Study on landscape pattern of Hegang City based on ANN-CA-Markov model

Yunhe Ding
Northeast Forestry University
Liang Mao (maoliang7802@163.com)
Northeast Forestry University
Jingmo Jia
Northeast Forestry University
Xinru Gui
Northeast Forestry University

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Abstract

The research purpose of this paper is to grasp the changing characteristics of the landscape pattern in Hegang City, Heilongjiang Province, which can provide a scientific basis for formulating food security and ecological security policies. Hegang City was selected as the research area, based on its Landsat remote sensing images and DEM data in 2000, 2010 and 2020, Fragstats 4.0 software was used, and the Ann-CA-Markov coupling model was used to study the city's 2000–2020 period. Changes in the landscape pattern, and simulate and predict the landscape pattern in 2030. The results show that during the period from 2000 to 2020 in Hegang City, the area of cultivated land decreased by 197.9824 km^2, the area of forest decreased by 52.7252 km^2, the area of grassland decreased by 29.28 km^2, the area of wetland increased by 217.27 km^2, the area of water body increased by 33.99 km^2, and the surface area of artificial land increased by 28.41 km^2; simulation prediction The land use situation in 2030 is that the area of cultivated land is expected to increase by 1.0368 km^2, the area of forest is expected to decrease by 0.0648 km^2, the area of grassland is expected to decrease by 0.0972 km^2, the area of wetlands will increase by 14.6448 km^2, the area of water bodies will increase by 3.1317 km^2, and the surface area of artificial land will decrease by 21.6513 km^2; and the related landscapes are calculated. pattern index. The final conclusion is that the degree of fragmentation of agricultural and forestry land in Hegang City is relatively low, but it is subject to strong external interference. The landscape pattern should be further optimized and adjusted to continuously reduce the impact on the ecological environment and ensure food and ecological security.

Introduction

At present, scholars' research on landscape pattern mainly focuses on the evolution of landscape pattern and its dynamic mechanism. In terms of the prediction and simulation of land use pattern, CA model is usually combined with other models to achieve. Such as CA and multi-agent model (MAM), Geo CAUrban model, CA and Markov model, neural network and CA coupling model, etc[1–2]. For example, Tong et al. and Hana et al. used ca-Markov model to simulate and predict land use change in little Miami River Basin of Ohio and southern coastal area of Iran respectively[3–4]. After years of research and attempts, ca-Markov model is the most widely used simulation prediction model at present. Combined with Ann model, which is good at dealing with complex nonlinear relations through learning, the coupling of multiple models makes up for each other's shortcomings, which has great research value for the simulation prediction of landscape pattern change[5–8].

In this study, Hegang City, Heilongjiang Province was taken as the research area, and the change of landscape pattern was calculated and analyzed, and the future landscape pattern was simulated and predicted by constructing ann-Ca-Markov coupling model. According to the land use situation and landscape type transformation in the study area, the change characteristics of landscape pattern in the study area from 2000 to 2020 were comprehensively analyzed, and the prediction results from 2020 to 2030 were compared to provide detailed basic information for rational land use. The analysis process can provide a method reference for understanding the landscape pattern characteristics in this region and even in all cities of the province, and provide an important reference and basis for the related research of food and ecological security in China[9–10].

Materials And Methods

Overview of the study area

Heilongjiang Province is a major ecological province in China. The dynamic changes and future development trend of its cultivated land and forest landscape pattern have an important impact on China’s food and ecological security. The proportion of cultivated land and forest in Hegang City is relatively large, which is basically consistent with the landscape pattern characteristics of agricultural and forestry land in Heilongjiang Province. This study takes the scope of Hegang municipal administrative region as the research object, and the research on landscape pattern and simulation prediction has demonstration significance. Hegang City covers an area of 14700 km^2, with a topography of high northwest and low southeast, and is a transitional section from Sanjiang Plain landform to Xiaoxing'an Mountain landform. The city is composed of plains, hills, rolling hills, valleys and floodplains and other landform types. Forests are distributed in the northwestern mountains, which is rich in forest resources, and the forest coverage rate is as high as 58%; The southeast is the edge of Sanjiang Plain, flat and open, which is an agricultural distribution area; The territory is rich in water resources, including 18 main rivers, such as Wutong River, Heli River, Alingda River and Jiayin river. (Fig 1)

Data sources and research methods

Data sources

The aerial and remote sensing image data for this study are obtained from GS Cloud, Globeland30, etc(accuracy of 30m×30m). The second type of forest resource investigation data are obtained from the National Forestry and Grassland Data Center (the distribution of the second type of forest resource investigation in 1997 and 2004, and the statistical data of the ninth forest resources inventory in 2016), and Heilongjiang Forest Industry(statistics in 1997 and 2006). The survey data of agricultural land resources are obtained from the Natural Resources Bureau of Hegang City and field application investigation. The administrative boundary and road distribution map are obtained from OpenStreetMap, and the Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences, and the Innovation Platform of Resource Discipline, etc. At the same time, through many investigations and visits in Hegang City, we collect relevant data and verify the interpretation results on the spot.

