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Application of Holdridge life-zone model based on the terrain factor in Xinjiang Automous Region

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Abstract: This study improved the application of the Holdridge life-zone model to simulate the distribution of desert vegetation in China which gives statistics to support eco-recovery and ecosystem reconstruction in desert area. This study classified the desert vegetation into four types: (1) LAD: little arbor desert; (2) SD: shrub desert; (3) HLHSD: half-shrub, little half-shrub desert; (4) LHSCD: little half-shrub cushion desert. Based on the classification of Xinjiang desert vegetation, the classical Holdridge life-zone model was used to simulate Xinjiang desert vegetation's distribution and compare the Kappa coefficient result of the model with table of accuracy represented by Kappa values. The Kappa value of the model was only 0.19, it means the simulation result was poor. To improve the life-zone model application to Xinjiang desert vegetation type, a set of plot standards for terrain factors was developed by using the plot standard as the re-classification criterion to climate sub-regime. Then the desert vegetation in Xinjiang was simulated. The average Kappa value of the second simulation to the respective climate regime was 0.45. The Kappa value of final modeling result was 0.64, which is the better value. The modification of the model made it in more application region. In the end, the model's ecological relevance to the Xinjiang desert vegetation types was studied.

Keywords: Xinjiang; desert vegetation types; Holdridge life-zone; terrain; climate regime

Introduction

The desertization in Xinjiang Province, China, leads to serious eco-environmental problems, such as further desertification, water loss, soil erosion, salinization, and secondary salinization(Lu, 2000; Zhu, 1999; Zhang, 2002; Jiao, 2001). It also leads to a lot of hazards as follows: the areas of available land resources reduces, the areas of moving dune increases continuously, the producitivity of land drops, etc.(Feng, 2000). This study used the Holdridge life-zone model to analyze key factors, which affect the desert vegetation distribution. The purpose of this study was to give statistics supporting to eco-recovery and ecosystem reconstruction in desert area.

Vegetation is the major and the most notable part of the ecosystem on the continent and the key link between ecosystems, climate, and the soil sub-system. Generally, climate is the most important factor that affects vegetation types and their distribution, vegetation in turn has a striking impact on the climate. The relationship between vegetation and the climate is corresponsive, which has been tested as a basic vegetation ecology law through long-term research (Zhang, 1993). It is important to understand the dynamic relationship between vegetation and climate. However, there are some factors that have influence on the distribution of vegetation, such as terrain, human activities and unexpected natural disasters. It is a long-term change of the climate that reflects quantity and distribution of vegetation.

The international research in this field can be classified into three stages: (1). the relationship between actual climate-vegetation and the climate; (2). climate-vegetation research based on the climate that has direct and apparent influence on the physiological activity of vegetation; (3). climate-vegetation research that comprehensively reflects the structure and function of the vegetation. As a whole, the climate-vegetation study in China is still on a rudimentary level, with the application of the foreign models or simple statistical analysis. The indicators of Chinese climate-vegetation classification system has not been set up, and climate factors which have obvious influence on the physiological activities of plant have not been applied to the research. This study introduced the terrain factor into the climate-vegetation model for the desert region in Xinjiang, which could improve the precision of the vegetation classification. There are many models, such as Holdridge life-zone model(Holdridge, 1947; 1967; Prentice, 1990), Box model(Box, 1981), Kria model(Liu, 1999), Penman model (Zhang, 1989a) and Thomthwaite model (Zhang, 1989a). Yang(Yang, 2003) contrasted the 4 major climate-vegetation models, which showed that the Holdridge life-zone model was a suitable model except in the dry area of northwestern China and Tsinghai-Tibet Plateau(Yang, 2003; Zhou, 2003). Therefore, the Holdridge life-zone model is required improvements so as to be employed in climate-vegetation research in northwest of China.

The Holdridge life-zone model's study mainly focused on the horizontal zone. This study added the terrain factor to the model to emphasize the model's altitudinal zonality. As to the Holdridge life-zone model, this study could offer higher precision to the vegetation classification result. This study served as a new method to climate-vegetation research in China.

