OPTIMAL HARVESTING FOR DAHURIAN LARCH PLANTATIONS UNDER RISK OF PEST OUTBREAK

Thesis for M.Sc. Degree in Forest Economics

University of Helsinki

Department of Forest Sciences

October 2012

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HELSINGIN YLIOPISTO — HELSINGFORS UNIVERSITET — UNIVERSITY OF HELSINKI

Tiedekunta/Osasto — Fakultet/Sektion — Faculty Faculty of Agriculture and Forestry	Laitos — Institution — Department Department of Forest Sciences

Tekijä — Författare — Author
Jin, Qi

Työn nimi — Arbetets titel — Title
Optimal Harvesting for Dahurian Larch Plantations under Risk of Pest Outbreak

Oppiaine —Läroämne — Subject
Forest Economics

Työn laji — Arbetets art — Level Master's Thesis	Aika — Datum — Month and year October 2012	Sivumäärä — Sidoantal — Number of pages 63

Tiivistelmä — Referat — Abstract

The optimal harvesting for a set of even-aged Dahurian Larch (*Larix gmelinii*) stands located in Aershan area of the northeast of Inner Mongolia, China, are studied. The effects of catastrophic pest outbreaks (i.e. Siberian moth) on the optimal harvesting plan are also studied, and the comparison on these two cases, namely deterministic and stochastic, are analyzed.

The simulation is based on an individual-tree diameter growth model, an individual-tree height model, and model for the tree mortality for the coming 5-year period. Combined with the simulation system, the optimization model modified from Hyytiäinen et al. (2005) is able to find the number of thinnings, intensity of thinning, type of thinning, subject to given rotation lengths. In even-aged management, the objective variable is the bare land value with 3.5% discount rate. In addition, a scenario approach is applied when simulating the effects of catastrophes, i.e., pest outbreaks. Stochasticity here is represented by a set of scenarios.

The timing of an insect outbreak is random. In order to know the frequency of insect outbreak, an exponential model is applied. The numerical results indicate that the probability that an outbreak at epidemic level will occur within an interval of 5 years is about 0.39. Within a 10-year interval the probability is about 0.63. It is nearly certain that an outbreak at epidemic level occurs within 45 years.

The optimal solutions are presented separately for deterministic and stochastic cases. For the deterministic case, the results indicate that high bare land values were associated with stands of high basal area, tree diameters and height. Typically, the higher the mean annual increment and the site quality, the higher the bare land value. Meanwhile, the results show that the optimal rotation may vary considerably (40-58 yrs) at 3.5% interest rate depending on the initial stand state.

In the stochastic case, considering the effect of catastrophe of pest outbreak, numerical results show that the optimum roation is shortened and the mean values of bare land value are about 14.8% to 25.6% lower compared with the deterministic case.

Avainsanat — Nyckelord — Keywords
Optimal harvesting, Dahurian Larch (*Larix gmelinii*), individual-tree growth model, scenario approach, risk, Siberian moth (*Dendrolimus sibiricus*)

Säilytyspaikka — Förvaringsställe — Where deposited
Viikki Campus Library

Muita tietoja — Övriga uppgifter — Further information
Supervisors: Prof. Lauri Valsta and Prof. Kari Heliövaara

Acknowledgements

Sincerely I want to thank my supervisors Professor Kari Heliovaara and Professor Lauri Valsta for guiding me through the process of this thesis. Without their invaluable help, comments and profound knowledge of the topic I would not have been able to finish my work.

I extend a big thankfulness to Mr. Li Jing from Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University (Beijing 100083, P.R.China). Thanks for his support and providing the biological data. In addition, I was amazed how quickly I got replies, even though he was half the globe away.

A hug is worth more than a thousand words. And for numerous hugs, words of encouragement and a listening ear to work on this thesis, I want to thank all my dear friends at the university. And the warmest hug goes to my closest friend Zou Xiaochen, Ph.D. student at the Faculty of Science, University of Helsinki, who drew the GIS-based map for me. And thank you for all the suggestions you gave me.

Finally, I extend my thanks to all those who have helped me in my study in the University of Helsinki.

Qi Jin
Helsinki, October 2012

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1 Introduction

1.1 Optimal Forest Management at the Stand Level

Bettinger et al.(2009, p.103) mentioned that there are at least four physical levels of forest management and planning where decisions must be made: at the tree level, the stand level, the forest level, and the landscape level. And most forest economics theory is based on stand level formulations, and the stand level offers the first meaningful level of decision making (Valsta 1993). According to Cao (2003), the advantages of such an approach on stand level include the mathematical simplicity, and the generality and applicability of results. In recent decades there has been increasing interest in including thinning and silvicultural activities in stand-level models (Hyytiäinen et al. 2005). Also, the diversity of decision problems and size of planning tasks has greatly increased, that has led to larger models and more restrictions led to constraints and restrictions of higher complexity (Rönnqvist 2003). However, with the development of advanced computer technology and powerful solution algorithms, numerical solutions of complex models have become possible to be solved.

A stand is a geographically contiguous parcel of land considered homogeneous in terms of tree vegetation (Davis et al. 2001, p.65). Even-aged stands are ones where the range of tree ages within a stand does not vary by more than 20 percent or so (Bettinger et al. 2009, p.77). Generally, even-aged stands can be created through the following approaches: (1) clear-cut harvesting and subsequent plantings, (2) seed tree or shelterwood harvests, where a minor amount of the overstory remains to provide seed for the new stand, (3) as a result of natural disturbances. In practice, most private, industrial, and public forests has been planned as even-aged silviculture while most forest research has focused on regeneration and growing plantations (Davis et al. 2001, p.93).

Among the factors which affect stand management, ecological characters of tree growth, harvesting technology and economical causes are the most important ones. According to Bettinger et al.(2009, p.107 - p. 110), in stand level optimization, the main concerns have captured the attention of forest managers are optimum timber rotation, optimum thinning timing, and optimum stand density or stocking.

Forest management involves the integration of silvicultural practices and business concepts (e.g., analyzing economic alternatives) in such a way as to best achieve a landowner’s objectives (Bettinger et al. 2009, p.2). While from the economic perspective, researches on stand management demonstrate that the circulation of management activities from stand establishment, fertilization, thinning to clearcutting are supposed to be optimal timed and scaled. By doing that, it is possible for the forest manager to yield the highest net benefit to humans while the management actions are ecologically sound and socially acceptable.

1.2 Forest Management and Planning Under Risk and Uncertainty

As in forest management, we have to consider a long planning period, considerable risks and uncertainties concerning the future state of the forest and the effect of different management activities have to be dealt with (Forsell 2009). According to United Nations (1992), risk has been defined as the expected loss due to a particular hazard for a given area and reference period. However, risk is not the same as uncertainty while uncertainty presents a risk if the result of the uncertainty is an expected loss (Dadow 2000). Among the source of uncertainties, some are due to natural disturbances such as forest fire, wind damage, disease, and insect attacks.

These natural disturbances can be viewed as stochastic, or random, events as we cannot precisely determine if, when, or where they will occur (Forsell 2009). Besides, other sources of stochasticity that enters forest management may come from incorrect or inaccurate information concerning the present forest, short- and long-term variations in the biological or economic environment, the actual outcomes of forest operations, and incomplete knowledge about the goals of forest management now and in the future (Valsta 1992b). Noticeably, natural hazards can cause significant economic losses in forestry. For example, Schelhaas et al. (2003) reported damage to 35 million m^3 timber, on an annual basis, in European forests in the years 1950- 2000, of which 54% was caused by storm, 16% by fire and 8% by insects (and 22% by other reasons). In order to get strategies and actions for reducing risk and uncertainty, risk management has to be undertaken (Hollenstein 1997). And one mature method is to take into account the risks such as tree growth, mortality, timber price and preferences of decision maker by stochastic optimization based on scenario technique. Through this, the research can produce results on optimal stand density, optimal rotation, and optimal timing and intensity of thinning under different circumstances of damage and its probability. This kind of knowledge is indispensable in the forest management decision making, especially valuable for the management of the huge amount of economic plantations in northern China. Since decisions made in forestry and forest planning in this part of China often concern large areas and long time horizons. Therefore, it is of particular importance to consider the risks related to specific management scenarios and expected uncertainties related to forest management. Besides, it is also significantly important for government officers who are responsible for forest policy and legal instructions on forestry practice to know the knowledge.

1.3 A Review of Previous Researches

Since Faustmann (1849) made the theoretical framework for solving the even-aged management problem, economic studies on stand-level forest management start to concentrate on analyzing the factors of optimum rotation. Numerous studies (e.g. Amidon and Akin 1968, Kilkki and Väisänen 1969, Brodie et al. 1978, Zhang 1986, Jiang and Li 1989, Sun et al. 1998) have focused on determining optimal timing, number and intensity of thinning by applying variable-density whole model. The state variables (basal area, number of trees, tree volume, etc,) contained in these models evolve over time because of tree growth, mortality and harvesting. Meanwhile, the classical rotation problem can be solved using univariate growth models, where stand development follows a predetermined trajectory over stand age (Getz and Haight 1989). However, their application is limited to solving optimum rotation with exogenously given prior management (Hyytiäinen et al. 2005). After that, more and more studies coming up on optimal timber management by using more advanced approaches of simulating tree growth, such as using individual-tree growth models (e.g. Valsta 1992a, Vettenranta 1996, Pukkala and Miina 1998, Vettenranta and Miina 1999). While in China, the relevant research was a little lagging behind, but still lots of research fruits came out during the past decades (e.g. Li and Hao 1991, Liu et al. 2003, Jiang 2009, Liu and Li 2010). Among the huge number of past studies, some pointed out that thinning from above or from both ends of the diameter distribution is superior to thinning from below (Haight et al. 1985, Valsta 1992a,b, Eriksson 1994), while thinning from below could be optimal for first commercial thinning (Haight et al. 1985) or precommercial thinning (Roise 1986).

Furthermore, lots of studies focusing on the stochastic optimization of forest management and management under uncertainties have incorporated scenario approach or scenario technique, as stochastic process do have effects on both the development of forest ecosystem and forest management activities such as the timing, intensity, and type of thinning, and rotation length. As Pukkala and Miina (1997) pointed out, scenario technique allows different states of nature are produced as realizations of stochastic models for uncontrollable variables such as timber price, mortality and growth rate of trees. Meanwhile, forest management and planning by using scenarios can reduce uncertainty by anticipating the future in a systematic way, thus reducing the likelihood of unexpected events (Gadow, K. v. 2000). In these circumstances, when the events are so influential to the management of forests, the potential effects are of interest to forest managers and decision makers (Davis et al. 2001, p.733). Previous studies to stochastic stand level under natural catastrophes include studies under the risk of wind damage (e.g. Pellikka and Järvenpää 2003, Meilby et al. 2001, Valinger and Pettersson 1996, Lohmander and Helles 1987), these studies have tried to incorporat the probability of wind damage into the optimization of the forest management; studies under the risk of forest fire (e.g. González et al., 2006, Caulfield 1988, Reed and Errico 1985, Reed 1984, Martell 1980), the optimization models in these research incorporate the risk of stochastic forest fire damage and resulted in the reduction of the optimal rotation period; and studies with the losses from insect (e.g. Hennigar et al.2007, Hof et al.1997, Moll and Chinneck 1992, Reed andErrico 1986), although most of them propose a number of deterministic optimization approaches for forest management when a pest outbreak has occurred. However, as the stochastic management strategies were optimized under the deterministic development of the forest, they only gave approximate solutions to the stochastic problem (Forsell 2009).

Besides, some work has also tries to incorporate multiple types of uncertainties and disturbances (Xi et al.2008, Wanga et al.2006a, 2006b，Valsta 1992b). Also, some of the simulated models were developed that can incorporate several types of risk, for example, the LANDIS model (LANdscape DIsturbance and Succession model) (Scheller et al., 2007; Mladenoff, 2004; Mladenoff et al.1996), which can incorporate stochastic wind, fire, and insect damage events.

1.4 Objectives of the Thesis

The general objective of this thesis is to analyze the optimal harvest regime for a set of even-aged Dahurian larch (*Larix gmelinii*) stands under the risk of pest outbreak. The simulation is based on an individual-tree growth model and stochasticity is incorporated by scenario approach. The sample plots are located in Aershan area of northeast Inner Mongolia, China. Management of 9 Dahurian larch (*Larix gmelinii*) stands was optimized, and the optimal solutions were characterized by bare land value, rotation length and number, timing, type and intensity of thinning.

The specific objectives of the thesis are: (1) to decide optimal thinning and rotation for a set of initial states; (2) to find out how the risk of insect attack affects optimal thinning and rotation; (3) to analyze differences of optimal solutions between deterministic and stochastic situation; (4) to compare the solutions to Chinese forest law, and previous research results.

This paper is organized as follows: Section 2, Models for Stand Development, describing the simulation models of tree growth and yield. Section 3, The Optimization Model, presenting the methodology of optimization. Section 4 explains the data, meterials and computations. Section 5, Results and Discussion, in which the main results on optimal stand management under both deterministic and stochastic situation are displayed, and then comparisons are discussed. The conclusion and limitation are further discussed in the last section.

2 Models for Predicting Stand Development and Outcomes

2.1 Classification and Description of Growth and Yield Models

Stand management optimization requires a projection model to compute the effects of chosen treatments (Cao 2003). Such models are customarily called (stand) simulators (Valsta 1993). A growth and yield simulator allows forest manager to project into the future the structural characteristics of a stand of trees, and forecast the likely characteristics of the stand under varying management regimes (Bettinger et al. 2009, p.93). Compare with the normal volume or yield tables, stand growth and yield models are more advanced since they are useful for developing estimates of projected future states of forests, and given the broader suite of factors involved in predicting growth dynamics. Table 1 shows the classification of growth and yield models based on Bettinger et al. (2009, p.94-96), Davis et al. (2001, p.186-187) and Liu and Ashton (1994).