According to Current Land Use Classification(GB/T 21010-2007) and the actual land use situation of Hegang City, the land in the study area is divided into six landscape types, as shown in Table 1. Using ArcGIS 10.8 software imports the remote sensing image, forestry resources investigation data, land resources data and administrative boundary in a unified way, and the unified coordinate is WGS 1984 UTM Zone 40N. The remote sensing image is analyzed manually, and finally the analysis results are corrected and supplemented according to the field investigation data.

Landscape Type	Description and Explanation
Ecological Forest (Forest)	All kinds of natural forests or artificial forests focusing on ecological benefits
Construction Land (Artificial Surface)	Land for various buildings, roads, infrastructure, and various supporting facilities, etc.
Wetlands	Areas where the water depth generally does not exceed 2 meters and where wetland organisms grow
Waters	Rivers, lakes, reservoirs, ponds, ditches, etc.
Arable Land	Agricultural production land
Grassland	Grasslands, meadows and artificial grasslands and other land covered by natural herbaceous vegetation

Table 1. Standard for classification of landscape types.

Research Methods

Ann-CA-Markov coupling model

The traditional CA model has some limitations due to the strong subjectivity of cell transformation rules. The characteristic of artificial neural network (ANN) model is that it can simulate complex nonlinear problems. Therefore, in order to avoid the uncertainty of subjective weight assignment, the conversion rules of CA model can be based on the generation of land use suitability probability atlas[11-13].

The Ann-CA-Markov coupling model is based on CA and couples Ann and Markov models. The structure of the coupling model consists of six parts: cell, cellular space, state, neighborhood, rule and cycle number. The most important rule part couples Markov and Ann models, which is basically defined as follows[14-16]:

1. Cell: a raster of size 30m×30m of the ecological spatial structure type map.
2. Cellular space: all rasters of the ecological spatial structure type map.
3. State: the state of the cell is the property of the raster, which is divided into arable land, forest, grassland, wetland, water and artificial surface (construction land).
4. Neighborhood: defining a 5×5 expanded Moore neighborhood for the study, that is, there are 24 cells around, which have an impact on the properties of cells.
5. Rule: The conversion rules of cells mainly include the spatial and quantitative conversion rules. The quantitative conversion rules are mainly calculated by Markov model, and spatial conversion rules are calculated by Ann model.
6. Cycle number: Since the interval between the basic data of each period used is 10a, the interval of years to determine the number of cycles is set to 10a.

Ann-CA-Markov coupling model simulation accuracy check

At present, Kappa coefficient and FOM (Figure of Merit) index are generally used to measure the accuracy of the landscape pattern simulation to verify the reliability of the constructed model in the application of the study area site. Kappa coefficient is used to test the consistency between the simulation results of landscape pattern and the actual situation. Kappa value is in the range of 0 ~ 1, and its value is closer to 1, indicating that the higher the accuracy of model calculation and simulation. It is generally believed that when it is greater than 0.75, the reliability of the simulation results is high. FOM is a method to evaluate the sensitivity value of the model. The FOM value is between 0 and 1, and the duration of simulation calculation directly affects the FOM value[17-19]. For each unit of increase in the duration of simulation calculation, the increased value of FOM shall not be greater than 0.01, when the model simulation results are better[20]. Geo SOS-FLUS V2.3 software is a land use change scenario simulation platform proposed by Professor Liu Xiaoping of Sun Yat-sen University. This study uses the software to complete the simulation and prediction of the future landscape pattern of the study area. Firstly, the five parts of information such as cell, cellular space, state, neighborhood and cycle number of CA model in addition to the rules are constructed, and then the transformation rules are determined by using Markov and ANN models based on the classification data of 2000 and 2010 respectively, so as to obtain the simulation diagram of 2020. Finally, the 2020 simulation diagram is compared with the actual state data, and the simulation accuracy is evaluated by using Kappa coefficient and FOM index.

