (Liu et al., 2021). In order to accurately evaluate the coupling coordinated development degree of ecological environment and industrial economy in the Russian Far East Federal District, based on the ecological environment data, the industrial economy data and the coupling theory, the ecological environment development levels and the industrial economic development levels are studied at the same level in the Russian Far East Federal District. Taking the principles of data availability and comparability, representativeness and matching of indicators, scientificity and relevance of the systems into consideration, and following the coupling coordination of related disciplines within and outside the system (Tian et al., 2021), the evaluation systems for the coupling coordinated development of ecological environment and industrial economy suitable for the Russian Far East Federal District are constructed.

As shown in Table 1, the ecological environment system and the industrial economy system are two complex systems that affect each

TABLE 1 Ecological environment systems and industrial economy systems.

System layer	Goal layer	Indicator layer (unit)	Property	Entropy weights	Coefficient variation weights	Comprehensive weights
Ecological Environment system	Pressure	polluted wastewater discharge (m^3)	-	0.064	0.063	0.064
		pollutants discharged from fixed sources to the atmosphere (t)	-	0.034	0.043	0.038
	State	area of woodland (m^2)	+	0.061	0.067	0.064
		forest land coverage (%)	+	0.005	0.015	0.009
		water used for extraction from natural water bodies (m^3)	+	0.040	0.045	0.042
	Response	reclaimed water and sustainable water use (m^3)	+	0.054	0.050	0.052
		captured and neutralized air pollutants (t)	+	0.073	0.068	0.071
		freshwater utilization (m^3)	+	0.040	0.046	0.043
Industrial economy system	Structure	fixed assets of the mining sector (millions of rubles)	+	0.137	0.107	0.121
		fixed assets of the manufacturing sector (millions of rubles)	+	0.087	0.075	0.081
		fixed assets of the electricity, gas and water sector (millions of rubles)	+	0.032	0.041	0.036
	Scale	number of enterprises and organizations of the mining sector (number)	+	0.033	0.039	0.036
		number of enterprises and organizations of the manufacturing sector (number)	+	0.045	0.050	0.048
		number of enterprises and organizations of the electricity, gas and water sector (number)	+	0.024	0.034	0.028
	Potential	total output value of the mining sector (millions of rubles)	+	0.107	0.088	0.097
		total output value of the manufacturing sector (millions of rubles)	+	0.059	0.059	0.059
		total output value of the electricity, gas and water sector (millions of rubles)	+	0.026	0.036	0.031
		total foreign trade (millions of rubles)	+	0.080	0.073	0.076

other. In the ecological environment system, based on the Pressure-State-Response (PSR) model (Xie et al., 2015), from the Pressure dimension, the indicators of polluted wastewater discharge and pollutants discharged from fixed sources to the atmosphere are selected to quantify the pressure exerted by human economic activities on the ecosystem, reflecting the negative externalities of resource consumption and pollutant emissions on the environment during the industrialization process. From the State dimension, the indicators of area of woodland, forest land coverage and water used for extraction from natural water bodies are chosen to represent the basic state of the regional ecosystem, among which the area of woodland and forest coverage rate are related to carbon sequestration capacity and biodiversity, and the ater used for extraction from natural water bodies could reveal the balance between water supply and demand. From the Response dimension, the indicators of reclaimed water and sustainable water use, captured and neutralized air pollutants and freshwater utilization are selected to assess the adaptive restoration capacity of technological intervention and policy regulation on ecological degradation. In the process of regional industrial economic development, the ecological environment serves as a carrier, and regional resource endowments are utilized to expand the industrial economy scale, continuously optimizing the industrial structure. In the industrial economic system, based on the Potential- Scale-Structure (PSS) model (Gao, 2020), from the Potential dimension, the indicators of total output value of the mining sector, total output value of the manufacturing sector, total output value of the electricity, gas and water sector, total foreign trade are selected to reveal the important potential of regional resources and the ability to participate in international labor division. From the Scale dimension, the indicators of the number of enterprises and organizations of the mining sector, the number of

enterprises and organizations of the manufacturing sector and the number of enterprises and organizations of the electricity, gas and water sector are selected to quantify the activity level of market entities and the agglomeration effect of industries, reflecting the volume characteristics of industrial expansion. From the Structure dimension, the indicators of fixed assets of the mining sector, fixed assets of the manufacturing sector, and fixed assets of the electricity, gas and water sector are selected to analyze the industrial configuration structure, providing the basis for the assessment of industrial structure upgrading and resource dependence.

2.2.2 Indicator pre-processing and weights confirmation

In order to avoid the non-objectivity and arbitrariness of subjective weighting, entropy weighting and coefficient variation weighting are used to eliminate the error and bias of single objective weighting, and the weights of ecological environment indicators and industrial economy indicators are comprehensively determined.

a. Indicator pre-processing: In view of the different dimensions, natures, and units of eight ecological environment indicators and ten industrial economy indicators of 11 Russian Far East federal subjects, it is necessary to standardize the original indicators and eliminate their dimensions, so the range standardization method is chosen to remove the dimensions of each indicator, reducing the interference of random factors (Liu and Ran, 2017).

x_{ij} is the original value of the jth indicator in the ith federal subject. m represents the number of federal subjects. n represents the number of indicators, i = 1, 2, 3., m; j = 1, 2, 3., n. Z_{ij} is the standardized value of the jth indicator in the ith federal subject, with the following formula:

$$\text{Positive "+" indicators: } Z_{ij} = \left(x_{ij} - \min x_j\right) \Big/ \left(\max x_j - \min x_j\right)$$

$$\text{Negative "-" indicators: } Z_{ij} = \left(\max x_j - x_{ij}\right) \Big/ \left(\max x_j - \min x_j\right)$$

where min x_j is the minimum value of the jth indicator in the ith federal subject. max x_j is the maximum value of the jth indicator in the ith federal subject.

b. Entropy weighting method: entropy is the measure of the order degree or disorder degree of a system in classical physical thermodynamics. It represents the possible state of each indicator and its contribution to the whole system in the ecological environment system or industrial economy system. The greater the contribution, the higher the entropy weight (Guo, 1998).

