



STUDY ON MONGOLIAN FOREST STAND DYNAMICS USING MATHEMATICAL MODELING

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Abstract: *A Global warming, climate change and negative human activities are expected to directly and negatively influence Mongolia's forest resource area and quality [21]. In 2015, Mongolian forested area was 12,188.2 thousand hectare and in compared with the forested area in 2010, it has decreased by 864.5 thousand hectare. The important causes of deforestation and forest degradation are fire, improper commercial logging, illegal collection of wood for construction and fuel wood, overgrazing, mining activity, and damage by pests and diseases. Mongolian forest stand is not only decreasing in quantity, but also forest age class has been changing into maturity forest classification in recent years. The maturity forest resource has counted for 74 percent of total forest resource is in National Forest Inventory, 2016.*

There are few study for Mongolian forest stand dynamics and this work is first research that used stochastic process to predict forest stand dynamics in Mongolian case. This paper considered the main factors such as Climate factors and Socio-Economic factors in predicting forest stand dynamics. The factors are chosen based on real situation of forest resource's changes in Mongolia. The study has estimated coefficients of relationship between forest resource and main factors, as well as main factors and their explanatory variables, using suitable regression model for all estimation. Moreover, Markov chain process has been used to extracted future dynamic of forest stand by age class structure based on imbalanced age structure of total forest resource today.

The result of this paper shows that the most important factors that influenced the future forest stand changes are forest fire, commercial logging and afforestation. The estimated model results shows the forest fire will be decreased (9%), commercial logging will be increased (25%) and reforestation will be increased (30%) by 2030. Specially, this paper presented that forest resource will be decreased by 13 percent in future 15 years. Additionally, this decrease is consist of forest age structure changes which is young aged forest would be increased by 27%, middle aged forest would be decreased by 15%, maturing forest would be decreased by 39% and maturity forest would be decreased by 16% in 2030.

Keywords: *Forest stand dynamics, Forest age structure, Transition matrix;*



INTRODUCTION

The sustainable forest management has been developing throughout the world to keeping a balance of environment, economic and social when people is using natural resources by optimal and suitable management in the local country. Mongolian forest reserve lands comprise 18.3 million hectares, with 12.9 million hectares of the forest-covered area; this includes 10.5 million hectares of coniferous and hardwood forests, which is equivalent to 67 percent of the forest reserve. There is protected area is around 80% and utilization area is 20% Besides, Mongolian forest annual growth rate is 10.5% that is compared to an average of the world's growth rate 5 times less.

Statics on deforestation is confusing and often conflicting, it has been estimated [37] that Mongolia lost about 1.6 million ha of forest 1950-1980, 660 thousand ha 1990-2002 and a further 32 million ha 2000-2015. The major of causes of forest loss have been unsustainable forest harvesting (both permitted and illegal) for timber and fuel wood, forest fire, insect and disease, mining, uncontrolled grazing and long-term fluctuations [40]. An unsustainable management has been affected in not only decrease of the forest resource, its effecting in forest age structure that it has been estimated that Mongolian forest consisting of 72% of maturity forest, 12% classed as maturing, 11% classed as middle aged and less than 5%

METHODOLOGY

In this study, we developed some mathematical models that are including regression model and Markov chain process.

Regression models

First, we have dealing with linear regression models which estimated some problems such as determined main factors of forest resource's changes, predicted main factors future dynamic and forest stand dynamic in the future.

In a simple linear regression model, a single response measurement Y is related to

classed as young trees [38]. Besides, there is 420 million cubic meters of dead standing trees and deadfall trees in total forest resource in 2015 year's statistic. This statistic shows that Mongolian forest has been used slightly and inappropriate. Main causes are global warming level is 3 times more than world average warming level, and forest management has some weakness such as unregulated use, over- use, and inadequate protection.

The main objective of this study is that to find the quantitative influence of the main factors of forest stand dynamics and to predict future changes in order to provide the information for sustainable management of forest stand in Mongolia.

Moreover, to know factors which are climate and socio-economical factors have been affecting in forest resource changes, as well as to analyze dynamic patterns of these main factors in future. The result of the study will provide information for decision makers to manage harvest permission and silviculture sustainability in long-term.

We believe that based upon results and recommendations which were done during the study of forest dynamics would help to implement appropriate management for a policy-makers and decision makers to protect and to control appropriate consumption of forest resource and biomass.

a single predictor (covariate, regressor) X for each observation.

