Urban Forest Cover: Change and Response to Climate

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ABSTRACT
Since 1990, due to Mongolia's transition to a free market economy, the migration of the population to cities, especially to the capital, has rapidly increased. As a result, urban lands are expanding, forest use around the cities is becoming more chaotic, and the impact of urbanization on forests is increasing. Impacts of natural and social factors, such as climate change and social transformations on suburban forests have been increasing over the last decade, which threatens urban green spaces as well as leads to the degradation of peri-urban natural and anthropogenic ecosystems. Therefore, urgent need to identify changes in urban forest areas over the past 30 years in connection with climate change have drawn attentions of scientists and policy makers in recent years. The purpose of this study was to identify urban forest cover changes of Ulaanbaatar city and define changes in forest characteristics in relation to climatic factors. In this study, both field measurement and remote sensing methods are used for developing map of urban forest cover change. Results show that the urban forest area of Ulaanbaatar was $96.3*10^3$ hectares in 1989, but as of 2019, the total forest area has decreased to $84.4*10^3$ hectares. Also, there is a weak negative correlation between the annual growth rate of trees and the air temperature in May-August, suggesting that this decline may be related to climate change. The findings from this study will contribute to further improvements in forest resource management, and formulations of climate change adaptation measures.

Keywords: *Urban forest growth, forest mapping, forest change detection, air temperature, Ulaanbaatar*

1. INTRODUCTION

Due to Mongolia's transition to a free market economy, the concentration of the population towards the capital city has increased rapidly since 1990. As a result, the impact of urbanization is increasing, forest use around the capital city is becoming more chaotic, and the impact of urbanization on forests and air pollution is increasing.

Urban forests play an important social, hygienic and recreational role in protecting the city from adverse weather events, improving the microclimate, reducing urban "overheating", reducing urban noise, and creating favorable living conditions for the population. Therefore, the ecological condition of the city depends on the stability of the urban forest. On the other hand, the average air temperature in Mongolia has increased by 2.4° C over the last 70 years, which is three times higher than the world average [1]. The most vulnerable ecosystem to global warming is the boreal forest, coniferous forests in the northern hemisphere. Researchers believe that permafrost thawing will take place here, which will lead to the spread of coniferous forests to the north [2]. There are also negative phenomena such as urbanization and the negative impact of air quality on forests near residential areas [3].

These climate changes and changes in forests associated with global warming threaten to degrade forests and further the degradation of suburban ecosystems. Therefore, there is an urgent need to identify changes in suburban green forest areas over the past 30 years of urbanization and climate change in relation to climatic factors, to further improve forest resource management, and to develop a scientific basis for climate change adaptation

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management. The main purpose of the study was to determine forest cover change of Ulaanbaatar area over the span of 30 years (1989-2019), and define changes in forest characteristics in relation to climate factors, namely temperature and precipitation.

2. STUDY AREA

We selected Ulaanbaatar, the capital city of Mongolia as the study area. Ulaanbaatar, the only metropolitan city in Mongolia, has 9 districts and covers an area of 4,704.4 km^2. The study area is surrounded by four mountains, Bogdkhan, Songinokhairkhan, Chingeltei and Bayanzurkh, at an altitude of 1,300-1,350 meters above sea level.

According to Articles 5.1, 8.1 and 8.2 of the Law on Forests, the green zone forest fund of Ulaanbaatar shall belong to the protected zone forest taking into account the form of protection and ecology-economical significance [4]. The forest area of Ulaanbaatar is $115.9*10^3$ hectares, of which $93.6*10^3$ hectares are covered by forest, $18.5*10^3$ hectares are not covered by forest, and $3.8*10^3$ hectares are non-forested area [5].

The main features of Mongolia's climate are the four seasons of the year, which are characterized by high temperature fluctuations, low precipitation, and a clear difference in latitude and altitude [6]. In Ulaanbaatar city, the annual mean temperature is -0.8℃, and the average temperature in January ranges from -16.7℃ to -25.2℃, in July from +15.5℃ to +18.3℃ during last 20 years. The total annual mean precipitation is approximately 240 mm [7].

