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Spatiotemporal evolution characteristics of coordinated development of urbanization and ecological environment in eastern Russia

——Perspectives from the 3D global trend and 2D plane analysis

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Abstract: Under the background of “the Belt and Road” and “the economic corridor of China, Mongolia and Russia” initiatives, it is of great significance to study the temporal and spatial evolution characteristics of the coordinated development between the urbanization and ecological environment in eastern Russia (the Siberian Federal District and the Far East Federal District). This paper studied the urbanization development level, eco-environment development level, and their coupling coordinated development degree during 2005-2018 in the eastern Russia from the perspectives of the 3D global trend and 2D plane analysis. First, combining with the Population-Economic-Sociology and Pressure-State-Response models, the paper constructed the index systems to evaluate the urbanization development level and eco-environment development level in eastern Russia. Second, based on the comprehensive weighting method of entropy weight and variation coefficient, this paper calculated the urbanization development level and eco-environment development level in eastern Russia. Third, the paper used the coupling coordination model to measure the coupling coordinated development degree of the urbanization development level and eco-environment development level in eastern Russia. Finally, the spatial differentiation of the urbanization development level, the eco-environment development level and their coupling coordinated development degree was performed respectively by the 3D global trend and 2D plane analysis using ArcGIS. The results are as following. First, the comprehensive urbanization development level of eastern Russia has increased from 2005 to 2018, and the urbanization level of the economic aspect is the main factor that affects the urbanization development of eastern Russia. The comprehensive eco-environment development level of eastern Russia has decreased from 2005 to 2018, and the eco-environment pressure is the main factor that affects the eco-environment development of eastern Russia. The coupling coordination degree of the urbanization development and eco-environment development has increased from 2005 to 2018, but it is still in the uncoordinated stage. Second, from 2005 to 2018, the urbanization development level of the Siberian Federal District is higher than that of the Far East Federal District. The eco-environment development level of the Siberian Federal District is balanced to that of the Far East Federal District. The coupling coordination degree of the urbanization development and eco-environment development in the Siberian Federal District is higher than that in the Far East Federal District. Among the Siberian Federal District and the Far East Federal District, most of the federal subjects belong to the uncoordinated stage of the urbanization development and the eco-environment development. Third, the urbanization development level, the eco-environment development level, and their coupling coordinated development level are all spatially imbalanced in the eastern Russia, which show the “High West, Low East” and “High Center, Low North and South” spatial pattern from the perspectives of the 3D global trend and 2D plane analysis. The areas with high levels are concentrated in the Novosibirsk Region, Altay Territory, Kemerovo Region, Krasnoyarsk Territory, and Irkutsk Region. The areas with low ones are mostly in the Republic of Altay and Chukotka Autonomous Area. Finally, we suggest policies and strategies that can boost the growth and development of the urbanization and the eco-environment in the Sino-Russian border areas, such as: promoting the division and cooperation of industries, implementing the division and cooperation of energy

projects, developing diversified tourism resources and products, accelerating the transformation of infrastructure, promoting the construction of the economic cooperation zone, and strengthening the protection and management of ecological environment, etc.

Key words: urbanization; ecological environment; coupling coordinated degree; spatiotemporal pattern; eastern Russia

1. Introduction

China proposed “the Belt and Road” initiative, including “the Silk Road Economic Belt” initiative and “the 21st-Century Maritime Silk Road” initiative in 2013. China issued the “Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road” in 2015, which meant that “the Belt and Road” initiative entered into a comprehensive promotion stage (Liu, 2015). In “the Belt and Road” initiative, relying on the important sea ports, the safe and efficient transportation channels will be built. And depending on the land transportation infrastructure, the six international economic corridors (new Eurasian Continental Bridge, China-Mongolia- Russia, China- Central Asia- West Asia, China- Indochina Peninsula, China- Pakistan, Bangladesh-China- India- Myanmar) will be constructed (Lu et al. 2017). And in the six international economic corridors, “China- Mongolia- Russia economic corridor” initiative will connect Russia’s “the Eurasian Economic Union” initiative and Mongolia’s “Grassland Silk Road” initiative. Under the background of “the Belt and Road” and “the economic corridor of China, Mongolia and Russia” initiatives, the Sino-Russian relations were upgraded to a “comprehensive strategic partnership of coordination in the new era” in 2019. And the economic and trade relations have been improving between China and Russia in recent years. Northeast China and eastern Russia are the frontier areas of Sino-Russian economic and trade cooperation. The cross-border cooperation between Northeast China and eastern Russia could be helpful to the economic revitalization, economic security ensuring, European and American sanctions resisting, opening systems building and Asia Pacific integration participating in the future.

Eastern Russia is an important neighbor area of Northeast China. As the key areas of “the Belt and Road” and “China- Mongolia- Russia economic corridor” initiatives, eastern Russia and Northeast China have entered into a new stage of comprehensive opening-up and cooperation (Lu et al. 2017). The coordinated development of urbanization and ecological environment is not only the inevitable trend of global economic and social development, but also an important content of transnational economic cooperation between China and Russia. Researches on the urbanization and eco-environmental development in eastern Russia mainly focus on the analysis of urbanization development process, the discussion of urbanization development problems, and the research of different eco-environmental problems. (1) Analysis of urbanization development process. Shang (2015) analyzed that the urbanization of eastern Russia had experienced three important stages, including the early eastward expansion of the Principality of Moscow, the expansion of Russia in the Amur River Basin, and the

73 climax of construction in the Tsarist Russian period. And relying on the rapid development of industrialization,
74 the urbanization development of eastern Russia went through a urbanization road from west to east developing,
75 from the center to around radiating, with military and administrative functions (Feng, 2014; Gao, 2014; Глушкова,
76 2004). Mishchuk (2013) reviewed the urbanization characteristics of immigrants in the Far East Federal District,
77 including the reasons and characteristics of European immigrants settling in the Far East Federal District, the
78 dynamics of forced and voluntary immigrants in the Far East Federal District, and the reasons for the formation of
79 reverse migration flow in the Far East Federal District. (2) Discussion of urbanization development problems. The
80 urbanization development in the Soviet Union was rapidly promoted by the industrialization development. After
81 the disintegration of the Soviet Union, in the transition process from the planned economy to the market economy,
82 the Russia's urbanization was in the stagnation because of the radical economic transformation and the regional
83 serious crisis. And the urbanization development was characterized by the shrinking and extinction of small cities,
84 the negative growth of urban and rural population, and the unstable development of urban system (Yu and Qiu,
85 2006). In the new era, Gao (2014), Li and Liu (2014) analyzed that the urban construction was developing slowly
86 in the eastern Russia. There were a series of problems in the urbanization of eastern Russia, such as the slow
87 development of urban agglomeration, the small number of mega cities, the single industrial structure of small and
88 medium-sized cities, the urban imperfect hierarchical scale structure, the single urban functional structure, and the
89 uneven distribution of urban spatial structure. Kuleshov and Seliverstov (2018) believed that the development and
90 interaction between eastern Russia and Northeast China would solve the regional development imbalance and
91 internal urbanization problems in eastern Russia. (3) Research of different eco-environmental problems. While
92 developing mining, forest harvesting and high-consuming military enterprises, the ecological and environmental
93 problems became more and more serious, such as the air pollution, water pollution, radioactive pollution, soil
94 heavy metals, offshore pollution and forest resources loss in eastern Russia (Koshkin and Yevdoshenko, 2019;
95 Zhou, 2008). Bityukova (2011) believed that the severity of urban air pollution mainly depended on the
96 specialization degree of the industrial sectors in eastern Russia. Vasilenko (2015) believed that the depletion and
97 quality deterioration of water resources were mainly affected by human water resources activities in the southern
98 areas of western Siberian Federal District in eastern Russia. Zhuravel (2016) analyzed the impact of coal mining
99 on the ecological environment, and he put forward the suggestions on sustainable and optimal operation efficiency
100 in the southern Yakutia and Kuznetsk basins in eastern Russia. Based on the comprehensive index of human
101 environmental intensity, Bityukova and Safronov (2015) rated the ecological environment status of cities in
102 eastern Russia, such as air and water pollution, solid waste quantity, thermal pollution and radiation pollution. At
103 present, most researches on the urbanization and ecological environment focus on unilateral analysis, and there

104 are relatively few studies on the coordinated development of urbanization and ecological environment in eastern
105 Russia. Moreover, on the basis of long-time series of historical documents and historical data, most Chinese
106 scholars have carried out the qualitative research, judgment and discussion on urbanization and ecological
107 environment in eastern Russia. Due to the data limitations, the quantitative and visual researches are obviously
108 insufficient on the urbanization and ecological environment in eastern Russia. Especially in the past 10 years, the
109 researches need to be continuously tracked and updated on the coordinated development of urbanization and
110 ecological environment in eastern Russia.