Over recent years, negative influences on forests, such as climate change, forest fire, harmful effects of human activities on biological systems, and harmful effects of insect and disease propagation have caused hotbeds of damaging activity that have led to critical injury.

In this paper, our general model of forest stand dynamic should be expressed by

equation (1).

$$Y = \beta_0 + \beta_1 * X_1 + \beta_2 * X_2 + \beta_3 * X_3, \tag{1}$$

where,

- Y – Forest Covered area, (ha)
- X_1 – Burnt forest area, (ha)
- X_2 – Harvested wood from forested area, (m3)
- X_3 – Reforested area, (ha)

Accordingly, we estimated future value of each main factor's changes which are determined in equation (1).

1. Prediction of factor X_1 which is forest fire.

A fire impact is huge in forest and steppe area in Mongolia. Wild land fire in Mongolia is mainly caused by humans [22]. There are the factors such as fire from neighbor countries, illegal logging, private tourisms are the reason of forest fire. Besides, the influence of climate changing is the reason to distribute in large area. About 95 percent of steppe and forest fires in Mongolia are caused by human

activities [12]. The impact of global warming is observed in Mongolia more than most of the regions in the world. The annual mean temperature of Mongolia increased by 2.14°C during the last 70 years. The spring is most dry season and most of percent of forest fire was burnt in spring season.

In Mongolia, average precipitation has been decreasing by 0.01mm/ year. A high temperature and dry air are keeping up the condition of to burn fire fast distribute in large area.

Therefore, Forest fire has explained by equation (2),

$$X_1 = \alpha_0 + \alpha_1 w_1 + \alpha_2 w_2 + \alpha_3 w_3, \tag{2}$$

where,

- X_1 – Burnt forest area, (ha)
- W_1 – Average temperature, (3,4 and 5th months)
- W_2 – Average precipitation, (3,4 and 5th months)
- W_3 – Illegal logging, (ha)

2. Prediction of factor X_2 which is Commercial Logging

A quantity of harvest from forest is determined by wood consumption, population growth and quantity of import wood in Mongolia. In statistical data, Mongolian population has been increasing constantly and wood consumption also has been increasing in past years [39].

Some general conclusions about the impacts of economic development and population growth on supply and demand for wood can be drawn in order to written in

$$X_2 = \gamma_0 + \gamma_1 * \ln(t), \tag{3}$$

where,

- X_2 – Quantity of Logging, (ha)
- t – Time factor in including population and wood consumption effect, (yearly)

Mongolian forestry outlook study, 2010.

- Wood consumption for housing and fences will increase as the proportion of population in urban areas grows.
- Wood consumption will increase as a result of growth in the construction sector [21].

Therefore, in this paper we supposed that logging would be change by time affect due to population and wood consumption is increasing over the time.

There is logging dynamic expressed in nonlinear regression equation (3).

3. Prediction of factor X_3 which is Reforestation activity

Since 1971, reforestation activity has been regulated by the State Central Plan. Reforestation activities implemented totally in 100.3 thousand ha area, its only 30% of all the logged area in the country. In next regression model, quantity of reforestation

$$X_3 = \theta_0 + \theta_1\phi_1 + \theta_2\phi_2 + \theta_3\phi_1\phi_2, \tag{4}$$

where,

- X_3 – Reforestation area, (ha)
- ϕ_1 – Amount of money for reforestation (only budget of government)
- ϕ_2 – Average inflation rate, (yearly)
- $\phi_1\phi_2$ – Interaction variable

This paper has developed 4 regression models to analyze forest dynamics and influencing factor in forest dynamics.

A Markov chain process

A Markov process is a random process for which the future (the next step) depends only on the present state. A Markov chain model was introduced in 1906 by Andrei Andreyevich Markov (1856–1922).

Recently, Markov process is useful in some fields such system dynamics are typical of those for queue lengths in call centers, stresses on materials, waiting times in production and service facilities, inventories in supply chains, parallel-processing software, water levels in dams, insurance funds, stock prices, forecasting labor supply and demand, forest dynamic, etc.

In this paper, we developed Markov chain process to predict of forest stand dynamics by age classes in future 15 years.

Suppose that forest resource has divided by such qualification in a group k . For example, forest resource has divided into a groups such as E_1, E_2, \dots, E_k and let be quantity of forest resource is determined by $Y(t)=(Y_1(t), Y_2(t), \dots, Y_k(t))$ in t time.