Landscape type area transfer matrix and index calculation analysis

In ArcGIS10.8, the software will carry out spatial superposition statistical analysis and land use change analysis on the remote sensing analysis results of adjacent periods[21-22], so as to intuitively obtain the actual situation of land use in the study area and the specific value of mutual transfer of landscape types at the three time points of 2000, 2010 and 2020. In this study, Fragstats4.0 software is used to calculate in the process of landscape pattern analysis, and select patch density PD, largest patch index LPI, landscape richness PR, landscape shape index LSI, Shannon evenness index SHEI and other indicators[23-24].

Results And Analysis

Landscape type and area change from 2000 to 2020

(1)From 2000 to 2010, the change characteristics of landscape type area within the research scope are as follows: forest area decreases by 31.7260 km^2, arable land area increases by 19.1651 km^2, grassland area decreases by 7.2873 km^2, wetland area decreases by 20.4536 km^2, water area increases by 24.1112 km^2 and artificial surface increases by 16.1907 km^2. The changes of landscape types in the study area are as follows: the net area of forest conversion to arable land and grassland is 12.3014 km^2 and 23.7927 km^2 respectively; The net area of wetland, water area and artificial surface transform into forest is 3.0635 km^2, 1.2445 km^2 and 0.0602 km^2 respectively; The net area of grassland and wetland transform into arable land is 8.7711 km^2 and 7.2958 km^2 respectively; The net area of arable land transforms into water area and artificial surface is 0.2014 km^2 and 9.0019 km^2 respectively. During this period, the study area is greatly affected by the urbanization process, the arable land area increases more, the forest area decreases relatively, the wetland area decreases, and the ecological function degrades slightly. (Table 2)

Area (km^2)		2010 Type						Total for 2000
		Forest	Arable Land	Grassland	Wetlands	Water Area	Artificial Surface	
2000 Type	Forest	4449.1960	82.2055	533.7474	1.8849	7.0716	4.6657	5078.7711
	Arable Land	69.9041	6581.0981	73.2963	6.3123	8.4917	39.1253	6778.2279
	Grassland	509.9547	82.0674	1018.4451	5.8876	19.8954	17.8357	1654.0860
	Wetlands	4.9484	13.6082	3.9699	503.4648	29.8817	0.0101	555.8832
	Water Area	8.3161	8.2903	7.2320	17.8797	292.1685	0.4614	334.3481
	Artificial Surface	4.7259	30.1235	10.1079	-	0.9502	251.4090	297.3166
Total for 2000		5047.0453	6797.3931	1646.7986	535.4293	358.4592	313.5073	14698

Table 2. Area Transfer Matrix in Reserve from 2000 to 2010

From 2010 to 2020, the area changes of landscape types within the research scope are as follows: forest area decreases by 21.2294 km^2, arable land area decreases by 217.543 km^2, grassland area decreases by 21.9122 km^2, wetland area increases by 237.4112 km^2, water area increases by 9.0769 km^2 and artificial surface increases by 12.1403 km^2. The changes of landscape types in the study area are as follows: the net area of forest transformation to arable land, wetland, water area and artificial surface is 29.0640 km^2, 10.0757 km^2, 4.0841 km^2 and 0.1960 km^2 respectively; The net area from grassland to forest is 22.1904 km^2; The net area of arable land transforms into grassland, wetland, water area and artificial surface is 8.1281 km^2, 208.7429 km^2, 2.0921 km^2 and 27.6439 km^2 respectively. During this period, the arable land area decreases significantly, about 213 km^2 of the reduced arable land is transformed into wetland area, and the main increase area is the border Heilongjiang Basin area. (Table 3)

Area (km^2)		2020 Type						Total for 2010
		Forest	Arable Land	Grassland	Wetlands	Water Area	Artificial Surface	
2010 Type	Forest	4406.8893	94.8103	519.0942	11.6773	10.4644	4.3397	5047.2752
	Arable Land	65.7464	6379.7236	79.8451	213.0910	7.3263	52.0560	6797.7884
	Grassland	541.2846	71.7170	1010.2380	4.4787	9.4855	9.5112	1646.7150
	Wetlands	1.6016	4.3481	3.5300	502.7510	23.3454	0.0090	535.5853
	Water Area	6.3803	5.2342	5.9394	22.2166	317.0017	0.5908	357.3631
	Artificial Surface	4.1437	24.4121	6.1560	18.9424	0.7121	259.2204	313.5868
Total for 2020		5026.0459	6580.2454	1624.8027	773.1571	368.3355	325.7271	14698

Table 3. Area transfer matrix in reserve from 2010 to 2020.