Table 1. A classification of growth and yield models

Model stand	Definition and escription
Whole stand models A. Density-free models 1. Normal yeild tables 2. Empirical yield tables for average current stands	Density-free models work as yield tables which illustrate the expected volume of wood using a combination of measurable stand characteristics such as age, site quality, and stand density. Traditional normal yield tables do not use density, while empirical yield tables assume nature's average density.
B. Variable-density models 1. Predict current volumes a. Explicit models b. Implicit models (diameter distribution) 2. Predict future growth and volumes a. Explicit models	These models are still in use in practice since their convenience for using. Variable-density models split by whether current for future volume is directly estimate by the growth functions. A second distinction in the variable density whole stand models is whether the model predicts growth directly or uses a two-stage process that first

ⅰ.Direct growth prediction ⅱ.Stand density prediction b. Implicit models (diameter distribution)	predicts future stand density and then uses this information to estimate future stand volume and subsequently growth.
Diameter class models A. Empirical stand table projections B. Diameter class growth models	Diameter class models use more detail than whole stand models in projecting forest conditions through time, and rather than project the entire stand condition at once, they project the development of each diameter class within a stand separately. The two diameter class methods are distinguished by whether actual rdial increment data collected from the subject stand are used to model the trees or whether generalized growth functions based on research sample data are used. Referred to stand table projection systems, they represent a compromise between the whole-stand models and individual tree models.
Individual tree models A. Distance-dependent B. Distance-independent	Individual tree models are the most complex and individually models the future for each tree on a sample tree list. These models are used by foresters to assist timber production and evaluate growth and yield of one to several commercial timber species in managed forests. Site-specific environmental and species information is necessary for constructing the models. A general distinction between model types is based on how the crown competition index is calculated, i.e. whether or not the calculation is based on utilizing information about the locations of other trees close to the subject tree within its zone of competition.
Gap Simulators	In gap simulators, trees serve as the basis for simulation. Each tree is represented spatially in the model by the gap that it might occupy in the canopy over a given space. Forest dynamics are then simulated based on the light made available from gaps in the canopy caused by mortality. These models were initially developed for ecological modeling purposes rather than timber production purposes. Ecologists developed these models to explore ecological mechanisms and patterns of structure and functional dynamics in natural forest ecosystems. Gap models include stochastic elements, and

therefore may need to be run multiple times to develop a pattern of forest growth behavior.

Source: Bettinger et al. 2009. Forest Management and Planning. p.94-96
Davis et al. 2001. Forest Management. p.185-187
Liu and Ashton. 1994. Individual-based simulation models for forest succession and management

Until now, whole-stand models especially variable-density whole stand models are still widely used in forest economics simulation and computation. For the most part, whole-stand models are relatively easy to use in comparison to individual tree models, but they may not provide information as reliable as individual tree models for stands with mixed species (Sironen et al. 2001). While to determine volumes using diameter class models, the diameter classes are grown, then expanded by the trees per unit area thatare represented by the class and applied the appropriate volume computation methods (Bettinger et al. 2009, p.96).

In order to get the optimal plans of action where the schedule of activities will best meet the objectives of the landowner within the scope of their perceived physical level of forest management (Bettinger et al. 2009, p.103), numerical methods have been used to solve the simulation models. For different types of models, such as whole-stand models (e.g. Shi and Feng 2005, Li 1987, Brodie et al. 1978), stage-structured models (e.g., Haight 1987, Solberg and Haight 1991), distance-independent models (e.g., Roise 1986, Haight and Monserud 1990) and distance-dependent or spatial model (e.g., Vettenranta 1996, Pukkala and Miina 1998), various numerical solutions were derived from the models.

However, all growth and yield models have their limitations. Some of these models make projections beyond the range of data that were used to create the growth and yield relationships. As Ritchie (1999) pointed out, the legitimacy of the output from a growth and yield model must ultimately be determined by the user. Bettinger et al.

(2009, p.94) supplemented that managers and analysts who need to project stand conditions into the future should consider the geographic location, management history, and composition of the data prior to deciding which model is more appropriate for the objectives of the effort.

2.2 Individual-tree Growth Models

Growth and yield simulators are programs that allow the user to understand how management may play out under different circumstances (Bettinger et al. 2009, p.103). Among all the simulators, individual tree models give us the best available tool for simulating how tree communities grow under different management prescriptions (Davis 2001, p. 210). Besides, individual tree models also provide us with our best tool to project future structure, habitat, and other ecological outcomes from the forest. Individual-based models simulate each individual tree as a unique entity in respect to establishment, growth and death (Huston et al., 1988, DeAngelis and Gross 1992). The growth and mortality of individual trees is a function of the size and location of trees in a stand with respect to other vegetation with which it will compete for light, water, and nutrients. Distance-independent growth and yield models use measures of stand density, such as basal area, as a proxy for competition among trees. Competition can also be implied given the diameter, height, and crown characteristics of a tree in a relation to other trees being modeled in the stand. On the other hand, distance-dependent models use detailed measurements of the spatial position of each tree in relation to their neighbors to model competition among trees. Some of these types of models emulate three-dimensional structures of tree attributes (tree location, height, diameter, and crown characteristics) to derive a three-dimensional view of the stand structures (Bettinger et al. 2009, p.94). Models such as these can be used in pure and mixed stands of all age combinations, thus are of value in projecting the growth and yield of uneven-aged stands (Hanewinkel and Pretzsch 2000). Furthermore, only individual tree models have the ability to simulate the competitive environment of each tree, although both stand and individual tree models can use sample survey plot data as input (Davis et al. 2001, p.211).

2.3 Use Individual Tree Models for Simulation

Davis et al. (2001, p.211) mention that the core idea of individual tree models is that they take detailed data about individual trees gathered from inventory plots and use this data to forecast how that set of trees will grow and change in the future under different management prescriptions. The model initiates the projection with the tree list and uses a mathematical simulation model, to implement the chosen prescription for that plot for one growth cycle of 5 or 10 years, or even a longer period. At the start of the cycle, each tree on the tree list is selected to be harvested, to die naturally, or to remain as a living tree at the end of the growth cycle. Then all remaining live trees, including the new reproduction and ingrowth, are grown in height, diameter, and crown to the end of the growth cycle. In order to determine stand-level characteristics using individual tree models (Bettinger et al. 2009, p.94), each tree record first is grown and perhaps subjected to a mortality probability function, then the volume of all the trees of a certain status (e.g., still alive) are determined and applied the appropriate expansion factor (trees per unit area). The sum of the contribution of each individual tree record for each stand-level characteristic is then used to produce stand-level estimates.

Furthermore, beyond the stand level, individual tree models can simulate the dynamics of a combination of stands within a forest which may be as large as hundreds or thousands of hectares in size. A large number of sample plots are customarily set up in a forest but each plot is small (usually less than 1 hectare) (Liu and Ashton 1994). For example, Adlard (1974) constructed his model from the record of approximately 1200 plots with several remeasurements in a majority of the plots.

Since Newnham (1964) published the first individual-based model, hundreds of models have been developed, tested, and applied to forest research and management (Mitchell 1969, Munro 1974, Shugart 1984). Subsequently, a series of dissertations focused on the development of individual-based tree models (Lee 1967, Lin 1969, Bella 1970, Hatch 1971, Arney 1972) were coming up. And among which, a large part were applied to uneven-aged pure and mixed stands. Munro (1974) distinguishes between distance-dependent models, which use actual stem positions for calculating distances and competition, and distance-independent approaches. After that, in the 1980s single tree models have been widely used in the United States (Wykoff et al. 1982, Burkhart 1987), whereas in Europe the practical application in actual forest management was a little later. Encouraged by these early models, individual tree models have been developing rapidly during the past three decades. Here, Table 2 and Table 3 show some examples of diameter growth functions and mortality functions in individual tree models.

Table 2. Examples of diameter growth functions in individual tree models

Source	**Equation**
Wan Razali and Rustagi, 1988	$Z=a+b\times D+c\times D^2+e\times LDG+f\times BAT+g\times LBAG+h\times LTBAG+i\times D/RS$ Z, annual diameter growth (cm $year^{-1}$); D, tree diameter; LDG, tree diameter growth rate during the previous measurement period (cm $year^{-1}$); BAT, total plot basal area (cm^2 $plot^{-1}$); LBAG, annual tree basal area growth rate during the previous measurement period (cm^2 $year^{-1}$); LTBAG, total annual basal area growth of all species per plot during the previous measurement period (cm^2 $year^{-1}$); RS, ratio of species group basal area to the total plot basal area; a-i, estimated constants
Wykoff and Monserud, 1988	DDS = POT x MOD DDS, squared diameter; POT, potential DDS: $POT=c_0+exp(c_1+c_2ln(DBH+c_3DBHC^4)$ c_0-c_4, site index dependent parameters MOD, modifier for the potential growth $MOD=c_5/[1.0+exp(c_6+c_7DBH+c_8BAL+c_9CR)]$ c_5-c_9, regression coefficients

Wykoff and Monserud, 1988	$\ln(DDS)=HAB+LOC+b_1\ln(DBH)+b_2DBH2+b_3BAL+b_4BAL/\ln(DBH+1)$ $+b_5CR+b_6CR,+b_7CCF+b_8SL\times\cos(ASP)+b_9SL\times\sin(ASP)+b_{10}SL$ $+b_{11}SL^2+b_{12}EL+b_{13}EL^2$ DDS, squared diameter; DBH, diameter at breast height; CR, crown ratio; SL, slope; ASP, aspect; CCF, crown competition factor; EL, elevation; LOC, intercept dependent on plot location; HAB, intercept dependent on habitat type; BAL, estimate of stand basal area represented in trees that are larger than the subject tree; b_1-b_{13}, regression coefficients
HiltadTeck, 1988	$DGROW=[(c\times DBH^2+POTBAG\times MOD)/c]^{1/2}-DBH$ DGROW, diameter growth rate; c, constant; DBH, diameter at breast height; POTBAG, potential basal area growth; MOD, modifier of basal area growth $POTBAG=b_1\times SI\times[l.0-\exp(-b_2DBH)]$ SI, site index; DBH, diameter at breast height; b_1-b_2, regression coefficients $MOD=\exp(-b_3BAL)$ BAL, basal area; b_3, regression coefficient
Zeide, 1989	$D= D_m\times[1-\exp(-at)]b$ (Chapman-Richards equation) $D=D_m\times\exp[-a\times\exp(-bt)]$ (Gompertz equation) $D=D_m/[(l+a\times\exp(-bt)]$ (Logisticequation) $D=D_m\times\exp[-a/(b-l)]\times t^{1-b}$ (Powerdeclineequation) $D=D_m\times[1-\exp(-at)^b]$ (Weibull equation) D, diameter at breast height at age t; D_m, maximum diameter (or asymptotic diameter); a, b, parameters specific for each equation

Source: Liu and Ashton. 1995. Individual-based simulation models for forest succession and management

Table 3. Examples of mortality functions in individual tree models

Source	Cause of mortality	Mortality functions
Chang, 1990	Suppression	$MP = (l+\exp(a+b_1DBH+b_2DGR)^{-1}$ MP, mortality; DBH, diameter at breath height; DGR, diameter growth rate; a, b_1, b_2, parameters
Ek and Monserud, 1974	Suppression	$MP = 1.0\ (RATIO < THOLD)$ $RATIO=\Delta D/D$ D, diameter; ΔD, average annual diameter increment; THOLD, a value derived from remeasurement data on dying trees
Hegyi, 1974	Random	MP = 0.20 (of all the trees to be removed)

Lin, 1974	Random	MP varies to match the field data
Ek and Monserud, 1974	Harvesting	MP (degree of cutting) may be set by the user
Reams, 1988	Pests and diseases	$f(t; Z)=f_0(t)\exp(Z \times b)$ f(t; Z), probability of dying at time t, given alive before t; f_0, baseline hazard at time t; Z, covariate matrix; b, vector of regression coefficients

Source: Liu and Ashton. 1995. Individual-based simulation models for forest succession and management

It has been over five decades, since the publication of the first individual-based growth-yield model (Newnham 1964). During this period of time, numerous individual-based models have been developed and applied. As Huston et al. (1988) pointed out, the individual-based modeling approach has a great potential to be explored. It is expected that during the coming years individual-based forest simulation models will become an even more important tool for understanding mechanisms of forest dynamics and for managing forests sustainably (Liu 1995).

2.4 Recent Approaches for Modeling Catastrophe

As a key part of this study, the effect of catastrophes on forest management had to be studied. Until now, various approaches for predicting the mechanisms and/or risk of catastrophes have been developed in recent decades. Hanewinkel et al. (2010) pointed out that these models, dealing with vulnerability and/or risk, can be grouped as being either empirical (statistical) models, mechanistic models or physical models. Mechanistic models have been developed as generic tools for risk assessment, predicting the threshold catastrophes needed for uprooting or stem breakage of trees under a range of silvicultural conditions, based on the properties of the trees within single species stands. Similarly, empirical models have been developed to assess the risk for single trees (Schmidt et al. 2010) or forest stands (Hanewinkel et al. 2004). Recently, they have also been used together with growth and yield model simulations to consider the potential risks of wind damage over time at a regional level (e.g. Zeng et al. 2006). In addition, fire risk has been simulated based on empirical and semi-physical models, which are able to predict surface fire spread and intensity with accuracy. These models usually require, as input data, information about the local weather conditions during the fire simulation period, and the amount and moisture of fine and dead fuels (Rothermel 1983). Table 4 gives an overview of recently developed mechanistic, empirical and physical models for different risk of catastrophes.

Table 4. Examples of recently developed mechanistic and empirical models for various catastrophes to forests.

models	Type of model	Country/species/remarks
ForestGALES (Gardiner et al., 2000, 2008)	Mechanistic	Great Britain/most European commercial coniferous species
HWIND (Peltola et al., 1999)	Mechanistic (snow)	Finland/Scots pine, Norway spruce, birch spp.
FOREOLE (Ancelin et al., 2004)	Mechanistic	France/Norway spruce
WINDA (Blennow and Sallnäs, 2004)	Mechanistic	Sweden/Scots pine, Norway spruce, birch spp.
FORGEM-W (Schelhaas et al., 2007)	Mechanistic	Netherlands/Douglas fir
GLM (Lanquaye-Opoku et al., 2005)	Empirical	British Columbia, Canada/no species specific models
GLMM, Cross Correlation, Spectral Analyses (Hanewinkel et al., 2008)	Empirical (snow, insects)	Black Forest (Germany) conifers + hardwoods, long term series
GLM, GAM (Schmidt et al., 2010)	Empirical	South-West Germany, large scale NFI-data, Lothar
FIRETEC (Dupuy and Morvan, 2005)	Physical	USA/adapted for pine stands in Europe
CL-CV (Mitsopoulos and Dimitrakopoulus, 2007)	Semi-physical	Greece/Alepo pine/crown fire potential
CL-CV (Fernandes, 2009)	Semi-physical	Portugal/conifers, hardwoods/fire behaviour, NFI data
BL (Fernandes et al., 2008)	Semi-physical	Europe/pines/post-fire mortality

BL (Rigolot, 2004)	Empirical	S- France/Mediterranean pines
BL (Sidoroff et al., 2007)	Empirical	Finland/Scots Pine/low intensity prescribed burnings
GLM, BL (González et al., 2007)	Empirical	Catalonia (N-E Spain)/conifers and hardwoods/long period, large scale, NFI data
BL (Moreira et al., 2007)	Empirical	South Portugal/cork oak/post fire survival
PPPY (Cruz et al., 2008)	Empirical, semi-physical	—/pine plantations

Legends: GL(M)M = generalized linear (mixed) models, GAM = generalized additive models, CL-CV = Classification and cross validation with existing fire spread models; BL = binary logistic models; GLM = generalized linear models

Source: Hanewinkel et al. 2010. Recent approaches to model the risk of storm and fire to European forests and their integration into simulation and decision support tools

Noticeably, all mechanistic models are sensitive to model inputs and parameter values, and thus, any inaccuracies in the input tree characteristics (e.g. dbh, height, crown depth and width) and parameters that control the magnitude of the catastrophes, while empirical models are statistical models that relate the presence or magnitude of wind damage to variables (e.g. tree/stand characteristic, topography, stand exposure, site conditions etc.) measured following a damage inventory.