In our case we assumed that $E_1, E_2, \dots, E_k, k=5$. In other hand, we have divided into 5 groups forested area such that 4 kind of age classes and other 1 group is light forested area which is including forest burnt area, logged area etc.

was determined by government cost for forestry and reforestation. Because, there is reforestation has not been increasing following by increasing financial budget for forestry. It depends on several reasons such as seedling price has increased, seedling quality has been changing and other impacts.

There is Mongolian forest resource divided into 4 age structure such as Young aged forest is including replanted trees(0-40 years old), middle aged forest (40-70 years old), maturing forest (70-120 years old) and maturity forest (under 120 years old).

We have several important assumptions about forest dynamic is written below.

- Some percentage of forest has been die from any age groups by some reasons such that forest fire, harvest, and others.
- Growth rate of forest is 10.1% per year. In other hand, after one year 10.1% of trees transfer into another age class.
- Old aged forest never transit into other age group.
- Reforestation depends on damaged forest area in that year. They has been planed about 34% of damaged area based on last 20 years statistic.
- The time unit is one year

Let's note $b(t), y(t), m(t)$ and $o(t)$ is young, middle, maturing and maturity forest in t th year, respectively. We should write that a vector of age probability by vector $X(t)$.

$$Y(t) = \begin{pmatrix} b(t) \\ y(t) \\ m(t) \\ o(t) \\ l(t) \end{pmatrix}$$

where, $X(t)$ – total forest resource in t^{th} year.

We have calculated probabilities that are to destroy trees influenced by harvest, forest fire, and other factor’s impact, to transit into other age class and to continue in actual age class. Noted, d - the probability that tree is destroyed,

a - the probability that transition into other age groups, and $1-d-a$ – the probability that stay in a group.

The probability transition matrix is written below with using probability of each age class’s dynamic.

$$P = \begin{pmatrix} (1-0.66*d_b - a_b) & a_b & 0 & 0 & 0.66*d_b \\ 0.34*d_y & (1-d_y - a_y) & a_y & 0 & 0.66*d_y \\ 0.34*d_m & 0 & (1-d_m - a_m) & a_m & 0.66*d_m \\ 0.34*d_o & 0 & 0 & (1-d_o) & 0.66*d_o \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

There is a sum of elements in a row should be equal to 1 in probability transition matrix according to theory.

Here, forest dynamic is going by written in each age classes.

$$\begin{aligned} b(t+1) &= (1 - 0.66 * d_b - a_b) * b(t) + 0.34 [d_y * y(t) + d_m * m(t) + d_o * o(t)] \\ y(t+1) &= (1 - d_y - a_y) * y(t) + a_b * b(t), \\ m(t+1) &= (1 - d_m - a_m) * m(t) + a_y * y(t), \\ o(t+1) &= (1 - d_o) * o(t) + a_m * m(t), \\ l(t+1) &= (0.66 (d_b + d_y + d_m + d_o)) * l(t). \end{aligned}$$

A Markov chain process can be written by process (5).

$$Y(t+1) = Y(t) * P(t), \tag{5}$$

where,

$P(t)$ - probability transition matrix of t^{th} year,
 $Y(t)$ - a vector of forest age structure of t^{th} year.

RESULTS AND DISCUSSION

Data

We used statistical yearly data from 1997 to 2016 and all of data were collected from different sources such as MEGDT, NSO, ArcGIS program, Statistics of FAO, and Statistics of World Bank.

An Estimation of Regression Models

We have developed model without impact of insect. Because forest fire is the one of the

reasons which is increasing effects of insects in forested area of Mongolia. In other hand, its problem of multicollinearity and shows that strong correlation between forest fire and effect of insect can lead to large standard errors for the OLS estimates. Then, we considered regression model that is eliminated effect of insects and disease.

Table.1 Information of Data

Category	ID	Name
Main Variables	Y	Forest Covered Area
	$X1$	Deforested area by Forest Fire
	$X2$	Deforested area by Logging
	$X3$	Degraded area by Insect and disease
	$X4$	Reforested area
Climate data	$w1$	Air temperature
	$w2$	Rainfall
Social Economic data	$w3$	Illegal logging
	t	Number of Population
	t	Wood consumption
	ϕ_1	Government's budget for replant
	ϕ_2	Inflation rate
Forest age stand	$\phi_1\phi_2$	Interaction variable
	$b(t)$	Young aged forest (0-40 years)
	$y(t)$	Middle aged forest (40-70years)
	$m(t)$	Maturing aged forest (70-120 years)
	$o(t)$	Maturity forest (under 120 years)
Probability Transition matrix	$l(t)$	Degraded forest area
	d	Probability to be destroyed forested area
	a	Probability to be transited into other age class
	$1-d-a$	Probability to be stayed in current age class

There is a result of regression analysis (1),

Table.2 An estimation result of regression equation (1)

Y	Coef.	$P> t $	$R\text{-squared}$
$_cons$	21917.27	0	
X_1	-0.09553	0.68	0.4
X_2	-10.2473	0.01	
X_3	5.0014	0.98	

Source: Stata13.0

However, an estimation of regression model shows coefficients and are statistical insignificant, these coefficients are practical significant. Therefore, this equation would be estimate forest stand dynamics of future.