111 Twenty-one federal subjects are distributed in the eastern Russia. There are great differences in physical
112 geography, energy resources, geo-politics, economy and society among these different federal subjects. After the
113 disintegration of the Soviet Union, Eastern Russia has experienced economic crises, and its urbanization and
114 ecological environment are in an uncoordinated development condition. Eastern Russia is an important neighbor
115 area of Northeast China. However, the urbanization and ecological environment development conditions of
116 eastern Russia are not clear for China. This phenomenon has seriously affected the future cross-border
117 cooperation in economy, trade, industry, transportation, communication, resources and environment between
118 China and Russia. By studying the pattern of urbanization and ecological environment development in eastern
119 Russia, it would be helpful to select cross-border cooperation nodes, building the cooperation channels and
120 cooperation platforms between China and Russia. It also could be helpful to explore the complementary growth
121 points of regional cooperation, so as to open a coordinated development pattern between China and Russia.
122 Therefore, it is very important to study the coordinated development pattern of urbanization and ecological
123 environment in eastern Russia. This paper studied the urbanization development level, eco-environment
124 development level, and their coupling coordinated development degree during 2005-2018 in the eastern Russia
125 from the perspectives of the 3D global trend and 2D plane analysis. Combining with the
126 Population-Economic-Sociology and Pressure-State-Response models, the paper constructed the index systems to
127 evaluate the urbanization development level and eco-environment development level in eastern Russia. Based on
128 the comprehensive weighting method of entropy weight method and variation coefficient weight method, this
129 paper calculated the urbanization development level and eco-environment development level in eastern Russia.
130 The paper used the coupling coordination model to measure the coupling coordinated development degree of the
131 urbanization development level and eco-environment development level in eastern Russia. And the spatial
132 differentiation of the urbanization development level, the eco-environment development level and their coupling
133 coordinated development degree was performed respectively by the 3D global trend and 2D plane analysis in
134 ArcGIS. In the theory, this study can enrich the theoretical systems of urban geography and urban ecology. It can

135 provide guidance and reference for similar related researches in other parts of the world, especially in China's
136 adjacent areas. In the practice, this paper could help to clear the complementary points of bilateral cooperation
137 between China and Russia. It can provide a scientific reference for regional development planning, economic
138 optimization layout, energy and resource development and infrastructure construction in the adjacent areas of
139 China and Russia in the future. It can provide suggestions for adjusting economic cooperation field and expanding
140 the investment scale in the border cities of China and Russia in the future. It also can provide policy implications
141 for determining the cooperation direction of border trade, transportation facilities, border tourism, border
142 cooperation zone and ecological environment protection of China and Russia in the future.

143 2. Materials and Method

144 2.1. Research area

145 Eastern Russia contains the Siberian Federal District and the Far East Federal District (Figure 1). It is an
146 important region connecting the Asia Pacific region and Europe, and it is also the frontier area of Russia's foreign
147 economic cooperation. Siberian Federal District has ten federal subjects, including Republic of Altay, Republic of
148 Tyva, Republic of Khakasia, Altay Territory, Krasnoyarsk Territory, Irkutsk Region, Kemerovo Region,
149 Novosibirsk Region, Omsk Region and Tomsk Region (Figure 1). It has an administrative area of 4.36 million
150 square kilometers, a population of 17.17 million, a population density of 3.9 people per square kilometer, a
151 population urbanization rate of 74%, and a regional GDP of 7.76 trillion rubles in 2018. Far East Federal District
152 has eleven federal subjects, including Republic of Buryatia, Republic of Sakha(Yakutia), Zabaikalsk Territory,
153 Kamchatka Territory, Primorsky Territory, Khabarovsk Territory, Amur Region, Magadan Region, Sakhalin
154 Region, Jewish Autonomous Area and Chukotka Autonomous Area (Figure 1). It has an administrative area of
155 6.95 million square kilometers, a population of 8.19 million, a population density of 1.2
156 people per square kilometer, a population urbanization rate of 73%, and a regional GDP of 3.88 trillion rubles in
157 2018. Although the urbanization rate in eastern Russia is high, the quality of urbanization is relatively low. Due to
158 the financial resources lack for maintaining the normal operation of ecological environment infrastructures, the
159 government is unable to modernize traditional environmental facilities. And the government is difficult to
160 popularize the high-tech pollution prevention technologies, and some factories discharge large amounts of waste
161 and toxic gases into the air. So the ecological and environmental problems have become increasingly serious in
162 eastern Russia.

Figure 1. Sketch map of the study area.

Note: a Omsk Region. b Tomsk Region. c Novosibirsk Region. d Altay Territory. e Kemerovo Region. f Republic of Khakasia. g Republic of Altay. h Republic of Tyva. i Krasnoyarsk Territory. j Irkutsk Region. k Republic of Buryatia. l Zabaikalsk Territory. m Republic of Sakha(Yakutia). n Chukotka Autonomous Area. o Kamchatka Territory. p Magadan Region. q Khabarovsk Territory. r Sakhalin Region. s Primorsky Territory. t Jewish Autonomous Area. u Amur Region.

2.2. Research methods

2.2.1. Index systems of urbanization and eco-environment

In the process of urbanization development, people are the subjects of behavior capacity and the ecological environment is the subjects of carrying capacity. The agglomeration of economic and industrial factors causes stress and squeeze effects on the ecological environment. At the same time, with the application and popularization of high and new technologies, the urban resource intensive utilization and environmental pollution control have been improving. With the improvement of ecological environment carrying capacity, cities are more suitable for human habitation. Therefore, the development of urbanization will bring “destruction” or “improvement” to the ecological environment. The ecological environment will also produce “containment” or “promotion” effect on urbanization development (Huang and Fang, 2003; Wang, 2011). According to the references (Chu et al. 2018; Fang, 2009; Li et al. 2012; Liang et al. 2019; Tan et al. 2015; Wang et al. 2014; Wang et al. 2015), in order to accurately evaluate the urbanization development level, ecological environment development level and their coordinated development degree in eastern Russia, this paper constructs the urbanization evaluation index system and ecological environment evaluation index system of eastern Russia following the principles of scientificity, representativeness, feasibility, comparability, systematicness and data availability, as shown in Table1 .

Table 1. Evaluation systems of the urbanization and eco-environment in eastern Russia

First-Level Indices	Second-Level Indices	Third-Level Indices, Unit	Attrib- ute	Entropy weight	Variation weight	Compre- hensive weight
Urbanization	Population	Proportion of non-agricultural population, %	+	0.01	0.02	0.01

system	urbanization	Population size (year-end), thousands	+	0.09	0.09	0.09
		Population density, person/km ²	+	0.16	0.13	0.15
		Annual average number of employees, thousands	+	0.09	0.09	0.09
Economic urbanization	Economic urbanization	Proportion of non-agricultural industrial output value in GDP, %	+	0.00	0.01	0.003
		Regional GDP, million rubles	+	0.12	0.11	0.12
		Integrated budget revenue, million rubles	+	0.08	0.09	0.09
		Fixed capital investment (in real terms), million ruble	+	0.12	0.11	0.12
		Total retail trade volume (current price), million rubles	+	0.11	0.10	0.11
		Highway operating mileage (at the end of the year), km	+	0.10	0.10	0.10
		Number of hospital beds per 10000 population	+	0.01	0.03	0.01
Social urbanization	Social urbanization	Number of mobile radiotelephone connected user equipment per 1000	+	0.02	0.03	0.02
		Number of students in general education institutions, thousands	+	0.08	0.08	0.08
		Urban per capita residential housing area, m ²	+	0.00	0.02	0.01
Ecological environment system	Ecological environment pressure	Pollutants discharged into the air from fixed sources, thousand tons	-	0.11	0.11	0.11
		Polluted waste water discharged to surface water, million m ³	-	0.09	0.09	0.09
		Area of forest fire, hm ²	-	0.17	0.15	0.16
	Ecological environment state	Sown area of crops, thousand hm ²	+	0.11	0.10	0.10
		Total grain harvest, thousand tons	+	0.13	0.10	0.12
		Forest coverage, %	+	0.01	0.02	0.01
	Ecological environment response	Area of forest land, thousand hm ²	+	0.08	0.08	0.08
		Supply of fresh water, million m ³	+	0.07	0.08	0.08
	Ecological environmental response	Share of captured and neutralized air pollutants in total waste pollutants in fixed pollution sources, %	+	0.01	0.02	0.01
		Recycled water capacity, million m ³	+	0.06	0.07	0.06
		Amount of pollutants collected from fixed sources, thousand tons	+	0.10	0.10	0.10
		Reforestation area, thousand hm ²	+	0.08	0.08	0.08