The specific steps of the entropy weighting method are as follows:

Solve the proportion of the same degree quantification P_{ij}: $P_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij}$

Solve the information entropy of the j indicator e_j: $e_j = -(1/\ln m \sum_{i=1}^{m} P_{ij*} \ln P_{ij})$

Solve the entropy weight of the j indicator ω_j: $\omega_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j)$

Solve the development level of i federal subject U_i: $U_i = \sum_{j=1}^{n} (\omega_j * Z_{ij})$

c. Coefficient variation weighting method: the coefficient variation is called the dispersion coefficient or standard deviation rate, which is the proportion of the standard deviation and the mean value (Chen et al., 2021). It considers the influence of the dispersion degree of the variable value and the average level. In the same federal subject, the larger difference of the same indicator, the greater the relative gap, the greater the weight value, and the greater the impact on the ecological environment system or industrial economy system.

The specific steps of the coefficient variation weighting method are as follows:

Solve the average of the j indicator: $\bar{x}_j$;

Solve the standard deviation of the j indicator: S_j

Solve the coefficient variation of the j indicator CV_j: $CV_j = S_j / \overline{x_j}$

Solve the coefficient variation weight of the j indicator λ_j: $\lambda_j = CV_j / \sum_{j=1}^{n} CV_j$

Solve the development level of i federal subject W_i: $W_i = \sum_{j=1}^{n} (\lambda_j * Z_{ij})$

d. Comprehensive weighting method: The geometric average value of entropy weight and coefficient variation weight is used as the comprehensive weight of the jth indicator. The geometric average value of the development level of ith federal subject combined with the entropy weight method and coefficient variation weight method is used as the comprehensive development level of the ecological environment and industrial economy of the ith federal subject. The weights of ecological environment indicators and industrial economy indicators are as shown in Table 1.

2.2.3 Coupling coordination model

2.2.3.1 Coupling degree

"Coupling degree" originates from the physics subject, referring the interaction degree of two systems or more systems. It also refers to the interdependence degree of one system on another system. The higher the coupling degree value, the stronger the dependence of one system on another system. The lower the coupling degree value, the weaker the dependence of one system on another system (Chu et al., 2022; Gao, 2020; Liu et al., 2021; Tian et al., 2021; Wang et al., 2015). There is a strong mutual influence and interaction relationship between the ecological environment and the industrial economy. Therefore, in this study, the ecological environment and the industrial economy are regarded as two interacting systems. Based on the concept of the coupling degree in physics subject, the coupling degree model of the ecological environment and the industrial economy in the Russian Far East is constructed to quantitatively represent the bidirectional effects of industrial economy and the ecological environment, the "destruction" effect or "improvement" effect of industrial economy on the ecological environment, and the "containment" effect or "promotion" efficacy of the ecological environment on the industrial economy. It is expected that the indicators and elements within the two systems

TABLE 2 Coordinated development stages of the ecological environment and industrial economy.

System layer	Formula layer (scale D)	Types (comparison between P_1 and P_2)	Symbol level
Coordinated development	High coordinated ($0.8 < D \leq 1.0$)	Ecological environment lag (P_1-P_2) > 0.1	I1
		Industrial economy lag (P_2-P_1) > 0.1	I2
		System Equalization ($0 \leq \lvert P_1\text{-}P_2 \rvert \leq 0.1$)	I3
	Basic coordinated ($0.5 < D \leq 0.8$)	Ecological environment lag (P_1-P_2) > 0.1	II1
		Industrial economy lag (P_2-P_1) > 0.1	II2
		System Equalization ($0 \leq \lvert P_1\text{-}P_2 \rvert \leq 0.1$)	II3
Uncoordinated development	Basic uncoordinated ($0.3 < D \leq 0.5$)	Ecological environment lag (P_1-P_2) > 0.1	III1
		Industrial economy lag (P_2-P_1) > 0.1	III2
		System Equalization ($0 \leq \lvert P_1\text{-}P_2 \rvert \leq 0.1$)	III3
	Severe uncoordinated ($0 < D \leq 0.3$)	Ecological environment lag (P_1-P_2) > 0.1	IV1
		Industrial economy lag (P_2-P_1) > 0.1	IV2
		System Equalization ($0 \leq \lvert P_1\text{-}P_2 \rvert \leq 0.1$)	IV3

of the ecological environment and the industrial economy could reach the optimal sustainable development state. The formula of the coupling degree is as follows:

$$C = \left[\frac{P_1 \times P_2}{(P_1 + P_2)^2} \right]^{1/2}$$

P_1 and P_2 are the ecological environment development level and the industrial economy development level of i federal subject, respectively. C is the coupling degree of the ecological environment development level and industrial economy development level of i federal subject.

2.2.3.2 Coordinated development degree

Similar to the concept of "coupling degree", "coordinated development degree" also refers to the interaction degree and the interdependence degree of two systems or more systems. However, in order to avoid the limitations of the single "coupling degree", which may lead to the false appearance of high coupling between two low-level systems, this study constructs the coordinated development degree model based on the coupling degree, thereby accurately determining the interaction intensity and symbiotic coordination status between the ecological environment and the industrial economy, and avoiding certain situations where the ecological environment level and industrial economy level of some federal entities are both low but their coupling degree is high (Chu et al., 2022; Gao, 2020; Liu et al., 2021; Tian et al., 2021; Wang et al., 2015). The coordinated development degree is equipped with a dual constraint mechanism, which requires maintaining a positive interaction between ecological environment system and the industrial economy system (C-value constraint), and also requires ecological environment system and the industrial economy system to reach the benchmark development level (T-value constraint), which can effectively identify the "pseudo-coordination of low levels" phenomenon. The formula of the coordinated development degree is as follows:

$$D = \sqrt{C \times T} \quad T = \alpha P_1 + \beta P_2$$

D is the coordinated development degree of the ecological environment development level and industrial economy development level of i federal subject. The closer D is to 0, the weaker interaction effect between the ecological environment development and industrial economy development. The closer D is to 1, the stronger synergy effect between the ecological environment development and industrial economy development. T is the comprehensive coordination degree. α, β is the weights of the ecological environment and the industrial economy, and these two are in the same important position, $\alpha = \beta = 0.5$. Referred Wang et al. (2015) and Chu et al. (2021), we divide the coordinated development stages of the ecological environment and industrial economy into four categories: high coordinated, basic coordinated, basic uncoordinated and severe uncoordinated, with three sub-categories under each category (Table 2).