To date, the effects of forest dynamics on the risk of catastrophes have been typically considered using time series of tree and stand characteristics as inputs in risk models without considering the feedback mechanism between them (see e.g. Zeng et al. 2006, Gardiner et al. 2008). Furthermore, Hanewinkel et al. (2010) summarized that the inclusion of risk can be done in different ways: i) a probability of a specific risk can be assigned to a single tree. In a stochastic approach, a random number can be drawn and the decision whether the tree will be damaged is taken by comparing the probability to the random number. In order to achieve stable results, the simulations have to be repeated; ii) Probabilities that are assigned to whole stands can either be distributed to the single tree level by randomly selecting trees or by applying rule based algorithms including expert knowledge. In addition, new approaches for combining tree- and stand-level growth models (Yue et al. 2008) may be promising for solving these types of problems.

2.5 Models for Stand Development in This Study

2.5.1 The Growth Models

Tree growth is a complex process, although growth modeling methodologies are evolving to better describe this process with the development of process based or mechanistic models (Landsberg 1986). Usually, growth-yield models describe growth rate as a regression function of variables such as site-index, basal area, and tree density (Liu 1995). And individual tree models are normally composed of models for tree basal area growth (measured at breast height), height growth, tree crown ratio and mortality. In the present application, trees are only of single species, namely Dahurian larch (*Larix gmelinii*). Here because of desirable properties with the error structure (e.g. homogenous variance), a logarithmic model for basal area increment as a function of tree size, competition, and site variables based on Monserud (1996) and Jiang (2009) were applied:

$$\ln(\mathrm{BAI}) = a + b \times \mathrm{SIZE} + c \times \mathrm{COMP} + s \times \mathrm{SITE} \qquad (1)$$

where BAI is the 5 year basal area increment (outside bark), a is the intercept, b is the vector of coefficients for the tree size variables, c is the vector of coefficients for the competition variables, and s is the vector of coefficients for the site variables.

In this study, on all trees, diameter at breast height was used as a measure of stem size and crown ratio as a measure of crown size, yielding the expression as:

$$b \times SIZE = b_1 \times \ln(DBH) + b_2 \times DBH^2 + b_3 \times \ln(CR) \tag{1.1}$$

where DBH (cm) is the diameter at breast height and CR is the crown ratio. Although here DBH and CR are referred as size variables, they also reflect the effects of past competition.

Also, competition effects were expressed as:

$$c \times COMP = c_1 \times BAL + c_2 \times CCF \tag{1.2}$$

where BAL is the basal area (m^2 ha^{-1}) of trees larger in diameter than the subject tree, and CCF is the crown competition factor of Krajicek et al. (1961). Noticeably, BAL for the largest tree is 0.0, and for the smallest tree equals stand basal area minus that tree's basal area.

Site description is a very important influencing the tree growth, site function was expressed as:

$$s \times SITE = d \times SITE_1 + e \times SITE_2 \tag{1.3}$$

The first term in Equation (1.3) describes the topographic effects of elevation, slope, and aspect:

$$d \times SITE_1 = d_1 \times (ELEV - d_2)^2 + d_3 \times SL^2 + d_4 \times SL \times \sin(AZ) + d_5 \times SL \times \cos(AZ) \tag{1.3.1}$$

where ELEV is the elevation in hectometers (100 m), SL is the tangent of the slope angle (% / 100), and AZ is the azimuth in radians.

The second term of Equation (1.3) combines qualitative and discrete site descriptors using dichotomous 0-1 dummy variables:

$$e \times SITE_2 = e_1 \times S + e_2 \times V + e_3 \times GD \qquad (1.3.2)$$

where S is a set of dummy variables for the soil groups, V is a set of dummy variables for the vegetation types, and GD is a set of dummy variables for the growth districts.

In order to estimate the coefficients of the model, stepwise regression analysis was used to get the calibrated model for larch plantation. During this process, variables without significant coefficient were omitted (Jiang 2009). In addition, the number of observations and the ecological similarity of the site descriptors were considered when hypothesizing the dummy variables (Monserud 1996; Jiang 2009). The purpose of these procedures was to against introducing unnecessary parameters that only described peculiarities of the sample that did not generalize to the wider population. The coefficients for the variables and the value of corresponding dummy variables of the basal area growth model for larch plantation are given in Table 5:

Table 5. coefficients for the necessary variables and value of the corresponding dummy variables.

(i) **coefficients for the necessary variables**

a	b_1	b_2	b_3	c_1	c_2	d_1	d_2	d_3	d_4	d_5	e_1	e_2	e_3
0.7144	1.1547	–0.000101	0.4999	–0.0159	0	–0.00174	0	0	0	0	0.1882	0.3309	0.2

(ii) **value of the corresponding dummy variables**

S	V	GD
1	1	0

Height growth is predicted by a dynamic height growth curve equation of site index, age at breast height and tree diameter. The height growth curve is originated from Chapman Richards model and adjusted for larch by Li (1994):

$$HT= h_0 + h_1 \times A_b^{h_2} \times [1 - \exp(h_3 \times SI^{0.7548} \times DBH)] \qquad (2)$$

where HT is tree height (m), A_b is age at breast height, SI is site index, DBH is diameter at breast height (cm). The coefficients for the variables of the height growth model are given in Table 6:

Table 6. coefficients for the variables of the height growth model.

h_0	h_1	h_2	h_3	h_4
1.3	1.3432	0.7571	–0.02296	0.7548

The site index of Equation (2) was decided by the following equation:

$$SI = H_{mean} * \exp\left(\frac{12.51004}{A} - \frac{12.51004}{A_1}\right) \qquad (2.1)$$

where H_{mean} is the stand mean height, A is the stand age, A_1 is the index age (the index age for larch plantation is 30).

Live crown ratio is the ratio of live crown length to total tree height. It is a good indicator of tree vigor. As such, it is an important predictor of periodic increment even though it has substantial shortcomings. For predicting tree crown ratio, the following model which is based on Wykoff et al. (1982) and Jiang (2009)was applied:

$$\ln(CR) = a_0 + a_1 \times BA + a_2 \times \ln(DBH) + a_3 \times \ln(HT) + a_4 \times \ln(PCT) \qquad (3)$$

where BA is stand basal area (m^2/ha), DBH is Current diameter at breast height (cm), HT is Current height (m), and PCT is tree's percentile in the stand basal area distribution. The coefficients for the variables of the live crown ratio model are given in Table 7:

Table 7. coefficients for the variables of the live crown ratio model.

a_0	a_1	a_2	a_3	a_4
– 0.95042	– 0.008886239175	0.30066	– 0.59302	0.19558

2.5.2 Mortality Model

Tree mortality model is an important part of tree growth model system. Individual tree survival rate is obtained with models predicting the probability of a tree dying during the next five-year growth period. The model is based on Monserud (1999) and Du (1999) for Larch:

$$P = [1 + \exp(b_0 + b_1 / D + b_2 \times CR + b_3 \times BAL + b_4 \times D + b_5 \times D^2)]^{-1} \qquad (4)$$

where P is the probability of mortality (5-year), D is diameter (cm) at breast height (1.3 m), CR is crown ratio, BAL is basal area in larger trees (m^2 ha^{-1}), and b0 - b5 are parameters. Furthermore, D, CR, and BAL are values at the beginning of the 5-year period. The coefficients for the variables of the mortality model are given in Table 8:

Table 8. coefficients for the variables of the mortality model.

b_0	b_1	b_2	b_3	b_4	b_5
4.407	–12.9395	2.2039	–0.0326	0	0

2.5.3 Auxiliary Model

Volumes of stems are predicted by applying the tree volume equation. The tree volume equation is predicted using information on tree diameter and height. Individual tree volume equations for larch (Zhang 1986,Wu and Wang 2000) were applied. Individual tree volume equation for sawlog and pulpwood:

$$V_s = 0.\ 000050168241 \times DBH^{1.7582894} \times H^{1.1496653} \tag{5.1}$$

$$V_p = 0.001569 + 0.00003582 \times DBH^2 \times H \tag{5.2}$$

where V_s is stem volume for sawlog, V_p is volume for pulpwood, DBH is diameter at breast height, H is tree height.

Noticeably, the minimum diameter for pulpwood here is 5 cm and the minimum length is 2 m. Additionally, log volumes obtained are based on individual tree volume equation 5.1. While in practice this usually overestimates log volumes, because it ignores all the various defects that generally appear in stems.

3 The Optimization Model

What is the value of land if we use it to grow trees? The answer can be found with a simple, yet powerful, formula originally developed by Martin Faustmann in 1894. Faustmann's fundamental insight can be generalized to define the value of any forest, regardless of its initial condition, and the values of the constraints that apply to its management. According to Getz and Haight (1989), if we assume that even-aged forest management would be practiced indefinitely, Faustmann defined forest value as the sum of the present values of harvests from the onging rotation, and land expectation value, which is the present value of an infinite series of plantations.

In this study, the optimization model is anticipatory, and stochasticity is introduced in the form of scenarios. Valsta (1992b) mentioned that anticipatory models are used for deriving optimal decisions for the whole period of time under planning, in advance. An anticipatory solution takes into account the uncertainties over time, and it is optimal overall, according to selected criterion.

3.1 Insect Outbreak Frequency

Siberian moth (*Dendrolimus sibiricus*) as an important defoliator of larch in northern China has several outbreaks and caused tremendous loss on both economic and ecological level in the past years. As previous research (Yuan et al. 2008) revealed, there had been several outbreaks occurred in the past years, while the outbreaks in 1992and 2002 were on a very large-scale. Therefore, the effects of catastrophes of insect outbreak have to be studied. In this study, catastrophes are modeled as random events that damage a part of the growing stock. Although the timing of insect outbreak is random, this random process can be described with probabilistic models (Buongiorno and Gilless 2003, p325). For each occurrence of a catastrophe, it is modeled as an exponential probability distribution. According to the exponential model, the insect outbreak probability P(T) is expressed by this exponential law:

$$P(T) = 1 - \exp(- T/a) \tag{6}$$

where T is the time span that an insect outbreak will occur within T years since last outbreak, *a* is the average interval between outbreaks.

Meanwhile, Buongiorno and Gilless (2003, p326) pointed out that stochastic simulation entails generating, every T years, a random number R_t between 0 and 1. Then a catastrophe of insect outbreak occurs if and only if R_t is greater than or equal to P(T); that is:

$$R_t \geqslant 1 - \exp(- T/a) \tag{6.1}$$

3.2 Optimal Solution of Bare Land Value

The optimization model for even-aged larch stands applied here is based on Hyytiäinen et al. (2005), under the situation where stand development is projected with an individual-tree growth and yield model. Noteworthily, the optimization model here is adjusted where the effect of catastrophe that damage a part of the growing stock, is incorporated into the model:

$$\max_{\{\mathrm{h_u}, \mathrm{t_u}, \mathrm{u}=1,\ldots,\mathrm{k};\, \mathrm{Z_0}\}} \mathrm{V} =$$

$$\frac{\sum_{\mathrm{u}=1}^{\mathrm{k}} \left\{ \left[\sum_{j=1}^{2} p_j \cdot \left(g_j(\mathrm{Z_{t_u}}, \mathrm{h_u}) + \mathrm{s} \cdot L_j(\mathrm{Z_{t_u}}, \mathrm{b_{t_u}}) \right) \right] - C_u(\mathrm{Z_{t_u}}, \mathrm{h_u}) - C'_u(\mathrm{Z_{t_u}}, \mathrm{b_{t_u}}) \right\} (1+\mathrm{r})^{-\mathrm{t_u}} - \mathrm{C_0}(\mathrm{Z_0})}{1 - (1+\mathrm{r})^{-\mathrm{t_k}}} \tag{7}$$

subject to

$$Z_{t_u} = f(Z_{t_{u-1}}, h_{u-1}, t_u - t_{u-1}, b_{t_u}), \quad \forall u = 1,..., k, \tag{7.1}$$

$$t_u \le t_{u+1}, \quad \forall u = 1,..., k-1, \tag{7.2}$$

$$h_u \in \sigma_{t_u}, \quad \forall u = 1,..., k, \tag{7.3}$$

where

V = bare land value,

u = 1,…, k harvests,

j = timber assortments (sawlog, j = 1; pulpwood, j= 2),

k = the final harvest,

Z_0 = matrix describing the inital state of the stand,

t_u = stand age at the u^{th} harvest,

Z_{t_u} = matrix describing the stand state before the u^{th} harvest at stand age t_u,

h_u = n-dimensional vector as the ratio of trees removed in the u^{th} harvest,

p_j = roadside price of timber assortments as products (RMB/m^3)

g_j = harvested volumes of timber assortments (m^3 ha^{-1}),

L_j = salvaged volumes of forest lost to the catastrophe (m^3 ha^{-1}),

b_{t_u}= a random number between 0 and 1, which gives the proportion of trees destroyed by the catastrophes

s = salvage rate,

C_u = harvest cost of the u^{th} harvest,

C'_u= cost of cleaning up and reforesting the insect-attacked stand area,

C_0 = establishment and silvicultural costs,

r = interest rate,

σ_{t_u}= the set of admissible thinning at stand age t_u.

Gross harvest revenues of the uth harvest are summed over number of trees, j timber assortments as products of prices p_j (¥/m^3), harvested volumes g_j (m^3 ha^{-1}), and salvaged volumes of forest lost to the catastrophe L_j (m^3 ha^{-1}). The net harvest revenues are attained by subtracting the harvest cost, C_u and C'_u, consisting of felling and on-site transport costs. The net harvest revenues are discounted to the beginning of the rotation period by a factor $(1 + \mathrm{r})^{-\mathrm{t_k}}$, where r is the rate of interest.

The value of bare land in Equation 7 is maximized subject to the stand dynamics that define the stand state just before the harvest at age t_u, and the scenario of catastrophes between present (t_u) and previous (t_{u-1}) harvest. This is given as a function of stand state before the previous harvest ($\mathrm{Z_{t_{u-1}}}$), intensity of the previous harvest (h_{u-1}), the possible of catastrophe happing and its damage intensity ($\mathrm{b_{t_{u-1}}}$) and time difference between present t_u and t_{u-1}. In this study, stand structure is described for n trees, each tree is characterized by variables reflecting its current dimensions (age, diameter, height etc.) and an expansion factor representing the number of trees per hectare. In the final (kth) harvest all the remaining trees are removed.