(1) Urbanization evaluation system based on Population-Economic-Sociology (PES) model

Urbanization is an economic and social development process in which non-agricultural industries gather in cities, rural population migrates to non-agricultural industries, the number of cities increases, the scale of cities expands, the mode of production and lifestyle of cities spread to rural areas, and the material and spiritual civilization of cities spread to rural areas (Chu et al. 2018). Based on the Population-Economic-Sociology (PES) model, this paper constructs the urbanization evaluation index system of eastern Russia (Chu et al. 2018; Fang, 2009; Huang and Fang, 2003; Li et al. 2012; Liang et al. 2019; Tan et al. 2015; Wang et al. 2015) (Table 1). And it measures the urbanization development levels with regard to the population urbanization, economic urbanization and social urbanization aspects in combination with fourteen indicators. Among them, population urbanization is the core content of urbanization development of eastern Russia. It is the process of rural population transferring to urban population. It is mostly measured by the proportion of urban population in the total population. It is the premise for the coordinated development of economic and social urbanization. Economic urbanization refers to the aggregation of economic factors and non-agricultural industries to cities, so as to promote economic

development and enhance economic strength. It is mostly measured by the proportion of the output value of secondary and tertiary industries in GDP. It is the material basis for the development of population and social urbanization. Social urbanization is the improvement of social services, social infrastructure and life quality. On the premise of complete social infrastructure, population and economic urbanization could get reasonable development.

(2) Eco-environment evaluation system based on Pressure-State-Response (PSR) model

Ecological environment is a compound system of water resources, land resources and biological resources affecting human survival and sustainable development. Based on the Pressure-State-Response (PSR) model, this paper constructs the eco-environment evaluation index system of eastern Russia (Fang, 2009; Li et al. 2012; Liang et al. 2019; Tan et al. 2015; Wang et al. 2014; Wang et al. 2015) (Table 1). And it measures the eco-environment development levels with regard to the eco-environment pressure, eco-environment state and eco-environment response aspects in combination with twelve indicators. Among them, eco-environment pressure refers to the destruction, load and negative impact of human economic activities on the ecological environment. Eco-environment state is the health and safe condition of natural resources and ecosystem. Eco-environmental response refers to the feedback and resistance of the ecosystem in the face of human destruction, and it also refers to the measures taken by human beings when there are security problems in the ecosystem.

2.2.2. Index preprocessing

Based on the spatial scale of the eastern Russian federal subjects, this paper constructs the 21*14 urbanization original data matrix and the 21*12 ecological environment original data matrix during 2005-2018. Since the quantitative dimensions and units of 14 urbanization indicators and 12 eco-environment indicators of 21 federal subjects are quite different, it is necessary to standardize the original indicators and eliminate their quantitative dimensions. In this paper, the range standardization method is selected to remove the quantitative dimension of each index, so as to calculate the urbanization and ecological environment development levels of 21 federal subjects. The formula is as follows:

$$X_{ij} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}} \quad (\text{"+" indicator}) \quad X_{ij} = \frac{x_{j\max} - x_{ij}}{x_{j\max} - x_{j\min}} \quad (\text{"-" indicator}) \quad (1)$$

where x_{ij} is the original j index value of the i federal subject. X_{ij} is the standardized j index value of the i federal subject. $x_{j\max}$ is the maximum value of the j index. $x_{j\min}$ is the minimum value of the j index.

2.2.3. Index weight determination

The methods for determining the weight of indicators include subjective weighting method and objective weighting method. Because the subjective weighting methods such as expert consultation are tendentious and the

single objective weighting method has some errors, the two objective weighting methods of entropy weighting and coefficient variation weighting are selected to calculate the urbanization development level and the ecological environment development level of each federal subject. They could not only avoid the uncertainty of the subjective weighting method, but also could get rid of the defects of the single objective weighting method (Liu et al. 2017).

(1) Entropy weighting method

Entropy is used to measure the order degree or disorder degree of a system in classical physical thermodynamics. This paper draws lessons from the concept of entropy weight, characterizing the possible state of various indicators and their contribution to the urbanization system or ecological environment system. Generally speaking, the smaller the information entropy of the index, the smaller the chaos degree in the system, the higher the order degree in the system, the more effective information provided by the index, the greater the contribution of the index to the system, the more significant effect in the comprehensive index evaluation, and the higher the entropy weight of the index. The calculation process of entropy weighting method is as follows.

①Calculate the j indicator proportion of i federal subject (p_{ij}):
$$p_{ij} = x_{ij} / \sum_{i=1}^m x_{ij} ; \quad (2)$$

②Calculate the entropy of the j indicator (e_j):
$$e_j = (-1/\ln m) \sum_{i=1}^m p_{ij} \times \ln p_{ij} ; \quad (3)$$

③Calculate the entropy weight of the j indicator (w_j):
$$w_j = (1 - e_j) / \sum_{j=1}^n (1 - e_j) ; \quad (4)$$

where x_{ij} is the original j index value of the i federal subject. m is the number of federal subjects. n is the number of indicators.

(2) Coefficient variation weighting method

Coefficient variation is the proportion of the standard deviation to the average value. It considers the influence of the dispersion degree and average level of variable values. The greater the difference value of the same indicator in different federal subjects, the greater the weight of the indicator. And this indicator can better reflect the relative disparity in different federal subjects, and it has greater impact on the whole urbanization system or eco-environment system. The calculation process of coefficient variation weighting method is as follows.

①Calculate the mean value of the j indicator ($\bar{x}_j$) and the standard deviation of the j indicator (S_j).

②Calculate the coefficient variation of the j indicator (CV_j):
$$CV_j = S_j / \bar{x}_j ; \quad (5)$$

$$③ \text{Calculate the coefficient variation weight of the } j \text{ indicator } (u_j): u_j = CV_j / \sum_{j=1}^n CV_j ; \quad (6)$$

where n is the number of indicators.

(3) Comprehensive weighting method

Two objective weights w_j and u_j of the indicator are calculated by entropy weighting method and coefficient variation weighting method respectively. The comprehensive weight value of the j indicator (p_j) is calculated by the comprehensive weight method to reduce the errors of the two objective weight methods. The calculation process of comprehensive weighting method is as follows.

$$p_j = \sqrt{w_j \times u_j} \quad (7)$$

where p_j is the comprehensive weight of j indicator. w_j is the entropy weight of j indicator. u_j is the coefficient variation weight of j indicator.

2.2.4. Development level model

Based on the development level model of linear weighting method, this paper calculates the population urbanization level, economic urbanization level, social urbanization level, comprehensive urbanization level, eco-environment pressure level, eco-environment state level, eco-environment response level, and comprehensive eco-environment level of 21 federal subjects in eastern Russia during 2005-2018. The calculation process of development level model is as follows.

$$W_i = \sum_{j=1}^n (w_j \times X_{ij}) \quad U_i = \sum_{j=1}^n (u_j \times X_{ij}) \quad P_i = \sqrt{W_i \times U_i} \quad (8)$$

where W_i is the urbanization level or eco-environment level of the i federal subject calculated by entropy weighting method. U_i is the urbanization level or eco-environment level of the i federal subject calculated by coefficient variation weighting method. P_i is the comprehensive urbanization level or comprehensive eco-environment level of the i federal subject.