1 Materials and methods

1.1 Study area

The study area is Xinjiang Province, China. Xinjiang lies in the northwest of China with a total area of 1.66×10^6 km^2 (73°40′—96°23′E, 34°25′—49°10′N). The terrain of three huge mountains nipping with two big basins leads to various types of ecosystems, which in turn comprise a mountain-oasis-desert system(MODS): the basic landscape pattern in this area(Wang, 2002). The special terrain situation of the area offers rich mineral resources. However, dry climate, water shortage, rare forest and vegetation, big desert range with sandy and salty soil have made the ecosystem in the area fragile. The elevation in the north Xinjiang is comparatively lower than that in the south. The north of Xinjiang has a temperate dry continental climate while the south has a warm-

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temperate-dry-continental climate. The average temperature in the north of Xinjiang Province is −4—9℃, the south of Xinjiang Province 7—14℃ with the highest temperature of 47.6℃ and a daily range of 11—16℃. Meanwhile, the non-frost period in the north is 120—180 d while in the south is 180—240 d. The Mean annual precipitation in the north is about 150 mm, except for Arltai and Tianshan mountains (Zhang, 2002), but the south has less precipitation. The altitudinal zonality of the climate in Xinjiang is more obvious than other places. The area mostly depends on the inner-rivers originating from the mountainous glaciers and snow, which flow to the basin desert or accumulate and form the salty lake in the end.

1.2 Materials

The vegetation types in Xinjiang are classified into 4 types: (1) LAD: little arbor desert; (2) SD: shrub desert; (3) HLHSD: half-shrub, little half-shrub desert; (4) LHSCD: little half-shrub cushion desert (Song, 2001; Wu, 1980).

The meteorological data of this study is taken from 50 years of measurement data from 54 standard weather stations in Xinjiang (Fig. 1). The three classification indicators of vegetation in Holdridge life-zone are mean annual biological temperature (ABT), annual precipitation (APT), and annual potential evaporation (APE), which are all taken from the 50 years data of the standard weather stations. Statistics analysis was carried out in data process system software (Tang, 2002). The spatial analysis is completed in the GIS software: Arcview 3.2 and ArcGIS 8.12.

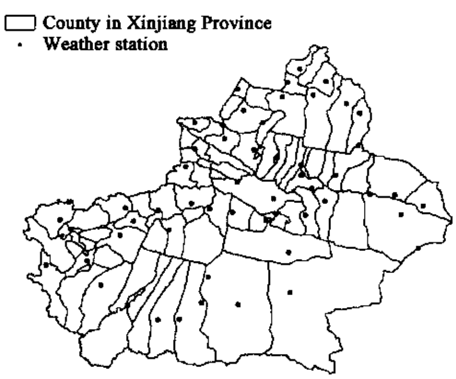

Fig. 1 Weather stations locate in Xinjiang Province

1.3 Classical Holdridge life-zone model and its modification

Based on the classical Holdridge life-zone model, the relationship between vegetation and climate was obtained by comparing the climate regime with the observed vegetation.

The climate regimes was divided into different climate regimes according to the three indicators (ABT, APT and APE) of the Holdridge life-zone model. In the classical Holdridge life-zone model, ABT has an indicative value, but in this study the authors regarded the ABT as a factor affecting the climate and places it in advance in the climate regime. For instance, "climate regime 423" means the ABT is in the forth level-the cool temperature zone, while APE level is in the second, and APT is in the third level. The APE and APT grade meanings are explained in the Holdridge life-zone mode (Prectice, 1990). The classification of this climate regime has a wider application range than that of the original Holdridge model, and it is more practical for simulating the Xinjiang desert vegetation and the north of China.

1.4 Vegetation-climate simulation principle of the Holdridge life-zone model

The simulation principle adopted in this study was based on the rule of maximum membership grade, which is invariably employed in the vegetation classification simulation of the first or second time. The major basis of the vegetation simulation principle is according to the largest vegetation's area in the corresponding climate regime, and then simulate the corresponding climate sub-regime to the desert vegetation type. As to the results of the first and the second vegetation classification simulation were evaluated using Kappa coefficients.