The thinning rate equation 7.3 defines thinning rates for each diameter class. In this study, thinning rate is a piecewise linear function of tree diameter, relative to the smallest and the largest diameters in the stand. The thinning parameters define the thinning rates at the corner points of the piecewise linear function. The thinning definition can be adjusted to simulate different types of thinning with only a few parameters per thinning. (for more details, see Valsta 1992b). In addition, more details about optimizing the management schedule (number and timing of thinnings) are explained in section 4.5.

The structure of the simulation-optimization system accommodates the relationships between different inputs and outputs, while optimization searches for the best combination of treatments, by way of which the forest yields the best combination of multiple products and services (e.g., Bare land value in this study). The parameters that specify the treatment schedule are called decision variables. The ‘goodness’ of the outputs obtainable from the forest with a given set of decision variables is described via the objective function.

In forestry, simulation program comprises various models and algorithms (Pukkala and Miina 1997). In addition, as in most situations, the objective function is to maximize the economic return in this study. Besides, Osyczka (1984) revealed that in multiobjective optimization, another possibility for the objective function is to simultaneously maximize several objective functions, one for each management objective. Thus, the basic technical tool for finding instructions for forest management consists of two computation parts, one for simulating stand development, and the other for computing the optimal plan.

Noticeably, the function applied in this study is made stochastic by the scenarios, where different states of nature are produced as realizations of stochastic models for uncontrollable variables such as timber price, growth rate of trees and severities of catastrophes.

4 Materials and Computations

4.1 Biological, Geographical and Economic Data

The biological data are collected from 9 sample Dahurian Larch (*Larix gmelinii*) stands. The sample stands are located in Aershan area (47°07′-47°55′N, 119°51′-120°57′E, mean elevation 1100 m), the northeast of Inner Mongolia, China (Figure 1). The site borders the Chuoer and Chaihe forests in the northeast and southeast respectively, shares an edge with the Great Xing'an Mountain and abuts the Bailang and Wuchagou forests to the south. Its northern brim is adjacent to Ewenke County and its northwestern fringe borders on Xinbaerhu County. The area belongs to the cold and wet temperate zone with annual average temperature is −3.2°C and precipitation 452.11 mm. Total area of the Ecological function zones is 4.83×10^5 hectare, with forest coverage accounting for 3.45×10^5 hectare. The forest coverage rate is 71.4%. The main forest species in this area are pure Dahurian Larch (*Larix gmelinii*) and White Birch (*Betula platyphylla)* plantations, while Dahurian Larch (*Larix gmelinii*) is the only tree species largely planted in this region (Li et al. 2009).

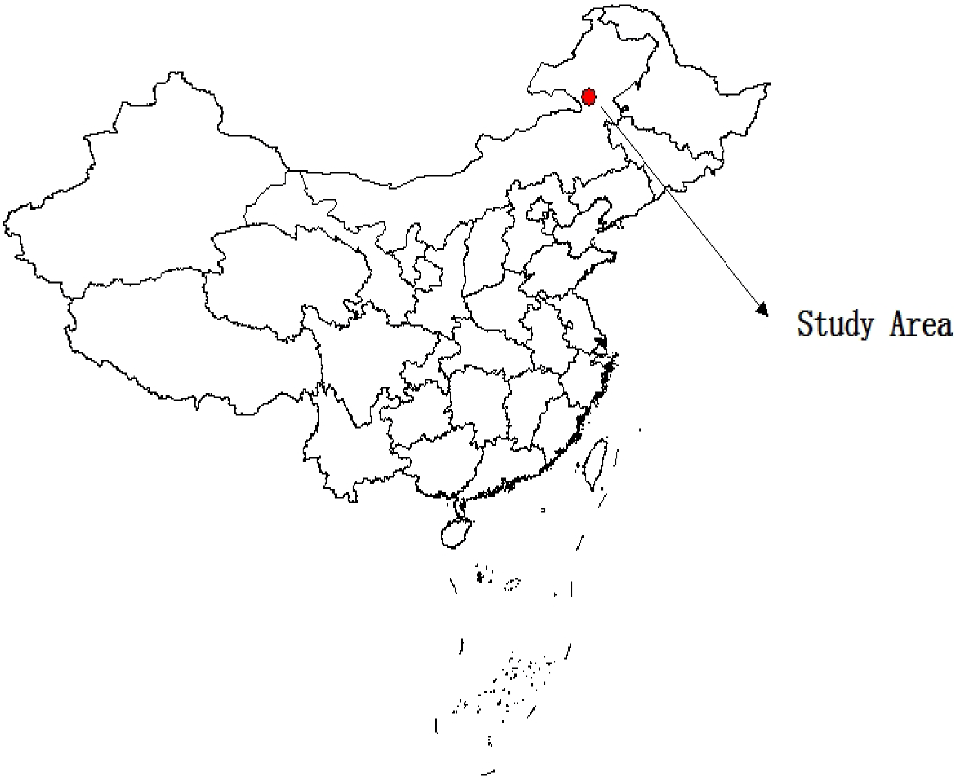

Figure 1. Location of the Aershan area included in the biological data.

4.2 Sample Plots and Data Collecting Methods

4.2.1 Sample plots

The sample plots were set and chosen by researchers from Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University (Beijing 100083, P.R.China), as part of the research plots in Aershan, Inner Mongolia. The field trial was carried out in July and August 2008. During the field trial, data of two types of forests, i.e., natural forests (NF) and plantations (PL) were recorded. All of the sample plots were as similar as possible in gradients, slopes and distribution proportion of tree species as well as corresponding effects from human activities.

4.2.2 Data Collecting Methods

As for the location and measurement of arbors, an original pole was placed in one corner of each of the 20m × 20m sample plots. Using one side as X axis and the other side as Y axis, a sample plot was divided into 16 quadrates (5m × 5m) by a measuring-rope. After this, the measurement of every tree was carried out according to a "Z" path from the original pole in the quadrates. Diameter at breast height (DBH), height, crown width, height to first live branch of trees, species names, degree of damage (healthy tree, disabled tree, dead tree, fallen tree) were recorded. Original data used in this study can be retrieved from Mr. Li Jing of Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University.

4.3 Pest Outbreak Frequency

Siberian Moth (*Dendrolimus sibiricus*) as one of the most destructive defoliators for larch in northern China has caused large impact. Noticeably, the disaster in 2002 caused by the Siberian moth (*Dendrolimus sibiricus*) has destroyed tens of thousands of hectares of larch forests, which has caused immensurable loss to the forest resources in northern China (Li et al. 2009). It is clear that when at endemic levels, the pest kills only a few trees in a stand. These trees are often weakened by fire, injuries, root disease, or competition. At epidemic levels, however, the pest causes considerable mortality in large-diameter trees. The shift of pest populations from endemic to epidemic levels has been attributed to several factors. If these trees are large, then brood survival is often high; and the next generation of these pests and many secondary pests build quickly to epidemic population levels (Marsden et al. 1993). In this thesis, the effects of pest outbreak at epidemic levels that cause considerable mortality are studied and simulated through scenario approach. Additionally, although the timing of the pest outbreak is random, this random process can be described with probalistic models. The models are necessarily simple, but they are consistent with the scarce information that is usually available. And in this study, previous outbreak information reveals that at the stand outbreak (i.e. at epidemic levels) probability at every cycle is normally 10 years.

Figure 2 shows the graph of the exponential distribution for an average interval between outbreaks at epidemic level a = 10 years. The graph shows that the probability that a pest outbreak will occur increases at a decreasing rate as T increases. The probability that an outbreak will occur within an interval of 5 years is about 0.39. Within a 10-year interval it is about 0.63. It is nearly certain that an outbreak at epidemic level would occur within 45 years.

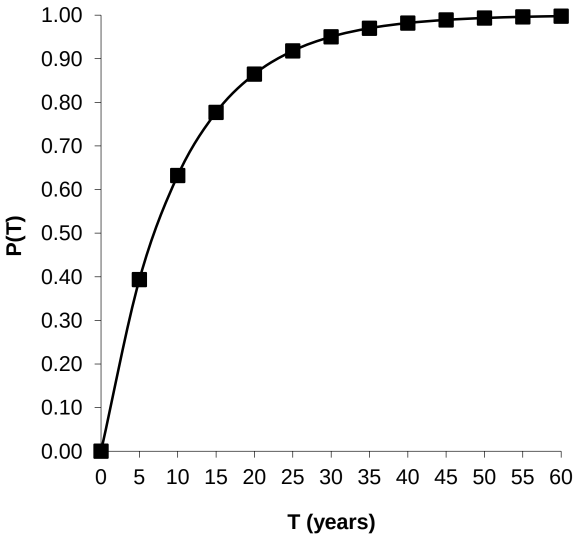

Figure 2. Probability that an insect outbreak at epidemic level occurs within *T* years, given an average time between outbreaks of *a* = 10 years.

The economic data consist of regeneration cost and roadside prices of larch sawlog and pulpwood. A 3.5% rate of interest is applied to calculate the optimal solutions. The regeneration cost is assumed to be ¥ 3828.15 yuan per hectare (including land preparation cost, planting and seedling cost, silvicultural operations cost, and tending cost). The roadside price of larch are ¥ 950 yuan/m^3 and ¥ 650 yuan/m^3 for sawlog and pulpwood, respectively (Gao et al. 2009).

4.4 Harvesting Cost

From forest harvesting point of view, harvesting cost consists of felling cost, transport cost and other fixed cost (Cao 2003). In this study, these costs were kept as constant. In detail, the felling costs employed here are ¥110 yuan/m^3 (including both direct and indirect cost) for thinning or selective harvest, and ¥149 yuan/m^3 (including both direct and indirect cost) for final harvest. The transportation cost is ¥0.5 yuan/m^3/km, while the average distance of transporting to timberyard is 57km. Since the other fixed costs were partly calculated within the felling costs, the remaining part mainly is loading and storage cost which is ¥10 yuan/m^3 (Gao et al. 2009).

4.5 Computations

As a development that is helping to bridge the gap between forest resource managers and model builders, the computer spreadsheet becomes popularity. Modern spreadsheets have sophisticated built-in functions, including optimizers that avoid the need for specialized computer programming. In this study, the Microsoft Excel was used for solving the problem. Like several other spreadsheets, Excel contains a Solver to find the best solution. Besides, Excel offers a friendly user interface, flexible data manipulation, built-in mathematical functions and instantaneous graphing of data. The Solver is capable of solving small-scale linear programming (LP) and mixed integer programming (MIP) problems. Included in nearly 100 million copies of Microsoft Excel, it offers Excel spreadsheet users an easy introduction to classical methods of optimization (Nenov and Fylstra 2003).

The computations in this study consist of two parts: optimal solutions at both deterministic and stochastic level, and the results comparisons. Maximum bare land value, optimal rotation, optimal thinning frequency, optimal thinning intensity, and timing of thinning and clearcutting at deterministic level are calculated using a 3.5% interest rate and three thinning points. For the effect of stochasticity which is pest outbreak in this study, it was modeled as random events that damage a part of the growing stock. And we assume the damaged trees have to be harvested with thinning with a 25% reduction in their stumpage volume and a doubling of the logging cost. These economic parameters were set subjectively as no data were available from applicable silvicultural conditions.

Noticeably, optimizing the management schedule means finding the optimal values for a set of decision variables (DV), i.e. the optimal values of decision variables for each thinning and final cutting (Minna 1996; Pukkala and Miina 1997, 1998). In addition, schedules with different number of thinnings are to be treated as separate optimization problems. The management regime was specified by the number of thinnings, and by the DVs. In this study, the DVs were chosen as follows:

For each thinning:

- Years (with 5-year accuracy) since previous thinning, or if it is the first thinning stand age when the thinning occurs.
- Remaining basal area.

For final cuttings:

- Years since the last thinning to the first regenerative cut.

In order to optimal management schedule, firstly the initial stand, timber prices, discounting rate were kept as constant, then an initial solution (a guess for the optimal combination of DVs) was first fed to the computation. By doing this, the value of the objective function with these values of DVs and the given set parameters (timber prices, unit costs, and discounting rate) was calculated. Based on the feedback from the simulation system, we made changes in the values of DVs, in an effort to improve the schedule, and then we calculated the objective function with the new DVs values again. The optimal management schedule for a given number of thinnings is eventually found, after repeating this search-process several times when a defined convergence criterion was met. The optimization was carried out for 0, 1, 2, 3, 4 and 5 thinnings to find the number of thinnings that maximized the objective variable. In addition, in order to get a better economic return, the limit for intensities of thinning for small and medium size trees were set as 40%, which was tested as effective for larch plantation in northeast China in previous research (Sun et al. 2005).

5 Results and Discussion

5.1 Deterministic Optimal Solutions at 3.5% Interest Rate

Table 9 shows the deterministic optimal solutions at 3.5% interest rate for different plots. The symbols in the tables are as follows: Dg is diameter at breast height in cm; S-trees (%) denotes the portion of small size tree removed; M-trees (%) denotes the portion of medium size tree removed; L-trees (%) denotes the portion of large size trees removed; Ro.dg denotes mean diameter at the end of rotation, in cm; M.A.I denotes mean annual increment in cubic meter per year; SI denotes the site index, which is the dominant height in meters at the index age (index age is 30 years for larch plantation in this study).

In this study, the criteria for grouping trees are based on their diameter at breast height. Thereby, tree volumes and stumpage values are computed by diameter class. Here, small size tree refer to tree with diameter ranging from 4 to 13 cm; medium size tree refer to tree with diameter ranging from 14 to 21 cm; large size tree refer to tree with diameter equals to or great than 22 cm. In addition, the computation of the amounts of sawlogs and pulpwood were also mainly based on the diameter classification. As Martin (2004) mentioned, in the logging of mixed forest stands, the better trees are usually used for sawlogs for lumber production, while the inferior trees and components are harvested for pulpwood production. Pulpwood usually derives from four types of woody materials in a mixed logging operation:

- Open-grown trees, that are heavily branched low on the trunk, and so make poor sawlogs.
- Dead or diseased trees.
- Tops cut from trees harvested for sawlogs (branches are rarely used since they contain little usable wood after the bark has been removed).

- Small trees, too small to harvest for sawlogs

Hereby, for the computation of the amounts of pulpwood in this study, small trees with diameter ranging from 4 to 13 cm, and dead or diseased trees (natural death or because of pest outbreak) were used as pulpwood; the computation of the amounts of sawlogs are based on the volume of medium size trees (diameter ranging from 14 to 21 cm) and large size trees (diameter equals to or great than 22 cm). This also corresponds to the Chinese national criteria for timber assortment and purpose (i.e. GB142-1995; GB /T 11717-2009).