3 Comprehensive measurement of the ecological environment and industrial economy

3.1 Ecological environment

From 2017 to 2023, in the ecological environment system in the Russian Far East Federal District, the influence of ecological environment pressure is the strongest, with an average weight of 2.14. And the impact of ecological environment status is the lowest, with an average weight of 0.99. On the one hand, due to the lack of funds, limited technical level, backward aging equipment, exploration and exploitation of oil, gas and mineral resources have different degrees of impact on the vegetation, surface and groundwater. On the other hand, solid waste from the industrial economy causes a certain degree of pollution to the atmosphere and water bodies in the Russian Far East Federal District.

TABLE 3 Ecological environment and industrial economy development levels in the Russian Far East federal subjects.

Federal subjects	Ecological environment				Industrial economy			
	Pressure	State	Response	Ecological environment	Structure	Scale	Potential	Industrial economy
Republic of Buryatia	0.227	0.129	0.153	0.510	0.043	0.081	0.053	0.177
Republic of Sakha (Yakutia)	0.121	0.212	0.160	0.492	0.186	0.114	0.254	0.554
Zabaikalsk Territory	0.197	0.091	0.174	0.462	0.059	0.071	0.067	0.197
Kamchatka Territory	0.245	0.069	0.026	0.340	0.026	0.019	0.053	0.098
Primorsky Territory	0.062	0.130	0.353	0.546	0.191	0.097	0.195	0.484
Khabarovsk Territory	0.143	0.146	0.213	0.502	0.169	0.108	0.169	0.445
Amur Region	0.190	0.058	0.166	0.414	0.081	0.100	0.056	0.237
Magadan Region	0.259	0.056	0.043	0.358	0.027	0.041	0.076	0.144
Sakhalin Region	0.239	0.050	0.036	0.325	0.222	0.035	0.225	0.482
Jewish Autonomous Area	0.260	0.012	0.008	0.280	0.003	0.005	0.005	0.013
Chukotka Autonomous Area	0.017	0.050	0.017	0.084	0.009	0.001	0.029	0.040

Based on the comprehensive weighting method of the entropy weight method and coefficient variation weight method, the ecological environment pressure, the ecological environment state and the ecological environment response development levels of the Russian Far East are calculated. From 2017 to 2023, in the Russian Far East, the ecological environment development levels generally show the trend of first increasing and then decreasing, of which the ecological environment pressure decreases slightly, the ecological environment state and the ecological environment response develop steadily. Federal subjects with high levels of ecological environment are located in Primorsky Territory, Republic of Buryatia, Khabarovsk Territory, etc. (Table 3). In recent years, the Russian Far East has sacrificed part of its ecological environment space to promote the economic development. In terms of air resources, large and medium-sized power and non-ferrous metal metallurgical heavy industries have emitted much pollutants, such as carbon dioxide, sulfur oxide, mercaptans, phenol, formaldehyde, ammonia, lead, and suspended particles to the atmosphere. In terms of water resources, the exploitation of mineral resources has produced a large amount of polluted wastewater, such as copper, iron, zinc, phenol, petroleum products, and mildly oxidized organic matter (Jiang, 2007). While in Yakutsk, there are phenomena such as thermal erosion, swamping, and waterlogging, which artificially form overflows and lead to groundwater pollution. In terms of land resources, the urban construction encroaches on the space of some natural resources, and there are many problems in the land development model.

3.2 Industrial economy

From 2017 to 2023, in the industrial economy system in the Russian Far East Federal District, the influence of industrial economic potential is the strongest, with an average weight of 0.96. And the influence of industrial economic scale is the weakest, with an average weight of 0.69. Although the industrial economic development of the Russian Far East has much development potential, the output value and total trade volume are relatively small, which is related to the severe factors, such as the harsh climate and economic backwardness. However, in recent years, with the strengthening of cooperation with China, the geographical advantages and resource advantages of the Russian Far East have been continuously stimulated, boosting its industrial economic development.

Based on the comprehensive weighting method of the entropy weight method and coefficient variation weight method, the industrial economy structure, the industrial economy scale and the industrial economy potential development levels of the Russian Far East are calculated (Table 3). From 2017 to 2023, in the Russian Far East, industrial economy development levels show the overall increasing trend, of which the industrial economy scale decreases slightly, the industrial economy potential and industrial economy structure increase significantly. Historically, the collapse of the Soviet Union led to a sharp decline in the number of heavy industries in the Far East Federal District, and the industrial economy levels of the Far East Federal District declined accordingly. In this stage, the industrial economy development of the Far East Federal District is constrained by the factors, such as the single industrial structure, harsh climate environment, loss population labor, difficult expansion of industrial scale. And the industrial economy development of the Far East Federal District is still in a backward position in the whole of Russia. They have carried out the cooperation projects in various of aspects, such as roads, pipelines, and railway transportation, providing new industrial economic development opportunities for the Russian Far East Federal District.