1.5 Kappa coefficient

The Kappa coefficient is normally used when comparing the results of the simulated type of the vegetation and the actual type. We can use the data processing system (DPS) to calculate the Kappa coefficient (Tang, 2002). The Kappa coefficient is one of the testing methods applied to the parameters in the data classification statistics of the DPS, which tests consistency between results of the two supervising methods.

It is defined, for computational purposes, as

$$K = \frac{p_a - p_e}{(1 - p_e)},\ p_a = \frac{1}{n}\sum_{i=1}^{r} x_{ii},\ p_e = \frac{1}{n^2}\sum_{i=1}^{r} x_{i+}x_{+i},$$

where K is kappa, r is the number of rows or columns in the confusion matrix, n is the total number of observations, x_{ii} is the number of observations in row i and column i, $x_{i+} = \sum_j x_{ij}$ and $x_{+i} = \sum_j x_{ji}$ are the marginal totals of row i and column i, respectively. When all of the elements of the confusion matrix outside the main diagonal have null values, the Kappa coefficient is equal to one, i.e., the performance is maximum. The bigger the value of k, the better the identification of the two methods, Kappa confusion matrix can be actualized by using the overlapping table in the Arcview 3.2, and each vacancy is set to zero (Table 1).

Table 1 Accuracy represented by Kappa values

K	Accurate level
0—0.2	Poor
0.2—0.4	General
0.4—0.6	Good
0.6—0.8	Better
0.8—1.0	Excellent

1.6 Terrain factor

The terrain factor is less important than the climate to vegetation distribution in Xinjiang. The landscape pattern of mountain-oasis-desert in Xinjiang in a large scale determines its vegetation distribution and the appearance of the desert. Water resource supply of Xinjiang mainly depends on high mountain glaciers' snowmelt runoff. The terrain factor is very important to control the altitudinal zonality and horizontal zonality of Xinjiang vegetation distribution. After testing the simulated vegetation type with the Kappa coefficient, if there are any climate regimes that are not of an expected result, we expect to quadratically simulate it by employing the terrain factors.

1.7 Quadratic simulation

Quadratic simulation in this study was to double the climate regime where the simulation result was poor according to the Kappa coefficient. We subdivide the climate regime into several climate sub-regimes, according to the rule of maximum membership grade, where we classified the climate sub-regimes into corresponding desert vegetation types.

For the climate regimes with less satisfactory simulating results, we quadratically simulated the vegetation type according to terrain factors, and re-classified the climate regimes into new climate sub-regimes. The following steps generate the re-classified criterion of climate regimes. According to the terrain factor, we re-classified the climate regime, which was needed to quadratically simulate for many times according to several criterion, and quadratically simulated the new vegetation types. The simulations result for multiple have been tested with the Kappa coefficient. The criterion of Table 2 are best fit according to the Kappa coefficient test.

Table 2 Re-classified criterion terrain factor to climate sub-regimes

Vegetation types	Criterion of different sea level elevations, m		
	South Xinjiang	North Xinjiang	East Xinjiang
LAD	0—1000	< 500	< 1000
SD	1000—1500	500—600	-
HLHSD	1500—3500	> 600	> 1000
LHSCD	> 3500	-	-

Note: - represents no corresponding vegetation

1.8 Application flow of the Holdridge life-zone model

The application flow to the model was given as following: Create a third class climate regimes map the data of BT, APPT and APE in Xinjiang→Overlay the third class climate regimes map with with the map of 1:1000000 desert vegetation→Simulate the desert vegetation types according to the rule of the maximum membership grade→First test the model with Kappa coefficient → Create the climate sub-regimes map and second simulation of the desert vegetation type → Second test the model with Kappa coefficient.