From the landscape pattern changes in the 20 years from 2000 to 2020, the arable land area has changed greatly, the total area has decreased by nearly 200 km^2, the forest area is also decreasing, the wetland area is increasing more, and the area of artificial surface (i.e. construction land) is also increasing. In terms of spatial distribution, the change of agricultural and forestry land is mainly concentrated in the urban intensive areas in the central region. The reduction of forest area caused by human activities, especially the construction of urbanization; The implementation of the protection policy of basic farmland has led to the continuous increase of arable land after 2010. The increase of wetland area is mainly attributed to the implementation of relevant national policies. Planning for the Ecology Protection and Economic Transformation in Da Xing'anling and Xiao Xing'anling (2010-2020), prepared by National Development and Reform Commission and the State Forestry Administration in conjunction with relevant departments, was printed and issued for implementation in 2010 and clearly strengthened the protection and construction of forest ecology and wetlands. The implementation of relevant national policies has curbed the momentum of forest area reduction and increased the area of wetlands. (Fig 2)

Landscape pattern simulation forecast for 2020-2030

Accuracy test

According to the method described in 2.2, the driving factors relate to the change of landscape pattern in the study area are selected through correlation analysis, i.e. three phases of relevant data in 2000, 2010 and 2020, average annual temperature, precipitation, DEM image, road, river, construction land range, etc. The landscape pattern of the study area in 2020 is simulated and predicted, and the simulation and prediction map of landscape pattern in 2020 is obtained.

The accuracy test of landscape pattern simulation in 2020 is as follows: high similarity can be found through the visual interpretation of the 2020 simulation prediction map and the 2020 real map, and the visual interpretation of the images of the simulation results of three typical areas enlarged locally. (Fig 3) After calculation, Kappa coefficient is calculated to be 0.825, which is greater than 0.75, and the FOM index is 0.04, which is less than 0.1, and the reliability of the model simulation is high.

Simulation prediction results

It is verified that the simulation accuracy in 2020 is high, and the landscape pattern in 2030 can be simulated and predicted. The prediction results are shown in Fig 4 and Table 4. Among them, the area change of landscape types within the research scope is predicted as follows: the forest area decreases by 0.0648 km^2, the arable land area increases by 1.0368 km^2, the grassland area decreases by 0.0972 km^2, the wetland area increases by 14.6448 km^2, the water area increases by 6.1317 km^2, and the artificial surface decreases by 21.6513 km^2. The changes of landscape types in the study area are as follows: the net area of forest transformation to arable land, grassland and wetland is 0.0324 km^2, 0.0243 km^2 and 0.0081 km^2 respectively; The net area of arable land transforms into wetland is 0.2025 km^2; The net area of grassland, water area and artificial surface transform into arable land is, 0.081 km^2, 0.0081 km2 and 1.1178 km^2 respectively.

Area (km^2)	2030 Type						Total for 2020
	Forest	Arable Land	Grassland	Wetlands	Water Area	Artificial Surface	
Forest	5027.9056	0.0567	0.0243	0.0081	-	-	5027.9947
Arable Land	0.0243	6571.6064	-	0.0243	-	0.0081	6571.6631
Grassland	-	0.0812	1626.3909	0.0162	0.0081	0.0162	1626.5124
Wetlands	-	0.0243	-	775.1538	0.0814	0.0648	775.3243
Water Area	-	0.0081	-	0.0891	370.9071	0.0243	371.0286
Artificial Surface	-	1.1259	-	14.4747	6.1641	304.1145	325.8792
Total for 2030	5027.9299	6572.9026	1626.4152	789.7662	377.1607	304.2280	14698

Table 4. Area transfer matrix in reserve from 2020 to 2030.

Landscape pattern change and forecast analysis

Landscape type area change characteristics

From 2010 to 2020 and the forecast for the next 10 years (Fig 5), it can be seen that the forest area is slowly decreasing, and the decreasing momentum will be effectively curbed in the next 10 years; The arable land area shows an increase followed by a decrease and remains stable in the next 10 years; Among other landscape types, wetlands have continued to increase since 2010 and will continue to increase in the next 10 years, while the area of artificial surface shows a decreasing trend.