2.2.5. Coupling coordination model

(1) Coupling degree model

There is a strong interaction between the urbanization development and the eco-environment development. Referring to the capacity coupling coefficient in the physics, a coupling model of urbanization and eco-environment suitable for eastern Russia is constructed. This model could characterize the “destruction” or “improvement” effect of the eco-environment in the process of urbanization development in eastern Russia, and the “containment” or “promotion” effect of the urbanization in the process of eco-environment development in eastern Russia. Through the stress, adaptation and interaction among the indicators within the urbanization system

287 and the eco-environment system, the optimal sustainable development situation of urbanization and
 288 eco-environment will be achieved. The calculation process of coupling degree model is as follows.

289
$$C = \left[\frac{P_1 \times P_2}{(P_1 + P_2)^2} \right]^{1/2} \quad (9)$$

290 where P_1 is the urbanization development level of the i federal subject. P_2 is the eco-environment development
 291 level of the i federal subject. C is the coupling degree of the urbanization development level and eco-environment
 292 development level of the i federal subject.

293 (2) Coordinated development degree model

294 On the basis of coupling degree model, in order to truly study the interaction intensity, overall coordination
 295 situation between urbanization development and eco-environment development in eastern Russia, a coordinated
 296 development degree model of urbanization and eco-environment suitable for eastern Russia is constructed. The
 297 calculation process of coordinated development degree model is as follows.

298
$$D = \sqrt{C \times T} \quad T = \alpha P_1 + \beta P_2 \quad (10)$$

299 where P_1 is the urbanization development level of the i federal subject. P_2 is the eco-environment development
 300 level of the i federal subject. D is the coordinated development degree of urbanization level and eco-environment
 301 level of i federal subject, with the value of [0,1]. The closer the D value is to 0, the stronger the stress effect
 302 between urbanization and co-environment, the weaker the interaction effect between urbanization and
 303 eco-environment. The closer the D value is to 1, the stronger the coordinated effect between urbanization and
 304 eco-environment, the weaker the stress effect between urbanization and eco-environment. T is the comprehensive
 305 coordination index of urbanization and eco-environment of i federal subject. α 、 β respectively are the weight
 306 coefficients of urbanization and eco-environment. This paper believes that the urbanization and eco-environment
 307 are in the same important position, and $\alpha = \beta = 0.5$ 。 According to the references (Liang et al. 2019; Tan et al.
 308 2015; Wang et al. 2015), this paper classifies the coordinated development types of urbanization and
 309 eco-environment in eastern Russia into four categories and twelve subcategories (Table 2).

310 **Table 2 Classification of coordinated development stages of urbanization and eco-environment**

First-Level	Second-Level (Scope of D)	Third-Level(Comparison of P_1 and P_2)	Symbol
Coordinated development	High-level coordinated development ($0.8 < D \leq 1.0$)	Eco-environment lagging ($P_1 - P_2 > 0.1$)	I 1
		Urbanization lagging ($P_2 - P_1 > 0.1$)	I 2
		Urbanization and eco-environment balance ($0 \leq P_1 - P_2 \leq 0.1$)	I 3
	Basic coordinated development ($0.5 < D \leq 0.8$)	Eco-environment lagging ($P_1 - P_2 > 0.1$)	II 1
		Urbanization lagging ($P_2 - P_1 > 0.1$)	II 2
		Urbanization and eco-environment balance ($0 \leq P_1 - P_2 \leq 0.1$)	II 3

Uncoordinated development	(0.3<D≤0.5)	Basic uncoordinated development	Eco-environment lagging ($P_1-P_2>0.1$)	III1
			Urbanization lagging ($P_2-P_1>0.1$)	III2
			Urbanization and eco-environment balance ($0\leq P_1-P_2 \leq0.1$)	III3
	(0<D≤0.3)	Serious uncoordinated development	Eco-environment lagging ($P_1-P_2>0.1$)	IV1
			Urbanization lagging ($P_2-P_1>0.1$)	IV2
			Urbanization and eco-environment balance ($0\leq P_1-P_2 \leq0.1$)	IV3

2.5 Data sources

The data of urbanization indicators in this paper comes from the *«РЕГИОНЫ РОССИИ ОСНОВНЫЕ ХАРАКТЕРИСТИКИ СУБЪЕКТОВ РОССИЙСКОЙ ФЕДЕРАЦИИ СТАТИСТИЧЕСКИЙ СБОРНИК»* published on the official website of the Russian Bureau of Statistics “<https://www.gks.ru>” for the period 2006-2019. The data of eco-environment indicators in this paper comes from the *«РЕГИОНЫ РОССИИ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИЕ ПОКАЗАТЕЛИ СТАТИСТИЧЕСКИЙ СБОРНИК»* published on the official website of the Russian Bureau of Statistics “<https://www.gks.ru>” for the period 2006-2019.

3. Results of urbanization and eco-environment

3.1. Development level of urbanization and eco-environment

3.1.1. Urbanization

From 2005 to 2018, in the urbanization system in eastern Russia, compared with the impact of population urbanization (with a comprehensive weight of 0.34) and social urbanization (with a comprehensive weight of 0.22), the impact of economic urbanization (with a comprehensive weight of 0.43) is the strongest. The population urbanization rate in eastern Russia has only increased from 68.37% in 2005 to 69.31% in 2018, which is far lower than the average level of Russia. The population loss phenomenon is serious, and the quantity and quality level of labor force are relatively low in eastern Russia. However, the eastern Russia has a vast area and rich energy resources. It relies on the export of energy resources to obtain a large amount of foreign exchange income. The mining industry, metallurgy industry, electric power industry, automobile industry, machinery manufacturing industry, computer industry, atomic energy industry, consumer goods industry and synthetic material industry are numerous, becoming the main driving force for promoting the economic urbanization development in eastern Russia.

The population urbanization development level, economic urbanization development level, social urbanization development level, and comprehensive urbanization development level of eastern Russia are calculated based on the development level model of linear weighting method. From 2005 to 2018, the comprehensive urbanization development level of eastern Russia has shown the increasing trend (from 4.38 to 7.28). And the economic urbanization development level of eastern Russia has also shown the increasing trend,

which is consistent with the comprehensive urbanization development trend. The population urbanization development level of eastern Russia has shown a stable change, and the social urbanization development level of eastern Russia has shown a slight increasing trend (Figure 2). The population urbanization development level, economic urbanization development level, social urbanization development level, and comprehensive urbanization development level of the Siberian Federal District are all higher than those of the Far East Federal District (Figure 3). The federal subjects with high urbanization development level are mainly distributed in the Novosibirsk Region, Krasnoyarsk Territory, Kemerovo Region, Altay Territory and Irkutsk Region. The federal subjects with low urbanization development level are mainly located in the Chukotka Autonomous Area, Jewish Autonomous Area, Magadan Region and Kamchatka Territory (Table 3).

Figure 2. Urbanization and eco-environment development trend of eastern Russia from 2005 to 2018.

Figure 3. Urbanization and eco-environment development trend of Siberian Federal District and Far East Federal District from 2005 to 2018.