In equation (2), we considered that average temperature and precipitation of March, April

and May of yearly data from 1999 to 2016. There is a dry season in Mongolia and most of the forest fire burnt during these three months. Also, factor of illegal logging could be expressed that human effect to burn fire in this equation.

Table.3 An estimation result of regression equation (2)

X_1	Coef.	$P> t $	R-squared
_cons	-8614.54	0.04	
w_1	515.26	0.03	0.83
w_2	-458.7	0.02	
w_3	1.86	0.06	

Source: Stata13.0

In equation (3), quantity of logging expressed by time's factor that factor of time would be including affect of population and consumption. Besides, there is used a

logarithm function. In Mongolia, a quantity of logging should not be increase linear, because 86 percent of total forest resource is protection forest area.

Table.4 An estimation result of regression equation (3)

X_2	Coef.	$P> t $	R-squared
_cons	-236763	0	0.76
t	31217	0	

Source: Stata13.0

An estimation of regression equation (4) shows that budget of government and inflation rate are affecting in reforestation. Note: government has been planting 40-50 percent of total reforestation in past years, others

of total reforestation were planted by local ownership and others [37]. Here, we assumed that government budget for plantation by regressor ϕ_1 .

Table.5 An estimation result of regression equation (4)

X_4	Coef.	$P> t $	R-squared
_cons	7200.65	0	
ϕ_1	0.13	0.05	0.43
ϕ_2	52.85	0.03	
$\phi_1\phi_2$	-6.09E-06	0.05	

Source: Stata13.0

However, a relationship between reforestation and inflation was estimated positive relation, their negative impact was affected in interaction value is .

shows that forest resource will be increasing influenced by factors such as forest fire, logging and reforestation. Table.6 shows that predicted value of forest resource and main factors according to each model.

Finally, there is a prediction of equation (1). The result of prediction of forest resource

Table.6 Numerical value of historical data and prediction for 2030

	1997	2007	2016	2030*
Forest resource	17852	14226.5	13354	11658.1
Forest fire	400	512	407	370
Logging	4.32	5.39	7.32	9.12
Reforestation	5	9.52	3.03	5.13