Landscape pattern change characteristics

(1) Characteristics of the changing landscape pattern in Hegang City

The 20-year time span of the study area and the overall changes of landscape pattern in the next 10 years are shown in Table 5. Among them, the number of patches (NP) shows a significant downward trend in the first 10 years of the study period, then begins to increase and remained basically stable in the next 10 years; Patch density (PD) first decreases and then increases, and the overall patch density will increase slowly in the future; Shannon evenness index (SHEI) has a negative correlation with the changes of patch number and density, that is, it increases first and then decreases, and will basically maintain a relatively stable trend in the future. The results show that from 2000 to 2010, the landscape richness and heterogeneity of Hegang City decreases, and the degree of fragmentation is low; From 2010 to 2030, landscape richness and heterogeneity increases, and the degree of fragmentation is high.

Year LID	Landscape Area TA	Number of Patches NP	Patch Density PD	Largest Patch Index LPI	Landscape Richness PR	Shannon Evenness Index SHEI
2000	1474215	157292	10.6695	35.3449	6	0.6477
2010	1471269	147946	10.0557	28.1412	6	0.7021
2020	1465767	155255	10.5921	34.3237	6	0.6708
2030	1465782	155285	10.5966	34.3598	6	0.6728

Table 5. Evolution of landscape patterns in landscape level from 2000 to 2030.

(2) Characteristics of changes in the pattern of agricultural and forestry land and other landscape types

The landscape pattern index of agricultural and forestry land types in Hegang City from 2000 to 2030 is shown in Fig 6.

▯ Patch density: the smallest is arable land(0.0341), followed by forest, and the maximum is artificial surface(1.2352). This indicates that the fragmentation degree of arable land and forest is low, especially the patch density of forest continues to decrease, and the fragmentation process of forest has been improved. In other landscape types, the patch density of grassland and water area decrease first and then increase, and the grassland increases more, and the degree of fragmentation deepens; Wetlands and artificial surfaces have been gradually decreasing, indicating that the overall fragmentation degree is gradually decreasing.

▯ Largest patch index: The largest patch index of arable land and forest is similar and significantly larger than that of other landscape types, showing a fluctuating trend of first increasing and then decreasing, which shows that arable land and forest are the dominant landscape types in the study area to a certain extent. In other landscape types, the largest patch index of water area shows a continuous decreasing trend, and the decreasing is very obvious, indicating that its integrity decreases and the degree of fragmentation deepens; Grassland, wetland and artificial surface have been increasing gradually, and the increase of wetland is large, which is consistent with the large increase of its area. Grassland, wetland and artificial surface have been increasing gradually, and the increase of wetland is large, which is consistent with the large increase of its area.

▯ Landscape shape index: the landscape shape index of arable land and forest decreases slightly and then increases significantly, and the maximum value appeared in 2030 (17.3426 and 32.7912), indicating that the shape of these two landscape types is relatively complex and the intensity of various disturbances (such as natural conditions and human factors) is large. Other landscape types increase slightly and then decrease, indicating that these landscape types are relatively less affected by external interference.

Conclusion

Based on the geographical information data of Hegang city from 2000 to 2020, the change characteristics of landscape pattern of main landscape types within the city area were studied, and the ca-Markov model coupled with ANN model was used to predict the landscape pattern in 2030. The conclusions are as follows:

(1) The simulation accuracy of the ANN-CA-Markov coupling model meets the requirements after the calculation of related indexes, and its simulation reliability is high, which can be applied to the simulation and prediction of landscape pattern in Hegang City.

(2) From 2000 to 2030, the forest area in Hegang city decreased slowly, while the arable land area decreased more, and the area was mainly converted into wetland. The prediction results reflect that the decreasing trend will be alleviated to a certain extent. Wetland and water area will continue to increase, grassland area will remain stable, and artificial surface area will decrease.

(3) From 2000 to 2030, arable land and forest were the dominant landscape types in Hegang city, and were strongly affected by external disturbance. The degree of fragmentation of cultivated land and forest was low, and the patch density of forest continued to decrease, and the fragmentation process of forest was improved.

Declarations

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Author contributions statement

Data curation, Y.D.; Methodology, J.J.,L.M.; Sofware, J.J.,X.G.; Validation, Y.D.; Formal analysis, L.M.,Y.D.; Supervision, L.M. All authors reviewed the manuscript.

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Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to L.M..

“Data availability” statement

All data generated or analysed during this study are included in this published article [and its supplementary information files].

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Figures

Figure 1

Map of the study area.