The sample plots in this study were different in initial stand age, site fertility, initial stand density and geographic location. Besides, the prior management treatment may be various. Also, the successful application of prior silvicultural management may vary. However, the bare land values were calculated assuming no prior harvest revenues and constant establishment costs in this study.

Table 9. Deterministic optimal solution with 3.5% interest rate

Initial state	Dulaer 76	Dulaer 80-2	Yiershi 48	Yiershi 53	Yiershi 57	Yiershi 58	Yiershi 57 opposite-1	Yiershi 57 opposite-2	Yiershi 57 opposite-3
Biological age (yrs)	28	24	30	33	25	28	24	22	20
Age at breast height (yrs)	21	21	27	26	19	21	19	17	16
Elevation (m)	809	829	893	904	907	857	907	908	910
Site Index (SI, m)	11.2	12.9	15.8	11.8	8.5	8.5	10.9	10.5	11.0
Dg (cm)	12.9	10.9	14.1	13.8	10.5	12.9	12.8	14.2	13.0
Mean height (m)	10.9	10.9	16.0	11.9	7.8	8.3	9.8	9.0	9.0
Basal area (m2/ha)	30.0	18.5	39.1	37.3	19.4	34.5	29.3	32.5	28.0
Trees/ha	2150	1875	2050	2100	2025	2250	2025	2100	1975
1st thinning (yrs)	33	29	35	38	30	33	29	27	25
Intensity (%)	36.4%	31.3%	43.5%	44.0%	40.0%	49.1%	37.5%	30.2%	31.6%
S-trees (%)	40.0%	28.0%	40.0%	40.0%	40.0%	18.0%	40.0%	40.0%	40.0%
M-trees (%)	30.0%	26.0%	20.0%	20.0%	36.0%	54.0%	30.0%	30.0%	30.0%
L-trees (%)	100.0%	100.0%	92.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2nd thinning (yrs)	38	34	40	43	35	38	34	32	30
Intensity (%)	27.1%	26.8%	31.1%	32.1%	44.1%	41.1%	32.1%	34.9%	35.6%
S-trees (%)	10.9%	21.0%	40.0%	40.0%	40.0%	35.0%	36.0%	38.6%	29.0%
M-trees (%)	30.0%	30.0%	30.0%	30.0%	33.2%	38.0%	32.0%	36.0%	36.5%
L-trees (%)	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3rd thinning (yrs)	43	39		48	40	43	39	37	35
Intensity (%)	26.3%	23.0%		37.1%	41.1%	41.6%	32.3%	41.0%	37.1%
S-trees (%)	0.0%	0.0%		40.0%	40.0%	36.5%	46.0%	32.0%	21.0%
M-trees (%)	30.0%	30.0%		30.0%	32.0%	36.5%	26.8%	31.6%	36.0%
L-trees (%)	100.0%	100.0%		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
4th thinning (yrs)		44			45	48	44		
Intensity (%)		29.7%			41.4%	50.3%	32.7%		
S-trees (%)		0.0%			40.0%	40.0%	52.0%		
M-trees (%)		28.0%			38.0%	40.0%	23.0%		
L-trees (%)		100.0%			100.0%	100.0%	100.0%		
5th thinning (yrs)					50				
Intensity (%)					41.2%				
S-trees (%)					32.0%				
M-trees (%)					43.5%				
L-trees (%)					100.0%				
Rotation (yrs)	52	54	48	56	55	58	49	42	40
Ro.dg (cm)	16.7	16.1	15.8	15.9	15.5	16.8	16.6	17.5	16.4
M.A.I. (m3/year)	7.8	7.2	8.9	6.9	6.2	5.8	7.2	9.4	9.2
Bare land value (¥)	87047	77074	103582	81015	68512	76165	93044	121814	121172

The deterministic optimization results indicated that the bare land values were associated with stands of high basal area, tree diameters and height. From this outcome, it is easy to affirm that the development of basal area, diameter and height are the key factors affecting bare land value. Besides, site fertility is another important factor as fertile site plots have higher bare land value than infertile sites. For all the plots in this study, Yiershi 57 opposite-2, Yiershi 57 opposite-3 and Yiershi 48 produced the highest bare land values among all the plots.

Stands that had high mean annual increment (8.9 m^3/yr/ha in Yiershi 48, 9.4 m^3/yr/ha in Yiershi 57 opposite-2 and 9.2 m^3/yr/ha in Yiershi 57 opposite-3) gave the higher bare land value. Besides, compared with other three plots, Yiershi 57 opposite-3 was characterized by a younger age (20 yrs biological age) and a lower initial density (1975 trees/ha) but high growth of tree diameters, height, basal area and timber volume. These lead to a short optimal rotation and a high level of timber production. In addition, for plot Yiershi 48, only two thinnings were exerted, while the rotation age was relatively shorter (with a rotation of 48 years) than the plots with lower bare land value. Noticeably, Yiershi 57 opposite-2 and Yiershi 57 opposite-3 are the youngest plots among all the nine plots but gave the high bare land value. This result revealed the fast growth of basal area possible after thinning during the tree's growing period.

Many factors can affect rotation age, such as planting density and thinning frequency and intensity. In table 9, the proportion of trees removed in optimal thinnings for all plots at 3.5% interest rate were illustrated. The thinning type is defined with three variables that define thinning rate for minimum, middle and maximum diameters. Thinning rates for other diameters are interpolated. In this deterministic optimal solution, except plot Yiershi 58 that was mainly with the thinning type from above in the first thinning, other plots were typically thinned from both above and below in first thinning. This is partly because that the development of diameter of larger trees had already reached sawlog dimensions before the first thinning. In addition, for all the sample plots, the first thinning removed intermediate trees with 20% or higher thinning rate.

Thinning can increase the quality of the remaining stock, improve the value growth of the remaining trees and, also yield income before rotation-end (Klemperer 1996, p.242-243). In this study, the first thinning typically removed pulpwood from small size trees as well as sawlogs from large size trees, with the exception of plot Yiershi 58 where the development of diameters of some smallest trees have not already reached pulpwood or sawlog dimensions. Additionally, the higher density of Yiershi 58 also played as another important factor.

According to the solution of Table 9, we can get that the intensity of the first thinning was 30-45% in the majority of the plots. After the first thinning, the subsequent thinning removed trees mainly from above with light or medium thinning intensities. The purpose of subsequent thinning might be to keep the level of basal area high, and to reduce mortality. Meanwhile, thinning for large size trees was on a relatively heavy intensity level. That also corresponds to the practice in China for larch plantation as an economic plant. In addition, normally, higher fixed harvesting costs decrease the optimal number of thinning.

Clearcutting would happen around 40 to 60 years old based on various plots. Noticeably, mean diameters at the end of rotation (Ro.dg) for all plots in this deterministic case are about 16 to 17 cm, which is different compared with some other studies (e.g. Zhang 1986, Li 1987, Sun et al. 2001, Shi and Feng 2005). In those studies, rotation ages are longer and mean diameters at the end of rotation are at a bigger level which is usually over 20 cm. On the other hand, Sun et.al (2005) and Gao et al. (2009) reported similar results about mean diameters at the end of rotation (Ro.dg) in their research as in this study. The heavy intensity cutting for large size trees in previous thinnings, and the variance of the initial state and site quality might be key reasons for the difference of mean diameters at the end of rotation (Ro.dg). In fact, most plots in this study include a part of tree with smaller DBH than average in the initial state. In addition, the volume equations (i.e. equation 5.1 and 5.2) used in this study give the total stem volume of a sawlog or pulpwood tree, instead of the sawlog part of a tree. Therefore, we can get sawlog volume from already trees with relatively medium or small diameters (i.e. diameter less than 22 cm) at a tree age. That makes the practice of a heavy cutting of large size trees in thinnings reasonable.

5.2 Optimization under Catastrophic Events

The optimum thinning schedule above was derived for the deterministic case. In order to reveal the effect of catastrophic events, which is pest outbreak in this study, scenarios with different probabilities and intensity of catastrophes were applied. In addition, since the uncertainty of the risk, the thinning in this study didn't depend on catastrophes. So the thinning rate was kept constant as in the deterministic case. Hereby, 100 scenarios were exerted so as to get a better picture of the variability of the results since the smaller number of scenarios application may cause instability.

In addition, in even aged management, one key decision variable is the rotation age (Buongiorno and Gilless 2003, p330). To make good statistical statements regarding the effect of the rotation age, the same scenario approach was used. This means 100 replications of the simulation at different rotation ages were made, holding all parameters constant except for the string of random numbers (e.g. timing and intensity of catastrophes). The statistics, which are described in detail in the Appendix, represent the effects of pest outbreak on bare land value at different rotation ages. Here, Table 10 is the summary statistics of the computation. For each different rotation, they give the largest and smallest bare land value observed in 100 replications with different scenarios, the mean bare land value, the standard deviation of the bare land value, and the standard error of the mean. Also, the optimal solution for each plot in the deterministic case was added in order to make comparison. The optimal bare land value for both deterministic and stochastic cases were in bold characters.

Table 10. Summary statistics of calculating 100 scenarios of the bare land value under pest risk with different rotations (bare land value, unit: ¥ yuan/ha) and the optimal bare land value under deterministic situation.

(a) Dulaer 76

	Stochastic					Deterministic
Rotation (y)	**58**	**53**	**52**	**51**	**48**	**52**
Max	81335	86806	91714	92056	93300	
Min	52429	42574	48371	45935	49000	
Mean	67917	70096	71403	73602	**74189**	**87047**
SD	6081	8220	9678	10323	9526	
SE	608	822	968	1032	953	

(b) Dulaer 80-2

	Stochastic					Deterministic
Rotation (y)	**54**	**50**	**49**	**48**	**44**	**54**
Max	72741	73508	74006	75467	68290	
Min	37830	39956	40416	35308	33088	
Mean	57491	58922	58171	**60013**	55595	**77074**
SD	8301	7352	8670	7818	8208	
SE	830	735	867	782	821	

(c) Yiershi 48

	Stochastic					Deterministic
Rotation (y)	**55**	**49**	**48**	**45**	**40**	**48**
Max	101678	101860	98915	104308	91292	
Min	62913	47041	54452	60583	43789	
Mean	84923	81301	82780	**85628**	77030	**103582**
SD	8303	11996	9788	10300	14625	
SE	830	1200	979	1030	1462	

(d) Yiershi 53

	Stochastic					Deterministic
Rotation (y)	**58**	**56**	**53**	**48**	**43**	**56**
Max	76000	79259	74034	75063	75056	
Min	40817	35256	43462	35071	32896	
Mean	65034	64644	65245	**66274**	62367	**81015**
SD	7190	8182	7001	7864	12566	
SE	719	818	700	786	1257	

(e) Yiershi 57

	Stochastic					Deterministic
Rotation (y)	**55**	**52**	**50**	**48**	**45**	**55**
Max	61991	59506	59100	68487	56910	
Min	36822	34614	30383	32541	23175	
Mean	51987	50567	50238	**52798**	48585	**68512**
SD	5962	6124	6693	7652	7068	
SE	596	612	669	765	707	

(f) Yiershi 58

	Stochastic					Deterministic
Rotation (y)	**58**	**56**	**53**	**48**	**43**	**58**
Max	71039	67473	67642	66684	65554	
Min	39763	42794	41903	41899	31387	
Mean	59465	59582	**60322**	58221	56131	**76165**
SD	6685	6187	6009	6477	8835	
SE	668	619	601	648	884	

(f) Yiershi 57 opposite-1

	Stochastic					Deterministic
Rotation (y)	**54**	**51**	**49**	**44**	**39**	**49**
Max	87618	88667	90375	93036	83748	
Min	57121	48748	53631	51199	41978	
Mean	75199	75355	74971	**78116**	71162	**93044**
SD	6926	8573	8461	8083	11412	
SE	693	857	846	808	1141	

(g) Yiershi 57 opposite-2

	Stochastic					Deterministic
Rotation (y)	**52**	**47**	**42**	**40**	**37**	**42**
Max	115881	120976	115602	113129	110156	
Min	73293	71025	59386	59035	59153	
Mean	97360	97774	98379	**99331**	93206	**121814**
SD	8719	10702	12704	11793	15096	
SE	872	1070	1270	1179	1510	

(h) Yiershi 57 opposite-3

	Stochastic					Deterministic
Rotation (y)	**45**	**42**	**40**	**35**	**30**	**40**
Max	118560	113971	116149	120401	113481	
Min	58442	69655	66545	60733	36819	
Mean	97631	94707	94835	**100879**	93492	**121172**
SD	10589	12568	11904	12636	21806	
SE	1059	1257	1190	1264	2181	

Legends: Max = maximum bare land value, Min = minimum bare land value, Mean = mean bare land value, SD = standard deviation, SE = standard error of the mean.

Table 10 indicates that the mean values of bare land value from the stochastic simulation are about 14.8% to 25.6% lower than the deterministic simulation, which are corresponding to different plots. Based on the comparison with the optimal solution of deterministic case, we can easily find that the effect of catastrophe shortened the optimal rotation length while the thinning rate was kept as constant.

The results in Table 10 show that in these 100 replications of various scenarios for each plot, the bare land value ranged from a minimum value to a maximum value. For example, for plot Dulaer 76 at rotation age 48, the bare land value ranged from a minimum of ¥93300 yuan/ha to a maximum of ¥49000 yuan/ha. The mean bare land value was ¥74189 yuan/ha, with a standard error of ¥953 yuan/ha. The 95% confidence interval of the mean bare land value is: 74189 ± 2 ×953 = (¥73237/ha, ¥75142/ha). This 95% confidence interval doesn't contain the bare land value obtained by the deterministic simulation, ¥87047/ha. Thus, the mean results from the stochastic simulation are very different from those of the deterministic simulation.

In addition, what has been gained from the stochastic simulation is information about the possible variability of outcomes. While the law of averages may be relevant for owners who have many stands of this type such as the owner in this study, it may not be for owners of a single woodlot. For them, any one of the outcomes of the stochastic simulation is possible, and variability in outcomes will affect property values and influence managerial decisions.