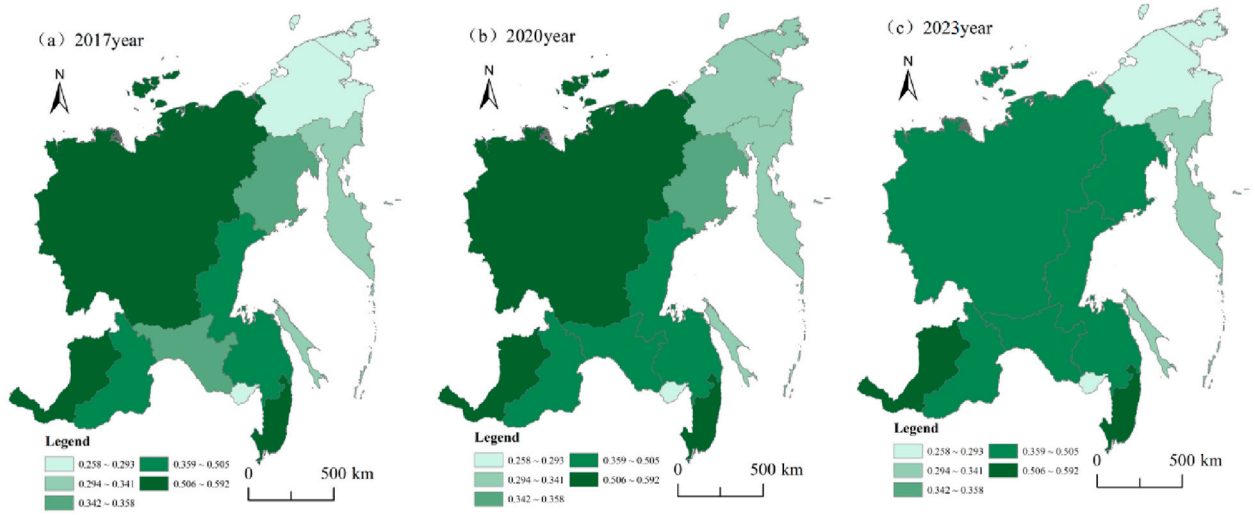

FIGURE 2
Spatial pattern of ecological environment in Russian Far East Federal District in 2017 year **(a)**, 2020 year **(b)** and 2023 year **(c)**.

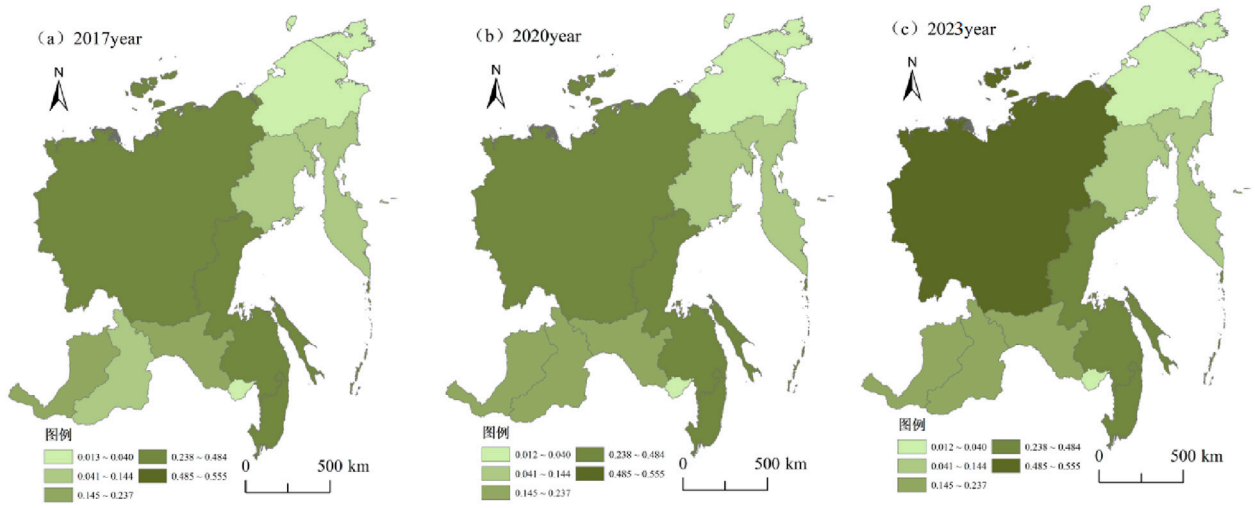

FIGURE 3
Spatial pattern of industrial economy in Russian Far East Federal District in 2017 year **(a)**, 2020 year **(b)** and 2023 year **(c)**.

3.3 Spatio-temporal patterns of ecological environment and industrial economy

The spatial analysis function of ArcGIS is used to explore the spatial pattern changes of ecological environment and industrial economy in the Russian Far East Federal District. From 2017 to 2023, in the Russian Far East Federal District, the ecological environment levels generally show the trend of first increasing and then decreasing (Figure 2), showing the pattern characteristics of "High West, Low East" and "High South, Low North", with the high value areas distributed in the Republic of Buryatia and Primorsky Territory, and the low value areas concentrated in Chukotka Autonomous Area and Kamchatka Territory. The water transparency remains above 40 m throughout the year along the shore of Lake Baikal in the Republic of Buryatia. The organisms are unique in the lake and the ecosystem is well-developed. Primorsky Territory also has rich forest resources. But in recent years, due to the lack of modern pollution prevention and control facilities in the vulnerable areas of serious oil and gas overexploitation, the pollution of surface water, atmosphere, and land has been exacerbated, resulting in the deterioration of the ecological environment.

From 2017 to 2023, in the Russian Far East Federal District, the industrial economy levels show the increasing trend (Figure 3), showing the pattern characteristics of "High Core, Low Northeast and Low Southwest", with the high value areas concentrated in the Republic of Sakha (Yakutia), Khabarovsk Territory and Primorsky Territory. These are mainly due to the fact that during the Soviet Union period, the local government develops the industrial and other economic sectors to meet the military strategic needs in the Far

TABLE 4 Coupling coordination types between industrial economy and ecological environment in Russian Far East Federal District from 2017 to 2023.

