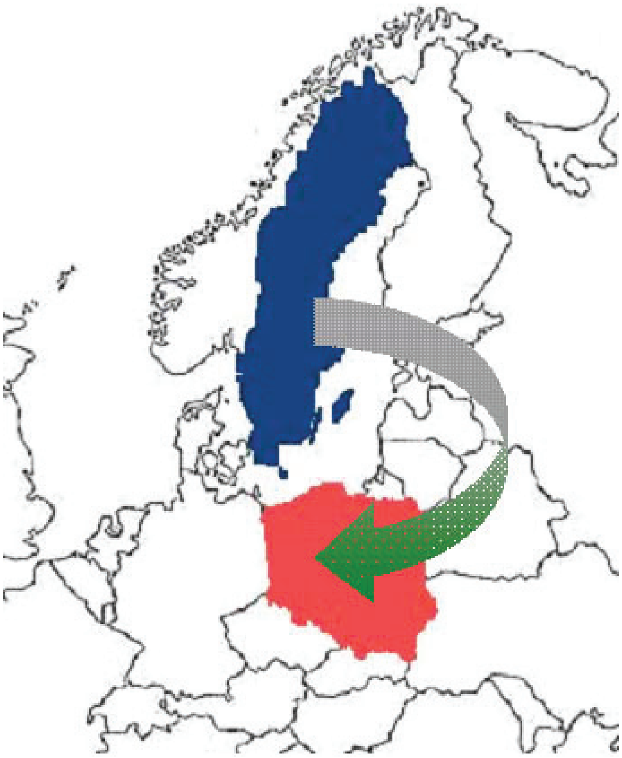
Applying Swedish programmes projecting forest development to Polish forestry conditions

A study made on data from Gostynin forest district in Poland



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Abstract

The paper deals with problems of applying Swedish programmes projecting forest development to Polish forestry conditions. The study was made on data from the Lucien forest sub-district in the Gostynin forest district (Regional Board of State Forests-National Forest Holding in Lodz). The data was applied to three programmes: Forest Time Machine, ProdMod and SFanalys with the matrix model.

The aim of the work is to test the potential for some Swedish forestry computer programmes' application to the data from other country. This was realized by comparing the volume output from computer programmes Forest Time Machine and ProdMod with the figures from Polish growth and yield tables, describing required modifications of input to the programmes and discussing the influence of data modifications on the output from the programmes, as well as on the possibilities of the programmes' application in Poland.

The volume estimations from ProdMod and Forest Time Machine were dissimilar to the data from Polish growth and yield tables. Further studies are needed to evaluate the reliability of the programmes' predictions. The thesis presents some recommendations for possible changes in the programmes' structure to make them more useful in Polish conditions.

Key words: forest development, programmes, Forest Time Machine, ProdMod, SFanalys, matrix model, Poland, Sweden, management planning.

Contents

1 Introduction

Forest is a long-lasting and sensitive complex, so the effects of human activity in stands can be seen far in the future (Andersson et al. 2005). Forestry in Sweden, as well as in Poland, is described as multi- objective oriented (Swedish National Board of Forestry 2000, Heureka 2005 a and b, State Forest National Forest Holding, 2005c). Nowadays the planning process in forestry requires the manager to know the consequences of the options before making the decisions.

Computer programmes projecting forest development, including both single-objective models projecting i.e. tree growth as well as multi-objective systems, are useful tools for decision-makers in modern forestry to solve problems connected with management and timber supply planning (Jonsson et al. 1993, Fries et al. 1998, Gadow and Hui 1999, Andersson et al. 2005). Growth models forecast the development of tree cover during time, and can illustrate the influence of different management regimes on tree growth. Multi-objective programmes are more complicated tools, which can handle information about forests and forest development in an integrated way. Such systems can include different components (sub-models) for estimations of: tree growth, economic output, biodiversity indicators etc. Thereby, it is possible to study the impacts of management regimes on i.e. economic result and nature conservation aspects. The forest is treated as a part of the landscape, so new multi-purpose programmes are often connected with a geographic information system (GIS), to facilitate the handling of spatial aspects on forest management (Andersson et al. 2005).