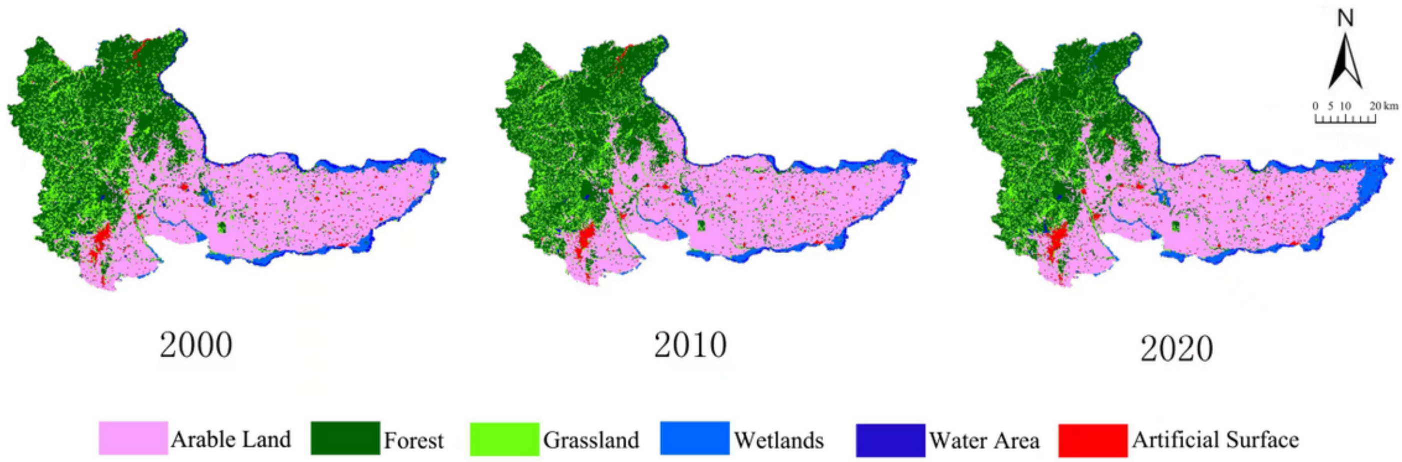

Figure 2

Spatial and temporal changes of landscape pattern from 2000 to 2020.