Federal subjects	2017		2019		2021		2023	
	Phrase	Types	Phrase	Types	Phrase	Types	Phrase	Types
Republic of Buryatia	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2
Republic of Sakha (Yakutia)	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic coordinated	II3
Zabaikalsk Territory	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2
Kamchatka Territory	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Basic uncoordinated	III2
Primorsky Territory	Basic uncoordinated	III2	Basic coordinated	II2	Basic uncoordinated	III2	Basic coordinated	II3
Khabarovsk Territory	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2
Amur Region	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2
Magadan Region	Severe uncoordinated	IV2	Basic uncoordinated	III2	Basic uncoordinated	III2	Basic uncoordinated	III2
Sakhalin Region	Basic uncoordinated	III2	Basic uncoordinated	III1	Basic uncoordinated	III1	Basic uncoordinated	III2
Jewish Autonomous Area	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Severe uncoordinated	IV2
Chukotka Autonomous Area	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Severe uncoordinated	IV2	Severe uncoordinated	IV2

East Federal District. Among them, the industrial economy of the Republic of Sakha (Yakutia) is dominated by the mining of diamonds and gold, the power industry, the fuel industry and the food industry. The industrial economy of the Khabarovsk Territory consists mainly of manufacturing, machine building, petroleum products, food, metallurgy, etc. The mining industry of Primorsky Territory is dominated by the non-ferrous metallurgical industry, mineral resources chemical industry, and coal industry. Although this development stage achieves great economic development progress, it also has caused the Far East to become overly dependent on mineral raw materials, resulting in the deformed industrial structure, which still adversely affects the whole economic development in the Far East Federal District. In recent years, under the background of the global financial crisis and the sharp decline in world oil prices, the Far East Federal District has become the new growth point for Russia's economic development. Under the demand for Russia's integration into the Asia-Pacific economic circle, on the basic principles of overall promotion and advanced development, the regional economic policies of the Far East Federal District pay more attention to the relationship between human being and ecological protection, realizing the agglomeration of innovative industries by building advanced development zones and free ports.

4 Coupling coordination between ecological environment and industrial economy

4.1 Coupling coordination types

Based on the coupling coordination degree model, the coupling coordinated development degree of the ecological environment and industrial economy is calculated in the Russian Far East Federal District. From 2017 to 2023, the coupling coordinated development degree of the industrial economy and ecological environment shows the increasing trend in the Russian Far East Federal District (Table 4), with the average degree of 0.363. But it is still in the basic uncoordinated stage. In the past 5 years, the *C* value of the Russian Far East has risen from 0.403 to 0.435, and the *D* value of the Russian Far East has risen from 0.349 to 0.378. In 2023, among all the Far East federal subjects, the Republic of Sakha (Yakutia) and Primorsky Territory have the highest coordinated development degree, and they are in the basic coordinated stages. They have the potential to be upgraded to the high coordinated degree. While the remaining Far East federal subjects are still in the uncoordinated stages. In terms of the changes in the coupling coordination types, the Republic of Sakha (Yakutia), Primorsky Territory, Kamchatka Territory, and Magadan Region have achieved positive development of coupling coordination, while other federal subjects remain basically unchanged.

The coupling coordination degree of the Republic of Sakha (Yakutia) and Primorsky Territory is much higher than that of other neighboring Far East federal subjects. The Republic of Sakha (Yakutia) has always been one of the most important resource bases in Russia. It has rich minerals, energy, forest resources, etc., which has great significance to Russia's economy and national defense. Primorsky Territory has very superior geographical location, with the largest and most excellent port "Vladivostok" in the Russian Far East, which is conducive to the industrial production development. Jewish Autonomous Area and Chukotka Autonomous Area has low coupling coordination degree. Their coupling coordination degree has no improvement trend. These two federal subjects are located in the relatively fringed closed area. And their development potential has not been fully explored. Among them, Chukotka Autonomous Area is located in a

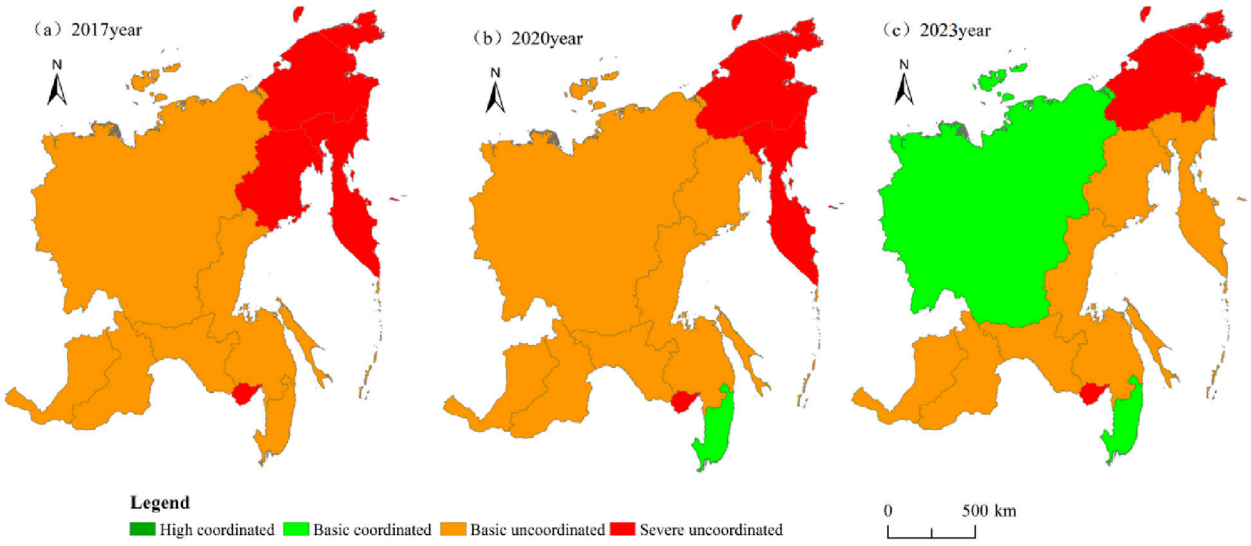

FIGURE 4
Spatial pattern of coupling coordination degree of ecological environment and industrial economy in Russian Far East Federal District in 2017 year **(a)**, 2020 year **(b)** and 2023 year **(c)**.

high-latitude region, which has polar ice tundra climate, cold and long winters, sparse population, and insufficient labor. Most of the areas are covered by permafrost, which do not applicable to the construction of the ecological environment.