2 Results

2.1 First simulation result of the Holdridge life-zone model

According to the climate data from Xinjiang, we generated a third-class climate regimes (Fig.2). Table 3 is generated by spatially overlapping analysis between the desert vegetation type map at the scale of 1:1000000 (Fig.3) and the climate regimes map (Fig.2). According to the desert vegetation type map at the scale of 1:1000000, the Kappa coefficient of first simulation is 0.19. According to the rule of maximum membership grading, we generate the desert vegetation type map in Xinjiang (Fig.4). In Table 3, the half-shrub, little half-shrub desert has a wider range in the desert climate regimes than the other three desert vegetation types, and it is mainly distributed in climate regime 411, 412, 421, 422, 423, 424, 432, 433 and 434 climate regime. The shrub desert mainly distribute in 311, 312, 322. The 413 climate regimes are distributed with the little arbor desert vegetation types. The simulation results show that there is no little half-shrub cushion desert vegetation type. According to the precise standard adopted by Yang (Yang, 2003) (Table 1) in classification of the Kappa coefficient, the result of the simulation is poor.

Fig.2 Third class cliamte regimes of the desert vegetation types in Xinjiang which is used in the Holdridge life-zone model

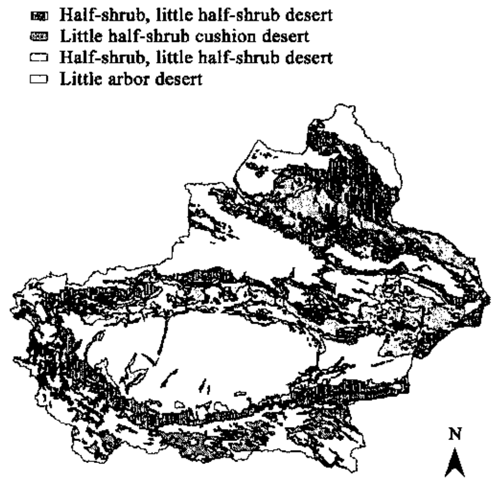

Fig.3 Desert vegetation type at the scale of 1:1000000 in Xinjiang

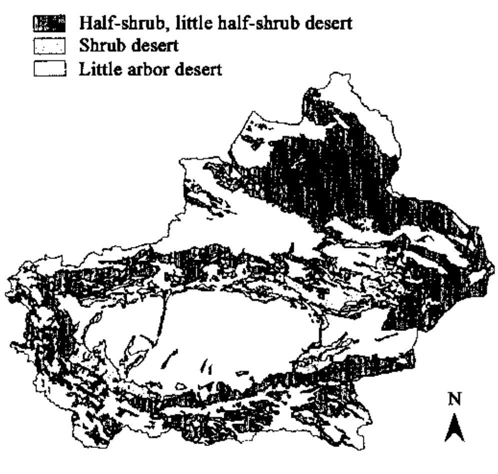

Fig.4 Desert vegetation types of first simulation in Xinjiang

2.2 Quadratic simulation result of the Holdridge life-zone model

According to Table 3, the distribution of the four desert vegetation types in Xinjiang largely overlap each other in seven third-class climate regimes, such as 311, 411, 412, 421, 422, 423, 424, in which the results of the simulation are not satisfactory (the Kappa coefficient is only 0.19). To improve the application value of the Holdridge life-zone model, the seven third-class climate regimes must be quadratically simulated.

Table 3 Area of the four vegetation types distributed in different climate regimes

Climate regime	Area of the four vegetation types distributed in different climate regimes, 10^2 km^2			
	LAD	SHD	HLHSD	LHSCD
311	0.02	782.01	384.50	52.09
312	0.00	106.27	22.39	0.00
322	0.00	10.72	3.89	0.00
411	29.33	598.26	692.75	579.37
412	126.95	111.57	228.36	51.20
413	21.53	6.61	2.26	2.32
421	72.27	34.03	102.94	0.00
422	131.80	172.47	434.13	47.97
423	460.94	98.80	853.81	0.02
424	43.37	13.97	56.55	0.00
432	1.60	0.20	6.59	1.75
433	1.02	9.72	92.98	3.36
434	0.88	6.69	44.21	0.00

According to the classification standard of the terrain simulation of the vegetation type climate model in Table 2, each climate sub-regime is presented. By counting on the spatial analysis function of the overlapping table in the Arcview 3.2, we figure out the distribution area of each vegetation type climate model under different climate sub-regimes, as shown in Table 4.

