Department of Forest and Soil Science
Institute of Forest Growth and Yield Research

HOW MANAGEMENT EFFECTS FOREST PRODUCTIVITY

- A Case Study Based on MOSES Modeling on Swiss Data

A dissertation submitted in partial fulfillment of the requirement for the degree of Master of Science in European Forestry in the University of Natural Resources and Applied Life Sciences, Vienna and University of Joensuu.

Author: Liu Xiaozhen

Supervisor: Ao.Univ.Prof.Dr.Hubert Hasenauer
External Supervisor: Dr.Georg Kindermann

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Abstract

As floods and some other disasters broke out in19th century, the Federal Forest Police Act came into force in 1920 in Switzerland, in which clear cutting in public forests and private protection forests was prohibited. In 1932 the clear cutting prohibition was extended to private forests. A sustainable and "close to nature" silviculture with natural regeneration and selection forest system were propagated in Switzerland influenced by Gayer (1882). In 1905 the Swiss forest Research Institute made 3-selection forest research plots for this reason. By 1931 a further 17 plots had been added in which three plots are still being surveyed today. According to this trend, the productivity and sustainability of forest had been studied, especially between clear-cutting in even-aged forest and single tree selection in uneven-aged forest. And the trend for transforming of even-aged to uneven-aged forests is well known. Some countries' forest administrations already strongly promote uneven-aged forests as leads to more stable forest stands. However, the forest management impact and comparison between even and uneven-aged forest under selection harvest method are often. This study is to illuminate the importance of forest management; to compare even and uneven-aged forest productivity and sustainability, and compare productivity among three different tree species: European larch, Norway spruce and Swiss stone pine; Analyze the parameters affect productivity and sustainability. The results show that the managed forest is more producible than unmanaged forest; the productivity of even-aged forests is higher than uneven-aged forests in Emmental, Switzerland.

Keywords: even-aged forest, uneven-aged forest, productivity, sustainability, European larch, Norway spruce, Swiss stone pine, Switzerland.

Zusammenfassung

Nach Überflutungen und ähnlichen Katastrophen im 19 Jahrhundert ist im Jahr 1920 das Eidgenössiche Forst Polizei Gesetz in Kraft getreten. Damit wurden Kahlschläge im öffentlichen Wald sowie in privaten Schutzwäldern untersagt. Im Jahr 1932 wurde dieses Verbot auch auf private Wälder ausgedehnt. Eine nachhaltige, natur-nahe Waldbewirtschaftung mit natürlicher Verjüngung und Auslesedurchforstung findet beeinflusst von Gayer (1882) immer mehr Verbreitung. Aus diesem Grund wurde 1905 vom Schweizer Forst Forschungs Institut drei Bestände zur Untersuchung von Auslesedurchforstungen angelegt, zu denen 1931 17 weitere hinzugefügt wurden und die heute noch beobachtet werden. Entsprechend diesem Trend wurde die Produktivität und Nachhaltigkeit von Wäldern untersucht und spezielles Augenmerk auf den Unterschied zwischen Kahlschlägen in gleichaltrigen Beständen und Auslesedurchforstungen in ungleichaltrigen Beständen gelegt. Infolgedessen ist nun der Verlauf zur Umwandlung von gleichaltrigen in ungleichaltrige Wälder bekannt. In einigen Ländern werden bereits durch die Forstverwaltungen besonders ungleichaltrige Wälder gefördert, weil diese zu stabileren Beständen führen. Dennoch werden immer wieder Untersuchungen zum Vergleich von gleichaltrigen und ungleichaltrigen Wäldern mit Auslesedurchforstung unternommen. Diese Studie soll die Bedeutung von Waldbewirtschaftung beleuchten, die Produktivität und Nachhaltigkeit von gleichaltrigen und ungleichaltrigen Beständen vergleichen, die Produktivität und Nachhaltigkeit dreier Baumarten (Lärche, Fichte, Zirbe) untersuchen und die Parameter analysieren, die die Produktivität und Nachhaltigkeit beeinflussen. Die Ergebnisse zeigen, dass bewirtschaftete Wälder produktiver sind als nicht bewirtschaftete und die Produktivität von gleichaltrigen Beständen in Emmental in der Schweiz höher ist als die von ungleichaltrigen.

Stichworte: Plenterwald, Altersklassenwald, Produktivität, Nachhaltigkeit, Mischbestände.

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1. Introduction

1.1. Backgrounds

As floods and some other disasters broke out in19th century, the Federal Forest Police Act came into force in 1920 in Switzerland, in which clear cutting in public forests and private protection forests was prohibited. In 1932 the clear cutting prohibition was extended to private forests. A sustainable and "close to nature" silviculture with natural regeneration (Engler 1900, Zingg et al, 1997) and selection forest system (Biolley 1901, Zingg et al, 1997) were propagated in Switzerland influenced by Gayer (1882). In 1905 the Swiss forest Research Institute made 3-selection forest research plots for this reason. By 1931 a further 17 plots had been added in which three plots are still being surveyed today (Zingg et al, 1997).

According to this trend, the productivity and sustainability of forest had been studied, especially between clear-cutting in even-aged forest and single tree selection in uneven-aged forest. And the trend for transforming of even-aged to uneven-aged forests is well known. Some countries' forest administrations already strongly promote uneven-aged forests as leads to more stable forest stands. However, the forest management impact and comparison between even and uneven-aged forest under selection harvest method are often.

1.2. Research objectives and expected results

- To identify the forest management impact on even and uneven-aged forests.
- To identify the annual productivity of even and uneven-aged forests.
- To identify the annual short time potential productivity of even and uneven-aged forests.
- To estimate the sustainability of even and uneven-aged forests.
- To identify the productivity of Europe larch, Norway spruce and Swiss stone pine in even and uneven-aged forests.

1.3. Study rationale

There are two kinds of stand structures under the selection harvest, even-aged and uneven-aged in Emmental, Switzerland. And both are mixed forests of Norway spruce, European larch and Swiss stone pine.

The following parameters had been observed on all plots (Zingg et al 1997):

(1) Tree species

(2) Diameter in millimeters callipered crosswise at 1.3m height

(3) Tree height

This study is to validate if the MOSES model fit the dataset of observations in Emmental, Switzerland and to gain the dbh and height of unmanaged forest by the model processing. After by using the volume function to estimate the standing volume of individual tree, first to compare the in-growth of managed and unmanaged forests; second is to compare productivity, potential productivity and sustainability of even-and uneven-aged forest and the productivity, potential productivity and sustainability among three tree species: Norway spruce, European larch and Swiss stone pine.

2. Literature review

2.1. Tree species

2.1.1. Norway spruce (*Picea abies*)

The Norway spruce (*Picea abies*) is a large evergreen coniferous tree growing to 35-55 m tall and with a trunk diameter of up to 1-1.5 m.

It grows throughout northeast Europe from Norway and Poland eastward, and also in the mountains of central Europe, southwest to the western end of the Alps, and southeast in the Carpathians and Balkans to the extreme north of Greece. The northern limit is in the arctic, just north of 70°N in Norway.

Norway spruce is one of the most widely planted conifers in Europe, both in and outside of its native range, used in forestry for timber and paper production. It is naturalized in some parts of North America, though not so extensively as to be considered an invasive weed tree (Conifer Specialist Group, 2006, Wikipedia, 2006).

Figure 2.1 Norway spruce (Picea abies) (Seehagel 2004)

2.1.2. Swiss stone pine (*Pinus cembra*)

The Swiss stone pine (Pinus cembra) occurs in the Alps and Carpathian Mountains of central Europe, in Poland (Tatra Mountains), Switzerland, France, Italy, Austria, Germany, Slovenia, Slovakia, Ukraine and Romania. It typically grows at (1,200-)

1,500-2,200 (-2,300) m altitude. It often reaches the tree-line in this area. The mature size is up to 25-35 m height, and 1.5 m trunk diameter.

Populations in southeast Europe tend to have on average longer cones with more pointed scales; these are sometimes distinguished as Pinus cembra, but there is extensive overlap in variation with trees from other parts of the range.

Swiss stone pine is a conifer that stays in cold climate. It is very tolerant of severe winter cold, hardy down to at least -50°C, and also of wind exposure (Conifer Specialist Group, 2006, Wikipedia, 2006).

Figure 2.2 Swiss Stone Swiss stone pine (Pinus cembra) (Kling, 2002)

2.1.3. European larch (Larix decidua)

European larch (Larix decidua) is a species of larch native to the mountains of central Europe, in the Alps and Carpathians, with disjunct lowland populations in northern Poland and southern Lithuania.

It is a medium-size to large deciduous coniferous tree reaching 25-45 m tall, with a trunk up to 1 m diameter (exceptionally, to 55 m tall and 2 m diameter). The crown is conic when young, becoming broad with age. It is very cold tolerant, able to survive winter temperatures down to at least -50°C, and is among the tree-line trees in the

Alps, reaching 2400 m altitude, though most abundant from 1000-2000 m. It only grows on well-drained soils, avoiding waterlogged ground.

The wood is tough and durable, particularly valued for yacht building (Conifer Specialist Group, 2006, Wikipedia, 2006).

Figure 2.3 European larch (Larix decidua) (Antony Sorrento 2004) Figure 2.)

2.2. Forest age class distribution

2.2.1. Even-aged forest

Even-aged forest is the simplest type of all forest age class distribution. Such stand is very common. They typically arise in nature after severe disturbance such as hot fires or, artificially, from programs of clear cutting and planting (Smith et al 1997). An even-aged forest usually contains only one species, but the situation of several species in one forest exists. The canopy in this kind of forest is almost at the same level of height, thus there is no stratification of the canopy. In young stands, all trees have almost the same opportunity of getting sunshine, nutrition and water, and have relative enough space to grow. The diameter of each tree can be similar. In old stands, when diameters of trees get bigger, the canopy of trees can touch each other, which affect tree growth of some weak trees. The influence of this sort of competition can result in a big different in tree diameter. And lots of trees are dying in the competition in virtue of the natural thinning. The remaining trees can have predominance of growing conditions, for instance, water and soil, and better gene

(Wittwer et al, 2001)

The advantages of even-aged forest are: if apply the clear-cut harvesting method, just requiring less entry into the forest than uneven-aged forests, which can make the less damage to residual and stand soil minimize; economically efficiency. Thus, the disadvantage of even-aged forest embodies on lack of biodiversity; low disease and disaster resistance; in the aspect of forest recreation, uneven-aged forest has a better review than even-aged forest (Wittwer et al, 2001)

2.2.2. Uneven-aged forest

There are three or more age-classes in the forest; each of the age-class occupies almost the same area. The view of the forest is that some small trees grow under a few of big dominant trees. The trees under story trees are shade tolerant tree species; intolerant tree species are less healthy or die. When there is small gap created by artificial thinning or natural decease, the under layer trees get their chance to pullulate. (Wittwer et al, 2001)

2.3. Single tree selection

The most common type of selection system is Single Tree Selection, in which scattered individual trees are marked and harvested (USDA Forest Service, 2006).

The goal of this method is to regulate the diameter distribution into a form that is known to be sustainable. A distribution is sustainable if enough trees remain post-harvest that they can grow back all that was harvested before the next harvest. Sustainable distributions can provide a steady even-flow of timber over an infinitely long time-horizon (Nyland, 1998).

Conducting a full stand inventory is rarely practical, and tracking the number of trees in small size-classes is tedious in the field. A typical single tree selection harvest will involve an inventory from a number of sample plots, which is used to estimate which size-classes contain excess trees. Based on this estimate, and the smooth residual curve, a marking-guide is constructed based on larger, more tractable size-classes Arbogast, 1957).

On the ground, the forester will use the techniques of Bitterlich Sampling to determine the basal area around a fixed point. If it is higher than the desired residual, trees are marked to bring it down. Whenever possible, they are marked from the surplus classes indicated on the marking guide. The result matches very closely the one given by a full inventory, but is much faster and more practical.

If production of high-quality saw logs is a management goal, then crop tree management may be an appropriate technique. Under this method the highest grade trees are selected and then "released" by removing lower grade trees, which would otherwise compete with the selected tree for sunlight and water. The selected tree can be pruned to grow logs with maximum value.

A similar approach, known as the 'Frame Tree' system, is employed in Western Europe. A number of high quality stems are identified at an early stage of the stand development and successive thinning interventions are aimed at releasing the growth potential of these trees. Commonly the final crop trees are harvested when they reach a specified size in order to maximize the financial return to the grower. Throughout the process natural regeneration is encouraged to infill the ground that has been opened up. This "continuous cover" approach can be seen as an alternative to clear felling.

Another common but sometimes-controversial method of selection is diameter limit, the removal of all trees above a certain diameter. Poorly planned diameter limit cutting is considered high grading by some (Webster, 2002).

2.4. Tree growth model

2.4.1. Historic development of tree growth model

The first tree growth models were developed in North America (Newnham 1964; Stage1973; Monserud 1975; Wykoff et al 1982; van Deusen and Biging 1985; Wensel and Koeheler 1985; Burkhart et al. 1987; Hasenauer 2005). For Scandinavia and central Europe, the main tree growth modeling were developed in early 1990s (Sterba1983; Pukkala 1988, 1989; Pretzsch 1992, 2001; Hasenauer 1994, 2000, 2005), their models basically extend the previous model approaches to all major species in Europe (Hasenauer 2005).

The steady increase in computing power and software has supported the rapid developing trend of providing the tools for model construction (Friend et al 1997).

2.4.2. General structure of a tree growth Model

With the shifting trend of even-aged forest management to uneven-aged forest management, many of the tree growth models are design to simulate the growth situation in uneven-aged forests (Hasenauer 2005), for instance, the PrognAus (Sterba and Monsereud 1997), BWIN (Nagel 1999), MOSES (Hasenauer 1994) and SILVA (Pretzsch et al. 2002).

Tree growth models consist of increment functions, crown model, mortality models and regeneration models to simulate growth and mortality for individual tree over a given time interval.

Each model has the same basic structure of (Gadow and Hui, 1999, Hasenauer 2005, Dash 2006):

(1) Competition algorithm

(2) Diameter increment model

(3) Height increment model

(4) Crown model

(5) Mortality model

(6) Regeneration model

2.4.2.1. Competition index

One of the main successful functions of tree growth model is that according to each tree's competitive situation, growth can be assessed. The working principle of competition index is that it assumes a certain distance among neighboring trees before competition occurs. The minimum distance is derived from the radius of crown area of an open grown tree (Krajicek et al, 1961). If the crowns overlap, tree competition will affect tree growth (Hasenauer 2005).

Many researchers has found out and tested a variety of individual tree competition indices, which can assess growth situation. There are two big groups of competition indices: (1) distance-dependent indices, the position of individual tree and distance among neighboring trees are known. For instance, PrognAus (Sterba and Monsereud 1997) and BWIN (Nagel 1999) (2) distance-independent indices, assume a mean distance among each tree, such as MOSES (Hasenauer 1994) and SILVA (Pretzsch et al. 2002) (Gadow and Hui, 1999, Hasenauer 2005, Jonathan Dash 2006).

2.4.2.2. Increment function

Two approaches are utilized for predicting 5-year interval diameter and height increment for individual tree in a given stand: (1) potential dependent ;(2) potential independent growth functions.

The potential dependent diameter and height increment predictions proposed by Newnham in 1964, which assume an upper limit of growth or growth potential. Models of this kind define site and species diameter and height increment potentials. There defined potentials will reduce as the competition works. Tree growth increment model based on the following function (Hasenauer 2005):

$$Inc = potinc * CR^{a} * (1 - e^{b*COMP}) + \varepsilon$$

Where *inc* actual 5-year increment for each tree

potinc predefined 5-year potential increment by species and site conditions

CR crown ratio

COMP competition indices

a and b parameter estimates

ε remaining error

The 5-year potential height increment is usually derived from dominant tree height development by using site indices function. The potential diameter increment is derived from "open grown trees" which are the trees have grown without neighboring competition (Hasenauer 1997, 2005).

Typical examples for the potential dependent approach are SILVA (Pretzsch 1992; Pretzsch et al. 2002), MOSES (Hasenauer 1994) and B-WIN (Nagel 1999).