4.2 Spatio-temporal pattern of coupling coordination

From 2017 to 2023, the coordinated development degree of the industrial economy and ecological environment show the overall increasing trend in the 11 Russian Far East federal subjects. But due to the differences in geographical location, economic base and natural conditions of these 11 federal subjects, the coupling coordination degree of each of them is significantly different, which is characterized by the unbalanced pattern of "High Northwest, High Southeast, Low Northeast and Low Southwest" (Figure 4).

From 2017 to 2023, the coordinated development degree of 11 federal subjects ranges from 0.169 to 0.512. In 2017, there are no federal subjects in the basic coordinated stages, of which Primorsky Territory has the highest coordinated development degree (0.488). In 2020, only Primorsky Territory achieves the basic coordinated stage, ahead of other federal subjects. In 2023, the coordinated development degree of Republic of Sakha (Yakutia) and Primorsky Territory reaches 0.5 or above, which are in the basic coordinated stage. Other federal subjects are still in the uncoordinated stage. While the Jewish Autonomous Area and Chukotka Autonomous Area are still in the severe uncoordinated stage. From 2018 to 2020, there are a slight decrease in the coordinated development degree of Kamchatka Territory, Primorsky Territory, and Jewish Autonomous Area, which is related to the uncertainty in the oil and foreign exchange markets in 2020, as well as the anti-epidemic restrictions imposed due to the spread of the Novel Coronary Pneumonia. Judging from the general trend, the relationship between the industrial economy and the ecological environment will be developing into more coordinated situation in the Far East Federal District, which is mainly related to the introduction of preferential policies by the Russian government, vigorously supporting the infrastructure construction in the Far East Federal District, and expanding the opening up of the Far East Federal District to the outside world.

5 Discussion

In recent years, the coupling coordination degree of the ecological environment and industrial economy is mostly in the basic uncoordinated stage in Russian Far East Federal District. So it is urgent to improve the industrial economy and protect the ecological environment.

From the perspectives of ecological environment protection and industrial economy enhancement, 1) Overall strategy of ecological environment and industrial economy: the Russian government should construct the new coordinated development model of ecological environment and industrial economy, promoting the leading role of advantageous regions among different federal subjects. It should also implement strategies based on local conditions of different federal subjects, achieving the dynamic balances between the industrialization process and the natural capacity. Internally, the Russian government should increase financial support, adjust the original policy system, optimize the industrial structure, and cultivate green industrial clusters driven by technological innovation. Externally, the Russian government should increase the opening up to the outside world, attach importance to cooperation with Northeast Asia, give fully play to the geographical advantages of China's Heilongjiang Province and Jilin Province, explore new models of cross-border ecological economic cooperation, jointly build a digital collaborative platform, form a composite development network that integrates

land and sea transportation channels, and promote the high-quality coordinated development of the industrial economy and ecological environment. 2) In terms of ecological environment protection: the Russian Far East Federal District should improve the ecological environment protecting policies, establish the classified control system and mechanism for the entire areas, promote the comprehensive management projects in key river basins, build the intelligent ecological monitoring network and ecological restoration system, and improve the quality of the living environment. What's more, it should implement the gradient governance strategies of "conservation in high value areas-improvement in medium value areas-restoration in low value areas". It should maintain the ecological environment quality in high-value areas, such as the Republic of Buryatia, Primorsky Territory, etc. It should promote the development of the ecological environment in medium-value areas, such as the Zabaikalsk Territory, Amur Region, Khabarovsk Territory, etc. It should strictly prohibit environmental destruction in low-value areas, such as the Chukotka Autonomous Area, Kamchatka Territory, etc. 3) In terms of enhancing the industrial economy: the Russian Far East Federal District should focus on low-carbon and intelligent development directions in the industrial system transformation, cultivating strategic emerging industrial clusters such as clean energy equipment and green metallurgy, and building smart industrial parks integrating internet technology. It should also deepen regional capacity cooperation in Northeast Asia, jointly promoting key projects in energy transition and high-end manufacturing, and building an efficient cross-border logistics service system. In addition, it should attract foreign investment, establishing cross-regional management institutions, and enhancing cross-regional cooperation. It should also expand trade channels, increase industrial economy scale, introduce advanced equipment, promote industrial upgrading, strengthen exploration of resources and energy, enhance industrial economic cooperation, and cultivate mining development talents.