Table 4 Area of the four vegetation types distributed in different climate regimes, 10^2 km^2

Climate sub-regime	LAD	SD	HLHSD	LHSCD
311a	0.02	725.13	118.56	1.20
311b	0.00	52.75	250.22	0.06
311c	0.00	0.00	13.99	49.96
411a	22.57	482.56	125.52	0.09
411b	6.64	108.76	439.54	5.89
411c	0.00	3.98	123.67	568.24
412a	107.64	16.94	2.27	0.00
412b	3.05	47.69	122.69	54.82
412c	0.88	0.00	3.37	46.75
412d	64.61	32.57	12.92	1.39
421a	47.22	12.87	34.37	0.00
421b	24.55	20.90	67.63	0.00
422a	106.41	32.48	87.13	0.00
422b	21.59	111.30	87.69	0.01
422c	3.73	27.98	248.23	6.11
422d	0.00	0.10	9.85	41.40
423a	288.96	56.38	95.71	0.00
423b	171.74	42.26	756.62	0.00
424a	22.86	2.72	17.84	0.00
424b	12.16	4.11	40.11	0.00
424c	6.69	7.27	0.00	0.00

In Table 4, the seven third-class climate regimes are reclassified into 21 climate sub-regimes. As to the various climate sub-regimes, they are simulated to various desert vegetation types according to the rule of their maximum membership grade. While simulating the climate regimes as different vegetation type we generated the quadratic simulation map of Xinjiang desert vegetation types (Fig. 4). We conducted a Kappa coefficient test and contrasted the final result with that of the eventual life-zone simulation to each climate regime, so that the statistical method of the model could be tested.

In Table 5, the Kappa coefficient of the first life-zone simulation result is 0.19, and the Kappa coefficient of the final life-zone simulation result is 0.64, which is in a better level according to Table 1. After the quadratic simulation of the seven climate regimes and the test by the Kappa coefficient, the average value is brought up to 0.47, which is in the good level according to Table 1, and the quadratic simulation results are also satisfactory. The simulated desert vegetation types and the actual desert vegetation types at the scale of 1:1000000 are shown in Fig.3 and Fig.5.

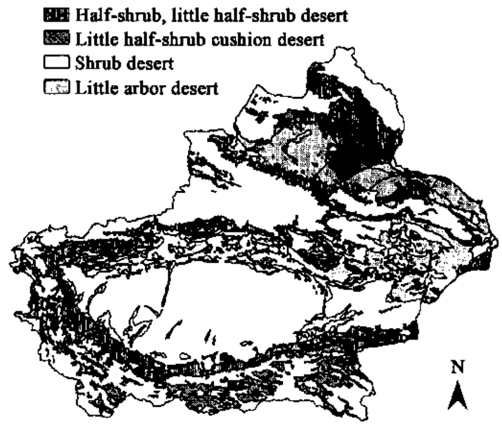

Fig.5 Desert vegetation types of second simulation in Xinjiang

Table 5 The Kappa coefficient of Holdridge life-zone model

Type	K	Pa	Pe
First simulation	0.19	0.53	0.42
Quadratic simulation			
311(3 types)	0.67	0.85	0.53
411(3 types)	0.69	0.79	0.33
412(4 types)	0.45	0.60	0.26
421(2 types)	0.22	0.55	0.43
422(4 types)	0.48	0.65	0.32
423(2 types)	0.46	0.74	0.52
424(3 types)	0.35	0.62	0.41
Average	0.47	0.68	0.40
Final simulation	0.64	0.75	0.31

Notes: The seven-climate regimes are reclassified into twenty one-climate sub-regimes; each climate sub-regime has the four types desert vegetation; each type of desert vegetation area is showed in the table

As to the two simulations of Xinjiang desert vegetation, through the Arcview 3.2 spatial analysis and excel(Table 6). Table 6 demonstrates that in the double simulation, the little arbor desert is more coincident. The shrub desert is the second coincident, and the half-shrub, little half-shrub desert is the third. In the second simulation the little half-shrub cushion desert is mostly transferred from the half-shrub, little half-shrub desert.