Table 3. Urbanization, eco-environment and their coupling coordination of each federal subject in eastern Russia in 2018

Federal subjects	Urbanization					Eco-environment			Coupling degree	Coordinated development degree	Coupling coordination stage
	Population	Economic	Social	Comprehensive	Pressure	State	Response	Comprehensive			
Republic of Altay	0.02	0.02	0.03	0.07	0.36	0.01	0.00	0.37	0.37	0.28	Serious uncoordinated

Republic of Tyva	0.03	0.02	0.04	0.09	0.35	0.01	0.01	0.38	0.39	0.30	Basic uncoordinated
Republic of Khakasia	0.08	0.05	0.05	0.18	0.35	0.02	0.02	0.38	0.47	0.36	Basic uncoordinated
Altay Territory	0.21	0.17	0.18	0.55	0.35	0.22	0.03	0.60	0.50	0.54	Basic coordinated
Krasnoyarsk Territory	0.20	0.42	0.17	0.79	0.13	0.19	0.16	0.48	0.49	0.55	Basic coordinated
Irkutsk Region	0.17	0.29	0.16	0.62	0.26	0.10	0.15	0.50	0.50	0.53	Basic coordinated
Kemerovo Region	0.31	0.27	0.14	0.72	0.26	0.09	0.11	0.47	0.49	0.54	Basic coordinated
Novosibirsk Region	0.26	0.28	0.15	0.69	0.34	0.12	0.03	0.49	0.49	0.54	Basic coordinated
Omsk Region	0.19	0.17	0.11	0.47	0.33	0.14	0.06	0.53	0.50	0.50	Basic coordinated
Tomsk Region	0.09	0.11	0.07	0.27	0.34	0.04	0.03	0.42	0.49	0.41	Basic uncoordinated
Republic of Buryatia	0.07	0.19	0.07	0.33	0.35	0.04	0.04	0.42	0.50	0.43	Basic uncoordinated
Republic of Sakha (Yakutia)	0.07	0.29	0.08	0.44	0.18	0.09	0.04	0.30	0.49	0.43	Basic uncoordinated
Zabaikalsk Territory	0.08	0.10	0.09	0.27	0.33	0.04	0.04	0.40	0.49	0.40	Basic uncoordinated
Kamchatka Territory	0.03	0.06	0.03	0.13	0.35	0.02	0.01	0.38	0.43	0.33	Basic uncoordinated
Primorsky Territory	0.19	0.21	0.11	0.51	0.31	0.05	0.08	0.44	0.50	0.49	Basic uncoordinated
Khabarovsk Territory	0.10	0.18	0.08	0.36	0.32	0.05	0.08	0.45	0.50	0.45	Basic uncoordinated
Amur Region	0.07	0.14	0.07	0.27	0.25	0.06	0.04	0.35	0.50	0.39	Basic uncoordinated
Magadan Region	0.02	0.04	0.03	0.10	0.35	0.02	0.01	0.39	0.40	0.31	Basic uncoordinated
Sakhalin Region	0.07	0.19	0.04	0.30	0.35	0.02	0.01	0.38	0.50	0.41	Basic uncoordinated
Jewish Autonomous Area	0.04	0.02	0.03	0.08	0.35	0.01	0.01	0.37	0.38	0.29	Serious uncoordinated
Chukotka Autonomous Area	0.01	0.02	0.02	0.05	0.35	0.01	0.01	0.37	0.33	0.26	Serious uncoordinated

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In recent years, the urbanization level in eastern Russia has shown an increasing trend. In terms of population urbanization, the government has introduced a preferential and assistance mechanism to stabilize the local population. The government has also attracted foreign high-tech talents through the land donation, housing

360 donation and special business methods, so as to vigorously promote the growth of the total population and
361 non-agricultural labor force. In terms of economic urbanization, the corresponding industrial sectors with different
362 advantages such as agriculture, forestry, fishery, energy, manufacturing, water conservancy, metallurgy, chemical
363 industry, mining, construction, transportation and tourism are planned according to the different urban functional
364 structures in different regions. For example, the government has built the wood deep-processing industrial clusters
365 in the south areas of Far East Federal District, the fishery industrial clusters in the coastal areas of Far East
366 Federal District, and tourism industrial clusters in Baikal Lake, Amur River and Primorsky Territory, so as to
367 promote the aggregation of various economic factors to non-agricultural industries. In terms of social urbanization,
368 the basic infrastructures such as transportation, energy and telecommunications have been planned. For example,
369 the government will upgrade the Siberian Railway, integrate the roads of Far East Federal District into the Russian
370 road network system, build the international aviation hubs such as Khabarovsk and Vladivostok, construct the oil
371 and gas pipeline system between eastern Siberian Federal District and the Pacific Ocean, and build high-speed
372 communication lines among the Primorsky Territory, China and Japan.

373 *3.1.2. Eco-environment*

374 From 2005 to 2018, in the eco-environment system in eastern Russia, compared with the impact of
375 eco-environmental response (with a comprehensive weight of 0.26), the impact of eco-environment pressure (with
376 a comprehensive weight of 0.38) and eco-environment state (with a comprehensive weight of 0.36) are stronger.
377 In the process of urbanization development, the impact on the ecological environment in eastern Russia is mainly
378 reflected in the eco-environment pressure, and the role of eco-environment protection needs to be further
379 strengthened. There are a large number of traditional industrial cities in eastern Russia. Various minerals, oil and
380 gas resources cause damage to vegetation, surface water and groundwater in the process of exploration, mining
381 and transportation. Solid waste from the industrial production pollutes air, water and land. And these phenomena
382 threaten the surrounding ecological environment, endanger the living environment, and reduce the environmental
383 support and carrying capacity of urban development.

384 The eco-environment pressure level, eco-environment state level, eco-environmental response level, and
385 comprehensive urbanization development level of eastern Russia are calculated based on the development level
386 model of linear weighting method. From 2005 to 2018, the comprehensive eco-environment development level of
387 eastern Russia has shown the slight decreasing trend. And the eco-environment pressure level, eco-environment
388 state level, and eco-environmental response level have also shown the decreasing trend (Figure 2). The
389 eco-environment pressure level, eco-environment state level, and eco-environmental response level, and
390 comprehensive eco-environment development level of the Siberian Federal District are all balanced to those of the

391 Far East Federal District (Figure 3). The federal subjects with high eco-environment development level are mainly
392 distributed in the Altay Territory, Omsk Region, Novosibirsk Region, Irkutsk Region, Krasnoyarsk Territory and
393 Kemerovo Region. The federal subjects with low eco-environment development level are mainly located in the
394 Republic of Sakha(Yakutia), Amur Region, Chukotka Autonomous Area, Jewish Autonomous Area and Sakhalin
395 Region (Table 3) .

396 The development of heavy industry in the Soviet Union left a series of environmental problems in eastern
397 Russia. In recent years, in order to promote the urbanization development, while vigorously promoting the market
398 economy in eastern Russia, the contradiction between natural resource development and ecological environment
399 protection has become increasingly serious. The production activities of industrial enterprises in eastern Russia,
400 such as fuel power industry, electric power industry, metallurgical industry, thermal power stations, and motor
401 vehicles, emit a large amount of carbon dioxide, sulfur oxide, phenol, formaldehyde, ammonia, lead, suspended
402 particles and other pollutants into the air. The continuous development of oil, gas, coal and other resources in
403 eastern Russia has led to a long-term high-level of carbon density in the air. Agricultural and industrial production
404 activities in eastern Russia, especially mining development and public utilities construction, discharge a large
405 amount of pollutants into rivers. There are varying degrees of surface water pollution and groundwater pollution
406 along Yenisei River, Amur River, Lena River and Obi river. The tributaries of these rivers, such as Ertis River,
407 Tobor River, Tula River and Tommy River, are more seriously polluted. In addition, Krasnoyarsk Territory,
408 Republic of Buryatia, Primorsky Territory, Sakhalin Region, and Kemerovo Region have high-risk land pollution
409 of heavy metal salts. Kamchatka Territory has missile fuel with extremely aggressive and highly toxic substances.
410 Primorsky Territory has decommissioned nuclear submarines to be destroyed. Some areas of Magadan Region
411 have large amount of dangerous element of Radon. These radioactive and nuclear wastes diffuse under the action
412 of air, causing serious threat and pollution to the ecological environment.

413 *3.2. Temporal and spatial pattern evolution of urbanization and eco-environment*

414 Based on the 3D perspective, the “global trend analysis” in ArcGIS was used to explore the change trend of
415 urbanization development level and eco-environment development level in eastern Russia in the three dimensional
416 space (Figure 4). The X-axis represents the east-west direction of the whole territory of eastern Russia (the arrow
417 points to the East), and the Y-axis represents the north-south direction of the whole territory of eastern Russia (the
418 arrow points to the North). The height of each vertical line of the Z-axis represents the urbanization development
419 level or eco-environment development level of each federal subject. From 2005 to 2018, the urbanization
420 development level and eco-environment development level in eastern Russia both show the spatial characteristics
421 of “High West, Low East” in the east-west direction, which is reflected in the decreasing trend of the first-order

422 function from west to east. From 2005 to 2018, the disparity of urbanization development level in eastern Russia
 423 shows an expanding trend in the north-south direction, which is reflected in the steady decreasing trend of the
 424 first-order function changing into a steep decreasing trend of the first-order function. The disparity of
 425 eco-environment development level in eastern Russia shows a shrinking trend in the north-south direction, which
 426 is reflected in the steep decreasing trend of the first-order function changing into the inverse U-shaped trend of
 427 second-order function.