3. METHODS

The main parameters of forest mensuration including diameter at breast height, tree height and tree-ring width were measured to determine the forest structure, characteristics and forest growth trends by the methodology of NP Anuchin [8]. The tree core samples were taken from stem cores at height of 1.3 m and measured using Velmex and COFECHA [9; 10], and it was developed in the Laboratory of Annual Ring Studies of the Institute of Geography and Geoecology, Mongolian Academy of Sciences. The correlation between air temperature data and annual tree growth rate was performed using R statistics software [11]. Landsat 5 and Landsat 8 satellite data were used for forest cover change mapping, and image processing was performed using ArcGIS 10.4 and ENVI 5.2 (Figure 1).

Table 1. Location of sample plots

№	Sample plot name	Coordinate	Altitude, m
1	Dendii	N47°58′56.4″ E107°18′28.2″	1963
2	Sanzai	N48°09′30.1″ E106°53′02.7″	1578
3	Jigjid	N48°03′10.2″ E106°51′37.1″	1557
4	Nukht	N47°49′20.3″ E106°51′50.7″	1582
5	Turgen	N47°49′07.8″ E106°53′44.5″	1935
6	Uliastai	N48°07′08.5″ E107°11′32.8″	1826
7	Khandgait	N48°06′18.9″ E106°56′20.0″	1682
8	Terelj	N48°06′18.9″ E106°56′20.0″	2000

The reliability of forest cover maps derived from remotely sensed data depends on an accurate classification. In this study, we have analyzed multispectral data using two different classifiers including Maximum Likelihood Classifier (MLC) and Support Vector Machine (SVM).

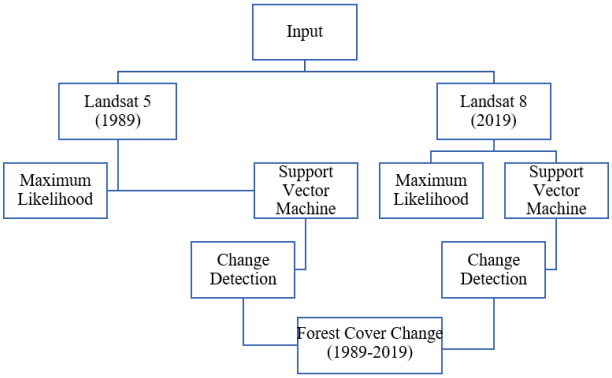

Figure 1. Forest Cover Change Detection Method

4. RESULTS

According to the main indicators of forest tree mensuration, the oldest forest in the urban area is growing in the Uliastai valley, and the youngest forest is growing in Baga Bayan.

Table 2. Forest mensuration parameters

Sample plot name	Forest components	Age class	Number of trees (trees/ha)	Density	Site index
Dendii	8L2SP+B	IY	1680	0,7	IY
Sanzai	8SP2L+B	III	1020	0,6	II
Jigjid	6P3SP1B	IY	1460	0,8	II
Nukht	7SP3P	IY	1160	0,7	II
Turgen	9SP1S	IY	940	0,8	III
Uliastai	5SP5L	YII	800	0,5	IY
Khandgai	5S3SP1L1B	IY	1940	0,7	IY
Terelj	9SP1L	IY	1460	0.8	IY

*L-larch, SP-Siberian Pine, B-birch, P-pine, S-Spruce

a) According to the samples of larch forest with forests in the Dendii of the urban area, 144 years have been counted, with an average annual growth of 0.6 mm. The years 1905-1908, 1924-1939, 1981-1983, 1987-1988, 2020, when the growth of tree diameter was higher than the average growth, and the years when the growth of tree diameter was lower than the average occurred in 1984-1988, 1992-1905, 1908-1924, 1956-1974, 1992-2019. The years of 1985-1986, 1993-1995, 2002, and 2014-2015 saw the greatest decline in forest diameter growth. The increase in the diameter of the forest increased sharply in 1905-1906, 1930-1936 and in the last year.