The potential independent approach is also important, it does not define a limited growth or growth potential, the actual diameter and height increments are estimated directly from the available data and only based on independent variations. The following function shows the relationship of each variation (Hasenauer 2005).

$$ln\ (inc) = a + b^*(tree) + c^*(comp) + d^*(site) + \varepsilon$$

Where	*ln (inc)*	logarithm of growth (diameter/height)
	tree	tree variation
	comp	competition variables
	site	site variables
	a, b ,c ,d	species coefficient
	ε	remaining error

The typical examples of potential independent approach are PROGNOSIS (Stage 1973; Wykoff 1990) and PROGNAUS (Monserud and Sterba 1996).

2.4.2.3. Crown model

Crown length and crown surface area are the key logs within growth and mortality functions. There are some models to define the relationships: "crown ratio models" (Hasenauer and Monserud 1996), which predict the crown ratio as a function of tree, competition and site variables. "Height to crown base models" (Pretzsch 1992; Nagel 1996) which estimate clear stem length as a function of tree and competition variables. And "change in the height of the live crown base model" (Short and

Burkhart 1992; Hasenauer 1994) are dynamic models which need repeated observations for model calibration (Hasenauer 2005).

2.4.2.4. Mortality model

Depending on competition and site variables, the mortality model calculates the death probably of each tree. LOGIT model (Neter and Maynes 1970) is a common method to derive the parameter by using maximum likelihood procedures (Monserud and Sterba 1996; Hasenauer 2000, 2005). The following is the typical mortality model used function (Hasenauer 2005):

$$P = 1/\left(1+e^{(a+bi*xi)}\right) + \varepsilon$$

Where	P	probability of mortality
	x_i	set of parameter selected
	a and b_i	estimated coefficients
	ε	remaining error

Because mortality is a rare event in the forest and mortality is often affected by external effect, for instance, drought, wind-throw, etc, is difficult to calibrate the mortality model. Individual tree mortality is seen to be the most difficult task within tree growth modeling (Hasenauer 2005).

2.4.2.5. Regeneration model

There is a threshold to judge whether the juvenile tree is a regeneration or belong to the over story layer. Usually in long-term plots, trees below the height of 1.3m belong to the regeneration group, while during forest inventory, a certain diameter at breast height is used, for instance, 5.5cm dbh (FBVA 1994).

One method of define trees entering over story group is the calibration of in-growth models (Ledermann 2002), this kind of models do not access regeneration establishment and juvenile tree growth, while recent approaches have take regeneration establishment (Pukkala and Kolström 1992; Ribbens et al. 1994; Schweiger and Sterba 1997; Hasenauer et al 2000; Biber and Herling 2002;

Hasenauer and Kindermann 2002) and juvenile tree growth (Monserud and Ek 1977; Golser and Hasenauer 1997; Biber and Herling 2002; Kindermann et al 2002) into consideration (Hasenauer 2005).

The regeneration process may as following (Kindermann et al 2002):

(1) Predict the probability of regeneration within 5-year interval;
(2) Predict the species distribution;
(3) Estimate regeneration density;
(4) Determine juvenile tree growth;
(5) Determine juvenile tree mortality.

2.4.3. Common tree growth models used in Europe

There are many European researcher had put much effort into the developing of tree growth models, thus each model deal with individual trees, there is still difference among each model due to the regional specific. For instance, there are silvicultural decision support system "BWINPro" (Nagel 1995), tree growth model "MOSES" (Hasenauer 1994), tree growth simulator "PrognAus" for Windows 2.2 (Monserud and Sterba 1996, and the individual tree based stand simulator "SILVA" (Pretzsch 1992; Pretzsch et al. 2002).

2.4.3.1. The silvicultural decision support system "BWINPro"

As the shifting of pure stands to mixed-species stands, the Forest Research Station of Lower Saxony in Germany begun to construct the tree growth model. This model was incorporated into a software program BWINPro (Nagel 1995) that allows for forest growth simulation and strategy development. And this program is used by the Forest Service of Lower Saxony to calculate future growth, thinning and timber harvest at the enterprise level for permanent plot inventory (Nagel and Schmidt 2005).

The main structure of BWINPro is as following (Nagel and Schmidt 2006):

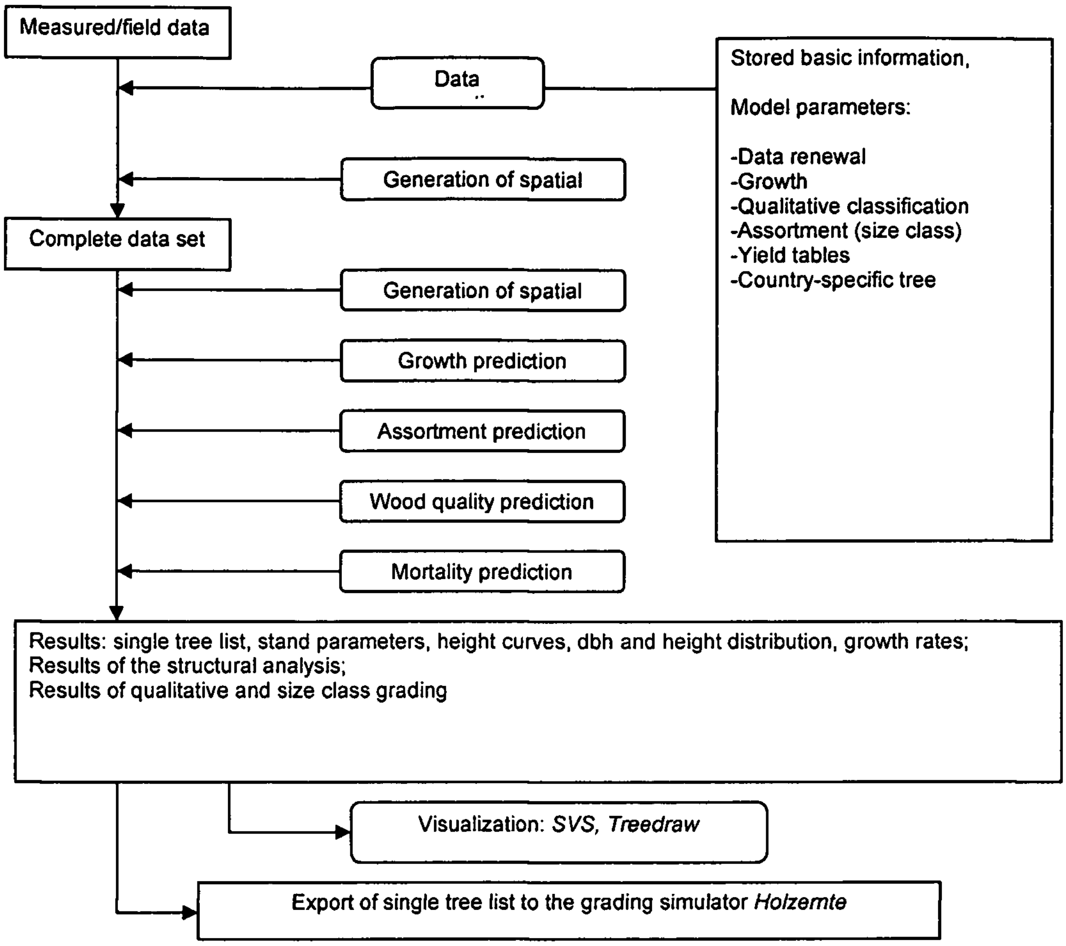


Figure 2.4 Main structure of the silviculture decision support system BWINPro (Nagel and Schmidt 2006)

BWINPro-S (for Saxony) simulates individual tree's dbh and stem position. Growth is estimated by using the particular age and species composition and the effect of competition is also resulted. The program consists of several different modules that can be combined according to a user's objectives.

The growth model in BWINPro-S comprises a set of regression functions for estimating individual height increment, basal area increment, height of crown base, and crown width. Competition can be position-independent or position-dependent. Height of crown base, crown width and juvenile growth can also be estimated. And there are two different approaches can be used to predict mortality in BWINPro-S (Röhle 2005).

Currently, the program is suitable for multi-layered stands such as forests in conversion from pure, even-aged coniferous to mixed-species; uneven-aged stands (H. Röhle 2005).

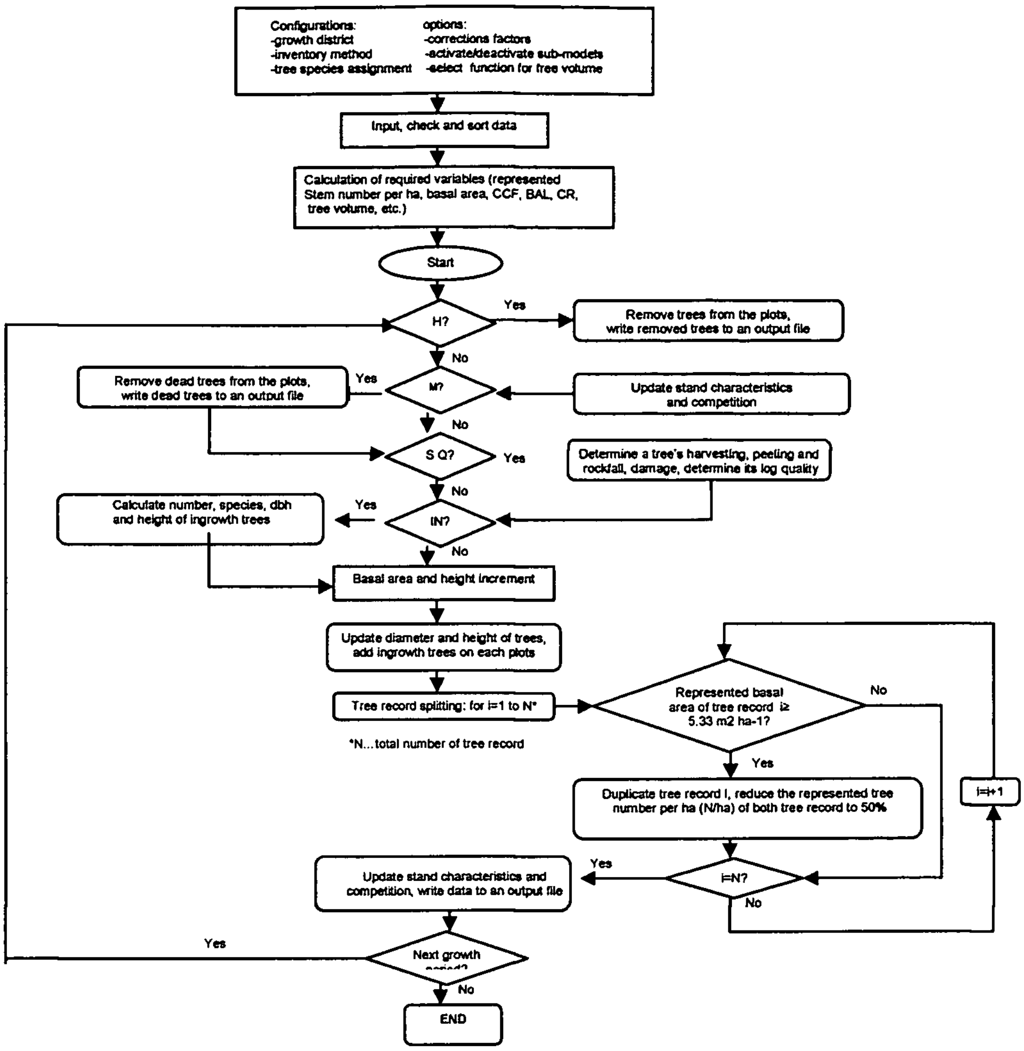
2.4.3.2. Tree growth model "MOSES" (see material and method)

2.4.3.3. Tree growth simulator "PrognAus" for Windows 2.2

The individual tree growth simulator PrognAus for Windows 2.2 is developed on the basis of tree growth model Prognaus (Ledermann 2006) that is an adoption of the U.S model Prognosis (Stage 1973) (Dash 2006).

PrognAus is an individual tree growth model, containing a major sub-model, which depicts basal area growth as a function of tree size, competition and a set of diagnostic site variables (Sterba et al 2000). The sub-models are individual tree basal area increment model (Monserud and Sterba 1996, Hasenauer 2000), individual tree height increment model (Schieler 1997), individual tree mortality model (Monserud and Sterba 1999) and an in-growth model (Lederman 2002)

The following is the flow chart of PrognAus for Windows 2.2:



*H is harvesting, *M is mortality, *S Q is stem quality, *IN is ingrowth.

Figure 2.5 Flow chart of the individual-tree growth simulator PrognAus for Windows 2.2 (Ledermann 2006)

The individual tree growth simulator PrognAus for Windows 2.2 is used to predict forest management scenarios also utilized in forest inventories and for enterprise decision makers (Ledermann 2006).

2.4.3.4. The individual tree based stand simulator SILVA

The forest growth simulator SILVA (Pretzsch 1992; Pretzsch et al. 2002) was first developed at technical University of Munich, Germany. SILVA can be applied to common tree species in Europe. It deals with large dataset from long-term observation, and has the following sub models: the 3-demension program decides the competition indices and situation; the mortality model decides if individual tree alive for current simulation period; height and diameter growth models; crown development simulator. The results can be divided into 3 parts: timber production (stem frequency, timber volume, tree height, basal area, etc.), economical and structural parts. SILVA is a good tool for decision making of forest and landscape management, as well as an instrument for education and training (Pretzsch et al. 2002).

3. Material and methods

3.1. Material

3.1.1. Switzerland selection forest management history

3.1.2. Stand distribution

In this paper, I used partial data from long-term forest stand observation in Switzerland (Zingg, 1997). In which, 3 even-aged management plots (No.1, No.25 and No.44) and 13 uneven-aged management plots in Switzerland, which are all in the two areas where selection forest management has a long tradition.

One is in Emmental (canton Berne) where the selection forest method evolved from the forest management methods of the farmers. The other is in canton Neuchatel in which BIOLLEY (1901) had a strong influence on the introduction of this form of silviculture (Zingg 1997).

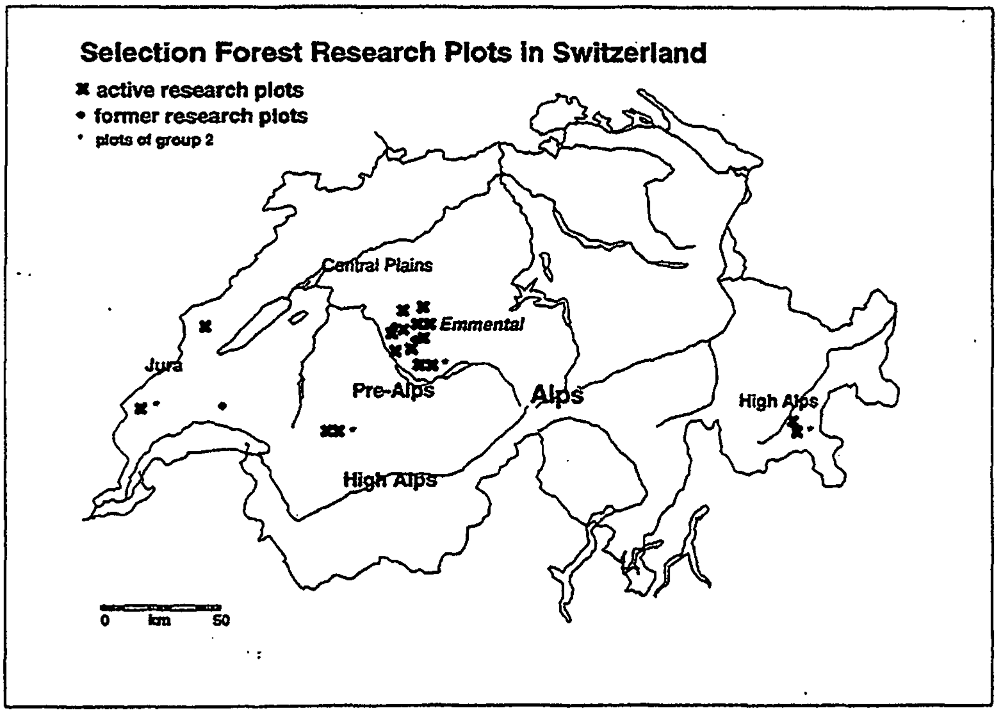


Figure 3.1 Geographical distribution of the experimental plots (Zingg 1997).

Most of the selection forest plots are located in Emmental. The plots in Emmental are in very similar sites.