3 Discussion

3.1 Mend effect to the Holdridge life-zone model

The result of the first simulation is not satisfactory, which may be caused by shortage of climate data for modeling. This is due to the condition that there are not enough standard weather stations in the desert region. Another reason is that the water distribution from non-precipitation sources affects the desert vegetation distribution to a large degree(Hou, 2002; Tian, 2003).

Table 6 Transfer matrix of desert vegetation area between the first simulation and the second simulation

First simulation	Quadratic simulation, 10^2 km^2				
	LAD	SD	HLHDS	LHSCD	Total
LAD	32.81	0.02	0.00	0.00	32.84
SD	0.00	983.16	304.42	65.01	1352.58
HLHSD	925.95	1032.35	2306.08	852.45	5116.82
Total	958.76	2015.52	2610.50	917.46	6502.24

The terrain factors have the vertical effect on the distribution of vegetation types and the natural complex as well. The water of the oasis in Xinjiang mainly melts from the snow on the top of the mountains, from which we can see the importance of the terrain factor to the distribution of the vegetation type. Meanwhile the terrain of Xinjiang is very peculiar, and the introduction of the terrain factor would help perfect the desert vegetation type simulation.

3.2 Desert vegetation type distribution in the climate regime

According to the simulation results of the Holdridge life-zone model, in Xinjiang warm temperate zone is mainly distributed with the shrub desert, which accounts for 72.9% total area of vegetation type, and then the half-shrub, little half-shrub desert, which takes up 22.4%, and at last the little half-shrub cushion desert 4.72%. The little arbor desert does not distribute in the warm temperate zone. In the cool temperature zone the half-shrub, little half-shrub desert vegetation type consists the largest part, which is about 48.7%, and the distribution of the little arbor desert, the shrub desert, the little half-shrub cushion desert occupy the similar area, which are 17.8%, 15.9%, 17.6% (data are calculated from Table 3 and Table 4).

3.3 Ecology meaning of the mend of the Holdridge life-zone model

We can derive the conclusion from Table 3 that the desert vegetation types are mainly found in the warm temperate zone and the cool temperature zone for the 11 climate regimes in Xinjiang.

Due to the terrain factor, the desert vegetation in Xinjiang is peculiar. Small amounts of little arbor desert vegetation type exists in southern Xinjiang, while there is no little half-shrub cushion desert vegetation type in northern Xinjiang. In the shrub desert and half-shrub, the little half-shrub desert vegetation type exists both in the south and the north of Xinjiang(Fig. 3, Fig. 5). In southern Xinjiang, because of the higher altitude, the distribution range of the desert vegetation type is relatively wider, and the shrub desert vegetation type is found at the altitude of the 1500—3500 m, while the little half-shrub cushion desert vegetation type is found above the altitude of 3500 m. In northern Xinjiang, most desert vegetation types are distributed in Junggar basin, due to lower altitude, the little arbor desert vegetation type mainly exists below the altitude of 500 m, and the shrub desert vegetation type is found at the altitude of 500—600 m, while half-shrub, little half-shrub desert vegetation type are above the altitude of 600 m. In eastern Xinjiang, the little arbor desert vegetation type exists below the altitude of 1000 m, while the half-shrub, little half-shrub desert vegetation types are found above the altitude of 1000 m.

4 Conclusions

This study employed the terrain factor as the parameter for quadratic simulation. This mend to the model make its application region wider. The Kappa coefficient of double simulation rised from 0.19 to 0.64, which offered data support for a new method of the vegetation type climate model. The result of the quadratic simulation was better according to Table 1. Terrain factor as a mending parameter to the model is a key factor to the improvement of the model simulation. The total result of the quadratic simulation was better at a large scale. This study improved the application scale of the Holdridge life-zone model.

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