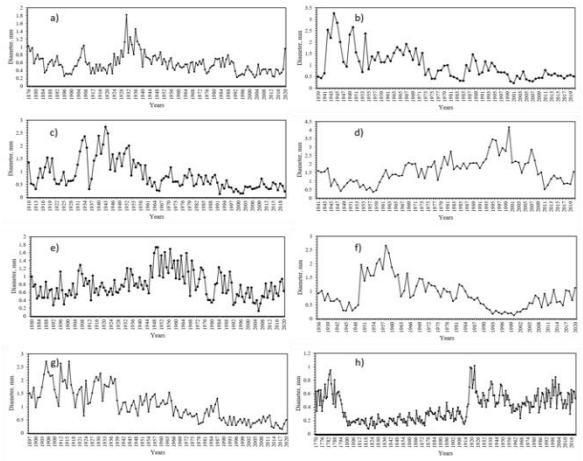

Figure 2. Diameter growth of trees in Sample plots including a) Dendii b) Khureltogoot c) Khuush d) Jigjid e) Nukht f) Sanzai g) Turgen h) Uliastai

b) As for the growth of trees in the Khureltogoot, 81-year rings were counted in the diameter growth sample. The 81-year average growth of tree diameter is 1.0 mm. The years 1943-1947, 1950-1953, 1954, 1957-1973, 1988-1989, 1992, 1994, when the growth of the diameter of the tree was higher than the average growth, and the years when the average growth was lower than the average growth were 1939-1942, 1953, 1956, 1973-1978, 1980-1987 and 1995-2020. The years with the greatest decline in larch diameter growth occurred in 1940, 1984-1985, 2001, and 2007. The increase in the diameter of the forest increased sharply in 1942-1945, 1950, 1954 and 1968. In the last 20 years, however, the increase in diameter has slowed.

c) Looking from the growth of the trees in the Khuush, the 110-year-old ring was counted in the diameter growth sample. The 110-year average growth of tree diameter is 0.9 mm. The years 1910, 1915-1916, 1917-1920, 1932-1935, 1938-1953, 1955-1957, 1972, 1979, when the growth of the tree's diameter was higher than the average growth, and the years when the average growth was lower than the average growth were 1911-1914, 1921-1924, 1926-1930, 1935-1936, 1960-1970, 1972-1978, and 1981-2020. The years with the largest decrease in the growth of larch diameter occur in 1913, 1936, 1965-1966, 1992-1993 and 2002. The increase in the diameter of the forest increased sharply in 1933-1934, 1941-1944, and 1951-1952. In the last 20 years, however, the increase in diameter has slowed.

d) In Jigjid, 79 years of tree ring were counted in tree core samples of urban forests. The 79-year average growth in tree diameter is 1.6 mm. The years 1941-1944, 1962, 1968-1971, 1974, 1976-1977, 1980-2008 were the time when the growth of tree diameter was higher than the average growth, and the years 1944-1961, 1962-1967, 1972, 1974, 1978 and 2010-2019 which were less than the average growth. The years of 1948, 1958, and 2011 saw the greatest decline in forest diameter growth. The diameter of the forest trees increased sharply in 1954-2000 and 2007-2008. However, in the last 10 years, the diameter growth has declined.

e) A total of 140 years was counted in tree core samples of the urban forest trees at Nukht in Bogd Khan Uul. The 140-year average growth of tree diameter is 0.8 mm. The years 1896, 1905-1908, 1910-1911, 1913, 1927, 1933-1936, 1940, 1943, 1946-1966, 1969, 1973-1975, 1985, 1987, 1991, 2018-2019 were the time when the growth of tree diameter was higher than the average growth, but the years below the average growth were 1882-1888, 1889-1894, 1897-1904, 1913, 1915-1917, 1920-1925, 1927-1931, 1945-1946, 1968, 1976-1981, 1985, 1987-1988, 1992-1995, 1997-2009, 2011-2012, and 2014-2017. The years with the greatest decrease in diameter were in 1892, 1897, 1979-1981, 1992, and

2005. The diameter of the forest increased sharply in 1949-1965. However, in the last 10 years, the increase in diameter has been relatively slow.