The following parameters have been measured on all plots (Zingg, 1997):

(1) Tree species

(2) Diameter in millimeters callipered cross wise at 1.3m high

(3) Tree height

(4) Height of the crown base and crown radii (not used in this thesis)

3.2. Methods

3.2.1. Tree growth model MOSES 3.0

3.2.1.1. Introduction

MOSES-MOdeling Stand rESponse (Hasenauer 1994, 2000) is a distance-dependent tree growth simulator consisting of diameter increment, height increment, dynamic crown model, and mortality components. The MOSES model can be applied for all major tree species in Austria and Switzerland. The tree species currently incorporated are: Norway spruce, fir, European larch, Scots Swiss stone pine, Swiss stone pine (Spyroglou 2004). The data source, which used to calibrating the model came from permanent sampling inventory plots. And in the data, it concluded the minimum and maximum x and y coordinates of the plots, 3 times repeated breast height diameter, tree height, and height to the base of the live crown. The prediction interval is 5 years, except for willow (Wohlgemut 2004). Which uses 1-year prediction interval (Hasenauer et al, 2005).

3.2.1.2. MOSES components

They are many sub-modeling within MOSES to predict the diameter increment, height increment, dynamic crown model, and mortality situation.

The 5 years increment model is predicted as follows:

$$Idobs/idpot,\ ihobs/ihpot = CR^{b1}[1-e^{b2/CI(l+b3*\Delta CI)}]+ \varepsilon$$

Increment predictions within MOSES follow the potential growth concept (Newnham 1964), which predicts the current annual height (ih_{obs}) and diameter increment (id_{obs}) according to a predefined potential height (ih_{obs}) and potential diameter increment (id_{pot}) for each tree (Hasenauer et al, 2005).

In the formula CR is crown ratio. Crown ratio (CR) is the ratio of crown length to total tree length. The crown ratio also plays an important role because it represents the past growing conditions for each tree; Over stocking impacts are expressed by competition index (CI) according to Monserud (1975); And ΔCI represents the changes in competition derived from crown changes. Different crown release or thinning (measured byΔCI) can result in either an acceleration or a decline in diameter or height growth for trees which had similar growing conditions at past (Hasenauer et al, 2005): b1, b2, b3 are function coefficients; id_{obs} is current annual diameter increment; id_{pot} is predefined potential diameter increment from empirical open crown dimensions in Austria (Hasenauer 1997); ih_{obs} is current annual height; ih_{pot} is predefined potential height increment, follows a suggestion of by Newnham (1964) as well as Monserud (1975), and use the height increment development of dominant trees for a given site (Hasenauer et al, 2005).

The potential periodical height increment for a given tree is derived from regional site index functions. After determining the site index the corresponding index function is rearranged to derive the circulatory age a given tree would have had grown as a dominant tree (Hasenauer et al, 2005). By adding the prediction period, and calculating the future dominant tree height, the difference is the potential periodical height increment.

Site index is a measure of a forest's potential productivity and usually is defined as the height of the dominant or co- dominant trees at a specified age in a stand. It is calculated in an equation that uses the tree's height and age. Site index functions differ by tree species and regions. Site index functions are developed through fieldwork and analysis of data by establishing research plots in stands of a particular tree species covering a range of site conditions, select representative dominant or co-dominant trees and measure their heights, ages, and diameters. Site index curves are constructed by using the tree heights at a base age. An equation is derived from the curves to estimate the site index when an individual tree's age is not the same as the base age. Site index functions are developed either by following a stand through time (King 1966) or comparing several stands of different ages at a single point in time (McArdle et al 1961) (Hanson et al, 2002).

Potential diameter increment is calculated from the algometry of open crown trees (Dash 2006). The dbh of an open grown tree can be calculated from tree height by using the diameter-height function (Hasenauer 1997) as follows:

$dbh = a.H^b$

Where dbh is the breast height diameter; "a" and "b" are function coefficients; H is the tree height. First, calculate the height of a given tree at the beginning of the period. Then, the incremental period is added to the effective tree age. Calculate the updated height, the updated potential diameter is calculated again by using the function. The difference between the two potential heights is the potential height increment.

The diameter and height increment models are the main part of methods applied in this thesis.

As mentioned before, crown ratio (CR) is an important role, it is the ratio of crown length to total tree length. Crown ratio is used as an input variable to estimate growth and mortality of individual trees and also is used to display changes in the appearances of stands over time for habitat suitability and visual changes (Temesgen et al, 2005).

It can be calculated directly for knowing a given tree's height (*h*), diameter (*dbh*), and competition index after crown release (*ciu*) and height diameter ratio (*hd*). See the following function (Hasenauer 2005):

$CR = 1/ (1+e^{(a0+a1*hd+a2*h+a3*dbh2+a4*ciu)})$

The static crown model is in the MOSES approach as an alternative to the dynamic crown model (Hasenauer 2005).

Hasenauer develops the dynamic crown model in 1994, in which crown dimensions are predicted after each growing period based on it other stand characteristics. Increment of crown height through time, like height and diameter increment are predicted, improves model predictions (Short and Burkhart 1992, Spyroglou 2004). The function of the dynamic crown model is as following (Hasenauer 2005):

$\square HLC = b_0 * h^{b1} * e^{(b2*sqrtCR+b3/ciu+b4*dbh)}$

Where $\square HLC$ the change in the height to live crown base

h height

ciu competition index after crown release

dbh diameter at breast height (cm)

The height to live crown base is calculated in the following function:

$$HLC = h*(1-e^{-(a0+a1*h/dbh+a2*dbh)})$$

Where a_0, a_1, a_2 are the regression coefficients.

The change in the clear bole length as it depends on tress, competition and site variables is derived for a given time interval. This approach requires repeated observations of height to the live crown for model calibration.

Thus the crown models are not used in this thesis, they are also an important component in MOSES, and so I mentioned them as above.

Tree mortality is a normal process that is an important facet of stand dynamics. Information about tree mortality can be used to determine if there are any unusual spatial or temporal patterns in mortality rates; or if the balance between growth and mortality is adequate to sustain a forest ecosystem (William A. Bechtold 2005).

Tree growth models predict the mortality for each tree by calculating the probability of mortality depending on tree competition and site variables (Hasenauer 2005). The dependent variable is binary (dead or alive-0 or 1), so LOGIT models (Logistic regression) are a common method (Neter and Maynes 1970) to derive the parameter coefficients using maximum likelihood procedures (Monserud and Sterba 1999; Hasenauer 2000, 2005).

The model function:

$$P = 1/(1+e^{a0+a1*CIA+a2*CR+a3*dbh+a4/dbh})$$

Where P Probability of tree death in the nest five years

CIA competition index after crown release

CR crown ratio

dbh diameter at breast height

a_0, a_1, a_2, a_3, a_4 are function coefficients

The mortality model is an important part in this thesis; it is used to simulate the situation of without management by activating the mortality part and deactivating the thinning and harvesting of the original data sets.

Usually, tree below a certain tree height or breast height diameter are considered as regeneration group. The thresholds between regeneration and over story population are depended on data monitoring program. MOSES includes a regeneration tool for the trees heights are smaller than 1.3m (Hasenauer 1997; Hasenauer and Kindermann 2002; Kidermann et al. 2002; Kindermann 2004). The algorithm predicts the probability of regeneration within a 5-year growth period, the species proportion and regeneration density. After the regeneration pass the threshold 1.4m of tree height, it will belong to over story and its data can be used in the model (Hasenauer et al, 2005).

Regeneration young trees are affected by a huge impact from the surrounding environment, climate, and micro site conditions, for instance, the soil type, gap size, etc (Hasenauer 2005).

The regeneration processes of MOSES are as following (Kindermann et al 2002):

1. Predict probability of regeneration in a 5-year interval
2. Predict species distribution
3. Estimate juvenile tree growth depending on the over story, inter-specific competition, intra-specific competition and compensatory effects due to edge effected incidence of light.

The regeneration tools are not used in this thesis, but it is an important part to know more about MOSES.

STANDGEN is an important simulation system in MOSES. It is a stand generation program (Kittenberger 2003) originated by Institute of Forest Growth Research, BOKU University of Natural Resources and Applied Life Science, Vienna. It has the function of estimating and creating the missing generation coordination, because in most cases, it is impossible to get the entire x and y coordination of each tree. That means, at the beginning, if no tree coordination is given, run a simulation in which a mean tree distance is given under each prediction interval. At each stage, an average competition situation in a giving plot would be assumed, because the actual stand situation is not given (Hasenauer et al, 2005).

STANDGEN has a graphical user interface, and allows the generation of all shape of forest stand -polygon model (Hasenauer et al, 2005). The STANDGEN includes three tree distribution patterns: (1) random, (2) raster, (3) structured (Kittenberger 2003). The typical working steps of STANDGEN are: (1) define a forest stand; (2) generate and/ or import available tree data; (3) assign the tree distribution according to certain rules (cluster, aggregation, etc.); (4) exporting the data so that they can be used in MOSES model (Hasenauer et al, 2005). The STANDGEN are not applied in this thesis, the X and Y coordination are measured from plots.

3.2.1.3. Software and data requirements

There are two versions of MOSES for Windows at present. One is stand level simulation program, which allows interactive individual tree treatment in the simulation (Steinmetz 2004). It has a stand level visualization tool used for education; training and silviculture hypothesis test (Hasenauer et al, 2005).

Another one is the batch version (Kindermann 2004), allows for large number of forest stand simulating. By using the batch version, the simulation of forest stand follows a sequential order, and each stand can be assigned to predefined treatment. It also can be used for historic stand data, and each equation within MOSES model can be deactivated. The batch version is very important for data from long-term stand observation and permanent inventories (Hasenauer et al, 2005). In this thesis, the batch version is applied.

Both versions require: (1) tree coordination that can be derived from measurement or from tree coordination generating tools; (2) dbh; (3) tree height; (4) height to the live crown base; (5) site index for each tree species. (Hasenauer et al, 2005).

3.2.1.4. MOSES Application and validity

The MOSES model has been applied widely, for instance, to access timber values with different treatment scenarios (Hasenauer et al 2005), treatment scenarios in beech forests (Hasenauer et al 1996), assess success of thinning, develop management for river bank forests (Wohlgemut 2004), regeneration establishment and juvenile tree growth scenarios according to different managements (Kindermann 2004), etc (Hasenauer et al, 2005).

The MOSES model has been validated for datasets from Switzerland and Austria including 52,500 growth periods (Hasenauer et al, 2005).

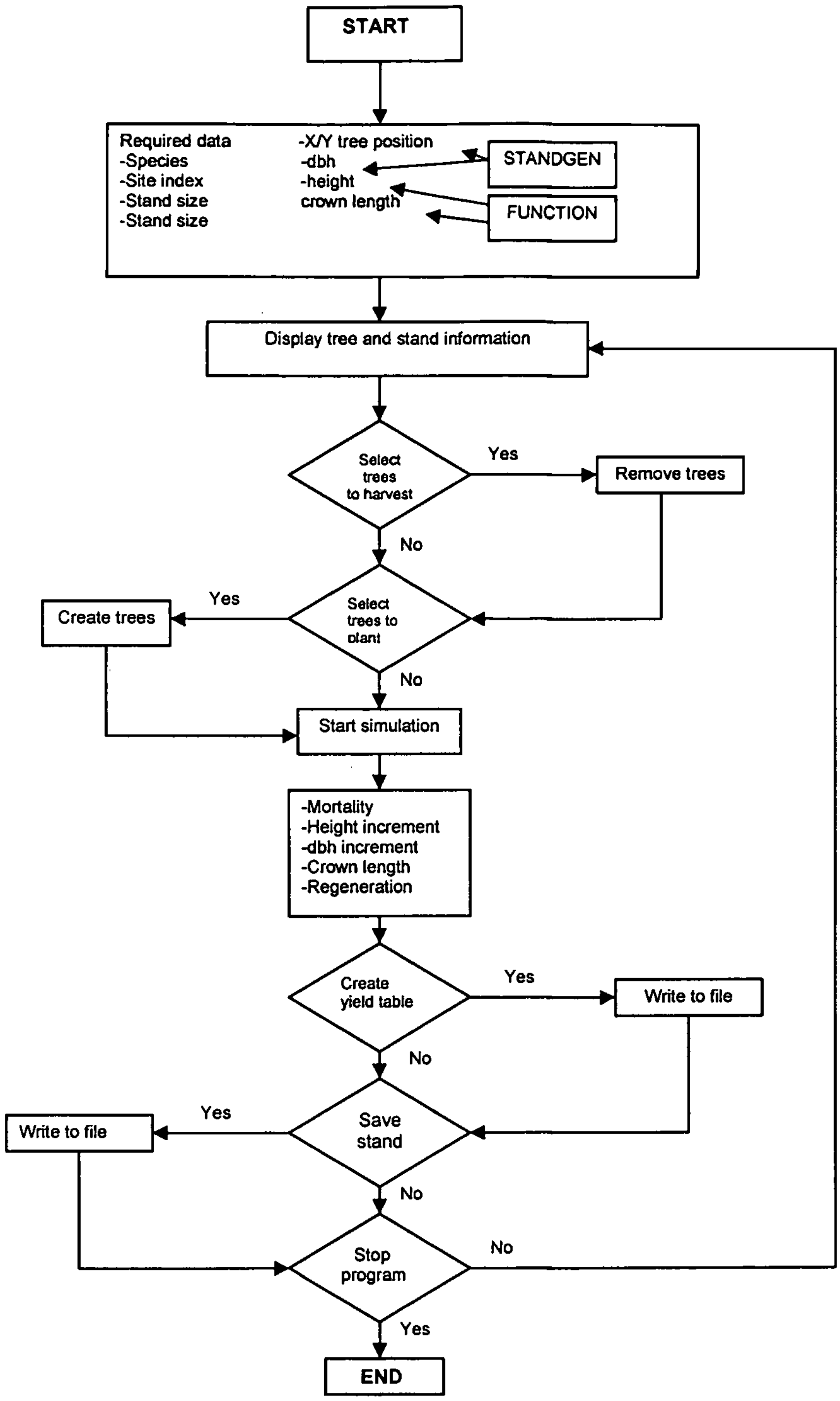


Figure 3.2 Flow chart of the tree growth simulator MOSES

3.3. Parameter within MOSES used in the current study

Table 3.1 The components within MOSES and whether utilized in simulation approach

MOSES parameters	Parameters utilized in simulation
Height increment model	Yes
Diameter increment model	Yes
Crown model	Yes
Mortality model	Yes
Regeneration model	No
Generation tool-STANDGEN 2.1	No

Height and diameter increment and also crown models are used in the simulation approach to predict future tree growth situation, thus the regeneration models are not used. The mortality model plays an important role in the process to simulate no management (thinning or harvesting).

3.4. Data description

The data I used in this study is coming from long-term forest site observation in Switzerland (Zingg, 1997).

Table 3.2 Observation duration, observation time and site type within individual plot

Plot No.	Site Type	Start Y	End Y	Obser No	Period
1	Even-aged	1975	1995	3	20
15	Uneven-aged	1979	1999	3	20

*Start Y is the first observation year

*End Y is the final observation year

*Obser No is total observation number in the plot.

The age-class within individual plot varies very different, this stand for that the plots are not young stands but mature forest stand.

Species, site index are described in the following table:

Table 3.3 Species and their site index in each plot

Plot No.	Species	Site Indices
	Spruce	22.6
1	Larch	24
	Pine	21.2
	Spruce	26.2
15	Larch	28
	Pine	22.5

4. Results and analysis

4.1. Evaluate tree growth model MOSES validity

A high validity is the precondition for using a model. To evaluate the validity of tree growth model MOSES, a statistical test has been used. Many statistical tests of model performance have been suggested, but no single criterion can incorporate all aspects of model evaluation. One simple but efficient technique is based on linear regression of observed versus predicted data. Some useful insights into the quality of predictions may be given by "r" or"r^2", slope and intercept of the fitted line (Vanclay et al. 1996).

The method used in this thesis to test the validity of MOSES is the Pearson's product-moment coefficient of the linear regression of observed and predicted values.

4.1.1. Annual dbh increment Validity

The correlation of the observed and predicted values is 0.25, which means the model fits 25% of the real situation. The observed annual dbh increment has some data which smaller than 0 cm/year due to the measurement error during forest inventory.