5.3 Comparison of Chinese Forest Law and Previous Research Results

According to the updated management approach of forest harvesting (National Forestry Bureau 1987), a stand must reach a certain minimum age before it can be clearcut. For larch plantation, the requirement is: stand age$\geq$ 41 years . From this point of view, the optimal rotation period for plots Yiershi 57 opposite-3 is illegal at 3.5% interest rate. However, some earlier studies reported that the optimal rotation can be shorter than the recommendations. For example, Sun et.al (2005) claimed that the rotation of larch is 37-39 years with the first thinning at 25 years old. Gao et al. (2009) even got a more surprising result that the economic rotation of larch plantation is 13-18 years. Of course, this result was found based on a different discount rate, timber price and site location. In the present study, the rotation of Dahurian larch depends on various plots. The catastrophes decreased the bare land value of different plots. And given a constant thinning rate, the optimum rotation was also shortened under the risk of catastrophes.

6 Conclusions and Limitations

From this study, we can get some clear conclusions about the optimal stand management of Dahurian Larch under the risk of insect outbreak in Aershan area, Inner Mongolia, China. It was found that compared with the deterministic case, the optimal rotation age under stochastic simulation is shorter than the deterministic optimal solution, which means increasing risk of catastrophe shortens the optimum rotation considerably. Similar results had also been found in some previous research (e.g. Caulfield 1988, Valsta 1992b). Noticeably, thinning in this study didn't depend on catastrophes since the uncertainty of the risk. Also, numerical results in a risk-neutral case show that in the stochastic simulation, the optimal bare land value is about 14.8% to 25.6% lower than the deterministic simulation, which are corresponding to different plots.

This study was restricted by the availability of biological, geographical and economic data. Firstly, the roadside prices of sawlog and pulpwood were constant in this study. In practice, the market price fluctuates with demand, supply, and the elasticity of demand with respect to price, since it implies that as the volume harvested increases, the market supply amplifies, the price received by the owner declines. This suggests the necessity of considering the timber price fluctuation in the modeling. On the other hand, non-timber values such as stand diversity, carbon storage, also sometimes affect decision making. This may require further study as well. As a hot topic recently, the strong assumption was made that the forest used as an effective tool of store carbon and ease global warming. If the carbon storage was considered, the optimal solution would be different from the pure seeking of timber income. In contrast to the timber revenues which depend on periodic harvests, carbon sequestration in the forest depends on the amount of timber that is left standing. As in the carbon storage market, with a good price per unit of carbon stored, carbon storage could be treated similarly to timber production to arrive at a global measure of economic performance. Then what we have to do is to seek the best combination of timber production and carbon storage.

In addition, the application of individual-tree growth model was based on statistics of extensive field measurements. That means that the parameters used in the simulation models are based on measurements from present forests and forests with similar geographic and biological attributes in the same area. Hence, these values can be applied only within the domain of the data.

In this study, the stochasticity was introduced relying on deterministic predictions. However, it would be theoretically sound and produces more realistic predictions of actual tree growth. FOX et al. (2001) mentioned that benefits from incorporation of stochastic structure include valid statistical inference, improved estimation efficiency, and more realistic and theoretically sound prediction. It is proposed that individual-tree modeling methodologies need to characterize and include structured stochasticity in future research.

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Appendix. Statistics of calculating 100 scenarios of the bare land value under risk of pest outbreak with different rotations

REPLICATIONS (Bare Land Value) for Dulaer 76

Rotation (y)	**58**	**53**	**52**	**51**	**48**
1	63815	68289	72279	82475	54835
2	74757	63369	66066	87389	67538
3	50216	74629	70929	70956	79610
4	65352	56969	75062	55591	63178
5	57767	68036	80304	92056	84645
6	80033	70381	63914	62752	78829
7	73153	79219	81962	79950	81025
8	72773	70410	75216	84929	86225
9	73896	72153	81520	65496	85918
10	64657	73328	68528	56232	62021
11	67817	81679	88333	88384	66561
12	64431	77501	57419	83066	74061
13	80714	59623	63432	71578	59400
14	69058	69097	53093	75422	70699
15	63644	83347	55587	78303	75400
16	74558	61730	81471	79421	86089
17	71853	54541	60886	80796	86785
18	69504	76604	87227	61868	71570
19	73896	72133	80304	53377	63834
20	56533	66356	75616	80304	77149
21	58040	61980	62525	65821	70013
22	73142	63444	56591	59161	79698
23	73485	78779	79806	72337	84072
24	71549	69180	80304	57835	79943
25	72105	72408	80304	75147	67928
26	75719	73333	73395	77553	76912
27	61807	69430	73058	64781	84635
28	64792	65444	81844	67214	66243
29	73896	78991	63182	66647	79998
30	65385	77226	76831	64065	74384
31	59280	72463	55477	75532	67324
32	75318	65437	67492	80066	73607
33	66288	77226	68285	90581	71241
34	72924	76930	73333	69694	67850
35	64324	77226	80304	80671	69954
36	73896	59824	80304	80304	56344
37	72965	79684	67080	60178	79820
38	45061	64792	76140	83207	64663
39	66199	59463	61064	58759	58804
40	61600	70921	70401	79780	77286
41	60852	62360	72334	62997	84201
42	69173	71708	66644	84459	86506
43	66542	71835	80189	81902	91040
44	58139	86806	80304	85851	65434
45	71983	67911	80304	59820	68969
46	73354	72034	91084	74516	57305
47	62463	72196	67735	54819	93300
48	75418	42574	53570	89309	76540
49	69629	73558	62228	72685	63456
50	75802	77102	84018	84939	61787
51	65732	73616	70051	80304	83169
52	62631	77226	50264	80304	78180
53	66817	73283	63995	83217	71008
54	51916	67873	59624	63954	52026
55	59204	73572	64765	73844	81272
56	62886	80567	63648	80304	86049
57	62461	78473	75234	67765	81719
58	72791	67942	73566	68618	81272
59	73734	58794	72393	71630	76004
60	59737	72409	69413	75186	80575
61	68017	64220	48371	81547	81272
62	69636	65737	85854	86512	77446
63	58576	69752	68689	51808	72071
64	66533	62162	66699	80304	81272
65	76782	72138	56341	73031	84735
66	60628	77226	66459	79927	74363
67	72573	59603	74493	74932	74268
68	65440	77226	84071	79045	76223
69	62828	76852	80304	79824	84663
70	63051	73716	75772	66571	71953
71	72971	72597	79731	75195	68100
72	71125	63354	72627	69885	72193
73	70107	61409	69748	67693	65461
74	66901	70128	81638	70791	82437
75	53012	48787	75620	57741	49000
76	73584	77226	78064	80304	57354
77	71740	74256	75914	77151	76153
78	63153	81161	91714	77457	90110
79	63165	67158	62053	81055	70252
80	67644	71642	80304	77240	63579
81	74030	59685	76217	45935	76352
82	55933	78265	72305	80304	83597
83	55087	69945	54219	80213	63970
84	66795	71704	70402	67502	79851
85	78053	77464	50822	68523	76659
86	72993	79600	74591	56726	68034
87	72674	63397	78992	80616	76821
88	61620	51235	70265	91566	70986
89	73896	53664	72268	47925	79976
90	77899	77917	80470	87357	88413
91	62946	77226	63942	80078	86975
92	74843	77226	75269	78337	76345
93	48369	49119	78970	79581	82211
94	72344	82135	73213	59260	83752
95	63968	66281	53665	68325	78005
96	73896	72787	65806	79293	54503
97	70316	71553	63585	62703	71638
98	71079	62841	61069	80304	74145
99	71382	68579	81240	80304	69063
100	73896	77226	80304	81236	58840

Rotation (y)	**58**	**53**	**52**	**51**	**48**
Max	81335	86806	91714	92056	93300
Min	52429	42574	48371	45935	49000
Mean	67917	70096	71403	73602	**74189**
SD	6081	8220	9678	10323	9526
SE	608	822	968	1032	953

REPLICATIONS (Bare Land Value) for Dulaer 80-2

Rotation (y)	**54**	**50**	**49**	**48**	**44**
1	60467	63585	66144	47164	63659
2	57970	66138	46669	75467	59378
3	60158	45351	60020	68938	52848
4	60417	50984	72229	48115	63614
5	58216	62117	61748	68938	62238
6	48389	58555	66375	55798	40664
7	66878	61444	60880	62747	57871
8	49252	51019	53465	68938	38557
9	64370	52987	61756	60097	49447
10	63854	58088	64637	60683	53828
11	71942	60171	58805	63389	65344
12	43271	66138	64950	51528	64928
13	51816	42254	53759	63440	43493
14	52450	62249	61742	71601	59301
15	63945	55614	56735	68938	65344
16	52177	63465	65772	62545	51598
17	45963	61288	48936	55603	38474
18	70589	66138	61350	54280	40873
19	39063	62585	66375	67943	56333
20	66931	63319	54803	68330	41909
21	61782	65331	46587	55125	47873
22	42738	66138	40846	64709	58922
23	60119	66138	47247	63147	65344
24	67336	59268	59990	52033	58461
25	63737	52513	59032	53372	60574
26	65491	46279	63564	64434	44870
27	50767	60307	61762	53410	49387
28	56876	50862	51372	44931	51245
29	60137	61549	62903	50032	60109
30	50610	54971	55255	64167	65344
31	58620	46252	45372	68938	58799
32	53888	58855	42913	75401	60606
33	44678	63050	42856	60115	33088
34	63534	62693	66375	59717	59987
35	41800	44741	54263	62835	63012
36	50733	49138	47705	62036	60467
37	43653	56640	54449	66005	52050
38	49633	59555	52641	55641	62672
39	59736	52689	63764	35308	60855
40	49122	73508	62562	60842	54461
41	54174	63864	40416	66623	65344
42	42452	56456	72058	66576	65344
43	65491	60972	60936	45676	65081
44	56690	59336	57673	52224	65344
45	72741	58911	50123	59908	56280
46	61806	66693	56862	61633	40373
47	62837	64755	66375	67934	63274
48	51644	62295	55461	60406	46108
49	68386	63381	63943	61924	61548
50	46046	64600	49933	68938	57980
51	55642	64934	42484	64632	53501
52	63570	44490	48073	57473	61834
53	48292	45803	71987	44929	56677
54	55306	65053	47331	57030	65344
55	65491	66138	59706	48803	47415
56	59656	60741	65907	55657	55258
57	59992	53172	67407	54575	41363
58	63690	50356	68886	71454	55541
59	49030	65203	66765	64291	57136
60	50629	62141	53322	66587	61735
61	61512	39956	50767	61801	58216
62	62054	60768	53725	72246	65344
63	49559	51836	59265	61701	42956
64	60691	66138	57207	60749	57753
65	53293	61800	63595	54265	62425
66	39114	44589	59839	65071	49235
67	71325	61516	48977	67924	44107
68	37830	65975	56754	58223	62704
69	58860	65067	51126	61844	62846
70	47820	52720	57930	72952	55425
71	61406	40301	41069	61459	65344
72	72598	66138	74006	66390	52811
73	65491	69398	43132	61889	54275
74	63857	60285	66375	56431	51779
75	61134	66138	42546	52896	55770
76	65491	61396	66375	55224	56933
77	52735	66138	45051	53144	47428
78	46226	64558	62846	54920	50286
79	61980	58280	65299	69319	59320
80	52918	72733	66375	48771	65344
81	52937	71549	61840	68938	59000
82	51650	53457	66375	66840	43747
83	50621	60254	57796	64170	47122
84	63737	54048	66545	68938	68290
85	64394	59310	73567	66230	60791
86	61737	65470	66080	53855	42131
87	71259	50956	72545	68938	59630
88	65491	60703	68584	63570	58638
89	57101	58199	42820	64761	65344
90	58409	57447	55749	48046	54504
91	62775	59524	56903	55848	45602
92	59476	54205	65916	47268	50594
93	53036	60013	66113	59704	61900
94	68918	63318	58276	49023	46840
95	64249	66430	59771	60376	63529
96	63869	55829	63142	49515	42139
97	63857	58574	62540	51571	65344
98	60382	54745	67961	56253	47120
99	61657	66101	54197	56539	56855
100	50983	43099	43908	49693	59793

Rotation (y)	**54**	**50**	**49**	**48**	**44**
Max	72741	73508	74006	75467	68290
Min	37830	39956	40416	35308	33088
Mean	57491	58922	58171	**60013**	55595
SD	8301	7352	8670	7818	8208
SE	830	735	867	782	821

REPLICATIONS (Bare Land Value) for Yiershi 48

Rotation (y)	**55**	**49**	**48**	**45**	**40**
1	84460	78760	97376	84587	78008
2	91950	62131	84218	87377	91292
3	71349	76340	83856	88998	91292
4	88145	92440	81773	98533	53996
5	90188	53926	71242	95693	91292
6	63183	92440	73834	70061	87223
7	93002	80211	90874	75593	91292
8	80102	95405	74045	80166	51931
9	87343	92440	81732	89945	47352
10	70538	85258	55797	66639	55989
11	86071	86130	88489	86285	91292
12	88982	70121	66121	81375	91292
13	91549	86531	85675	104308	83400
14	91229	86576	86366	85810	53133
15	89151	68254	85060	88595	60854
16	84685	76800	93224	89423	91292
17	92136	47041	85945	70879	87726
18	74755	72594	88049	72918	91292
19	89777	86117	80440	95693	57744
20	91834	92563	93224	82963	65499
21	88129	86470	54452	81039	60220
22	80792	87613	79410	70892	53697
23	87434	92440	67701	80361	68348
24	96264	101860	91550	71597	70122
25	88947	83096	69607	71422	91292
26	87968	86687	84192	104097	76156
27	91834	78353	93224	95693	66033
28	80459	77699	80537	100225	91292
29	90323	92440	93224	68361	91292
30	71198	65622	70221	92040	81115
31	82322	82978	86204	95693	91292
32	63841	92440	71039	73544	73302
33	62913	83485	79808	86329	82082
34	91834	78247	68908	86822	91292
35	77295	101217	67154	72230	91292
36	88758	68712	71974	79745	71656
37	86874	92060	87360	69985	91292
38	85660	69776	93224	87420	82792
39	88095	92440	83534	81411	72657
40	87036	90507	87672	90946	91292
41	76180	84698	90856	84934	54581
42	89905	70780	93224	82426	57368
43	83243	76757	86758	95693	91292
44	65619	71471	78059	88871	74801
45	73188	63379	74181	90674	57643
46	72033	92440	93224	68316	46352
47	71346	76490	88598	99554	60676
48	91834	88325	86836	103346	74984
49	91834	92440	76644	84613	54303
50	87192	86758	69119	82171	91292
51	81912	87956	93537	86287	91292
52	92317	82677	93224	91255	75291
53	87950	84362	89012	92365	68781
54	86451	77867	77842	65498	62054
55	97349	96887	66447	88859	91292
56	89886	88963	84058	95693	76793
57	94581	65499	80913	86526	91292
58	91575	83919	93224	90822	68734
59	81909	59067	66760	102681	50885
60	77089	82008	93224	90608	91292
61	85518	82087	93224	86707	91292
62	85054	67255	93224	65156	76902
63	90345	82755	91555	80444	69667
64	88224	84238	93224	82678	91292
65	101678	86483	67924	60583	60093
66	91834	81511	82139	70390	76010
67	92976	80067	93659	90016	91292
68	87314	87496	75078	74685	60434
69	73621	59179	94670	95693	91292
70	81563	88491	78408	91369	88419
71	85590	79803	93224	91525	91292
72	90307	61963	91656	91923	85319
73	91199	77872	84335	90359	91292
74	75464	81662	81911	91340	91292
75	95328	97967	78663	99490	80738
76	83839	92440	78113	85524	67498
77	86189	100046	96583	88729	77584
78	79630	87778	84975	85490	83533
79	84515	84747	93224	82069	69949
80	91279	101507	73784	77382	91292
81	81730	86283	73314	85636	91292
82	89969	87844	76339	75301	91292
83	66042	75834	75301	95693	90086
84	91834	92440	76879	85357	60547
85	91387	85425	71940	96936	64787
86	86004	100981	93224	95693	67033
87	79775	92440	74305	95693	91292
88	91199	83406	76828	95693	91292
89	87890	54915	67444	90623	91292
90	85136	68497	90989	90446	67924
91	69770	71134	90068	90174	91292
92	86224	66393	87274	96479	65353
93	91870	97108	98915	95693	84425
94	87109	71127	94698	95693	46522
95	87598	49658	93224	88197	80593
96	90249	92440	79225	70397	91292
97	65173	87137	80018	82126	43789
98	82953	70323	90065	62166	68841
99	97012	71048	93224	68645	73616
100	80160	61398	71105	97773	91292