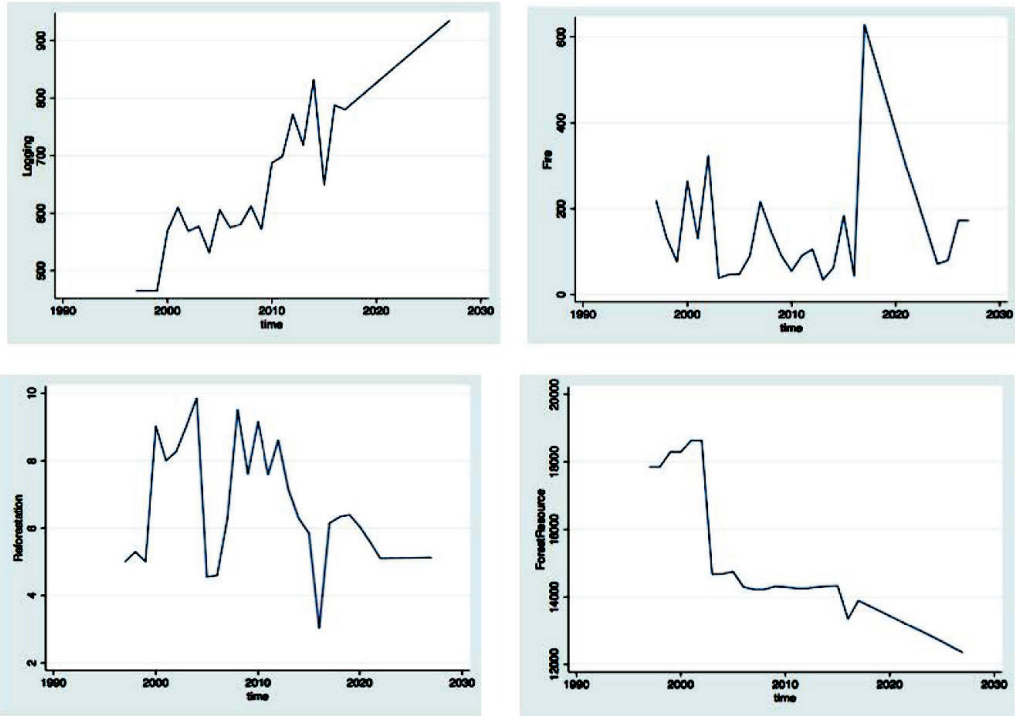
Source: Microsoft Excel

Figure.1 shows that dynamics of logging, forest fire, reforestation and forest resource, respectively. The graphs are including statistical value of past years and predicted value of future years.

climate factors, human effects, socio-economic factors in the future based on estimated result. Specially, impact of logging (both permitted and illegal) is affected high in changes of forest resource.

Forest resource would be decreased by

Figure.1 An estimated prediction of Forest resource, thousand ha



Source: STATA13.0

A Figure.1 presents that forest fire will be going decrease in future 10 years. The reasons of forest fire is from abroad 23.3%, thunder 13.3% and others by human 65% were written in report of MEGD, 2008. In past years, government focusing on illegal logging and government started to own forest for

local people and villagers who are working in forest sector. These activities will be continued successfully, and in result of these activity illegal logging has been decreasing. As well as, dynamic of reforestation presented that reforestation is keeping up constantly around 4000-6000 hectare per year.

An Estimation of Markov chain

In our case, probability transition matrix is determined by matrix P.

$$P = \begin{pmatrix} 0.89953 & 0.1 & 0 & 0 & 0.00047 \\ 0.00561 & 0.88349 & 0.1 & 0 & 0.01089 \\ 0.00603 & 0 & 0.88224 & 0.1 & 0.01171 \\ 0.03848 & 0 & 0 & 0.88680 & 0.07471 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

A Markov process (5) written in algebra notation:

$$Y(t+1) = \begin{pmatrix} b(t) \\ y(t) \\ m(t) \\ o(t) \\ l(t) \end{pmatrix} \times \begin{pmatrix} 0.8995 & 0.1 & 0 & 0 & 0.0005 \\ 0.0056 & 0.8835 & 0.1 & 0 & 0.0109 \\ 0.0061 & 0 & 0.8825 & 0.1 & 0.0117 \\ 0.0385 & 0 & 0 & 0.8868 & 0.0747 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

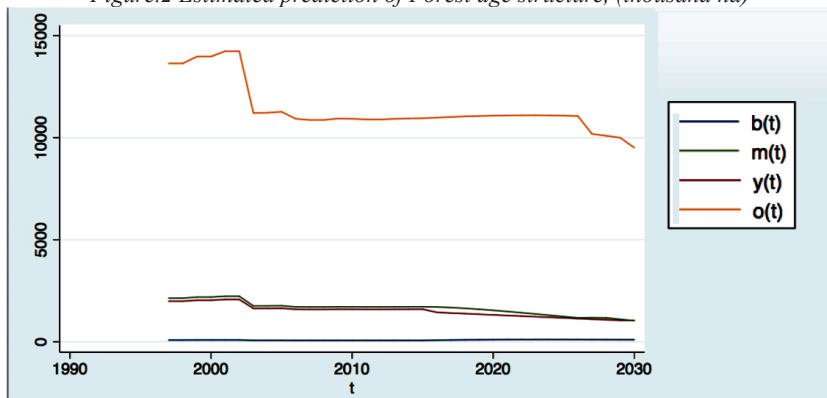
According to result of a process (5), young aged forest will be increasing slowly, middle, maturing and maturity aged forests will going

to decreasing in next 15 years. Table.7 shows details of age class's changes in 2030.

Table.7 Numerical value of historical data and prediction

	1997	2007	2016	2030*
Young aged forest	85.7	68.3	79.0	101.0
Middle aged forest	1988.7	1584.8	1443.6	1217.2
Maturing aged forest	2138.7	1704.3	1704.7	1033.6
Maturity forest	13638.9	10869.0	10982.9	9306.2

Figure.2 Estimated prediction of Forest age structure, (thousand ha)



Source: Stata13.0

Figure.2 shows that forest resource will be decreased in totally, because of many reasons we have calculated in regression models. Markov process is showing that, old aged resource will be decreased rapidly, middle and maturing aged forest will be decreased slowly and young aged forest will be increased in the future.