4.1.2. Annual height increment Validity

The model validity of height development evaluation is also good. The correlation is 0.144. There are many negative residuals of the observed annual height increment much more than negative residuals of the annual dbh increment, the reason is: when trees become older, the annual height increment slows down and increment rate stays steady (see Figure 4.1), which results to the forest inventory error of minus annual height increment values.

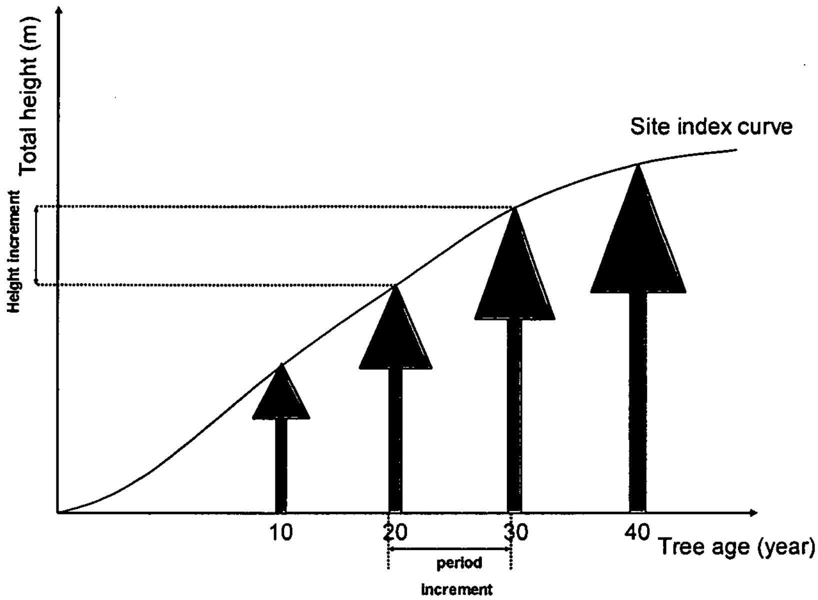


Figure 4.1 Site index curve

The annual dbh increment fitness is larger than the annual height increment fitness.

The reason is that the equipment of caliper carries on the dbh measurement, thus the height measurement via equipments, which are, not truly touch the bole of tree. And if there are unavoidable situations like distance limitation, slop and incline of trees, the error may extend.

4.2. Compare with management and without management sites development

The basal area and growing stock of managed plot are smaller than unmanaged plot's in each year due to no pruning; thinning and final harvest (Table 4.1).

Table 4.1 Site static situations under each observation within Individual plots

		with management					without management				
plot No	year	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)
1	1975	640	35.7	22.9	67.7	773.7	645	36.2	22.9	67.7	773.7
1	1985	558	36.3	22.4	65.6	791.9	598	36.6	23.4	66.3	781.4
1	1995	385	41.3	25.6	56.1	719.0	570	38.6	24.1	66.9	810.8
2	1981	522	34.5	23.2	50.4	583.9	524	34.5	23.2	50.3	583.2
2	1992	376	37.8	25.1	43.6	542.9	480	36.9	24.6	51.1	619.2
3	1981	724	30.7	24.0	55.5	663.7	727	30.8	24.0	55.4	663.1
3	1992	427	35.2	25.4	42.7	548.0	606	31.7	24.6	49.6	610.7
6	1975	285	36.6	34.6	30.7	529.2	286	36.6	34.6	30.7	529.2
6	1983	324	33.8	28.1	29.7	515.2	216	41.8	35.6	30.2	536.5
6	1991	389	31.6	25.9	31.2	540.5	306	36.3	35.3	32.4	569.2
6	1999	431	30.0	31.2	32.6	543.2	420	32.0	34.8	34.4	595.8
8	1981	245	29.0	29.7	16.6	244.5	245	28.9	29.7	16.5	244.3
8	1988	231	29.3	24.9	16.0	243.6	210	30.6	30.6	15.8	241.2
8	1996	234	30.5	30.0	17.4	267.9	268	28.5	30.8	17.5	268.0
9	1974	463	25.0	27.8	23.5	324.5	464	25.0	27.8	23.5	324.4
9	1981	440	22.8	20.0	24.4	341.7	369	26.3	28.9	21.1	302.0
9	1988	408	27.2	27.9	24.3	341.9	398	26.5	29.1	22.6	326.5
9	1996	357	28.3	27.2	23.1	334.0	430	27.1	29.8	25.4	376.6

Table 4.1 (continued)

		with management					without management				
plot No	year	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)
10	1974	210	42.1	40.2	30.2	604.7	211	42.1	40.2	30.1	604.6
10	1983	204	40.5	39.7	26.9	511.4	117	50.4	41.4	23.7	489.4
10	1990	206	38.8	32.9	24.7	486.7	130	48.7	41.2	24.4	502.2
10	1997	208	38.5	35.2	24.6	462.8	149	46.3	41.3	25.4	523.0
13	1973	859	26.2	29.8	47.6	704.7	863	26.1	29.8	47.6	704.7
13	1981	775	27.5	24.6	47.5	700.8	859	27.1	30.0	50.9	757.3
13	1989	675	29.7	23.3	47.5	721.9	907	27.7	30.3	56.0	843.1
13	1997	626	30.4	29.1	46.5	700.8	1098	26.4	30.5	61.7	936.8
14	1979	306	28.3	22.7	19.8	218.8	307	28.2	22.7	19.8	223.9
14	1989	269	28.1	22.6	17.2	195.9	230	29.7	23.1	16.4	189.3
14	1999	239	29.5	23.4	16.8	200.6	232	31.2	24.0	18.1	217.3
15	1979	505	30.2	23.4	30.3	436.3	505	30.2	23.4	37.3	436.3
15	1989	444	30.0	23.9	32.5	393.3	519	31.3	24.4	41.1	500.6
15	1999	260	31.6	24.6	20.9	262.1	347	31.8	24.9	28.3	351.5
16	1987	535	29.5	30.8	37.5	574.9	539	29.4	30.8	37.5	574.3
16	1995	544	28.5	29.8	35.7	544.5	534	30.7	31.0	40.6	626.2
17	1987	428	26.5	30.5	24.2	367.0	429	26.6	30.7	24.2	366.6
17	1995	447	25.0	28.9	22.8	332.6	420	27.5	31.0	25.6	394.6

Table 4.1 (continued)

		with management					without management				
plot No	year	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)
18	1973	396	32.9	33.1	34.6	569.2	398	32.9	34.6	34.6	569.2
18	1980	404	32.8	26.7	35.1	572.4	331	36.2	33.5	34.8	580.7
18	1988	416	33.0	31.4	36.4	596.8	406	33.2	33.2	36.3	600.9
18	1996	438	31.7	29.6	35.4	590.2	396	34.3	33.3	37.3	618.5
25	1942	644	25.5	27.1	34.2	463.0	660	25.4	27.2	34.2	463.0
25	1947	560	27.8	28.7	35.1	496.7	680	26.5	28.7	38.6	552.0
25	1952	496	29.7	30.1	35.4	534.0	696	27.7	30.1	42.8	643.4
25	1959	416	33.4	30.0	37.4	601.3	656	28.7	31.7	46.0	729.7
25	1964	388	35.5	33.2	39.5	663.4	696	30.0	32.9	50.3	825.7
25	1971	388	37.6	34.8	44.3	802.3	680	31.2	34.2	52.9	906.4
25	1979	364	40.6	33.9	48.4	941.2	656	32.5	35.8	56.0	1001.4
25	1989	364	41.9	28.4	51.7	1041.1	632	33.8	37.4	58.4	1091.7
25	1999	240	47.9	40.0	44.6	954.6	580	35.6	38.9	59.6	1159.2
28	1982	1476	32.9	31.2	128.7	1998.5	1488	32.8	31.2	128.6	1996.6
28	1990	1718	30.7	25.8	130.4	2084.3	1474	33.3	31.2	131.7	2045.4
28	1998	1964	29.6	29.3	137.9	2168.5	1624	54.9	31.2	133.9	2086.5

Table 4.1 (continued)

		with management					without management				
plot No	year	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)	N/ha	mean dbh(cm)	mean height(m)	BA(m2/ha)	V(m3/ha)
29	1992	638	30.8	30.3	49.0	743.1	646	30.6	30.3	48.9	741.2
31	1976	366	31.4	32.1	29.0	463.9	367	51.4	32.4	29.0	463.5
31	1987	341	33.3	21.4	30.4	492.0	268	60.1	32.4	24.0	388.7
31	1995	323	32.8	30.4	28.0	461.4	278	59.0	32.4	25.1	407.5
38	1965	364	31.0	24.3	28.3	344.8	372	30.8	24.4	28.3	344.8
38	1973	366	33.5	21.7	33.4	452.4	360	32.2	25.3	30.2	381.4
38	1981	336	35.4	22.5	33.7	474.0	374	33.7	26.3	27.7	355.9
38	1989	334	36.3	26.6	35.3	534.2	372	35.0	27.0	25.2	344.5
38	1997	316	38.1	27.1	36.7	583.3	398	34.9	27.7	22.7	307.2
39	1987	224	33.8	28.5	20.9	298.0	224	33.7	28.5	20.9	298.0
39	1997	247	32.1	29.1	20.4	293.3	277	33.1	29.6	19.7	285.6
40	1987	259	34.7	28.4	25.1	355.7	259	34.7	28.4	25.1	355.7
40	1997	239	35.5	28.2	22.6	324.8	298	35.2	29.7	21.6	313.4
41	1982	471	26.7	20.1	27.1	271.6	472	26.6	20.1	27.1	271.6
41	1994	471	27.4	21.6	28.7	302.5	471	29.7	21.9	30.3	326.1
44	1990	556	31.2	27.4	43.7	595.6	574	31.2	27.4	43.7	595.6
44	1999	432	33.3	27.1	41.1	550.2	548	31.3	27.9	34.2	476.7

*N/ha— tree number/ha *BA—basal area *V—volume of stem

In both even-aged and uneven-aged plots, the managed annual basal area in-growth is bigger than that in unmanaged plot (Table 4.2).

Table 4.2 Management and without management even and uneven-aged annual basal area increment (m^2/ha/year)

	Managed	Unmanaged
Even-aged	0.73	0.23
Uneven-aged	0.38	0.21

The annual volume increment also shows the same trend as annual basal area increment (table 4.3).

Table 4.3 Management and without management even and uneven-aged annual volume increment (m^3/ha/year)

	Managed	Unmanaged
Even-aged	12.47	3.98
Uneven-aged	6.01	3.49

4.3. Compare managed even and uneven-aged stand

4.3.1. Even-aged site

The following figures show the development trend of mean dbh, mean height, and number of trees per hectare, basal area and volume of even-aged plot 1 under management. Each year, the mean dbh of European larch is bigger than Swiss stone pine and Norway spruce, thus the mean dbh of Swiss stone pine and Norway spruce are similar (Figure 4.2).

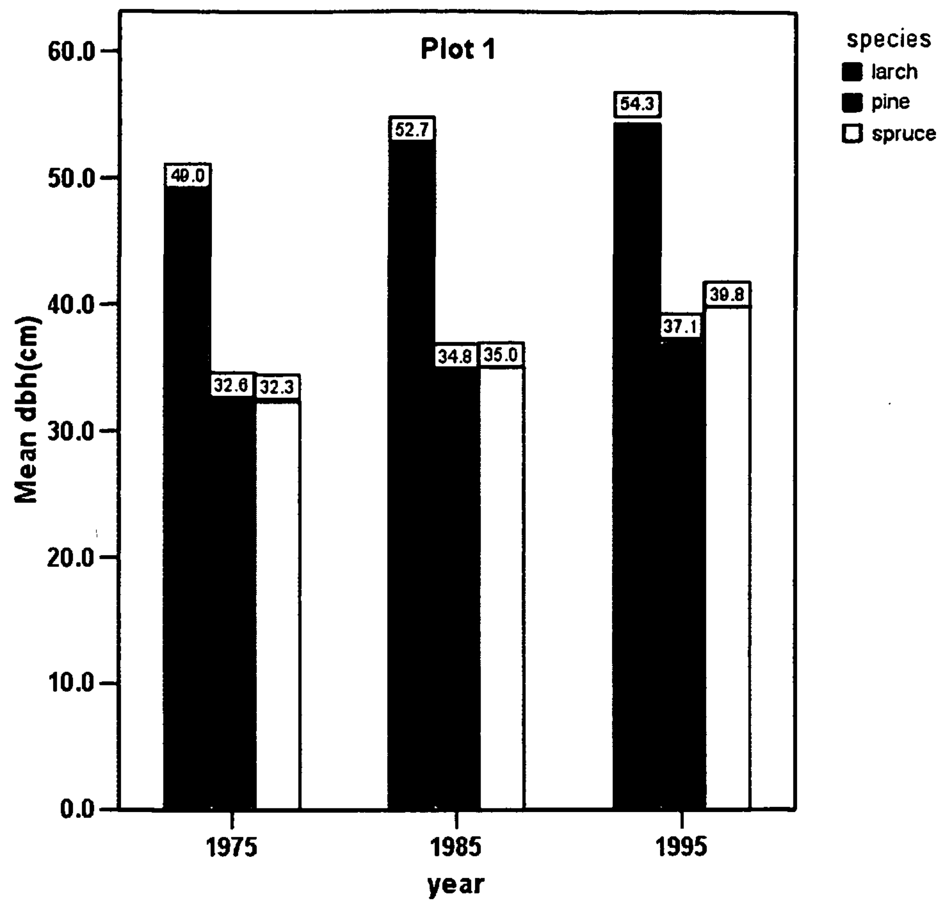


Figure 4.2 European larch, Swiss stone pine, Norway spruce Mean dbh of each observation year 1975, 1985, and 1995 in even-aged plot 1

The ranking of mean height in year 1975, 1985 and 1995 is the same: European larch>Norway spruce>Swiss stone pine (Figure 4.3).

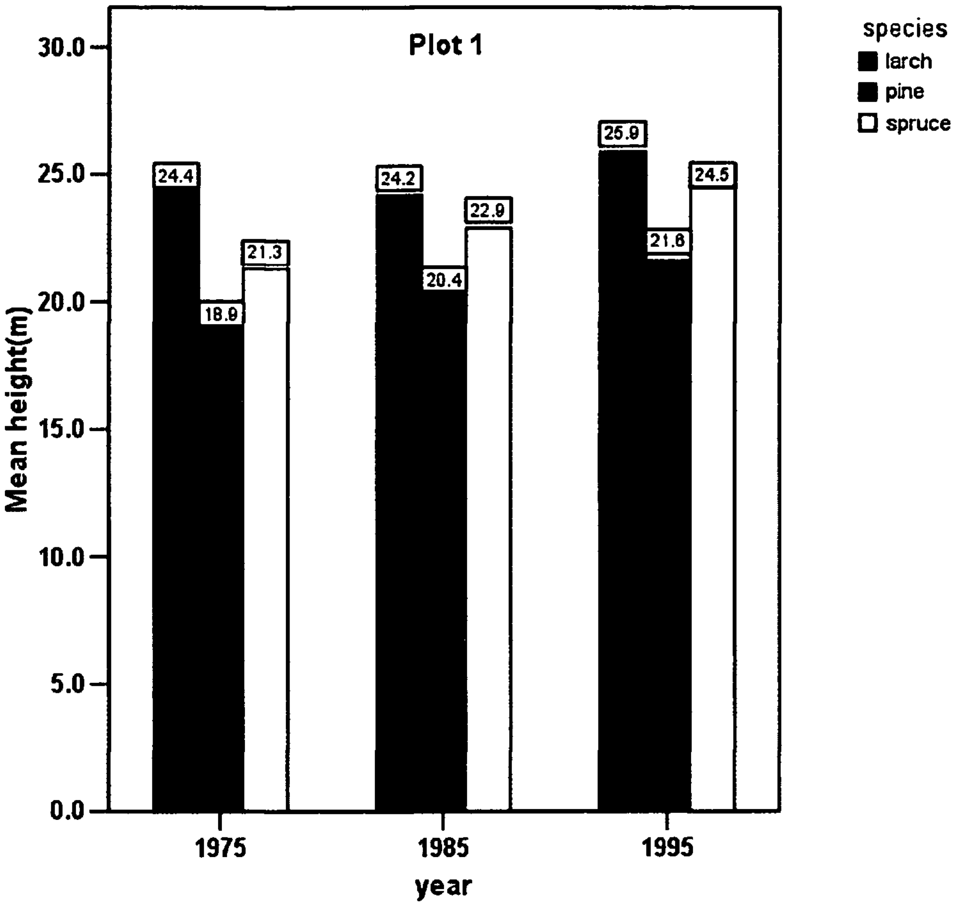


Figure 4.3 European larch, Swiss stone pine, Norway spruce Mean height of each observation year 1975, 1985, and 1995 in even-aged plot 1

The tree species composition is Norway spruce>Swiss stone pine>European larch (Figure 4.4).