The development and monitoring of forest ecosystems after the Rio Conference in 1992 became an international issue (Weber 2005). Timber supply for international companies must be studied in an integrated way, not stopping at a country's boarders. New tools for predicting forest growth should provide the information about forest cover for areas bigger than one country. The programmes of forest development, like growth models or multi-objective systems, constructed nowadays in Poland and Sweden can be integrated in international programmes of forest development in the future (Heureka 2004 b, Zasada et al. 2004).

Sweden and Poland have different forestry traditions, due to various reasons but to some extent to the importance of this branch in country's economy and culture. In Sweden, woodlands cover more then half of the country. Forest products are significant for the economy and citizens' everyday life (Swedish National Board of Forestry 2000), while for Poland, the share of woodlands is low, 28.6% of country's area (State Forest Information Centre 2003), and forest's functions are considered mainly as protection.

Nordic countries have long tradition of using different kind of growth simulators to forecast the development of timber resources (Ask 2002) and the studies on multi-objective programmes, which connect economical aspects of forestry with other values i.e. biodiversity, recreation etc, started in Sweden recently. The development of multi-objectives programmes projecting long term development of the stand, volume yield, costs and benefits distribution from chosen management alternatives started in the 1970s with development of the HUGIN system (Andersson et al. 2005). Multi-objective systems, like Forest Time Machine (FTM), appeared in the 1990s.

Polish forestry has long tradition of growth and yield related studies (Zasada et al. 2004). Development of stand and single tree growth models began thirty years ago. The work on multi-objective systems, estimating future stand development depending on management regime and economical factors was planned, but still there is no research in this field (Zasada et al. 2004). In both countries these kinds of tools, can have both scientific and practical applications. It means that they can be used by researchers and students in various studies and projects connected with forest and its development. In practical forestry the programmes should provide an aid for foresters, forest owners in planning and give them reliable information, which can help them in decision-making, choosing the best solution or formulating the goals of their forest management.

The Swedish programmes have been tested only in Swedish conditions so far. They include growth models based on data collected in Swedish forests, but they are constructed for the whole range of site conditions found in Sweden. When applying these programmes to another forestry tradition, the credibility of the output should be tested carefully. The possibilities of their use, without changes in some of their components might be limited, but the experience from Swedish field can be a basis for constructing similar tools in other countries.

1.1 Objectives of the studies

In Poland, there is a great need of meeting other experiences in this area, so in my work I have focused on testing Swedish programmes of forest development. I used three of them: a computer model estimating yield and growth of stands (ProdMod), computer system projecting multi-objective development of the area (FTM), and a computer programme (SFanalys), connecting a growth model (matrix model) with evaluation of some economical features, to study the possibilities of applying them to Polish conditions.

The aim of the work is to test the potential to apply the Swedish programmes to the conditions of Polish forestry. This was studied by comparing the volume output from Forest Time Machine and ProdMod with the figures from Polish growth and yield tables, presenting required modifications of input to the programmes and discussing the influence of data modifications on the output, as well as on the possibilities of programmes' application in Poland. Some recommendation for possible changes in the programmes' structure to fit them better to Polish conditions were described.

2 Forestry in Poland and Sweden

2.1 Polish forestry

Poland, with its 304 465 square kilometres and a population of approximately 39 million inhabitants, has 9 million ha of forest (State Forest-National Forest Holding 2005 f). The percentage of forest cover is 28.6% of the total national area (State Forest-National Forest Holding 2005 b, d). A growing stock of about 1 649.6 million cubic meters gives Poland the third largest volume of standing timber in Europe, excluding European part of Russia (Zasada et al. 2004, State Forest-National Forest Holding 2005 e).

The majority of the forest is under the management of State Forest-National Forest Holding (SFH), which administrates 7.6 million ha of State Treasure owned land. Privately owned forests account for about 17% of all forests. Private forest estates are small (1.3 ha in average) and scattered.