432 **Figure 4.** Global trend changes of urbanization and eco-environment in eastern Russia from 2005 to 2018.
 433

434 Based on the 2D perspective, the “spatial analysis function” in ArcGIS was used to explore the change trend
 435 of urbanization development level and eco-environment development level in eastern Russia in the two
 436 dimensional space (Figure 5). From 2005 to 2018, the urbanization development level of the federal subjects in
 437 eastern Russia shows the increasing trend, and the ecological environment development level of the federal
 438 subjects in eastern Russia shows the decreasing trend, which both characterize the “High West, Low East” pattern.
 439 With Irkutsk Region as the boundary, the urbanization development level and the eco-environment development
 440 level of Siberian Federal District are obviously stronger than those of the Far East Federal District. The areas with
 441 high urbanization development level and high eco-environment development level are mainly distributed in the
 442 series areas of Novosibirsk Region- Altay Territory- Kemerovo Region- Krasnoyarsk Territory- Irkutsk Region.
 443 The areas with low urbanization development level and low eco-environment development level are mainly
 444 located in the series areas of Republic of Altay- Republic of Tyva in the south of Siberian Federal District, and
 445 Kamchatka Territory- Chukotka Autonomous Area- Magadan Region in the northeast of Far East Federal District.

Figure 5. Spatial pattern changes of urbanization and eco-environment in eastern Russia from 2005 to 2018.

The urbanization development level and eco-environment development level in Siberian Federal District are stronger than those in the Far East Federal District. Historically, Siberian Federal District was the Russia's economic and industrial center. It has dense population, strong immigrants attraction, high labor quality, strong economic strength, diversified industrial structure, outstanding foreign trade, strong scientific and technological innovation ability and dense transportation network. Its population, economic and social urbanization development levels are stronger than those of the Far East Federal District. The development purposes of the Far East Federal District is mainly for the territorial security and military defense. The opening of the Siberian Railway in 1916 meant the real development of the Far East Federal District. However, after the disintegration of the Soviet Union, the military industry shrank, which seriously damaged the economy of the Far East Federal District. In addition, Far East Federal District has unbalanced natural resources, lost human resources, underdeveloped economy, weak foreign cooperation, outdated technology and equipment, backward high-tech level, deep resource curse effect and imperfect social infrastructure (Ассекритов and Широбокова, 2011; Баранов and Скуфьина, 2005; Иванова, 2003). In particular, in recent years, the vulnerable areas with serious over exploitation of oil and natural gas lack modern pollution prevention and control facilities, aggravating their surface water, air and land pollution in the Far East Federal District. The forest coverage rate has decreased, and the eco-environment problems such as the shortage of water resources have become more serious in the Far East Federal District. In the future, under the background of meeting the shift of the world economic focus to the Asia Pacific region, under the influence of policies such as the «Federal Special Outline for Economic and Social

470 Development of the Far East Federal District and Zabaikalsk Territory before 2013》 and 《Economic and Social
471 Development Strategy of the Far East Federal District and Baikal Region before 2025》, the Far East Federal
472 District has planned the southern urban agglomeration and island economic belt. The Far East Federal District has
473 increased infrastructure construction in transportation and communications, energy resources and environmental
474 protection, continuously consolidating its economic position in the Asia Pacific region. The Far East Federal
475 District will become an important reserve economic security area of Siberian Federal District, and the
476 urbanization and ecological environment disparity may be reduced between the Siberian Federal District and Far
477 East Federal District.

478 4. Results of coupling coordination between urbanization and eco-environment

479 4.1. Types of coupling coordination degree

480 The coupling coordination model was used to measure the coupling coordinated development degree of the
481 urbanization development level and eco-environment development level in eastern Russia. From 2005 to 2018, the
482 coupling coordination development degree of urbanization and eco-environment in eastern Russia has showed an
483 increasing trend, with C value rising from 0.43 to 0.46, T value rising from 0.32 to 0.39, and D value rising from
484 0.37 to 0.42. However, the overall situation of the urbanization and eco-environment in eastern Russia is still in
485 the basic uncoordinated development, and the changes of its internal system is from the urbanization lagging to
486 the urbanization and eco-environment balance. The urbanization and ecological environment of the Siberian
487 Federal District and Far East Federal District are also in the basic uncoordinated development, with C value:
488 Siberian Federal District (0.47) > Far East Federal District (0.46), T value Siberian Federal District (0.45) > Far
489 East Federal District (0.32), D value: Siberian Federal District (0.46) > Far East Federal District (0.38). The
490 coupling coordination development degree of Siberian Federal District is slightly stronger than that of the Far East
491 Federal District. The changes of internal system is from the urbanization lagging to the urbanization and
492 eco-environment balance in the Siberian Federal District. The internal system is still the urbanization lagging in
493 the Far East Federal District. In 2018, the proportion of federal subjects with high-level coordination development,
494 basic coordination development, basic uncoordinated development and serious uncoordinated development is
495 0.0%, 28.6%, 57.1% and 14.3% respectively. Most federal subjects are in the stage of basic uncoordinated
496 development and the number of high-level coordination development is the least (Table 3 and Table 4).
497 Krasnoyarsk Territory, Novosibirsk Region, Kemerovo Region, Altay Territory and Irkutsk Region have high
498 coupling coordination development degree ($D > 0.50$), with the potential to achieve the high-level coordination
499 development in the future. Other federal subjects are still in a state of uncoordinated development, with D value
500 less than 0.50.

Table 4. Coupling coordination stage of urbanization and eco-environment in each federal subject in eastern Russia

Federal subjects	2005	2010	2013	2014	2015	2016	2017	2018
Republic of Altay	IV2	IV2	IV2	IV2	IV2	IV2	IV2	IV2
Republic of Tyva	IV2	IV2	IV2	IV2	IV2	IV2	IV2	III2
Republic of Khakasia	III2	III2	III2	III2	III2	III2	III2	III2
Altay Territory	III2	III2	II 3	II 3	II 3	II 3	II 3	II 3
Krasnoyarsk Territory	III2	II 3	II 1	II 1	II 1	II 1	II 1	II 1
Irkutsk Region	III3	III3	II 3	II 3	II 3	II 1	II 1	II 1
Kemerovo Region	III3	II 1	II 1	II 1	II 1	II 1	II 1	II 1
Novosibirsk Region	III3	II 3	II 1	II 1	II 1	II 1	II 1	II 1
Omsk Region	III2	III2	III3	III3	III3	III3	III3	II 3
Tomsk Region	III2	III2	III2	III2	III2	III2	III2	III2
Republic of Buryatia	III2	III2	III2	III2	III2	III2	III2	III3
Republic of Sakha (Yakutia)	III2	III2	III2	III2	III2	III3	III3	III1
Zabaikalsk Territory	III2	III2	III2	III2	III2	III2	III2	III2
Kamchatka Territory	IV2	III2	III2	III2	III2	III2	III2	III2
Primorsky Territory	III2	III3	III3	III3	III3	III3	III3	III3
Khabarovsk Territory	III2	III2	III2	III2	III2	III2	III2	III3
Amur Region	III2	III2	III2	III2	III2	III2	III2	III3
Magadan Region	IV2	IV2	IV2	IV2	III2	III2	III2	III2
Sakhalin Region	III2	III2	III2	III3	III3	III3	III3	III3
Jewish Autonomous Area	IV2	IV2	IV2	IV2	IV2	IV2	IV2	IV2
Chukotka Autonomous Area	IV2	IV2	IV2	IV2	IV2	IV2	IV2	IV2

The coordinated development of urbanization and eco-environment is serious in eastern Russia. Under the situation of ecological environment decreasing, it is urgent to improve the “quality” of urbanization. According to Table 4, in 2005, eighteen federal subjects in eastern Russia belonged to the urbanization lagging type, and only three federal subjects belonged to the urbanization and eco-environment balance type. Urbanization lagging was the main type, and urbanization had a significant restrictive effect on the eco-environment in eastern Russia. In 2010, sixteen federal subjects in eastern Russia belonged to the urbanization lagging type, four federal subjects belonged to the urbanization and eco-environment balance type, and only one federal subject belonged to the eco-environment lagging type. Urbanization lagging was still the main type in eastern Russia. In 2018, nine federal subjects in eastern Russia belonged to the urbanization lagging type, seven federal subjects belonged to the urbanization and eco-environment balance type, and five federal subjects belonged to the eco-environment lagging type. The stress effect of urbanization on eco-environment has gradually decreasing in eastern Russia.