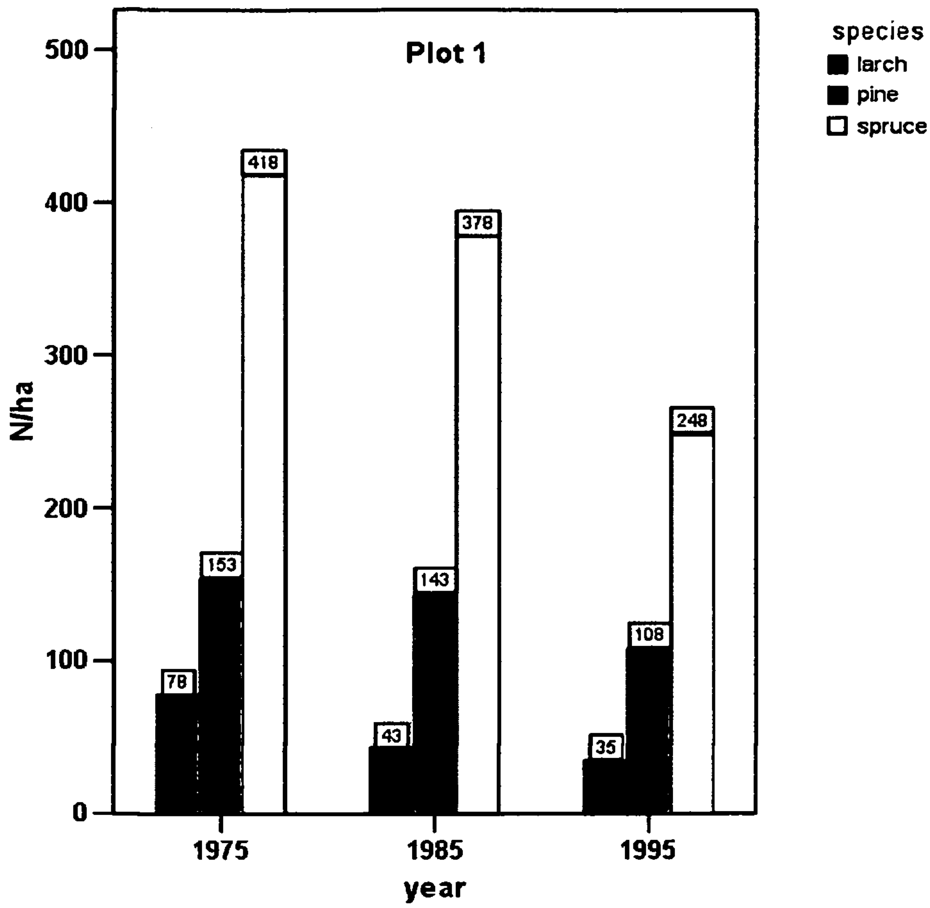


Figure 4.4 European larch, Swiss stone pine, Norway spruce stand density of each observation year 1975, 1985, and 1995 in even-aged plot 1

The basal area and volume of Norway spruce per hectare is much higher than European larch and Swiss stone pine because of its large number per hectare (Figure 4.5and Figure 4.6)

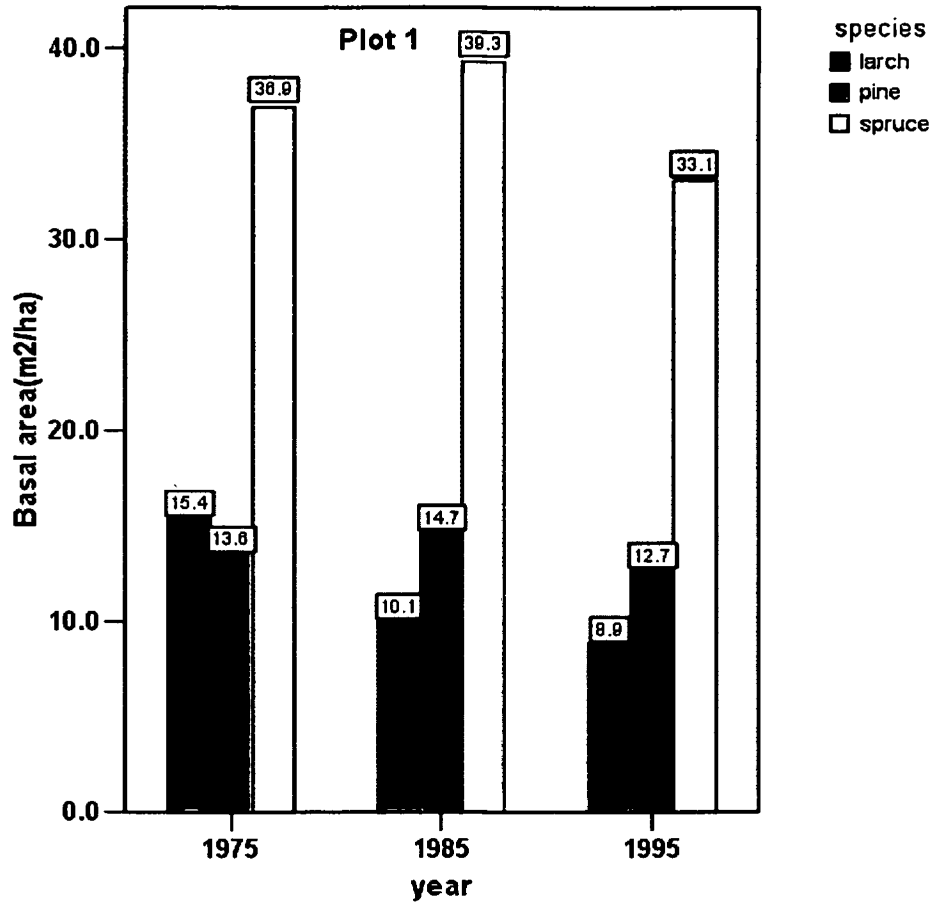


Figure 4.5 European larch, Swiss stone pine, Norway spruce basal area of each observation year 1975, 1985, and 1995 in even-aged plot 1

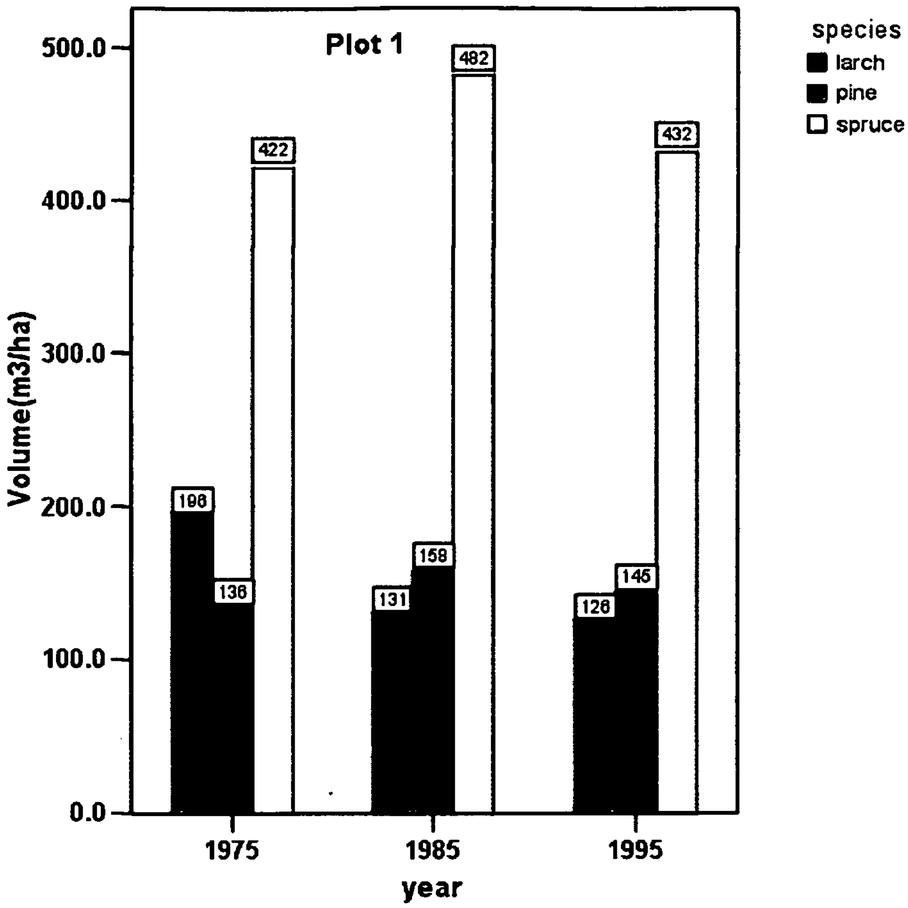


Figure 4.6 European larch, Swiss stone pine, Norway spruce standing volume of each observation year 1975, 1985, and 1995 in even-aged plot 1

4.3.2. Uneven-aged site

The following figures show the development trend of mean dbh, mean height, and number of trees per hectare, basal area and volume of uneven-aged plot 15 under management. Each year, the mean dbh of European larch is bigger than Swiss stone pine bigger than Norway spruce (Figure 4.7).

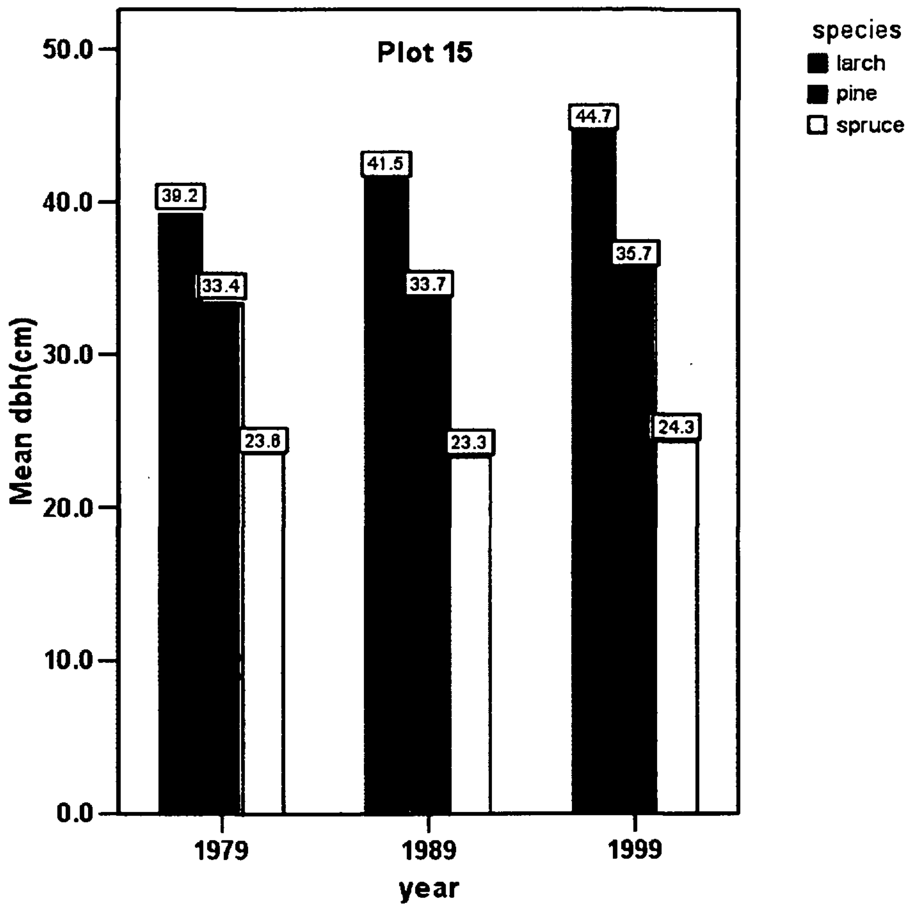


Figure 4.7 European larch, Swiss stone pine, Norway spruce mean dbh of each observation year 1979, 1989, and 1999 in uneven-aged plot 15

The mean height of each year is: European larch > Swiss stone pine > Norway spruce (Figure 4.8).

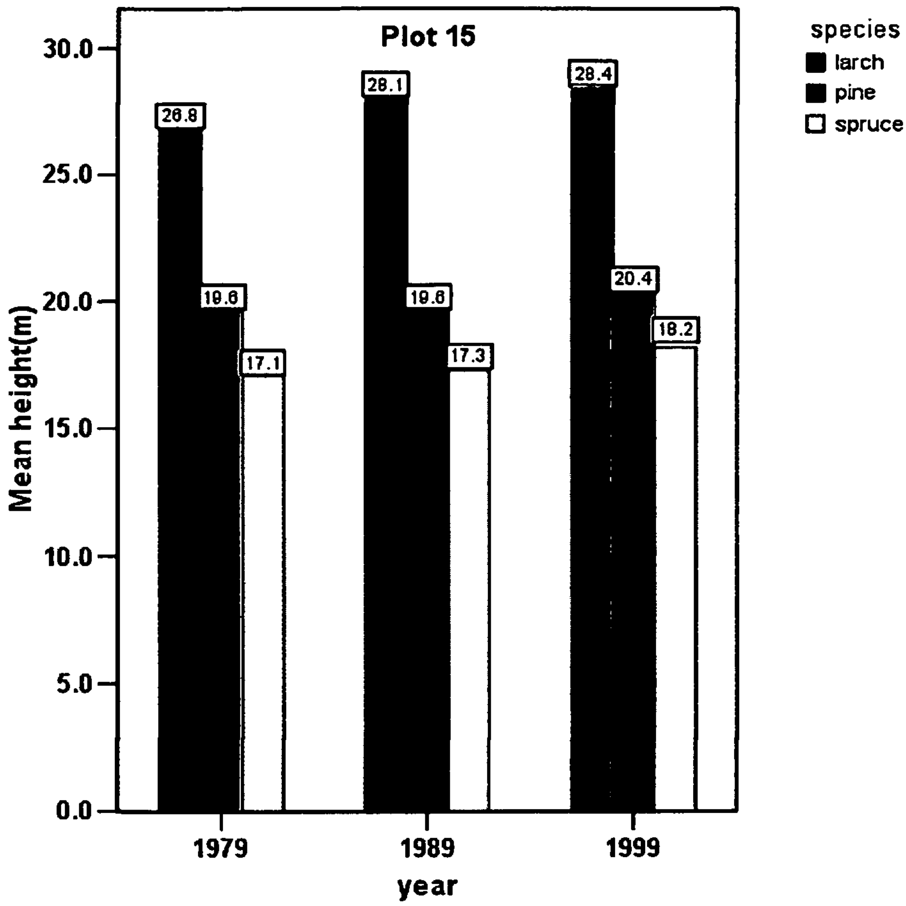


Figure 4.8 European larch, Swiss stone pine and Norway spruce mean height of each observation year 1979, 1989 and 1999 in uneven-aged plot 15

The number per hectare of Norway spruce is much higher than Swiss stone pine and European larch (Figure 4.9).