DISCUSSION

We have obtained following results from estimations. Estimation is consisting of 2 sections such as to know main factors of forest resource changes and to predict future value using econometric model and to develop Markov chain of forest resource's age class dynamic.

In first section, estimated relationship between forest covered area and main factors which are forest fire, logging and reforestation. We have developed 4 different regression models for forest stand dynamics and their main factors dynamics.

The result of this research shows that relationship between forest stand dynamic and main three factors.

- There is negative and weak relationship between forest stand and forest fire.
- There is negative and strong relationship between forest stand and logged area.
- There is positive and weak relationship between forest stand and reforested area.

The result which is mentioned above is shown that direct relationship between forest stand and main three factors of forest sector. The result of estimation of regression models

CONCLUSIONS AND RECOMMENDATION

This paper aimed that to know relation between forest stand dynamics and environmental and socio-economical factors. Within the scope of the thesis, we have developed some mathematical models which regression models and Markov chain model.

also has presented relationship between forest stand and other climatic factors and socio-economic factors.

- Climate factors that is average temperature has been affecting positive for fire, and negative for forest stand.
- An average precipitation (rainfall) was one factor of climate factor in this thesis. Effect of precipitation is negative for forest fire and positive for forest stand.
- Illegal logging has been causing damage of forest resource during past years. Illegal logging affected positive for fire and negative for forest stand in empirical.
- The time factor is including effects of population and wood consumption in the future. A coefficient of the time factor has shown that there are relationship between logging and time factor is positive, and relationship between forest stand and time factor is negative.
- The budget of government for replant forest has been affecting positive for to be reforested area and total forest stand.
- An inflation rate was influenced for reforestation activity negative.

In second section, we developed Markov chain model to extract forest stand dynamics by age class. Result of Markov chain shows that young aged forest will be increasing including replant, middle aged forest, maturing forest and maturity aged forest will be decreased by forest fire, logging and impact of other factors.

Further, we estimated coefficients of four kinds of regression models. First regression model expressed that relationship between forest stand and main factors which forest fire, commercial logging and reforestation. Second one shows that relationship between forest fire

and climatic factors which are temperature and precipitation, and socio-economic factor which is illegal logging. However, we used another methodology to estimate correlation between forest fire and climate impact that positive correlation between forest fire and average temperature and negative correlation between forest fire and precipitation in Mongolia suggest that same result with other papers about fire risk in Mongolia. The one of the main reason of fire is human negative activity [30]. In our case, according to positive correlation between fire and illegal logging, this fact was true. Third model presented that relationship between commercial logging and socio-economic factors that are population and wood consumption. A Result of relationship between logging and time factor shows that logging will be increased due to increasing population and wood consumption. The last regression model expressed that relationship between reforestation and socio-economic factors that are government budget for replant trees and inflation rate. At the end, we have predicted forest stand dynamics has influenced by result of these four regression models. Finally, we have estimated probability transition matrix for transit groups into each other. As well as, we predicted future dynamics of forest age class structure using prediction value which is estimated by regression models and a probability transition matrix.

In concluding, logged area was affected high in forest stand dynamics of Mongolia. Further, an effect of reforestation is weak in forest stand accordingly surviving rate is weak

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for replanted trees. Mongolian forest stand would be decreased 13% in 2030 compared with current forest covered area as a our result of estimation. Then Markov process shows that young aged trees would be increased by 27%, middle aged forest would be decreased by 15%, maturing forest will be decreased by 39% and maturity forest will be decreased 16% in 2030.

Based on our result, we recommended that government have to implement sustainable forest management in Mongolia, according to calculate real demand of wood consumption based on current forest resource and future prediction. This process should be manage many problems that are to decrease illegal logging, to keep balance of age structure, to rise income of households and forest ownership due to forest sanitation cutting activity. Also, Decision makers should to manage reforestation activity correspond closely to commercial logging at the same time. If could be managed sustainable both of reforestation activity and logging activity, would be kept balance of forest stand dynamics.

Limitation of study

The thesis focused on three main factors that are influencing forest stand dynamics. The study is not considered other factors such as uncontrolled grazing, mining effect, volunteer and other long-term fluctuations. Besides, probability transition matrix can be changed due to effect of other factors. Besides, in this paper we considered that general age structure of 4 groups.

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