Rotation (y)	**55**	**49**	**48**	**45**	**40**
Max	101678	101860	98915	104308	91292
Min	62913	47041	54452	60583	43789
Mean	84923	81301	82780	85628	**77030**
SD	8303	11996	9788	10300	14625
SE	830	1200	979	1030	1462

REPLICATIONS (Bare Land Value) for Yiershi 53

Rotation (y)	**58**	**56**	**53**	**48**	**43**
1	65693	59970	68179	35071	51187
2	71665	68714	50608	67580	75056
3	72832	71686	60644	61543	42394
4	51337	64688	69628	73198	75056
5	66507	69732	66275	75063	75056
6	72832	68315	67463	60703	58561
7	57274	49487	72052	65156	64538
8	54478	72392	70707	60154	75056
9	69393	51242	69132	56319	36348
10	66787	65272	68223	75063	53814
11	73069	70229	61679	61440	75056
12	72832	72401	65368	61753	75056
13	69839	74897	63090	45646	64998
14	65597	63417	72276	47647	48442
15	72832	54103	57515	69515	64318
16	69801	58926	52105	63800	44387
17	70424	65347	50777	55439	75056
18	63757	62189	56171	75063	42480
19	68625	49661	72276	60394	75056
20	53302	69288	63820	75063	59622
21	65042	48044	70668	68649	63391
22	61410	49882	72276	69546	75056
23	67377	60083	68074	51954	75056
24	51027	70060	69381	75063	64925
25	65172	59805	60931	68421	58233
26	73503	64296	64396	66535	54206
27	69961	64406	63198	63606	60091
28	57798	71010	65033	71529	75056
29	59220	47976	55255	66078	60284
30	54122	66352	57075	56284	57470
31	62831	54547	63786	72825	60858
32	67629	61060	70428	70883	75056
33	55851	71369	71259	75063	44332
34	65859	75181	51200	67123	60570
35	53154	61667	57019	59577	64677
36	67118	52111	62991	63859	60896
37	72832	51718	53740	54720	50138
38	67454	70474	72276	73319	46483
39	62930	69372	64117	63915	58593
40	46561	52612	72276	75063	73020
41	69954	66692	67277	75063	46526
42	63912	68946	59002	69936	75056
43	60427	49751	66992	66948	47160
44	70897	59334	65646	53281	75056
45	72287	70323	52225	75063	50965
46	68083	70841	72276	75063	57583
47	60665	62149	61804	59383	75056
48	52163	79259	70634	75063	75056
49	74790	55692	65145	63739	37516
50	65065	71472	67851	61685	68825
51	72832	69157	72276	64099	43492
52	68473	71929	58409	66763	75056
53	67245	59475	58565	75063	61017
54	67698	35256	62712	75063	75056
55	57161	72914	68342	63197	75056
56	68663	59669	72383	71237	75056
57	70925	66733	59941	73617	67801
58	74117	73658	72274	54617	51179
59	68531	60529	71174	73607	75056
60	64664	72049	72276	75063	75056
61	67854	67772	54948	63541	60112
62	67804	62846	70654	68815	48679
63	60408	69450	72276	42739	75056
64	55655	68021	70278	69849	48724
65	48884	61777	58634	74292	46924
66	71136	75083	61640	66388	75056
67	66482	63681	54561	73388	66938
68	62757	69772	60360	65173	32896
69	71168	72122	66805	59408	67562
70	72832	64703	55443	67009	72528
71	61178	75046	69739	71547	67885
72	62261	70226	50883	63191	40462
73	70928	72129	72276	57235	75056
74	68042	69145	64129	65401	52388
75	40817	51339	67727	70858	50429
76	66297	65757	43462	75063	75056
77	68810	65604	72276	72932	44850
78	64757	72522	66631	75063	51341
79	69459	72380	72026	64401	52124
80	65217	47297	72049	63962	75056
81	59833	57181	72276	68305	75056
82	69717	68587	71687	75063	42658
83	64265	71003	72276	67014	64997
84	66388	72914	72276	65232	75056
85	61134	75130	73230	75063	75056
86	76000	64140	59182	67407	75056
87	74283	62641	69231	69145	57065
88	72832	56711	55420	64413	49460
89	67668	67619	72928	61848	75056
90	68805	60678	62580	64582	75056
91	75242	72914	69506	72647	58685
92	52234	64895	74034	70879	56794
93	72725	72914	71797	64905	51610
94	56847	67202	62058	64990	75056
95	58520	67506	63211	71744	64258
96	66124	72837	72029	64695	75056
97	68645	55857	72276	75063	75056
98	62435	72914	56569	60961	75056
99	63081	64756	72276	55162	75056
100	49570	59533	72276	70909	33841

Rotation (y)	**58**	**56**	**53**	**48**	**43**
Max	76000	79259	74034	75063	75056
Min	40817	35256	43462	35071	32896
Mean	65034	64644	65245	**66274**	62367
SD	7190	8182	7001	7864	12566
SE	719	818	700	786	1257

REPLICATIONS (Bare Land Value) for Yiershi 57

Rotation (y)					
	55	**52**	**50**	**48**	**45**
1	61661	59506	53802	49925	39869
2	45774	54160	44415	68196	56350
3	50601	39648	59100	55872	48114
4	52252	53783	48048	53942	33160
5	54378	49901	55084	56032	50974
6	39276	55355	39240	49921	42105
7	48877	59478	45731	49310	41326
8	57012	49265	42033	58752	56910
9	52111	48380	53540	59272	43561
10	48831	59271	42672	52662	56910
11	58451	55749	59100	62708	56910
12	58423	51712	45030	45532	45716
13	60401	53643	40620	50127	53665
14	46928	58521	45201	50294	23175
15	49422	59478	47411	60307	45545
16	55613	45833	42562	56048	50707
17	52901	37409	59100	47635	56910
18	49129	53970	48190	47018	48343
19	36822	52397	44625	38842	44535
20	42345	52677	51633	47706	38226
21	53902	48124	53574	54749	56910
22	51414	51209	51867	51538	38846
23	53756	54675	54972	54735	41318
24	55265	34614	31280	58003	50446
25	50649	53818	58750	60307	46855
26	56614	59478	38693	49389	49085
27	50853	43360	45665	54672	56910
28	49501	47360	40403	58245	44164
29	61661	46687	53089	50901	53968
30	57878	40584	44773	53664	50080
31	54276	57411	59100	42422	32357
32	48243	56484	47118	45598	42365
33	48914	48769	52197	53814	50371
34	42196	54047	55114	32541	52141
35	47306	41375	59100	42848	52319
36	50806	59478	47774	55298	51515
37	48460	53851	50351	41809	54256
38	55966	54780	49858	52314	49655
39	50629	57042	57627	55264	46870
40	43433	41229	51795	53124	44884
41	52076	47714	59100	60307	50378
42	60797	55271	48241	34035	56910
43	49306	46361	51887	32758	45270
44	52756	51405	59100	52823	45839
45	59372	42205	47762	51933	36191
46	55607	42769	47676	52079	45538
47	56643	48067	43182	49653	56910
48	51113	37586	41570	51626	47102
49	56044	54543	49584	53396	54869
50	40875	59478	56692	57023	31702
51	55817	48323	48837	60307	39804
52	52832	54543	46631	54316	56910
53	47848	52520	56950	52917	42626
54	43325	49278	49605	56948	46565
55	59425	46375	54073	57060	50229
56	61747	48010	53601	55756	48988
57	48507	45695	51936	54650	49522
58	51280	51509	57191	51541	51466
59	52426	56975	46151	62076	54171
60	52014	50371	33117	47185	56910
61	56547	49453	49333	55945	44954
62	54361	59478	48713	67582	53236
63	57788	49704	52601	59629	51504
64	49441	56319	59100	53031	56910
65	46094	38531	43783	51372	54292
66	57328	44275	49335	60307	56910
67	61661	53660	55215	46382	52952
68	49767	54426	47855	38258	37205
69	46263	56020	56930	45206	45599
70	49951	51889	46276	57788	38925
71	57487	39313	46975	60307	40809
72	56640	48466	57277	56312	48306
73	58036	44055	50784	50042	56606
74	61991	46681	54945	53235	42561
75	53220	48859	54327	61892	53737
76	56441	46447	56976	60643	46440
77	51959	43578	59100	65261	48422
78	53837	55533	50173	57611	46891
79	61661	47032	57838	59956	56910
80	43145	52727	43809	53467	56910
81	54445	55702	56890	45257	53280
82	58853	54792	55209	68487	50372
83	44096	54079	54743	38270	56910
84	48118	50258	47016	53525	36928
85	43411	37208	47882	46669	47432
86	61154	56586	54274	48369	52092
87	57742	48392	59100	39567	52119
88	41941	59478	44132	39186	56910
89	45910	53358	38788	44705	38020
90	58737	49762	55847	53950	56910
91	57551	49103	30383	49761	56910
92	52941	55399	41446	54981	56910
93	53451	58135	50449	58331	46637
94	40133	56258	59100	60307	56910
95	55756	54769	59100	35543	45994
96	39660	39719	50852	59261	49257
97	43039	51236	54247	60307	39609
98	49823	40235	51639	68071	51364
99	45329	49564	39120	60307	54070
100	50281	52694	59100	50960	43562

Rotation (y)	**55**	**52**	**50**	**48**	**45**
Max	61991	59506	59100	68487	56910
Min	36822	34614	30383	32541	23175
Mean	51987	50567	50238	**52798**	48585
SD	5962	6124	6693	7652	7068
SE	596	612	669	765	707

REPLICATIONS (Bare Land Value) for Yiershi 58

Rotation (y)

	58	**56**	**53**	**48**	**43**
1	59615	63669	62723	63981	57006
2	64794	62771	59800	55060	50799
3	60716	57654	66127	56101	65554
4	68549	64856	62853	45657	64135
5	56275	58004	62590	43976	60336
6	58351	65663	62581	66442	42945
7	64912	62052	60464	57569	59311
8	61722	65030	67633	58750	59766
9	67008	64185	63621	47365	46515
10	53045	48073	55022	59276	58646
11	53245	52042	61610	66442	65554
12	61873	67415	56741	64198	54931
13	61807	56342	56416	49469	65554
14	60802	56820	66691	52721	47674
15	57770	61896	59028	58583	31895
16	58424	64752	41903	62572	54417
17	49632	62529	65272	61759	48342
18	52108	67415	66744	55490	65554
19	70887	67415	60240	66442	63965
20	49721	67415	63716	66442	37149
21	65704	63627	65071	66442	65554
22	51973	54856	57669	45205	65554
23	63901	59374	62211	66442	61361
24	55450	66528	65547	51529	49795
25	49795	66406	63354	66442	65554
26	51235	65422	58910	57464	65554
27	54980	49222	61943	58722	37975
28	61252	49358	67633	58413	54594
29	68979	61118	61444	52252	65554
30	56050	59770	55557	59708	64282
31	53917	62327	60165	58739	65554
32	54745	65010	52927	41899	49818
33	71039	63819	58409	61809	31387
34	54906	42794	62048	64010	42433
35	56555	48575	66492	59510	57461
36	55420	58892	61202	66442	60625
37	66888	60042	64751	62761	51379
38	53333	61606	63215	60915	57947
39	63572	54450	63208	54809	64898
40	50071	61824	55862	46342	62991
41	39763	65497	62212	66684	43731
42	45925	60604	56505	63047	41710
43	65261	58756	63171	60578	64115
44	64894	63635	61684	66442	65554
45	67593	64848	67633	62892	58602
46	58238	48378	48484	65467	65554
47	57510	63466	55708	58866	52777
48	68549	50885	44785	66442	63296
49	62161	67415	62742	62096	49029
50	68450	65494	53602	45454	53627
51	55894	52877	56994	66442	65554
52	52229	63930	54357	58845	57477
53	62219	65543	66323	48549	65554
54	60827	50854	56494	58210	65554
55	49303	58073	47990	53203	62179
56	52898	60519	55530	54558	43096
57	65250	50093	64019	53858	51980
58	68549	50495	62627	54791	49461
59	66938	67415	54242	52481	52453
60	47099	59560	48068	66442	50449
61	68549	58668	61979	54802	63133
62	54218	62556	63275	55532	56359
63	63667	44020	60601	58703	65554
64	67974	56482	56703	66442	61826
65	63802	65150	54324	51040	57996
66	59355	57225	62811	61978	55805
67	59331	56918	44861	53248	57432
68	55154	51677	66715	61093	42303
69	66358	59609	64191	50753	52439
70	64425	63587	63427	46185	48391
71	43629	57569	58995	63601	62363
72	66449	54517	61262	47077	64106
73	68549	64807	64216	52844	65554
74	68549	67415	64363	63322	54032
75	58767	45669	51077	65178	65554
76	54129	50788	58556	63949	65554
77	54338	60478	58060	51864	47679
78	58486	67415	64366	59737	45020
79	67010	65893	65211	62256	45032
80	64772	60931	58101	66442	50382
81	58651	52739	67633	65212	64683
82	55339	67415	67642	53204	53731
83	65378	67473	61023	60393	64816
84	61716	50803	67633	62741	47034
85	53520	54487	50667	49707	57375
86	62768	64523	66344	56216	60483
87	50032	57802	66439	49722	62133
88	58586	54862	63265	53330	42527
89	66161	58092	65887	61348	51374
90	50259	53229	67633	66442	65554
91	52259	60756	67210	56030	53122
92	67638	58400	62555	62227	65554
93	64758	62214	42892	62505	52106
94	61172	57668	62964	60829	44077
95	62785	53690	67633	66442	45317
96	56242	56476	51742	54118	65554
97	58841	65038	58047	57371	61790
98	66398	56984	50004	54917	65554
99	58974	67415	62433	51798	43667
100	56907	67415	66892	57995	58016