The habitat structure includes a prevalence of coniferous forest types, which occupy about 60% of the total forest area (Zasada et al. 2004). Scots pine (*Pinus sylvestris*) and larch (*Larix decidua*) are dominating, while the other species are of less significance (see Table 1)

Table 1. Tree species composition (area dominated by) in Polish State Forests (State Forest Information Centre, 2003)

Dominating tree species	Part of forest area, %
Scots pine (*Pinus sylvestris*) and Larch (*Larix decidua*)	69.5
Oak (*Quercus robur*)	7.1
Birch (*Betula pendula*	5.9
Norway spruce (*Picea abies*)	5.5
Beech (*Fagus silvatica*),	4.9
Alder (*Alnus glutinosa)*	4.3
Fir (*Abies alba*) and Douglas Fir (*Pseudotsuga menziesii)*	2.0
Other broadleaves	0.8

Approximately half of the stands are older than 20 and younger than 60 years (Zasada et al. 2004). Average age of the trees is 58 years in State, and 40 years in private owned stands. 52% of timber resources is in the stands aged 41-60 or 61-80 years. Stands over 100 years old account for about 6% of forest area and 10% of standing volume (Zasada et al. 2004). The average volume of the stands is 215m^3 per ha in SFH and 119m^3per ha for private or municipality owned estates. The mean annual increment of merchantable timber in public forests is 8.84 m^3/ha.

The annual harvest in State Forest Holding was 23.67 million m^3 of merchantable timber under bark in 2002. With an additional 1 million m^3 timber harvested from private owned land it makes a total of almost 25 million m^3, which is 4 million m^3 more compare to the level from 1981 (State Forest-National Forest Holding 2005 e). In production of the timber, Poland is on the fifth place in Europe (State Forest-National Forest Holding 2005 e). The average harvesting level from State Forests is 3.27 m^3 per ha. From private owned estates this figure is very small, 0.77 m^3 per ha. This disproportion is an indication of the activity of private owners and their importance in Polish forest sector.

The Polish *Act on Forests* (1991) and the Forest Policy of Poland (1997) are the main tools of Polish forest legislation. In 1997, the *Act on Forests* was changed. The paragraph about intensification of management was replaced with the declaration of protection and durability of forest resources (Szujecki 2001). This turned forest policy into the concept of sustainable development of forest cover.

In the *Act on Forests*, the aims of forest management are formulated. Wood production is placed on the last position, after, the most important goal, which is preservation of the resource for future generations and protection of forest. The protective function of forest (soil, water, air) is above the productive one (State Forest-National Forest Holding c 2005). Multifunctional, pro-ecological management characterizes Polish forestry. The sustainable management is consistent with building mixed, multi-species, ecologically stable stands, which fulfil social, ecological and timber production functions (Smykala 1993).

Some of the aims of the Polish Forest Policy are: to develop the multifunctional, sustainable model including protective and social functions of forests, ensure the protection of the ecosystems and forest, as a part of the landscape, improve the knowledge about forest, especially to develop new monitoring and inventory techniques (Szujecki 1998).

Polish forestry, unlike Swedish in these respects, is characterized by the very strong position of the State Forests-National Forest Holding, the big share of protective forests, 46.8% of State owned forests has a protective function (State Forest Information Centre 2003), and lack of forests owned by wood industry (Zasada et al. 2004). State Forests is a big, centralized organization (directly employing some 26 thousand people) and has very detailed regulations regarding its activity, management and planning. Each of the 435 forest districts, units in the organization, operating in areas varying from a few to as much as thirty thousand hectares, have a detailed management plan elaborated every 10 years down to a stand level. The management plan specifies when and what kinds of activities should be conducted in each stand. The plans are made accordingly to the instruction, which specifies the tools and methodology used during the preparation of the plan. The modern Polish growth models were included into management planning recently, with the new instruction (Zasada et al. 2004).

Beside sustainable management of Treasury owned forest, the State Forest-National Forest Holding has to fulfil functions specified in the *Act on Forests*, like: monitoring of forest resources, organizing large-scale forest inventories, gathering and storing the data about forests. Forest Service is obligated to educate society about forest and forest management. In practice, foresters supervise the afforestation of state and private owner land, and provide the advisory services for private owners according to the orders of territorial State administration.

2.2 Swedish forestry

Sweden with approximately only a quarter of the Polish population occupies the area of 408 430 square kilometres (Swedish National Board of Forestry 2005 b).