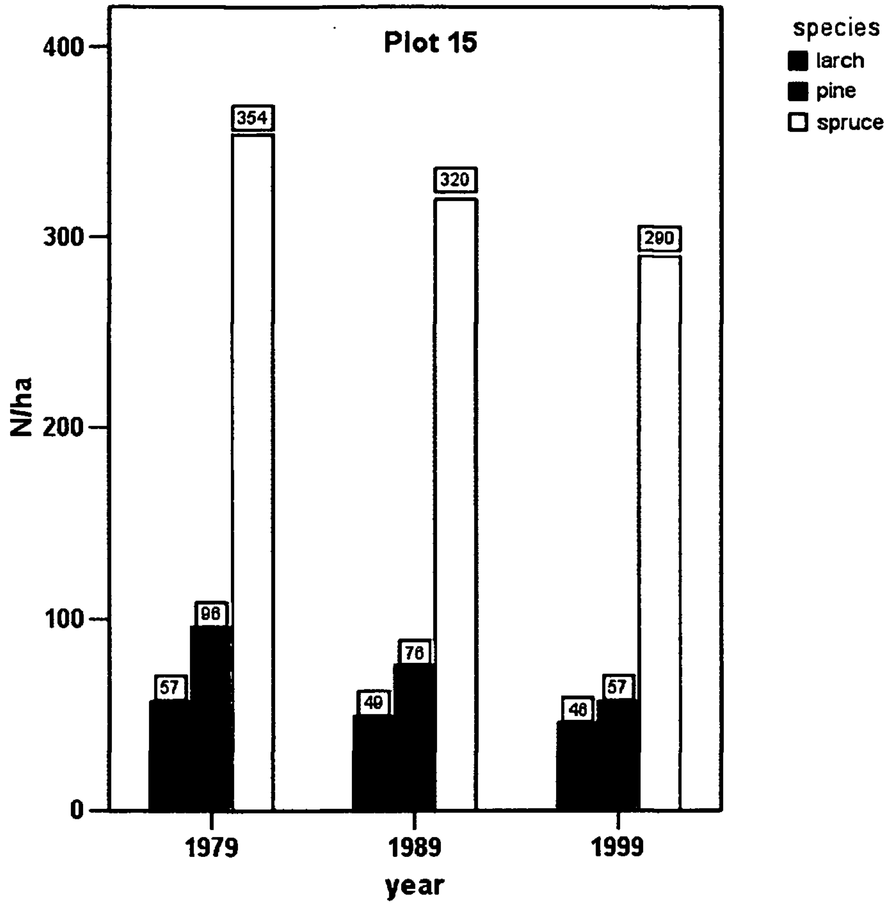


Figure 4.9 European larch, Swiss stone pine, and Norway spruce stand density of each observation year 1979, 1989, and 1999 in uneven-aged plot 15

The basal area and volume of Norway spruce are larger than European larch and Swiss stone pine (Figure 4.10 and Figure 4.11)

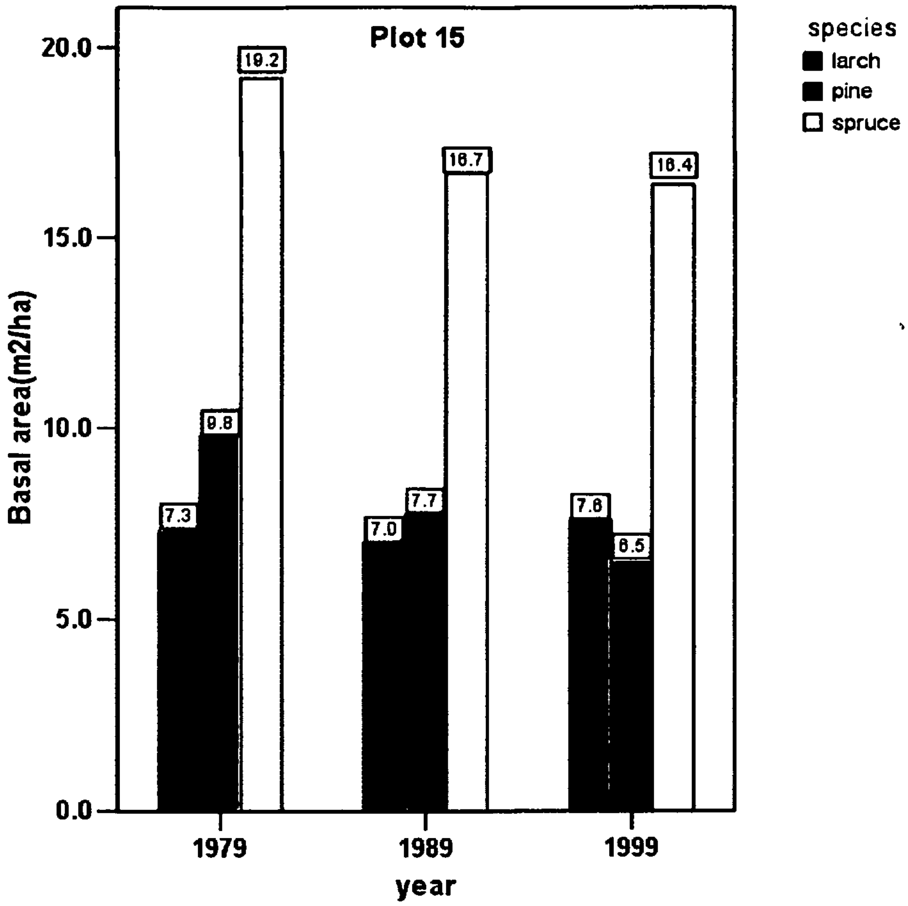


Figure 4.10 European larch, Swiss stone pine, and Norway spruce mean basal area of each observation year 1979, 1989, and 1999 in uneven-aged plot 15

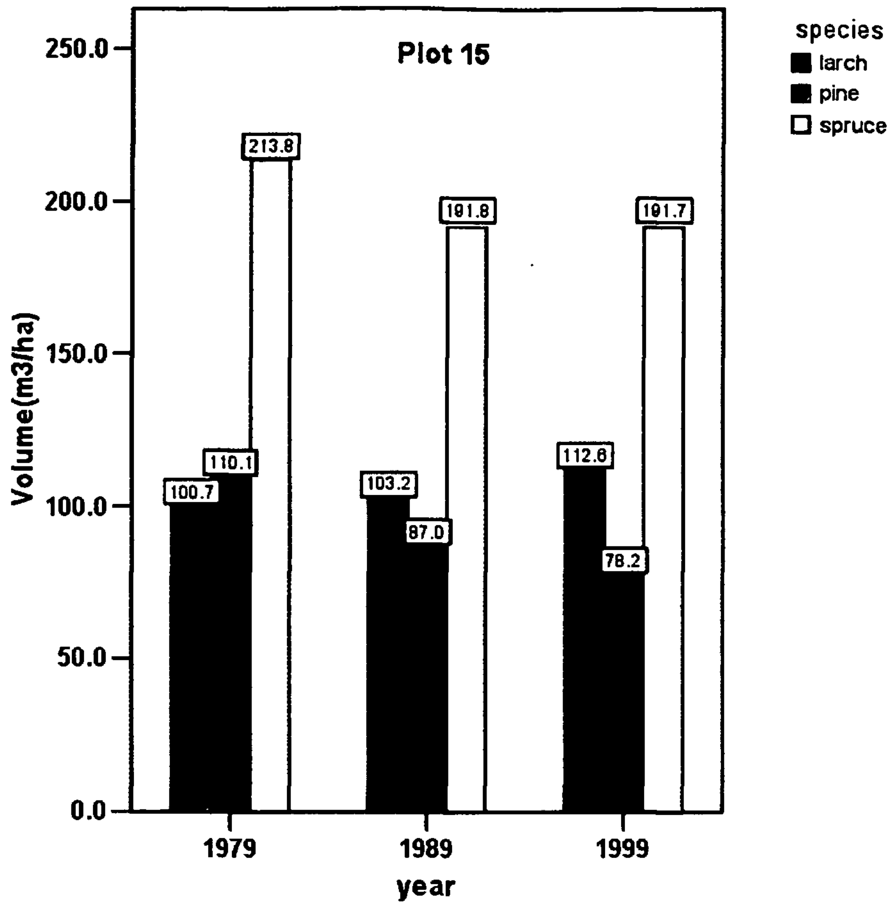


Figure 4.11 European larch, Swiss stone pine, and Norway spruce mean basal area of each observation year 1979, 1989, and 1999 in uneven-aged plot 1

4.3.3. Productivity

Here is to compare even-aged and uneven-aged annual productivity during 20 years and to compare different species annual productivity both in even and uneven-aged plots at the same duration: for even-aged plot 1 is from 1975 to 1995, for uneven-aged plot 15 is from 1979 to 1999.

The even-aged plot productivity is bigger than that in uneven-aged plot (Table 4.4).

For species comparison: both in even-aged and uneven-aged plots, the ranking of productivity is: Norway spruce > European larch > Swiss stone pine. In both even and uneven-aged plot, the European larch has the highest productivity (Table 4.4).

Table 4.4 Mean productivity (m^3/ha/year) in even and uneven-aged plots

	All species	Spruce	Larch	Pine
Even-aged	40.9	22.1	11.1	7.7
Uneven-aged	28.9	14.9	7.2	6.8

4.3.4. Short time potential productivity—in-growth of trees with a dbh ≥ 45cm

Here is to assume that trees with a dbh about 50 cm are the mature trees can be harvest. Thus the trees with a dbh ≥ 45cm are the potential productivity in short time, which means after 20 years growth, they may enter the mature trees to be harvest.

The potential productivity of trees with a dbh ≥ 45cm in even-aged plot is larger than that in uneven-aged plot (Table 4.5).

To compare different tree species volume increment: in even-aged plot, Norway spruce is higher than European larch than Swiss stone pine; in uneven-aged plot, European larch grows faster than Norway spruce than Swiss stone pine (Table 4.5).

There is no significance difference between three tree species' annual dbh and height increment in even-aged plot (Table 4.5, Table 4.6 and Table 4.7). In uneven-aged plot, no significance difference between the three tree species' annual dbh increment, thus the annual height increment of spruce is significant higher than larch, but no significance between spruce and pine, larch and pine (Table 4.5 and Table 4.9).

Table 4.5 Mean tree potential in-growth (m^3/ha/year) of trees with a dbh ≥ 45cm in even and uneven-aged plots

		All species	Spruce	Larch	Pine
Even-aged	DI(cm/year)	0.359±0.023	0.376±0.030	0.368±0.042	0.244±0.007
	HI(m/year)	0.096±0.023	0.091±0.037	0.112±0.030	0.065±0.068
	BAI(m2/ha/year)	0.24	0.13	0.98	0.02
	VI(m3/ha/year)	4.13	2.10	1.77	0.26
Ueven-aged	DI(cm/year)	0.231±0.013	0.204±0.017	0.258±0.023	0.213±0.043
	HI(m/year)	0.105±0.018	0.153±0.031	0.046±0.020	0.164±0.043
	BAI(m2/ha/year)	0.06	0.02	0.03	0.01
	VI(m3/ha/year)	1.23	0.45	0.55	0.23

*DI—annual dbh increment

*HI—annual height increment

*BAI—annual basal area increment

*VI—annual volume increment

*N/ha—tree number per hectare

Table 4.6 T-test for annual dbh in-growth of trees with a dbh ≥45cm in even-aged plot

	Spruce	Larch	Pine
Spruce		0.840	0.437
Larch	0.840		0.903
Pine	0.437	0.903	

***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$

Table 4.7 T-test for annual height in-growth of trees with a dbh ≥45cm in even-aged plot

	Spruce	Larch	Pine
Spruce		0.928	0.957
Larch	0.928		0.79
Pine	0.957	0.790	

***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$

Table 4.8 T-test for annual dbh in-growth of trees with a dbh ≥45cm in uneven-aged plot

	Spruce	Larch	Pine
Spruce		0.103	0.758
Larch	0.103		0.229
Pine	0.758	0.229	

***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$

Table 4.9 T-test for annual height in-growth of trees with a dbh ≥45cm in uneven-aged plot

	Spruce	Larch	Pine
Spruce		0.026*	0.770
Larch	0.026*		0.125
Pine	0.770	0.125	

***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05

4.3.5. Sustainability of productivity – in-growth of dbh < 45cm of different tree species

The volume in-growth of trees with a dbh < 45cm in even-aged plot is higher than that in uneven-aged plot (Table 4.10).

For different species cooperation, in even-aged plot, the annual dbh increment of Norway spruce is significant larger than European larch, thus no significant difference between Norway spruce and Swiss stone pine, no significant difference between European larch and Swiss stone pine, either (Table 4.10 and Table 4.11); for the annual height increments: Swiss stone pine is significant larger than Norway spruce, but no significance between Norway spruce and European larch, Swiss stone pine and European larch (Table 4.10 and Table 4.12).the volume increment ranking is: Norway spruce > Swiss stone pine > European larch(Table 4.10).

In uneven-aged plot, the annual dbh increment of European larch is significant larger than Norway spruce than Swiss stone pine (Table 4.10 and Table 4.13); the annual height increments of Norway spruce and European larch are significant larger than Swiss stone pine, but no significance between European larch and Norway spruce (Table 4.10 and Table 4.14); the annual volume increment is: Norway spruce > European larch > Swiss stone pine (Table 4.10).

Table 4.10 Mean in-growth (m^3/ha/year) of dbh < 45 cm of different tree species in even and uneven-aged plots

		All species	Spruce	Larch	Pine
Even-aged	DI(cm/year)	0.224±0.009	0.237±0.011	0.213±0.062	0.193±0.015
	HI(m/year)	0.142±0.006	0.137±0.008	0.205±0.105	0.148±0.010
	BAI(m2/ha/year)	0.49	0.36	0.01	0.12
	VI(m3/ha/year)	8.34	6.12	0.13	2.08
Ueven-aged	DI(cm/year)	0.206±0.007	0.209±0.005	0.224±0.015	0.177±0.011
	HI(m/year)	0.123±0.008	0.143±0.006	0.099±0.018	0.037±0.010
	BAI(m2/ha/year)	0.32	0.22	0.04	0.06
	VI(m3/ha/year)	4.78	3.26	0.77	0.74

*DI—annual dbh increment *HI—annual height increment

*BAI—annual basal area increment *VI—annual volume increment

*N/ha—tree number per hectare

Table 4.11 T-test for annual dbh increment of trees with a dbh < 45cm in even-aged plots

	Spruce	Larch	Pine
Spruce		0.045*	0.482
Larch	0.045*		0.066
Pine	0.482	0.066	

***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05

Table 4.12 T-test for annual height increment of trees with a dbh < 45cm in even-aged plots

	Spruce	Larch	Pine
Spruce		0.347	0.036*
Larch	0.347		0.300
Pine	0.036*	0.300	

***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05

Table 4.13 T-test for annual dbh increment of trees with a dbh < 45cm in uneven-aged plots

	Spruce	Larch	Pine
Spruce		0.000***	0.000***
Larch	0.000***		0.002**
Pine	0.000***	0.002**	

***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05

Table 4.14 T-test for annual height increment of trees with a dbh < 45cm in uneven-aged plots

	Spruce	Larch	Pine
Spruce		0.218	0.040*
Larch	0.218		0.000***
Pine	0.040*	0.000***	

***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05

4.3.6. dbh class distribution

In even-aged plot, the dbh of all classes of Norway spruce spared evenly in the year 1975, 1985 and 1995. The number of trees that has a dbh bigger than 45cm is increasing, but the smaller trees number is decreasing (Figure 4.12). For European larch, there are no trees between 10 and 30cm, the smaller trees with a dbh of or below 10cm remain the same, but the large trees are decreasing (Figure 4.13). The smaller trees of Swiss stone pine are getting less thus bigger trees are increasing (Figure 4.14).

The Norway spruce and Swiss stone pine shows the trend of sustainable productivity due to the dbh class balance of each year (Figure 4.12 and Figure 4.14). The lack of middle age trees may result in the decrease of productivity in the long run (Figure 4.13)

In uneven-aged plot, the dbh class distribution of Norway spruce, Swiss stone pine and European larch all show the trend of sustainable productivity due to the dbh class balance of each year (Figure 4.15, Figure 4.16 and Figure 4.17).