Although the urbanization development has brought harm to the eco-environment in eastern Russia, Russia has always been committed to the restoration and governance of the eco-environment. It has issued a series of

518 laws, such as the 《Natural Environment Protection Law of the Russian Federation》, 《the National Ecological
519 Environment Law of the Russian Federation》, 《the Law of the Special Nature Protection Zone of the Russian
520 Federation》. It has also signed the 《Convention on International Trade in Endangered Species of Wild Animal and
521 Plant Species》, 《Convention on Biological Diversity》, 《Convention on Wetlands》, 《the United Nations
522 Convention on the Law of the Sea》 and other international agreements with other countries. Eastern Russia have
523 implemented various measures for eco-environment security protection in terms of improving the people's
524 awareness of eco-environment protection, improving laws and regulations on eco-environment protection,
525 strengthening the functions of corresponding administrative organs, establishing economic laws and regulations
526 on environmental protection, implementing ecological insurance mechanism, and establishing special nature
527 protection zones, so as to avoid the problems that the rapid urbanization development brings overload to the
528 carrying capacity of resources and environment.

529 4.2. Temporal and spatial pattern of coupling coordination degree

530 The coordinated development degree of urbanization and eco-environment in eastern Russia from the 3D
531 perspective shows the unbalanced pattern characteristics of “High West, Low East” and “High Center, Low South,
532 Low North”. The difference of coordinated development degree of urbanization and eco-environment in the
533 east-west direction is greater than that in the north-south direction (Figure 6). From the 2D perspective, the
534 coordinated development degree of urbanization and eco-environment in eastern Russia shows an increasing trend,
535 which is similar to the pattern of urbanization and eco-environment, presenting the unbalanced differentiation
536 characteristics of “High West, Low East”. Compared with the Far East Federal District, the Siberian Federal
537 District has larger coordinated development degree of urbanization and eco-environment. The federal subjects
538 with high coordinated development degree of urbanization and eco-environment are mainly distributed in the
539 serious areas of Omsk Region- Novosibirsk Region - Altay Territory- Kemerovo Region- Krasnoyarsk Territory-
540 Irkutsk Region. The federal subjects with low coordinated development degree of urbanization and
541 eco-environment are mainly located in the Republic of Altay in the south of Siberian Federal District, and
542 Chukotka Autonomous Area in the northeast of Far East Federal District (Figure 7) .

545 **Figure 6.** Global trend changes of coupling coordination degree between urbanization and eco-environment in

Figure 7. Spatial pattern changes of coupling coordination degree between urbanization and eco-environment in eastern Russia from 2005 to 2018

From 2005 to 2018, the coordinated development type of urbanization and eco-environment changes from the basic uncoordinated development type into the basic coordinated development type in Novosibirsk Region, Altay Territory, Kemerovo Region, Krasnoyarsk Territory and Irkutsk Region. And their internal system changes from the urbanization and eco-environment balance to the eco-environment lagging. These federal subjects have the leading levels of urbanization eco-environment in eastern Russia. As the economic development engine of the whole eastern Russia, relying on good regional advantages, rich resources and energy, diversified economic structure, dense transportation network, perfect logistics facilities and comprehensive security system, these federal subjects have developed into the economic zone along Siberian railway corridor. These federal subjects undertake the migration of economic factors in western Europe, becoming the gathering place of heavy industries such as machine manufacturing, energy processing, coal mining and metallurgy in Russia. All these have greatly promoted the urbanization development, but they also have a certain pressure on the eco-environment in these federal subjects. From 2005 to 2018, the coordinated development type of urbanization and eco-environment is still in the basic uncoordinated development type in Primorsky Territory, Khabarovsk Territory, Republic of Buryatia, Amur Region, Sakhalin Region, Republic of Sakha(Yakutia) and Omsk Region. And their internal system changes from the urbanization lagging to the urbanization and eco-environment balance. Primorsky Territory, Khabarovsk Territory, and Amur Region are the important economic growth areas in the Far East Federal District. They have the important function of Russia's integration into the Asia Pacific region, promoting the economic and trade cooperation in the Sino-Russian border areas. Republic of Sakha(Yakutia) and Sakhalin Region have great exploitation potential in energy resources. Excellent resource endowment is not only the value subject supporting the development of some resource-based cities, but also the source power of their economic urbanization development. Omsk Region is the connecting area of western Europe and eastern Asia in Russia. Republic of Buryatia is the border of China, Mongolia and Russia. Relying on location advantages, they have

574 deepened the internal and external integration by creating superior internal and external markets, accelerating the
575 investment attraction. From 2005 to 2018, the coordinated development type of urbanization and eco-environment
576 is still in the basic uncoordinated development type in Zabaikalsk Territory, Tomsk Region and Republic of
577 Khakasia. And their internal system is still in the urbanization lagging type. Attracted by the neighboring federal
578 subjects with superior economy, these federal subjects have weak agricultural and light industrial production,
579 small energy industry scale, insufficient scientific and technological innovation ability, weak economic diversified
580 development, excessive external market dependence, outflow of capital and shortage of funds. Therefore, the
581 urbanization development of these federal subjects lags behind the eco-environment. From 2005 to 2018, the
582 coordinated development type of urbanization and eco-environment changes from the serious uncoordinated
583 development type into the basic uncoordinated development type in Republic of Tyva, Kamchatka Territory and
584 Magadan Region. The coordinated development type of urbanization and eco-environment is still in the serious
585 uncoordinated development type in Republic of Altay, Jewish Autonomous Area and Chukotka Autonomous Area.
586 And their internal system is still in the urbanization lagging type. These federal subjects are located in the
587 marginal areas of eastern Russia. Limited by the severe climate conditions, low degree development, serious
588 population outflow and poor transportation infrastructure, the resource and energy advantages and economic
589 development potential of these federal subjects have not been fully utilized. Although the urbanization of these
590 federal subjects is relatively slow, the ecological environment is maintained well.

591 5. Discussion

592 In recent years, the urbanization and eco-environment in eastern Russia are in an uncoordinated development
593 stage. In the future, on the basis of solving the contradiction between natural resource development and ecological
594 environment protection, eastern Russia should vigorously promote the improvement of urbanization quality. In
595 addition, eastern Russia should coordinate the economic and social development strategies of twenty-one federal
596 subjects, so as to achieve the goal of promoting the economic balanced development and the ecological
597 environment protection. For example, on the basis of increasing regional financial support, optimizing regional
598 infrastructure, protecting regional resources and environment, developing innovative economic model, optimizing
599 industrial structure, and encouraging local governments functions, eastern Russia should create conditions for
600 economic, social and ecological environment development, driving the development of marginal areas with
601 advantageous areas to realize diversified development.

602 In the future, Siberian Federal District should build a modern economic metropolitan area with Novosibirsk
603 Region as the core, radiating Altay Territory, Kemerovo Region, Krasnoyarsk Territory and Irkutsk Region. It
604 could integrate production factors, implement innovation driven development strategy, promote economic

605 transformation in resource-based areas, and vigorously develop modern service industry. At the same time,
606 Siberian Federal District should develop the Arctic Development Zone on the basis of strengthening resource and
607 energy exploration, restoring Arctic routes development, and protecting the original ecological environment.
608 What's more, Siberian Federal District should develop the Northern Development Belt, focusing on automobile
609 manufacturing, chemical industry, electric power and other industries. Siberian Federal District also should
610 promote the Southern Development Belt, innovatively transforming its traditional economic sectors so as to
611 develop industrial and economic cooperation zones with Asia Pacific and Central Asia.