Rotation (y)	**58**	**56**	**53**	**48**	**43**
Max	71039	67473	67642	66684	65554
Min	39763	42794	41903	41899	31387
Mean	59465	59582	**60322**	58221	56131
SD	6685	6187	6009	6477	8835
SE	668	619	601	648	884

REPLICATIONS (Bare Land Value) for Yiershi 57 opposite-1

Rotation (y)	**54**	**51**	**49**	**44**	**39**
1	83950	59730	86439	64690	64487
2	73604	72729	69355	86948	83748
3	73478	85203	81022	73434	48339
4	76553	63382	78516	83197	70155
5	65299	70435	60084	66590	74552
6	75383	70023	69569	79416	62599
7	65675	81323	75720	80218	79499
8	66070	70102	80267	70954	77199
9	66216	65956	83739	78685	41978
10	77503	82651	84901	74344	59336
11	74717	71694	62475	87915	73365
12	79737	74407	83416	73657	66610
13	63463	79743	71030	71865	83748
14	76472	84055	70023	75214	69299
15	65641	88418	73860	87373	78111
16	64185	81378	84485	71350	64770
17	87618	82977	71561	87474	79519
18	66892	76872	72369	83987	83748
19	74345	85512	78343	78495	57301
20	80264	84338	82565	73766	65636
21	82465	71533	89406	87474	83748
22	68392	87520	54970	93036	46769
23	75420	84441	83739	74363	54027
24	72022	84338	85729	77379	83748
25	76008	78310	77278	56689	62239
26	60909	70109	90375	79286	80629
27	82593	79776	76635	80655	83748
28	78943	85172	77008	78486	83748
29	64518	84338	68484	81320	71494
30	79240	84306	71862	80320	83748
31	73381	74055	81369	66010	77032
32	78621	78298	53631	68314	83748
33	77255	56701	73259	79923	75985
34	68650	66547	89375	82912	72377
35	71686	82804	83739	63053	43939
36	67589	70934	72452	88194	83748
37	72623	79728	63504	79453	59945
38	80517	60766	85941	81657	57277
39	83051	78412	78993	51199	59189
40	83654	81211	77290	90194	70462
41	78261	87301	63060	75009	83748
42	75575	58175	54083	88614	83748
43	76600	86310	76306	77988	72389
44	70972	76510	76510	70047	76332
45	73134	64869	83265	78443	57895
46	83654	73377	85411	75263	83748
47	67794	75403	78806	88993	67911
48	66481	85372	61185	79651	70635
49	87405	66854	68762	64529	63791
50	79269	75837	73200	81356	83748
51	84242	48748	62168	87474	68573
52	82612	71131	81534	80987	71890
53	73351	84058	63838	79820	73532
54	76246	77542	80937	81783	83748
55	76914	81662	88129	79934	83748
56	79389	69729	78159	81799	81468
57	76064	66715	81120	74522	64550
58	72686	65430	69291	66181	77150
59	83089	87326	66196	60178	83748
60	82116	72000	68189	78683	83748
61	81075	73271	67638	75259	80987
62	76623	67385	68100	82039	47134
63	83956	73566	73426	87474	76746
64	77923	59569	81081	77006	83748
65	61018	81530	64606	88131	77233
66	68183	60718	74888	72490	44203
67	81081	84338	72576	87474	51626
68	79180	82557	85066	81651	67693
69	77367	79202	76503	78085	81098
70	66791	77395	73577	62474	75722
71	75379	73721	78978	76189	61790
72	67160	74829	70580	81732	76112
73	76920	68572	83739	69556	73149
74	85912	78434	62755	86132	75375
75	63533	84338	72969	72720	67346
76	71065	73525	72908	86868	65871
77	76182	57968	76920	77705	76805
78	80371	71883	65105	74942	74741
79	76243	71473	63211	76753	79062
80	64033	76023	69530	65313	67430
81	77344	75642	82038	70596	50006
82	83654	69621	69225	72048	72258
83	57897	88284	87091	77876	66953
84	79343	74892	80624	86100	76256
85	57121	80286	64934	87474	83748
86	77969	65964	82308	86407	60121
87	81668	70399	83739	84498	60498
88	85718	70325	80314	76737	63591
89	77010	80876	63147	79575	80260
90	84354	80683	78912	91599	83748
91	80380	88667	70802	81310	51903
92	73222	72370	67788	80593	75646
93	70078	74288	68833	87474	45146
94	83654	84874	75958	86547	83748
95	78931	86851	89413	71492	77094
96	74050	62827	78108	79765	83748
97	80002	84338	79042	86338	65425
98	75091	79181	83739	86886	72862
99	70036	65125	75040	66411	68184
100	81897	65083	66990	71170	73470

Rotation (y)	**54**	**51**	**49**	**44**	**39**
Max	87618	88667	90375	93036	83748
Min	57121	48748	53631	51199	41978
Mean	75199	75355	74971	**78116**	71162
SD	6926	8573	8461	8083	11412
SE	693	857	846	808	1141

REPLICATIONS (Bare Land Value) for Yiershi 57 opposite-2

Rotation (y)	**52**	**47**	**42**	**40**	**37**
1	107061	109906	89907	112465	99510
2	81784	85468	91580	111125	93156
3	108468	100640	106293	99077	69395
4	101758	96536	101845	101980	92064
5	89129	97962	102233	90836	91891
6	90866	100610	112533	111689	90256
7	90428	120976	105743	79131	107779
8	86443	83290	93026	99267	109811
9	109561	90988	95053	113072	110156
10	100147	101003	103530	90542	106327
11	87769	103844	73151	113129	110156
12	99972	95121	70708	90950	103078
13	94786	97918	104399	78949	83474
14	87480	109543	105334	101947	68984
15	99420	90339	98771	111125	79353
16	99468	82710	109633	111125	65632
17	90966	101766	74088	105480	94666
18	102430	103879	95629	111125	110156
19	97404	111305	115602	105135	107648
20	103740	108900	106307	112805	107472
21	91207	99383	109633	104523	99867
22	96738	102687	102286	94631	78143
23	103790	109806	88380	111125	104042
24	106004	94546	108967	87683	90027
25	86969	104537	94778	94979	110156
26	105688	108988	113160	104131	61286
27	96520	103570	109633	82561	94392
28	94312	98386	99453	111125	72643
29	100300	80537	61056	111125	110156
30	87066	112024	93379	91491	65126
31	104141	96705	109633	105102	91184
32	109561	90048	96186	111125	110156
33	108838	109560	109633	101375	110156
34	80572	100918	70971	111125	89205
35	94676	104130	100175	89449	81942
36	110061	87878	67221	111125	110156
37	89066	94344	95688	100097	110156
38	83978	102617	114834	111125	110156
39	91754	91609	109633	111125	88540
40	108636	109935	90351	104414	102760
41	100768	95953	87783	105659	99985
42	89888	110939	100724	99247	83363
43	96898	104970	105561	72858	68853
44	109830	109560	94494	97732	97918
45	81186	95975	100952	99037	110156
46	97656	82685	103449	111125	89976
47	96396	86646	109633	86493	84824
48	98821	91863	105162	111125	110156
49	96390	109560	109633	97142	99013
50	93944	82594	103830	96999	96362
51	102190	78051	59386	106686	110156
52	92388	116296	91928	97918	84339
53	109561	100664	109633	111125	95868
54	110422	113951	92996	93486	90506
55	102233	88668	101186	102171	80680
56	99848	109560	70063	112366	94392
57	108675	91888	87227	110639	91087
58	82068	94688	99437	82411	64641
59	98854	86671	109633	84278	71203
60	101679	93943	108955	102482	110156
61	97412	94322	90614	112163	94085
62	93152	106750	78564	111125	91055
63	103842	93028	109633	91590	110156
64	94206	99871	76380	109990	69257
65	73293	95142	107709	111125	77769
66	95550	73791	103557	85378	102665
67	97311	94121	109633	98851	82980
68	103759	115109	100248	94634	93004
69	78355	104331	97956	73912	83520
70	81463	106609	93147	86521	59153
71	104036	104523	82010	111125	95638
72	106381	76318	109633	110924	90512
73	100903	92769	101273	97540	104101
74	102517	86644	109633	105625	110156
75	95145	93814	111092	80471	110156
76	100774	100808	89237	106709	103638
77	115881	96067	106332	107711	101770
78	88269	91200	104860	59035	103690
79	91323	119685	102710	111125	60184
80	87172	106743	93673	100263	95682
81	89845	109560	112415	102981	63804
82	100018	109560	101053	92100	75627
83	110369	102731	94937	89743	110156
84	94351	86905	89049	90895	110156
85	100617	107278	109633	111125	68462
86	100932	95299	109633	75079	59789
87	100556	90014	114149	99504	77267
88	83134	76830	109633	81438	100064
89	104150	104278	108565	92031	99246
90	107077	71025	86515	94746	101354
91	87729	99125	74305	68266	85044
92	109561	88924	96193	105056	110156
93	100284	71065	111938	99686	105135
94	98077	97847	89586	97828	105748
95	84034	78951	104921	103389	110156
96	96864	95929	80800	84553	101372
97	95311	104991	102933	103699	102107
98	112302	99880	95187	87975	97910
99	97430	97575	106820	111125	92002
100	103987	97962	109633	94677	81022

Rotation (y)	**52**	**47**	**42**	**40**	**37**
Max	115881	120976	115602	113129	110156
Min	73293	71025	59386	59035	59153
Mean	97360	97774	98379	**99331**	93206
SD	8719	10702	12704	11793	15096
SE	872	1070	1270	1179	1510

REPLICATIONS (Bare Land Value) for Yiershi 57 opposite-3

	Rotation (y)				
	45	**42**	**40**	**35**	**30**
1	94600	89660	98107	116298	68880
2	85221	81114	82633	96607	113481
3	79915	108141	110882	100194	85450
4	107696	90201	108922	116298	103924
5	113729	93669	93415	102935	113481
6	98411	110232	66545	108769	113481
7	86660	108503	103937	104626	86177
8	107550	101556	87550	81496	106670
9	92720	105294	66597	97625	85564
10	91354	110415	111531	86130	113481
11	111981	101280	100559	110825	53847
12	103760	113971	77476	105530	91129
13	85189	112664	100397	86155	83355
14	87972	108503	102478	116171	113481
15	93080	112991	102936	86918	85116
16	104314	108503	88676	104948	68340
17	89169	69655	88572	98642	113481
18	109218	76105	78589	109241	113481
19	85487	72180	97303	106839	60095
20	99042	104647	98418	114434	113481
21	108511	97828	79938	101308	111885
22	102878	97567	79374	106836	63175
23	109558	85670	89604	109345	63992
24	90347	113362	108922	95725	113481
25	99749	108503	95794	106472	84247
26	75128	85150	101698	60733	80680
27	102964	78970	99322	115838	113481
28	101971	91457	108922	95848	57756
29	103427	97619	95411	97232	72230
30	104546	77149	100554	99014	91554
31	96937	90286	100022	118158	113481
32	89348	98399	97563	118914	68593
33	92827	100694	86808	94212	113481
34	93418	88167	97577	96562	113481
35	89710	95697	98934	89528	94522
36	98067	108503	103153	92188	113481
37	81950	87882	96953	101378	36819
38	101541	111364	108922	84415	113481
39	104429	76914	108922	109708	60931
40	115728	108503	82928	114879	110607
41	94622	95850	108922	94444	113481
42	109307	78565	108420	91778	99298
43	93232	74955	96953	80093	74050
44	92718	79169	84999	111754	59927
45	118560	98073	80756	88748	90439
46	97617	83544	108922	116298	113481
47	95939	91861	81622	92766	69579
48	96941	96774	85816	80576	67683
49	100919	73904	101029	85684	113481
50	109727	82690	81795	92831	113481
51	88767	87767	95029	94805	113481
52	94007	80682	93973	93053	84185
53	88745	108503	106358	83718	113481
54	95125	108503	108922	95363	113481
55	102006	88604	89225	105187	113481
56	116069	86745	79298	75133	113481
57	98018	108503	105456	115462	113481
58	107550	110938	90023	116298	113481
59	104466	89830	86435	112014	113481
60	88085	77850	111850	96488	113481
61	104842	101559	108922	116321	113481
62	105078	107086	105990	100838	50639
63	111806	75916	103903	114420	92956
64	104117	108503	72684	88685	68369
65	98172	105519	108922	104370	113481
66	104833	88082	107473	91054	77802
67	104017	96201	89580	116298	90404
68	98462	104977	67028	110811	53266
69	98951	108503	103846	85010	113481
70	58442	108503	105425	93577	113481
71	100512	105356	90101	84212	113481
72	104534	81033	71208	115169	59241
73	104321	96180	94848	99489	113481
74	76410	92769	80633	96842	113481
75	101761	86243	103175	116289	111772
76	98289	96775	85355	100098	113481
77	96417	89689	83557	82501	113481
78	94185	105166	98309	119516	82424
79	99652	90634	86432	107470	81750
80	116118	107207	84064	116298	68943
81	107550	108503	102288	102975	60868
82	88559	93253	108922	79193	113481
83	107654	95551	72563	116298	113481
84	87116	85179	84276	116210	60969
85	112631	107530	95011	120401	113481
86	92029	79262	88118	73311	66523
87	98153	72661	106702	116298	103231
88	110338	82641	87642	114755	93198
89	88749	89400	104061	110553	59061
90	103853	70529	82870	101737	69782
91	86953	111372	108922	96234	113481
92	76197	108503	100063	94379	76589
93	77617	103970	108922	112114	71413
94	107550	96626	108922	84754	89634
95	88427	80091	89962	113685	113481
96	82259	108503	82287	105688	113481
97	78517	102315	91247	102159	74241
98	102294	78632	116149	93430	92748
99	95665	75445	79613	105710	79489
100	107550	82533	100893	87291	113481

Rotation (y)	**45**	**42**	**40**	**35**	**30**
Max	118560	113971	116149	120401	113481
Min	58442	69655	66545	60733	36819
Mean	97631	94707	94835	**100879**	93492
SD	10589	12568	11904	12636	21806
SE	1059	1257	1190	1264	2181