From the perspectives of coupling coordination development between ecological environment and industrial economy, 1) For the federal subjects with high coupling coordination degree, such as the Republic of Sakha (Yakutia), the Primorsky Territory, etc., it is recommended to focus on strengthening the synergy effect of their resource endowment and location advantages. For example, the Republic of Sakha (Yakutia) could rely on rich mineral and forest resources to promote the upgrading of deep processing technologies such as precious metal purification and rare earth element extraction. At the same time, it could establish the forest carbon sink trading pilot project to feed back the benefits of ecological protection to the green industrial transformation. The Primorsky Territory could play the strategic hub role of Vladivostok port, building the economic system that integrates port logistics, port industries, and cross-border trade. The federal subjects with high coupling coordination degree need to be vigilant against the unilateral pressure of resource development on the ecological environment, increasing the ecological protection momentum into the industrial upgrading. 2) For the federal subjects with medium coupling coordination degree, such as the Khabarovsk Territory, Sakhalin Region, etc., it is recommended to enhance their risk resistance and industrial added value. For example, the Khabarovsk Territory could develop low-carbon energy industries to resist the risks of fluctuations in traditional resource prices, cultivating characteristic industrial clusters. The Sakhalin Region could build the regional ecological industrial symbiosis network, forming the resource recycling system. In addition, as for the vulnerable federal subjects affected by the international market, they could achieve supply chain elastic management through the construction of industrial internet platforms, establishing the cross-regional ecological compensation funds to balance the distribution of development benefits. They could also extend the value chain of ecological tourism, such as transforming abandoned oil wells into the geothermal science education bases, etc. 3) For the federal subjects with low coupling coordination degree, such as the Jewish Autonomous Area, Chukotka Autonomous Area, etc., it is recommended to break through the dual constraints of natural conditions and infrastructure construction. For example, the Jewish Autonomous Area could use the adaptive technologies, such as the remote industrial control systems to activate the resource potential. The Chukotka Autonomous Area could establish the ecological compensation funds to resist market fluctuations, promoting the overall coordination development degree to leap from the government infrastructure driven to the market oriented technological innovation driven. What's more, some federal subjects could implement the "migratory bird employment" socialized service innovation system, attracting seasonal technical workers through high-salary rotation systems, and building the drone medical delivery network to ensure the basic livelihood of remote settlements.

6 Conclusion

(1) From 2017 to 2023, in the ecological environment system, the influence of the ecological environmental pressure is the strongest, and the impact of ecological environment status is the lowest. The ecological environment development levels generally show the trend of first increasing and then decreasing, of which the ecological environment pressure decreases slightly, the ecological environment state and the ecological environment response develop steadily. Spatially, the ecological environment levels show the pattern characteristics of "High West, Low East" and "High South, Low North", with the high value areas distributed in the Republic of Buryatia and Primorsky Territory, and the low value areas concentrated in Chukotka Autonomous Area and Kamchatka Territory.

(2) From 2017 to 2023, in the industrial economic system, the influence of industrial economic potential is the strongest, and the influence of industrial economic scale is the weakest. The industrial economy development levels show the overall increasing trend, of which the industrial economy scale decreases slightly, the industrial economy potential and the industrial economy structure increase significantly. Spatially, the industrial economy levels show the pattern characteristics of "High Core, Low Northeast and Low Southwest", with the high value areas concentrated in the Republic of Sakha (Yakutia), Khabarovsk Territory and Primorsky Territory.

(3) From 2017 to 2023, the coupling coordinated development degree of the industrial economy and ecological

environment shows the increasing trend in the Russian Far East Federal District. But it is still in the basic uncoordinated stage. Spatially, the coordinated development degree of the industrial economy and ecological environment show the unbalanced pattern of "High Northwest, High Southeast, Low Northeast and Low Southwest". Among them, the coupling coordination type of the Republic of Sakha (Yakutia) and Primorsky Territory has changed from basic uncoordinated to basic coordinated. They have the potential to be upgraded to the high coordinated degree. The coupling coordination type of the Kamchatka Territory and Magadan Region has changed from severe uncoordinated to basic uncoordinated. The coupling coordination type of the Republic of Buryatia, Zabaikalsk Territory, Khabarovsk Territory, Amur Region, Sakhalin Region has been the basic uncoordinated. The coupling coordination type of the Jewish Autonomous Area and Chukotka Autonomous Area has been the severe uncoordinated.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

NC: Conceptualization, Funding acquisition, Methodology, Writing–original draft, Writing–review and editing. XH: Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing–original draft, Writing–review and editing. PZ: Funding acquisition, Resources, Writing–review and editing. ZT: Data curation, Formal Analysis, Investigation, Software, Visualization, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Bityukova, V. R. (2011). Dynamics of atmospheric pollution by stationary sources. *Regional Res. Russ.* 1 (4), 394–398. doi:10.1134/S2079970511040010

Bityukova, V. R., and Safronov, S. G. (2015). Assessment of the ecological situation in Russia using the method of potential surfaces of human impact. *Regional Res. Russ.* 5 (4), 367–377. doi:10.1134/S2079970515040048

Chai, Lu, Bao, Q., and Zhou, Y. (2017). General situation and potential of diamond-precious metals in Russian far East Federal District. *Geol. Rev.* 63 (S1), 31–32. doi:10.16509/j.georeview.2017.s1.016

Chen, H., Xiaoning, Li, and Chenyang, Li (2021). Resilience evaluation of water resource system based on coefficient of variation entropy weight method: a case study of water resources in Heilongjiang Province from 2007 to 2016. *Ecol. Econ.* 37 (1), 179–184. doi:10.13969/j.issn.1671-4407.2021.01.030

Chi, C. (2008). *Research on exploitation and utilization of natural resources in the Russian Far East and Sino-Russian resource cooperation*. Jilin University. Chinese Excellent Master's Thesis.

Chu, N., Wu, X., and Zhang, P. (2022). Spatiotemporal evolution characteristics of coordinated development of urbanization and ecological environment in eastern Russia—perspectives from the 3D global trend and 2D plane analysis. *PLoS ONE* 17 (7), e0267272. doi:10.1371/journal.pone.0267272

Chu, N., Zhang, P., Wu, X., Li, H., and Yang, Q. (2021). Spatiotemporal evolution characteristics of coordinated development between urbanization and ecological environment in eastern Russia. *Acta Ecol. Sin.* 41 (24), 9717–9728. doi:10.5846/.stxb202009302528

Fan, H. (2009). *Study on the pattern of marine economy in the Russian Far East*. Northeast Normal University. Chinese Excellent Master's Thesis.