f) A total of 84 years was determined in samples of Sanzai forest. The 84-year average growth of tree diameter is 0.9 mm. The years of 1950-1961, 1965, 1968-1975, 1977-1979, 1983-1985, 2013, 2017-2018, 2020 were when the growth of tree diameter was higher than the average, and the years when the growth of tree diameter was lower than the average growth occurred in 1937-1949, 1963, 1966-1967, 1976, 1979, 1956-2010, 2011-2011, 2014-2016, and 2019. The years of 1943-1948 and 1990-2003 were the years of the greatest decline in the growth of the forest. The diameter of the forest increased sharply in 1950-1960. In the last 10 years, however, the increase in diameter has been close to the average.

g) In Turgen, a total of 123 years was determined in samples of the tree core of urban forest. The 123-year average growth of tree diameter is 1.1 mm. The above-average years were in 1902-1909, 1910-1918, 1920-1922, 1924-1939, 1942-1943, 1946, 1949, 1951-1953, 1955-1964, 1987, but the years of growth below-average growth occurred in 1923, 1940-1941, 1944-1945, 1949, 1954, 1965-1985, 1988-2020. The years with the greatest decline in forests diameter growth were 1978-1980 and 1992-2001. The diameter of the forest increased sharply in 1905-1906, 1913, 1916, 1930-1931, and 1937-1938. In the last 20 years, however, the increase in diameter has been close to the average.

h) A total of 250 years was counted in forest diameter growth sample in Uliastai. The 250-year average growth in tree diameter is 0.4 mm. The years with the highest increase in diameter are 1770-1795 and 1918-2020, and the years with the lowest increase are 1800-1915. However, in the last 10 years, the increase in diameter has increased dramatically.

The following figure shows the climate trends in Ulaanbaatar from 1940 to 2015 (Figure 3). The figure shows that the average temperatures in May, June, July and August have been increasing for the last 30 years.

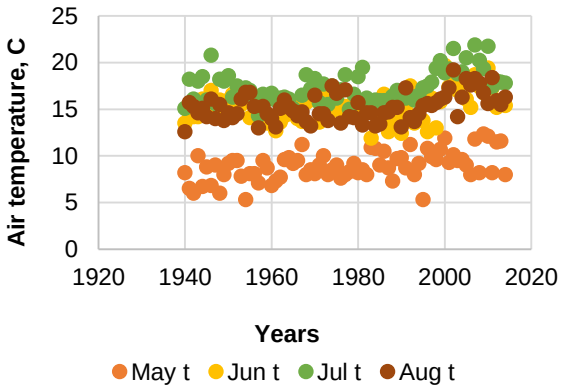

Figure 3. The climate trends in Ulaanbaatar from 1940 to 2015

Since the growth of woody plants begins in the middle of May, we calculated the correlation coefficient to see if the long-term temperature data for May-August were related to the growth of the sample trees in the study areas (Table 3).

Table 3. Correlation between average air temperature (May-August) and annual tree growth rate in the study areas

	Deendii	Khureltogoot	Khuush	Jigjid	Nukht	Sanzai	Turgen	Uliastai
r	-0.32	-0.28	-0.33	-0.26	-0.36	-0.28	-0.43	-0.14
Correlation	Moderate	Weak	Weak	Weak	Moderate	Weak	Moderate	Weak

Description: r – Correlation coefficient

The table shows that there is a weak inverse relationship between the annual growth rate of trees and the air temperature in May-August, suggesting that this decline in tree growth may be related to climate change. However, precipitation was not considered to be related to tree growth rate in the study areas.

We used the 1989 and 2019 data from the Landsat 5 and Landsat 8 satellites to develop the map of urban forest cover of Ulaanbaatar and detected the change in the urban forest area using SVM and MLC. As the classification results, SVM was more accurate than MLC. Therefore, we developed map of urban forest cover change using SVM (Figure 4).