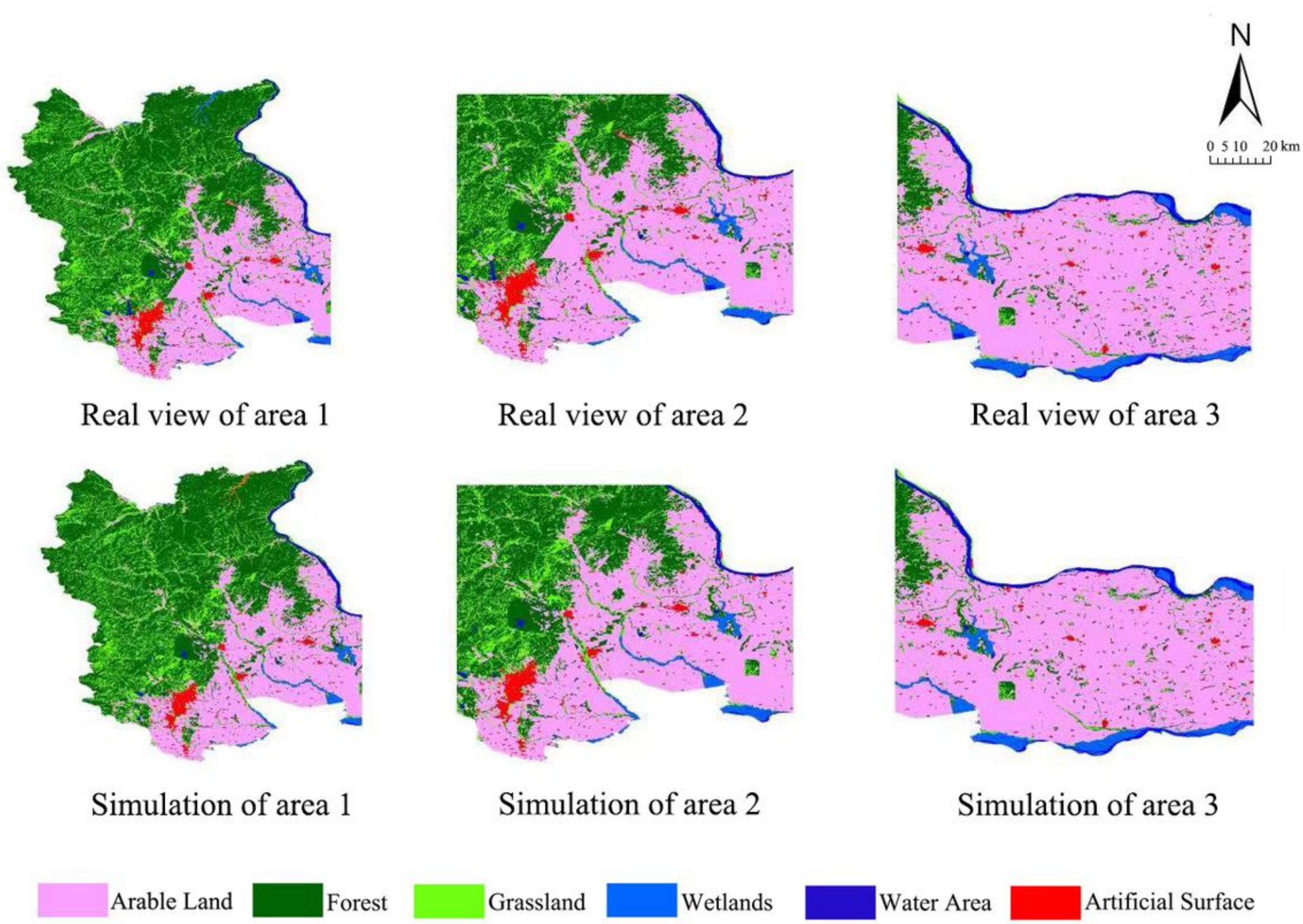

Figure 3

Comparison of the real map and the simulated map of the landscape pattern of the study area in 2020.

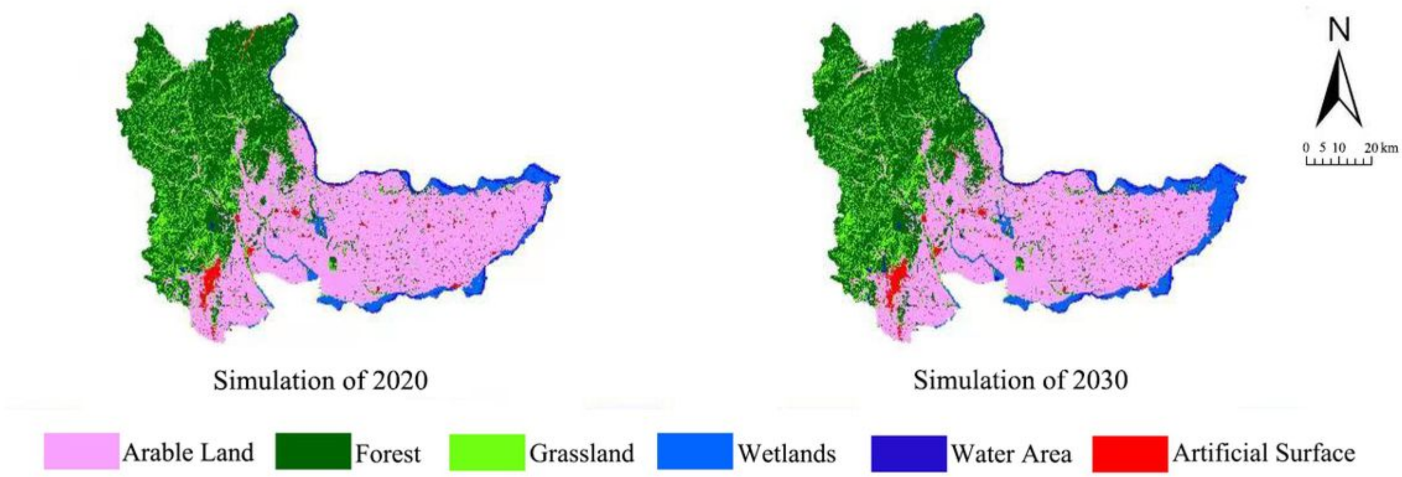

Figure 4

Simulation map of landscape pattern from 2020 and 2030.