Feng, C. (2014). New characteristics of Russia's urbanization during the transitional period. *Shanghai Urban Plan. Rev.* (5), 72–78. doi:10.3969/j.issn.1673-8985.2014.05.016

Gao, J. (2014). Urbanization and urban development in Russia. *Russian,East European&Central Asian Stud.* (1), 38–45. doi:10.3969/j.issn.1004-9479.2014.02.007

Gao, L. 'an (2020). Research on judgment and optimizing path of coupling and coordination between economy and eco-environment in Northeast China. *Statistics& Inf. Forum* 35 (1), 74–81. doi:10.3969/j.issn.1007-3116.2020.01.009

Glazyrina, I. P., Kalgina, I. S., and Lavlinskii, S. M. (2013). Problems in the development of the mineral and raw-material base of Russia's Far East and prospects for the modernization of the region's economy in the framework of Russian-Chinese cooperation. *Regional Res. Russ.* 3 (4), 405–413. doi:10.1134/S2079970514010055

Guo, X. (1998). Application of improved entropy method in evaluation of economic result. *Syst. Engineering-Theory and Pract.* (12), 99–103. doi:10.1088/0256-307X/16/9/020

Huang, F. (2016). Strategic analysis of the China- Mongolia- Russia economic corridor. *Renming Luntan·Xueshu Qianyan* (13), 62–73. doi:10.16619/j.cnki.rmltxsqy.2016.13.007

Jiang, Z. (2007). Analysis of measures to protect ecological security in Russia. *Russ. East Eur. and Central Asian Stud.* (6), 8–15+95. doi:10.3969/j.issn.1671-8461.2007.06.002

Koshkin, E. S., and Yevdoshenko, S. l. (2019). Diversity and ecology of hawk moths of the genus Hemaris (Lepidoptera, Sphingidae) of the Russian Far East. *J. Asia-Pacific Biodivers.* 12 (4), 613–625. doi:10.1016/j.japb.2019.07.002

Li, H. (2015). *Analysis of groundwater characteristics in cold region of Yakutsk region*. Heilongjiang University. Chinese Excellent Master's Thesis.

Liu, C., Deng, M., and Ran, C. (2017). Research on the coordinated development of agricultural modernization and new urbanization in Northeast China. *China Popul. Resour. Environ.* 27 (6), 155–162. doi:10.12062/cpre.20170356

Liu, G., Ju, W., Ye, J., and Chu, G. (2021). Analysis and prediction of the coupled and coordinated development of resource utilization-ecological environment-economic growth: a case study of provinces along the Silk Road Economic Belt. *Ecol. Econ.* 37 (11), 191–200. doi:10.1016/j.scitotenv.2021.148311

Liu, J. (2005). Current situation, problems and prospects of oil and gas development projects in the Russian Far East and East Siberia. *Sib. Stud.* (4), 27–29. doi:10.3969/j.issn.1008-0961.2005.04.014

Liu, W. (2015). Scientific understanding of the Belt and Road Initiative of China and related research themes. *Prog. Geogr.* 34 (5), 538–544. doi:10.3969/j.issn.1003-9082.2016.07.085

Lu, D., Jiang, D., Dong, S., Wang, C., Wang, J., and Chen, M. (2017). *Scientific understanding of the belt and road initiative*. Beijing: Science Press.

Mazitova, M. G. (2022). Foreign trade of the far eastern federal District: regional characteristics during the COVID-19 pandemic. *Regionalistica* 9 (3), 22–37. doi:10.14530/reg.2022.3.22

Saniev, R., and Sun, M. (2013). Priority directions for energy cooperation between the Russian Far East and China. *Study and Explor.* (2), 98–101. doi:10.3969/j.issn.1002-462X.2013.02.017

Tian, S., Xueming, Li, Yang, J., Zhang, W., and Guo, J. (2021). Spatio-temporal coupling coordination and driving mechanism of urban pseudo and reality human settlements in the three provinces of Northeast China. *Acta Geogr. Sin.* 76 (4), 781–798. doi:10.11821/dlxb202104002

Wang, B. (2016). The coupling and interaction between the revitalization of the old industrial base in Northeast China and the development of the Russian Far East. *J. Northeast Asia Stud.* (3), 25–31. doi:10.19498/j.cnki.dbyxk.2016.03.004

Wang, S. J., Fang, C. L., and Wang, Y. (2015). Quantitative investigation of the interactive coupling relationship between urbanization and eco-environment. *Acta Ecol. Sin.* 35 (7), 2244–2254. doi:10.5846/stxb201306021271

Xie, H., Qu, L., Yao, G., and Tan, M. (2015). Measuring regional land use sustainability of the Poyang Lake Eco-economic Zone based on PSR modeling. *Resour. Sci.* 37 (3), 449–457. doi:10.07-7588/(2015)03-0449-09

Yang, B. (2002). *Development of natural resources in the Russian Far East and international cooperation*. Heilongjiang University. Chinese Excellent Master's Thesis.

Yang, Y., Dong, S., Li, F., Cheng, H., Liu, Q., Li, Z., et al. (2019). Study on the coordination mechanism between strategies of Northeast China revitalization and development of Russian Far East and Baikal region. *Resour. Sci.* 41 (1), 43–52. doi:10.18402/resci.2019.01.05

Zhou, H. (2008). A preliminary study of environmental problems in the Russian Far East. *Sib. Stud.* (4), 56–58. doi:10.3969/j.issn.1008-0961.2008.04.021

Zhou, Y., Liu, J., Lu, C., Wu, D., and Wu, T. (2017). Supporting design and optimization of large section roadway with straight wall and semicircle arch. *China Min. Mag.* 26 (11), 118–125.

Zhuravel, N. M. (2016). Systematic evaluation of environmental and economic effectiveness of the best available technologies: regional dimension. *Regional Res. Russ.* 6 (2), 193–202. doi:10.1134/S2079970516020118