612 In the future, on the basis of the common development of eco-environment protection and economic interests,
613 the Far East Federal District should stabilize the local population, attracting foreign labor force. It also should
614 focus on planning infrastructure such as energy, transportation and information, especially paying attention to the
615 cooperation with Northeast Asia. In the northeast marginal areas Far East Federal District, it should get rid of the
616 inherent anti-immigration and ethnic discrimination, improving the stable resettlement system for labor
617 immigrants. It also should formulate economic and urban construction investment plans, restoring its economic
618 activity in order to attract immigrants from other regions. In the south of Far East Federal District, it should
619 develop the agricultural industrial complexes and tourism leisure clusters in Khabarovsk Territory and Primorsky
620 Territory on the premise of protecting the eco-environment. It should use eco-environment protection raw
621 materials to transform the industrial structure, developing its diversified advantages of innovative resources. It
622 also should take advantage of the ports' advantages to enhance investment attraction, expanding production
623 factors to other federal subject. In addition, it should deepen ecological and economic cooperation with northeast
624 China, North Korea, South Korea and other neighboring countries, accelerating the planning and construction of
625 transportation facilities synchronized with economic development.

626 In the future, eastern Russia also should vigorously implement the strategy of opening and developing,
627 accelerating the urbanization and eco-environment development in the border areas, especially in the border areas
628 between China and Russia. This has great significance in the realization of all-round and in-depth cooperation
629 between China and Russia. Its future development and cooperation path includes six aspects. (1) Promote
630 industrial division and cooperation. China and Russia should integrate the industrial production factors,
631 implementing the innovation driven development strategy. They also should promote the economic transformation
632 of resource-based areas, vigorously developing modern service industry. (2) Expand cooperation on energy
633 projects. China and Russia should transform "loan for oil resources" into "joint investment and cooperative
634 technology development". Chinese enterprises should settle in Russian border cities, extending the industrial
635 chain of upstream exploration and production, midstream logistics and transportation, downstream sales and deep

636 processing of oil and gas projects. (3) Create the tourism model of “internal connection and external expansion”.
637 China and Russia should develop diversified urban tourism products based on bilateral resource base and market
638 demand, improving tourism projects such as vacation and self driving. (4) Accelerate the construction of
639 infrastructure. China and Russia should speed up the construction of “Primorsky No. 1” and “Primorsky No. 2”
640 international channels, developing the interconnection of Harbin-Dalian railway, Manzhouli-Harbin-Suifenhe
641 railway, Siberian railway, and Baikal-Amur railway. And they also should comprehensively upgrade the software
642 and hardware facilities of different border trade ports. (5) Construct the Free Trade Zone. On the basis of Harbin,
643 Heihe and Suifenhe free trade zones, China and Russia should determine different leading industries in different
644 cooperation parks, vigorously promoting the construction and development of bilateral cooperation parks. They
645 also should implement the models, such as “two countries, one zone”, “closed operation”, “domestic and foreign
646 customs”, and “one zone and multiple parks”. (6) Strengthen the protection and management of the
647 eco-environment. China and Russia should establish protection and cooperation mechanism of tiger and leopard
648 park. They should promote the ecological environment protection and governance of Khanka Lake. And They
649 also should strengthen the ecological protection of Heilongjiang (Amur River) basin.

650 6. Conclusions

651 Since the implementation of Russia's “Eastward Migration Strategy”, the urbanization of eastern Russia has
652 been promoted rapidly, but the contradiction between natural resource development and ecological environment
653 protection has become increasingly severe. Based on the comprehensive weighting method of entropy weight and
654 variation coefficient weight, this paper studied the urbanization development level and the eco-environment
655 development level in the eastern Russia during 2005-2018. And combined with the coupling coordination degree
656 model, the paper studied the temporal and spatial evolution characteristics of the coordinated development of
657 urbanization and eco-environment in eastern Russia during 2005-2018. The conclusions are as following.

658 From 2005 to 2018, the economic urbanization contributes the largest share to the urbanization system in
659 eastern Russia. And the eco-environment pressure contributes the largest share to the eco-environment system in
660 eastern Russia. The comprehensive urbanization development level of eastern Russia has shown the increasing
661 trend. The economic urbanization development level of eastern Russia has also shown the increasing trend, the
662 population urbanization development level of eastern Russia has shown a stable change, and the social
663 urbanization development level of eastern Russia has shown a slight increasing trend. The comprehensive
664 eco-environment development level of eastern Russia has shown the slight decreasing trend. And the
665 eco-environment pressure level, eco-environment state level, and eco-environmental response level have also
666 shown the decreasing trend. From 2005 to 2018, the coupling coordination development degree of urbanization

667 and eco-environment in eastern Russia has showed an increasing trend. However, the overall situation of the
668 urbanization and eco-environment in eastern Russia is still in the basic uncoordinated development, and the
669 changes of its internal system is from the urbanization lagging to the urbanization and eco-environment balance.
670 Under the situation of ecological environment decreasing, it is urgent to improve the “quality” of urbanization.

671 From 2005 to 2018, the population urbanization development level, economic urbanization development
672 level, social urbanization development level, and comprehensive urbanization development level of the Siberian
673 Federal District are all higher than those of the Far East Federal District. The eco-environment pressure level,
674 eco-environment state level, and eco-environmental response level, and comprehensive eco-environment
675 development level of the Siberian Federal District are all balanced to those of the Far East Federal District. The
676 coupling coordination development degree of Siberian Federal District is slightly stronger than that of the Far East
677 Federal District. The changes of internal system is from the urbanization lagging to the urbanization and
678 eco-environment balance in the Siberian Federal District. The internal system is still the urbanization lagging in
679 the Far East Federal District. Most federal subjects are in the stage of basic uncoordinated development and the
680 number of high-level coordination development is the least. Krasnoyarsk Territory, Novosibirsk Region,
681 Kemerovo Region, Altay Territory and Irkutsk Region have high coupling coordination development degree, with
682 the potential to achieve the high-level coordination development in the future. Other federal subjects are still in a
683 state of uncoordinated development.

684 Spatially, from the 3D perspective, the urbanization development level, the eco-environment development
685 level and their coupling coordination development degree in eastern Russia all show the spatial characteristics of
686 “High West, Low East” in the east-west direction and “High Center, Low South, Low North” in the north-south
687 direction. And the difference of the urbanization development level, the eco-environment development level and
688 their coupling coordination development degree in the east-west direction is greater than that in the north-south
689 direction. From the 2D perspective, the urbanization development level, the eco-environment development level
690 and their coupling coordination development degree in eastern Russia could characterize the “High West, Low
691 East” pattern. The federal subjects with high urbanization development level, eco-environment development level
692 and their coupling coordination development degree are mainly distributed in the serious areas of Novosibirsk
693 Region - Altay Territory- Kemerovo Region- Krasnoyarsk Territory- Irkutsk Region. The federal subjects with
694 low ones are mainly located in the Republic of Altay in the south of Siberian Federal District, and Chukotka
695 Autonomous Area in the northeast of Far East Federal District.

696 From 2005 to 2018, the coordinated development type of urbanization and eco-environment changes from
697 the basic uncoordinated development type into the basic coordinated development type in Novosibirsk Region,

Altay Territory, Kemerovo Region, Krasnoyarsk Territory and Irkutsk Region. And their internal system changes from the urbanization and eco-environment balance to the eco-environment lagging. The coordinated development type of urbanization and eco-environment is still in the basic uncoordinated development type in Primorsky Territory, Khabarovsk Territory, Republic of Buryatia, Amur Region, Sakhalin Region, Republic of Sakha(Yakutia) and Omsk Region. And their internal system changes from the urbanization lagging to the urbanization and eco-environment balance. The coordinated development type of urbanization and eco-environment is still in the basic uncoordinated development type in Zabaikalsk Territory, Tomsk Region and Republic of Khakasia. The coordinated development type of urbanization and eco-environment changes from the serious uncoordinated development type into the basic uncoordinated development type in Republic of Tyva, Kamchatka Territory and Magadan Region. The coordinated development type of urbanization and eco-environment is still in the serious uncoordinated development type in Republic of Altay, Jewish Autonomous Area and Chukotka Autonomous Area. And their internal system is still in the urbanization lagging type.

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Data Availability Statement

Some or all data, models or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Contributions

Conceptualization, literature search, original draft and editing were done by Nanchen Chu. Pingyu Zhang reviewed the manuscript and Xiangli Wu provided the necessary resources to improve the manuscript.

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Ethics declarations

Competing interests

The authors declare no competing interests.

Ethics approval

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