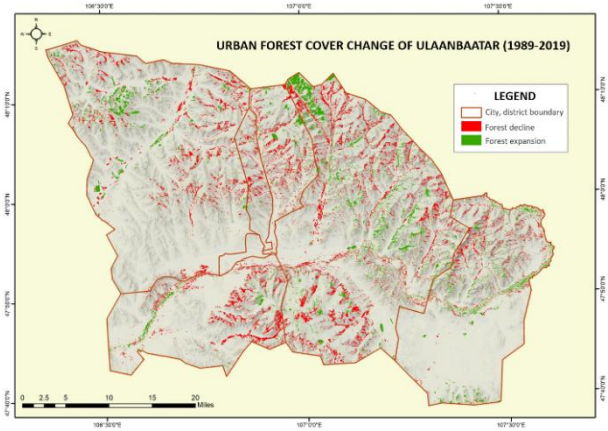

Figure 4. Urban forest cover changes of Ulaanbaatar: 30 years (1989-2019)

Table 4. Urban forest cover changes of Ulaanbaatar: 30 years (1989-2019)

Year	Area, ha
1989	96348.42
2019	84470.31
Change	Area, ha
Decline	23905.8
Expansion	12027.7

According to Table 4, the urban forest area of Ulaanbaatar was $96.3*10^3$ hectares in 1989, but as of 2019, the total forest area has decreased to $84.4*10^3$ hectares. In terms of forest cover expansion in the last 30 years, it increased by $12.0*10^3$ hectares and it could be related to the results of national programmes, such as UN-REDD Mongolia National Programme [13].

5. DISCUSSION

The Ulaanbaatar Green Zone Forest Change Study estimates that the urban forest area is 8,1536.67 ha as of 2019, and that 23035.77 ha of urban forest area or 22% of the forest cover has been declined since 1989 [12]. This is consistent with the results of our study (24.8%). According to the World Forest Resource Assessment, Ulaanbaatar had 278,000 hectares of forest cover in 2010. From 2001 to 2018, Ulaanbaatar had 6,510 hectares of forest cover degraded and depleted, and forest cover decreased by 13%. The highest deforestation losses occurred in 2003 and 2008 [13].

In terms of forest growth in the urban area, the growth of trees in the total populated areas has generally declined since 1990, and the natural and human factors are comparable to those studied by other researchers: in the 19 years from 1989 to 2017, in total of 77 areas, logging have been made [12]. The intensity of forest fires was estimated to be highest in 2007 and 2008, and moderate in 2002 and 2003. From 2013 to 2017, 47 forest and steppe fires were registered in the capital city by the National Statistics Office [14]. The number of sample plots affected by the spread of pests, one of the natural factors, was 132 between 1991 and 2018, or 23 years. In addition, the number of pest-affected areas has increased since 2000, peaking in 2003 and 2011, respectively, impacting to change [13].

Studies have shown that the most important influence on the growth of coniferous forests in temperate regions is the temperature and precipitation in early summer or May and June [15-16]. According to our research, the growth rate of forest trees has been declining for the last 30 years since 1990, and when we compare the growth rate with the air temperature between May and August of 1940-2015, it is moderately weak, which is consistent with the work of other researchers. However, no correlation was observed with summer precipitation.

According to the Unified Statistical Database in 2020, the population of Ulaanbaatar is 2,316,499. This high population density increases the impact of urbanization on the environment. According to the World Health Organization (WHO), it is recommended that each city have at least 9 square meters of urban green space per capita. As of 2012, Ulaanbaatar has 5% of the land area, or 1.6 square meters of green space per person [17].

6. CONCLUSIONS

Amongst study areas, the growth of the diameter of urban forest trees remained normal until 1990, but has generally declined since the 1990s. There is a weak (r=-0.16) to medium (r=-0.43) inverse relationship between the average temperatures in Ulaanbaatar in 1940-2015 and the tree ring growth of the trees, which suggest that the decline in the tree growth might be due to climate factor.

The oldest forest of Ulaanbaatar grows in the Uliastai valley (XII-XIII age class) and the youngest forest grows in Baga Bayan (IV-V age class), according to the forest mensuration data, which shows that the urban forest in the study area has diverse age classes.

According to satellite imagery of urban forest cover change of Ulaanbaatar from 1989 to 2019, the forest area decreased by $23.9*10^3$ hectares or 24.8%. During the same period, $12*10^3$ hectares of area were reforested.

The changes in the forest area in Ulaanbaatar from 1989 to 2019 can partially be due to climate change; however another major factor was social changes, such as increased number of residents near forest area to access forest resource.

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