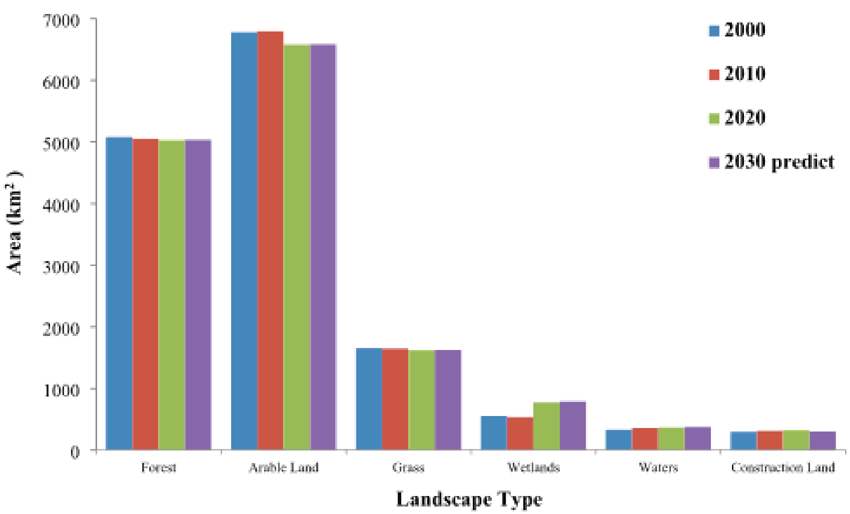

Figure 5

Area change of landscape types.

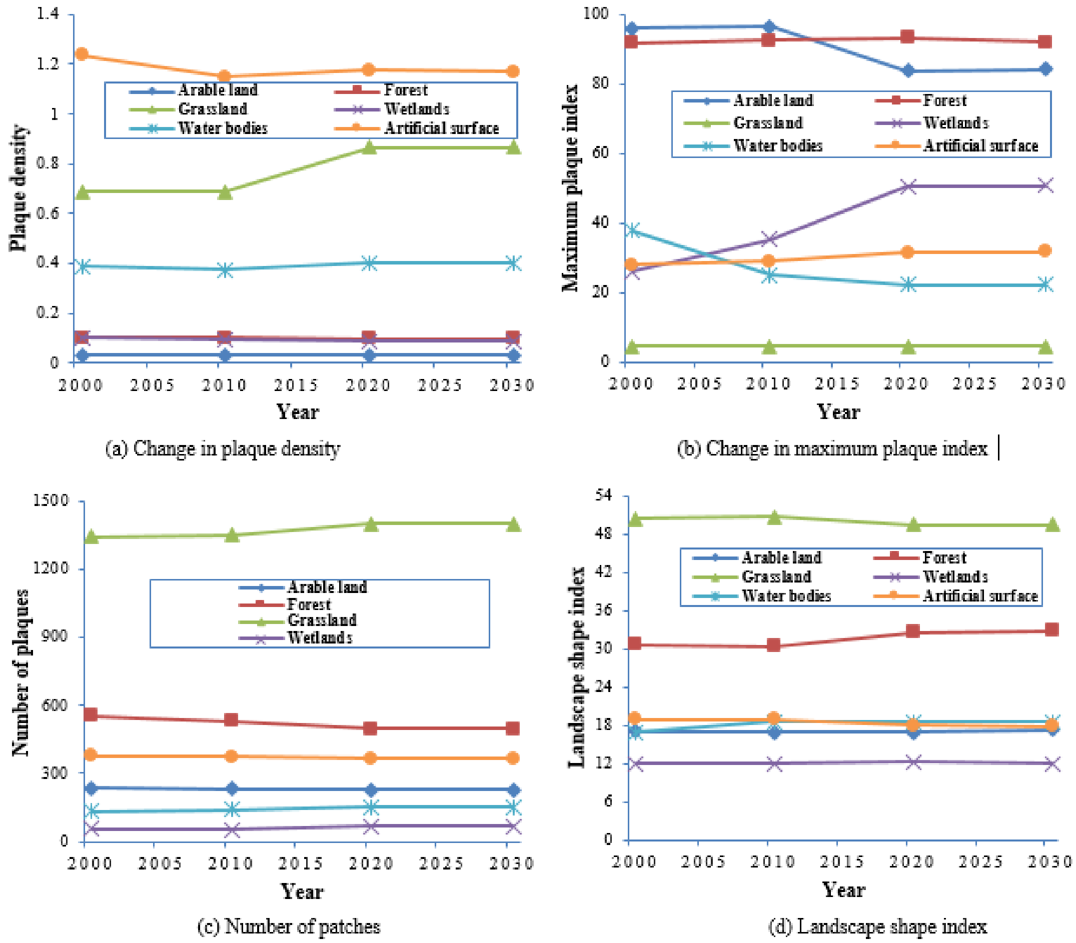

Figure 6

Landscape index changes on agricultural and forestry land types level in Hegang from 2000-2030.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- rawdata6.27.zip