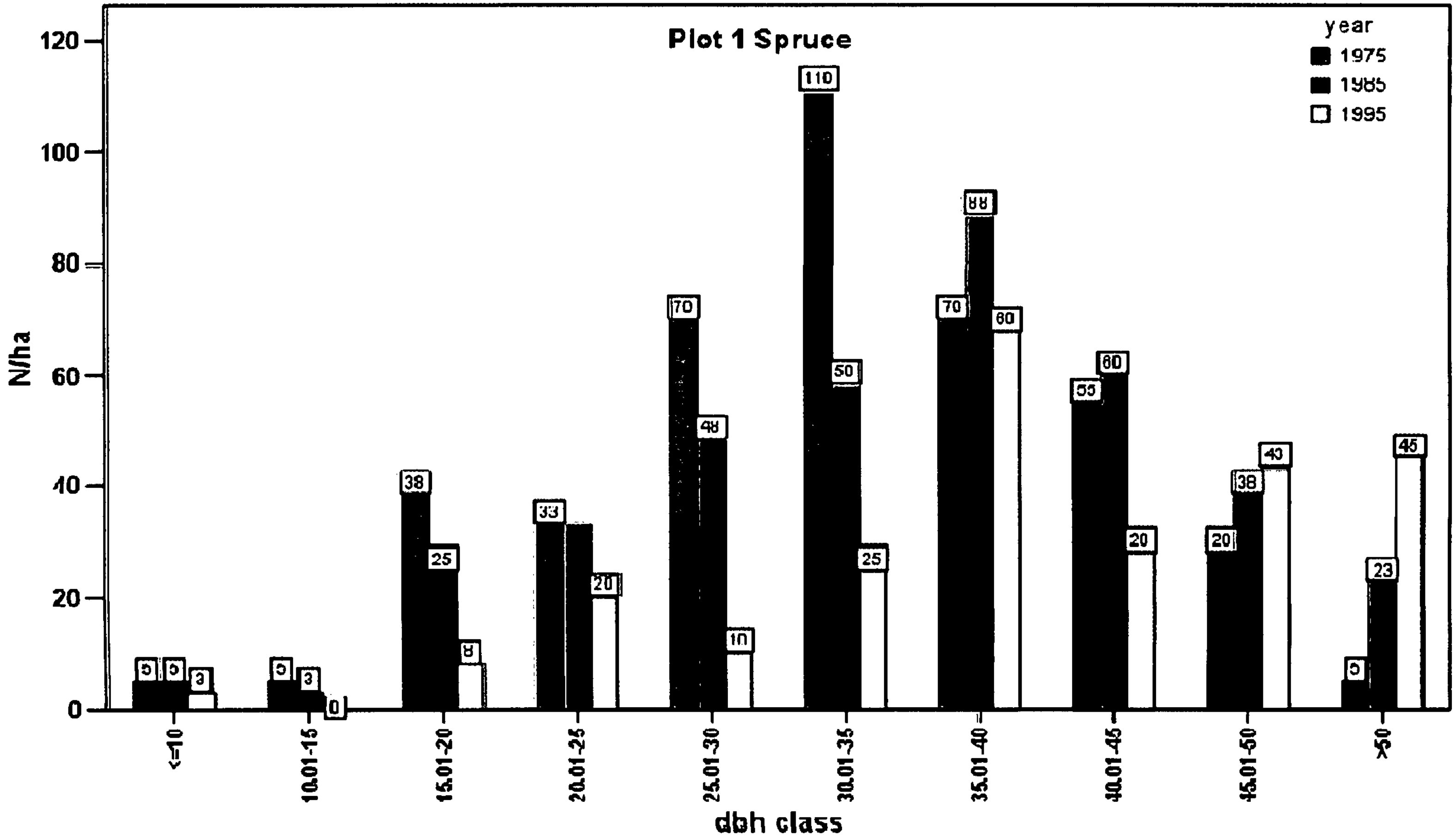


Figure 4.12 Norway spruce stand structure developments during year 1975-1995 in even-aged plot 1

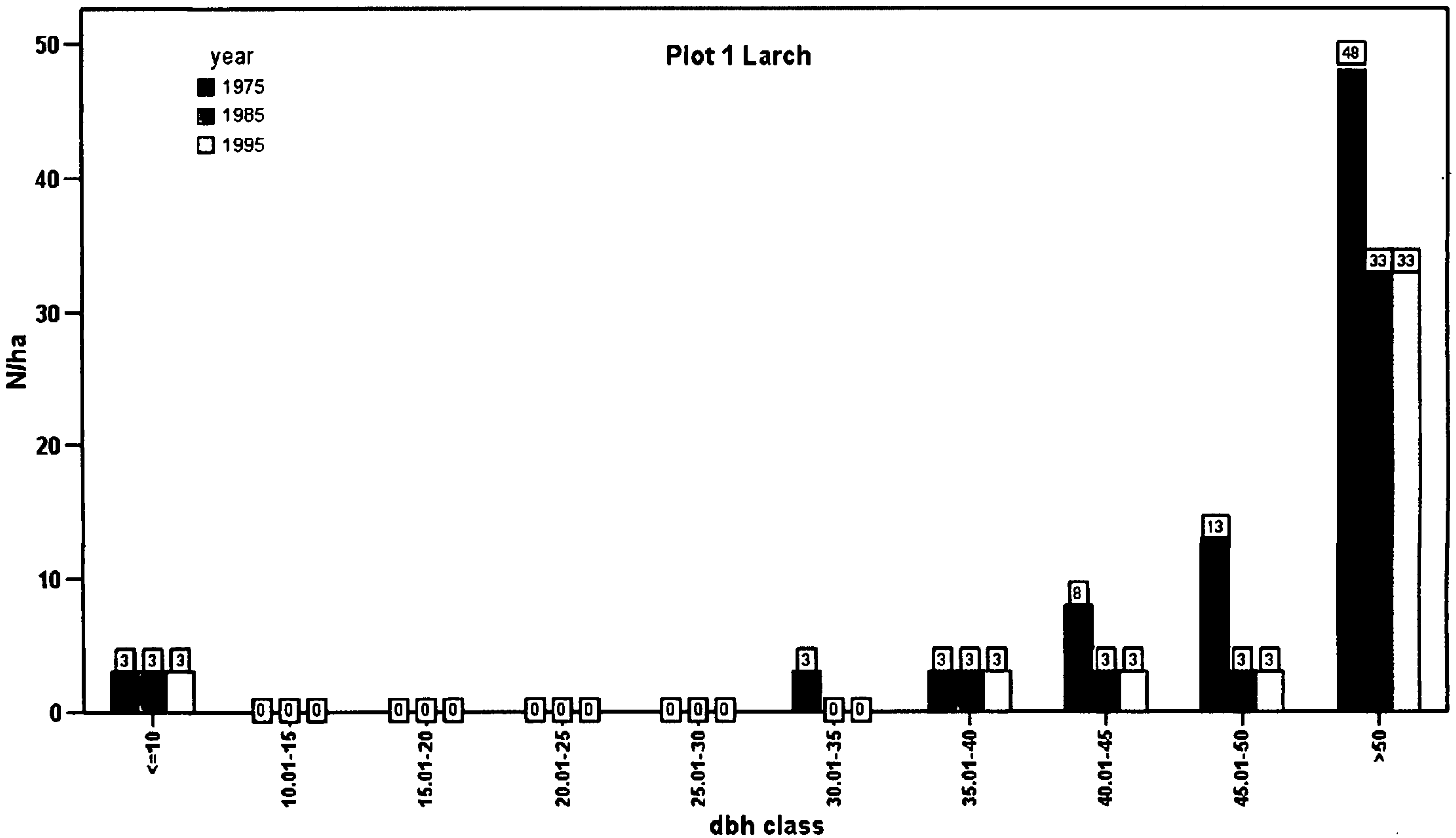


Figure 4.13 European larch stand structure development during year 1975-1995 in even-aged plot 1

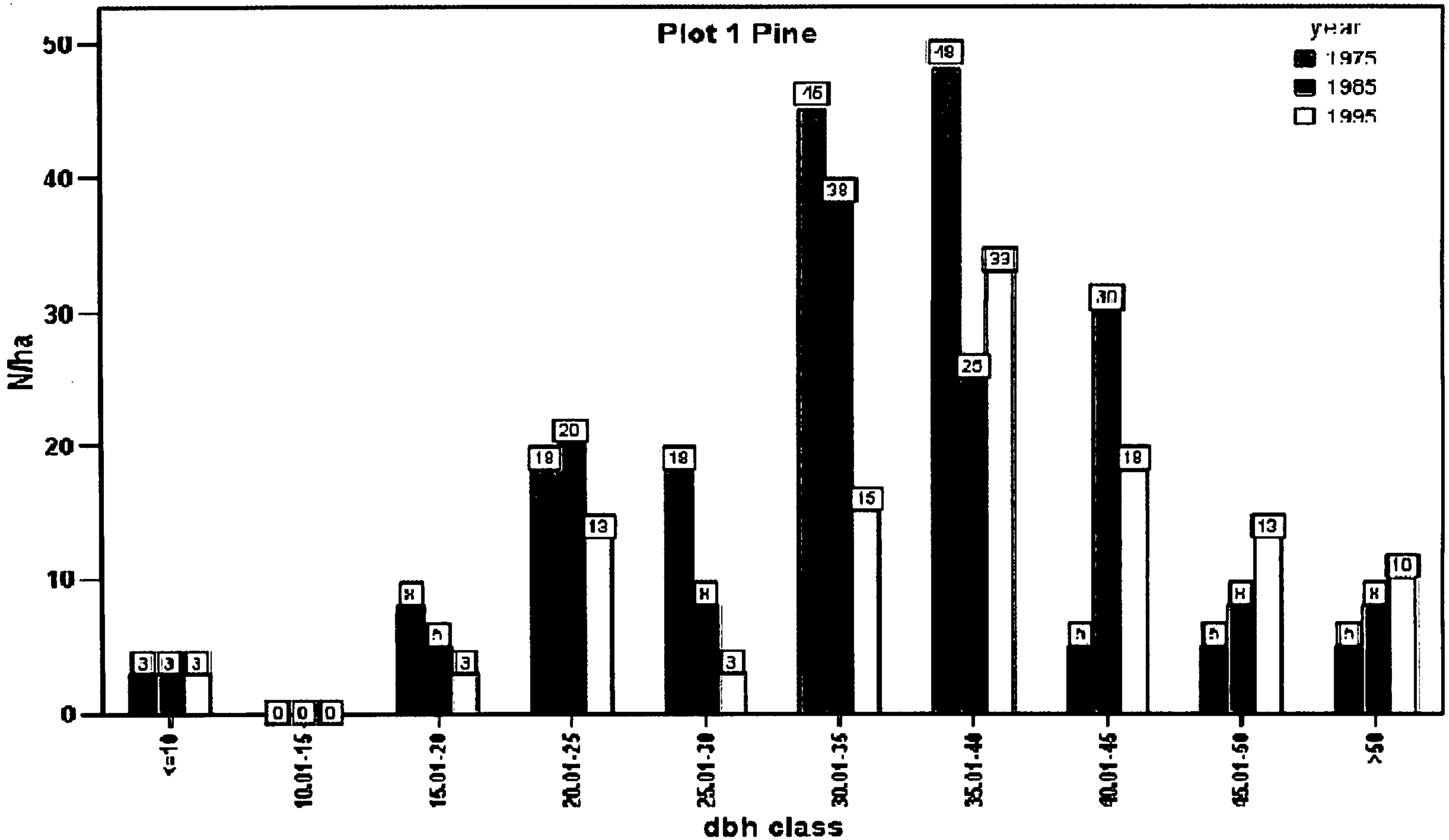


Figure 4.14 Swiss stone pine stand structure development during year 1975-1995 in even-aged plot 1

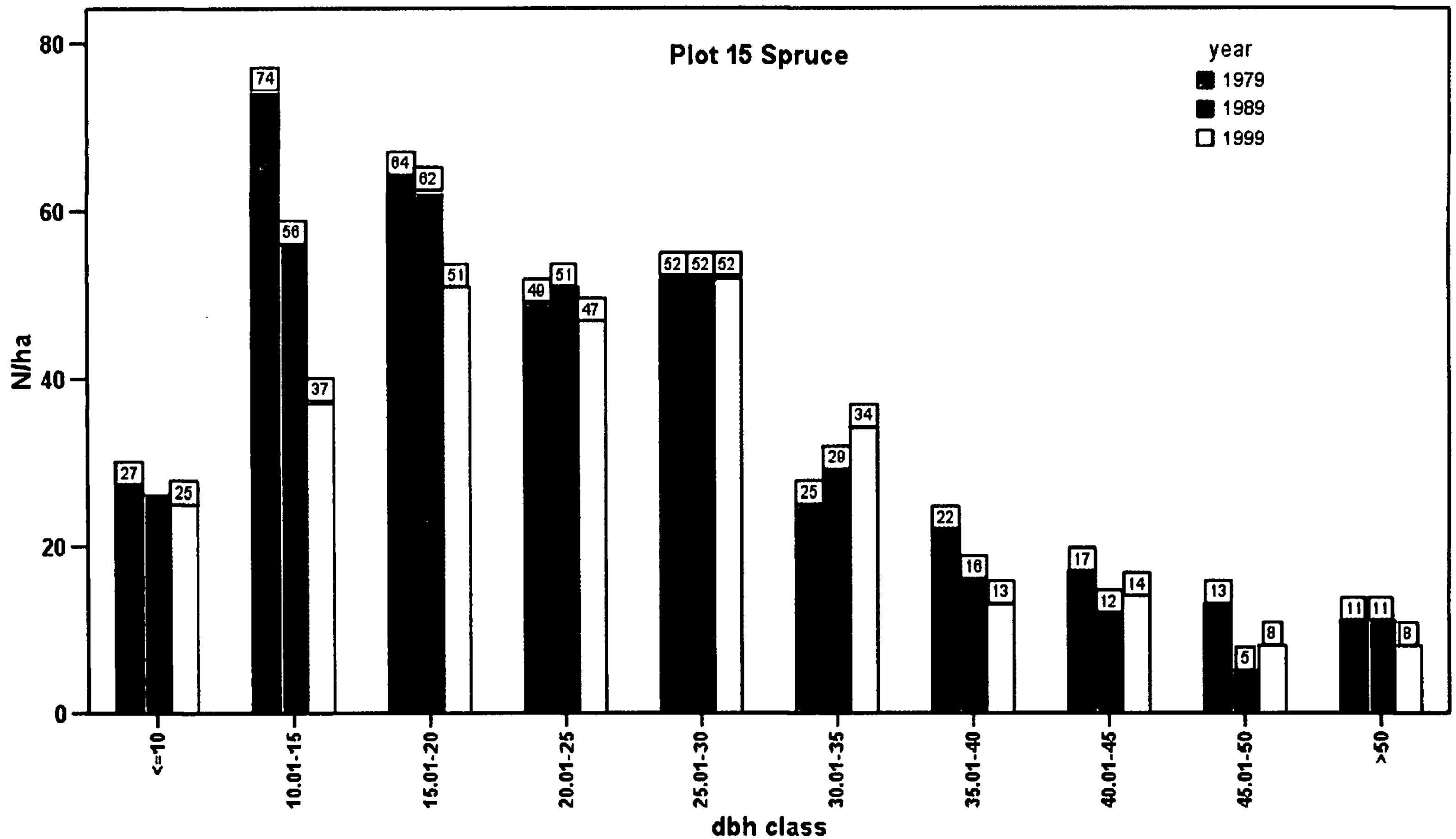


Figure 4.15 Norway spruce stand structure developments during year 1979, 1989 and 1999 in uneven-aged plot 15

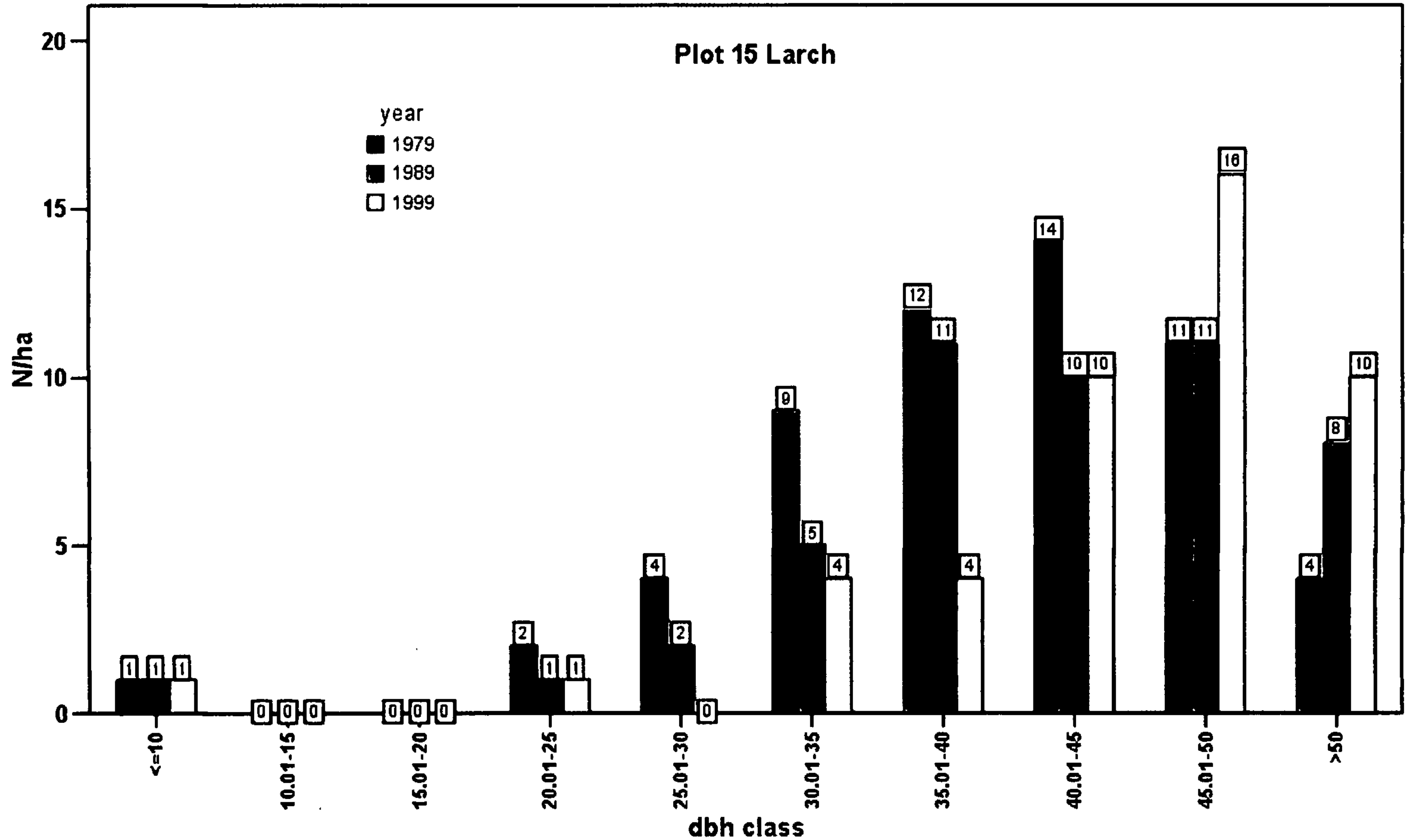


Figure 4.16 European larch stand structure developments during year 1979, 1989 and 1999 in uneven-aged plot 15

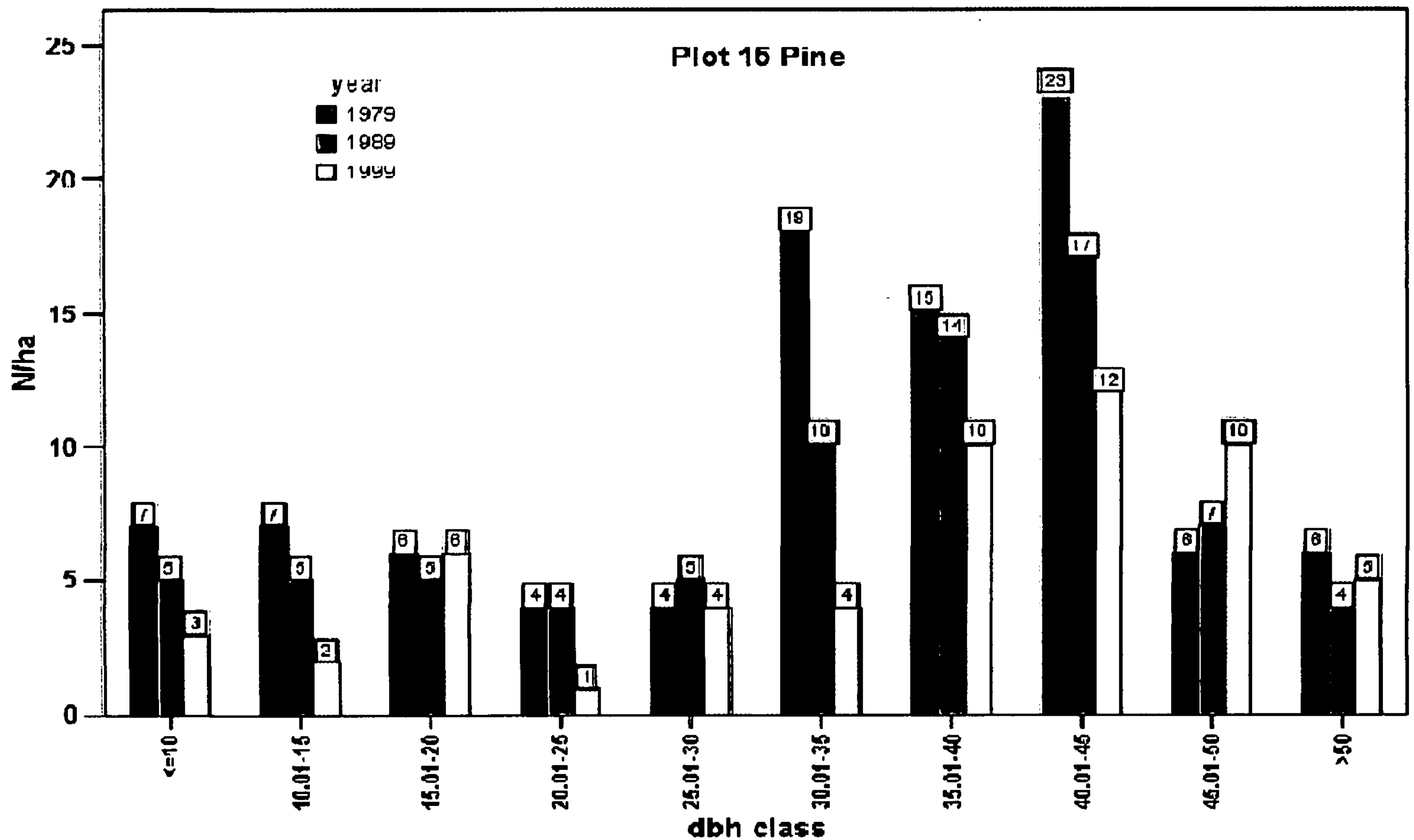


Figure 4.17 Swiss stone pine stand structure developments during year 1979, 1989 and 1999 in uneven-aged plot 15

5. Discussion

5.1. What effect forest productivity

5.1.1. Site quality and age

Site quality has a great influence on and often longest-lasting effect on differences in the productivity of various indigenous and plantation forests. The important components of site quality are: soil depth and drainage; soil physical and chemical composition (including pH); amount and pattern of yearly soil moisture availability; frequency and nature of common and occasional winds, storms and fires; and the general climate of the area. The presence and importance of such things as competing vegetation, and of populations of animals, insects and microorganisms that are either damaging or beneficial to trees, can and should also influence selection and later management of forest plantation sites. The size and health of trees already present on the sites are good but imperfect indicators of site quality. Different species of trees on candidate sites will index them differently, and genetic differences within the same species can also result in substantial differences in derived site-indexes between similar sites, or vice versa (Libby, 2002).

Site index is a measure of a forest's potential productivity and usually is defined as the height of the dominant or co- dominant trees at a specified age in a stand. It is calculated in an equation that uses the tree's height and age. Site index functions differ by tree species and regions. Site index functions are developed through fieldwork and analysis of data by establishing research plots in stands of a particular tree species covering a range of site conditions, select representative dominant or co-dominant trees and measure their heights, ages, and diameters. It is also a method to weight the quality of the site.

The site indices of even-aged and uneven-aged plot show the potential height growth of plots according to different site quality and different species (Table 3.4). The site quality of the observed plots is in uneven-aged plot, better than the even-aged plot, but even-aged plot has a higher productivity than uneven-aged plot, thus the site quality is not the key parameter effect productivity in this study.

But other parameters can affect productivity must be taken into consideration, for instance, the site age, if even aged stands are in the range of 30 to 90 years, they have high increment and if an uneven-aged forest has a mean age of more than 100 they have low increment even if they have a better site index. In this study, the even-aged forest's site age is 96-116 years old from year 1975 to 1995, so it is in the low increment range, the dominant tree age of uneven-aged forest is 139-159 years old from year 1979 to 1999, also in a low increment range. Thus site age is not key parameter effect productivity either.

5.1.2. Stand density

Stand density is a quantitative measure of how completely a stand of trees occupies a site, usually expressed in terms of number of trees or tree basal area per acre per hectare (Helms, 1998).

The basal area of even-aged plot is 67.7 m^2/ha, uneven-aged plot's basal area is 30.3 m^2/ha, and the density in even-aged plot is higher than uneven-aged plot. Thus the stand density is not the key parameter effect productivity in this study either.

5.1.3. Different tree species productivity and utilization

The first decision to be made about each forest plantation site is whether it will be a mono-species plantation, or whether it will be planted to two or more species in mixture. European tradition has favored mono-species forest plantations, largely based on European experience in trying to domesticate their indigenous species.

In both even-aged harvest method-shelter wood method and uneven-aged harvest method-single tree selection, the shade-tolerant and shade-intolerant tree species composition plays an important role of sustainable high productivity (Libby, 2002).

Both of the plots are European larch-Norway spruce-Swiss stone pine mixed stand. In even-aged plots (site age is 96-116 years old from year 1975 to 1995), the volume increment of Norway spruce is higher than European larch and Swiss stone pine; In uneven-aged plot (site age is 139-159 years from year 1979 to 1999), the highest productivity is also Norway spruce.

European larch is intolerant of shade at any age (Josef, 1956). Its open crown transmits a considerable amount of light so that it does not tend to suppress more tolerant under story species. European larch can be planting in mixtures with more tolerant species works well if the stands are thinned to allow European larch to maintain a dominant crown position; it does not usually suppress its more tolerant neighbors (McComb, 1995). European larch is fast growing, that establishes itself rapidly and is also said to improve the quality of the soil, and it can be used as a pioneer species on cleared and exposed land in order to assist the establishment of other woodland trees (Grieve, 1984). But European larch grows slow down when it gets to mature, and has a short rotation than pine and spruce result in the uneven-aged plot, the spruce shows faster than it.

Norway spruce is a shade-tolerant conifer that is able to grow normally in the shade and in competition; it grows slowly, but steadily and eventually overtake the tree stand.

Swiss stone pine is a shade-intolerant conifer grows steady though not fast growth on a wide range of sites where the climate is cold. Thus it grows rate can not compare to European larch, the regeneration can only survive in gaps, since in both even-aged and uneven-aged plots, the Swiss stone pine need more pay attention to manage.

European larch is a potentially important timber species throughout Europe increasing the environmental and amenity value of forests. It is one of the fastest growing conifers with valuable wood properties high productivity goes hand in hand with high quality in this tree. European larch wood is durable and strong (Elwes and Henry 1907), of moderately high density, with excellent toughness and stiffness. Apart from the Yew, it is perhaps the strongest and toughest conifer wood (Einspahr and Wyckoff, 1984). It is used for pulp, framing timber, roof tiles, flooring, and log houses. It is suitable for veneer and other decorative purposes (Miller and Knowles 1988). Larch wood is resistant to rot, and is therefore valuable for posts, poles, railroad ties, wharves, pilings and mine props.

Norway spruce wood is strong, soft, straight- and fine-grained, and easily worked (Collingwood and Brush, 1964). It is not durable in contact with soil. It is widely used for construction, pulp, furniture, and musical instruments (Collingwood and Brush, 1964; Vogel, 1981). Norway spruce is one of the most common and economically important coniferous species in Europe and Scandinavia (Liedeker, 1988)

Besides the aesthetic functions, the Swiss stone pine timber is highly valued, especially for paneling, carvings and traditional furniture because of its special wood characteristics which are soft, light, resistant, warm reddish color, perfume of resin (Ulber, 2003).

5.2. Compare even-aged and uneven-aged stand structure

5.2.1. Sustainable capabilities

Whether or not a sustained yield is possible in selection forests depend on their structure and their change in the course of time. In a selection forest in equilibrium, balanced structures are also to be found on small areas (Zingg, 1997). The most important structure index is the diameter distribution. If it is a balanced dbh distribution, the in-growth will be constant, and volume production will sustainable. The Figures 4.17, 4.18 and 4.19 shows the constant dbh distribution in uneven-aged plot 15, but in even-aged plot 1, larch do not have small dbh classes to maintain timber productivity for a certain time period (Figure 4.15). Thus the sustainable of larch in even-aged plot 1 cannot be kept.

But to scale a forest's sustainability, not only focus on its sustainable yield, but also to look at the aspect of environmental, economic, social and cultural sustainability at the same time. With rapid development of forestry industry nowadays and a sharply increasing desire of environmental conservation worldwide, sustainable forest management become a popular discipline, and forest management knowledge is demanded by most stakeholders involved in forestry industry and forest conservation organizations. This trend results in a positive move of development and implement of sustainable forestry. More than 150 countries all over the world are presently involved in inter-Governmental processes or initiatives on criteria and indicators for sustainable forest management. (Walter, et al., 2001)

Forest management should be a tool of achieving sustainability. It defines a criteria on utilizing forest resource in a right way, not only keep the sustainability for current generation, but also including consideration of next and following generations.

6. Summary

This study is first to illuminate the impact of forest management. The following is to compare even and uneven-aged forest productivity and sustainability, and compare productivity among European larch, Norway spruce and Swiss stone pine. Analyze the parameters affect productivity and sustainability.

In even-aged plot 1, the annual basal area increment under management is 0.73m^2/ha/year, without management is 0.23m^3/ha/year; in uneven-aged plot, the increment under management is 0.38m^2/ha/year, without management is 0.21m^2/ha/year.

In even-aged plot 15, the annual volume increment under management is 12.47m^3/ha/year, without management is 3.98m^3/ha/year; in uneven-aged plot, the increment under management is 6.01m^3/ha/year, without management is 3.49m^3/ha/year.

Both show that the increment of managed plot 1 larger than that of unmanaged plot 15.

About even and uneven-aged plots productivity: in 20 years development, the productivity of even-aged plot 1 is 40.9m^3/ha/year higher than 28.9 m^3/ha/year of uneven-aged plot 15.

To compare tree species: in even-aged plot 1, the annual harvest of Norway spruce is 22.1 m^3/ha/year, European larch is 11.1 m^3/ha/year, Swiss stone pine is 7.7m^3/ha/year; in uneven-aged plot 15, Norway spruce is 14.9m^3/ha/year, European larch is 7.2m^3/ha/year, and Swiss stone pine is 6.8 m^3/ha/year. The European larch has the highest productivity in both plots.

The results about potential productivity-the in-growth of trees with a dbh $\geq$ 45 cm in 20 years show that even-aged plot 1 has a higher productivity (4.13m^3/ha/year) than uneven-aged plot 15 (1.23m^3/ha/year). To compare tree species: in even-aged plot 1, Norway spruce has the highest increment of 2.10m^3/ha/year. In uneven-aged plot 15, European larch has the highest increment of 0.55m^3/ha/year.

To estimate the sustainability of productivity is to look at the increment with a dbh < 45cm, and if a forest has a balanced dbh class distribution. The results show that the potential productivity of even-aged plot 1 ($8.34m^3$/ha/year) is higher than that of uneven-aged plot 15 ($4.78m^3$/ha/year).

To compare tree species: Norway spruce volume increment in even-aged plot 1 is $6.12m^3$/ha/year, European larch is $0.13m^3$/ha/year, Swiss stone pine is $2.08m^3$/ha/year; in uneven-aged plot 15 are 3.26, 0.77 and 0.74 m^3/ha/year. So in even-aged plot 1, the ranking is: European larch > Norway spruce > Swiss stone pine; in uneven-aged plot 15, the ranking is: European larch > Swiss stone pine > Norway spruce.

The dbh distribution of European of larch in even-aged plot 1 is not balanced, thus cannot guarantee the sustainable productivity. The other species in both even and uneven-aged plot 15 have a good dbh distribution.

In conclusion, the managed forest is more producible than unmanaged forest in this study. The productivity of even-aged plot 1 is higher than uneven-aged plot 15, thus the sustainability of uneven-aged plot 1 is higher than even-aged plot 15. Norway spruce always has the highest volume increment in even-aged and uneven-aged plot 1 and 15.

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