Woodlands in the country (according to Swedish definition of forest land[1]) cover about 27 mln ha, which corresponds to over a half of total country area. In the enlarged European Union, Swedish forests make 20% of community's forest area (Swedish National Board of Forestry 2005 b). Growing stock, according to data from National Forest Inventories (Swedish National Board of Forestry 2005 d) is 2 898 million cubic meters over bark (volume of stems from the base to the top).

Swedish forest stands are dominated to some accent by monocultures in terms of tree species and momentous management (Sverdrup & Stjernquist, 2002). Species composition consists mainly of conifers, 85% of standing volume (45% Norway spruce and 39% of Scots pine). Birch makes 10% of standing stock, 6% belongs to other species. It is difficult to compare those data in both countries, because in Poland, species composition is described as an area occupied by the species, not as a share of standing volume. Sweden, contrary to Poland, is situated outside the natural distribution of fir (*Abies alba*) (Tomanek 1995) and European larch (*Larix decidua*) (Larsson-Stern 2003).

The biggest proportion of the area, in country scale, belongs to site index quality 28 to 30 meters for spruce and 20 to 22 meters for pine (Swedish National Board of Forestry 2005 d). The mean annual increment for the whole country is about 4.36m^3/ha and year (Swedish National Board of Forestry 2005 d). The average site quality (potential growth) is 5.3m^3 per ha and year. It differs taking ownership category into account. The lowest value can be found in the forests belonging to the companies (4.4 m^3 per ha and year), the highest in public and private owned ones, 6.0 m^3 per ha and year. The average standing volume also varies by the owners categories; it is the highest in private forests (145 m^3 per ha) and the lowest on company owned land (106 m^3 per ha). For all forests, the figure is 127m^3 per ha (Swedish National Board

1 Swedish definition of forest land according to National Board of Forestry (2005 c). (abbreviated): 'Land suitable for wood production and not substantially used for other purposes. Production potential >1m^3 per ha and year.'

of Forestry 2005 d).

Ownership structure is dominated by private small owners (more than half of forest area). Forest companies own almost 25 % of forest land, and the rest is owned by state and other public owners (Swedish National Board of Forestry 2005). The average area of forest owned by private owner (family forestry) is 47 ha (Swedish National Board of Forestry 2000).

Forest products are important for Swedish economy and culture of society (Swedish National Board of Forestry 2000). In some ways, forest industry is a generator for the country's economy. The direct employment in the sector is 100 000 people, and total processing volume of the industry contributes of 3.7% of GNP.

Sweden has a long tradition in private-own forestry, which has an influence on legislation. Forestry Act confirms general standards of management in forest. According to forest legislation from 1993, production and environmental goals has equal weight (Swedish National Board of Forestry 2005 a).

Forest administration consists of National Board of Forestry and 10 regional boards, which are divided into 100 forest districts. The total employment in the organization is 1000 people. The main tasks of foresters employed there are: to promote sustainable forest management by providing extension services and information for forest owners, supervise the Forestry Act. Forest Administration makes contractual services to owners of woodlands. Supervision of forest legislation includes monitoring and notification of final fellings and establishment of new stands. According to the law, forest owner also has a duty to declare: temporary ditching after final felling, removal of forest fuel, use of foreign tree species for regeneration and change of the land use from wood production to other purpose. To check the information about state of the forest properties, Swedish foresters have a GIS based forest support system (KOTTEN). Extension services and information are the most important mean in forest policy implementation. The handshake between forest owner and the employee of Forest Administration symbolizes the Swedish forest policy's direction in reaching agreements on how the forest should be managed (Swedish National Board of Forestry, 2000). The forest service is an advisor for the owner and legislation provides only general standards of forest management. The role of foresters is to provide advice for individual forest owners, as well as organize training courses, National Informational Campaigns and information evenings in different subjects. Forest administration is responsible for publishing books, brochures and information in the Internet about forests and forest management. One of their duties is to organize forest inventories. Contractual services of forest service include: valuation of forest land, training, planning and organization of 'Green Jobs', preparation of forest management plans and international contractual services.

Forestry in Sweden is conducted almost without any subsidies from the society, which makes it more profit-oriented than Polish. The only possibilities to get subsidies is for environmental measures, like management of broadleaved stands, preservation of key-habitats and areas linked with cultural heritage. Economic efficiency is considered in each operation, satisfactory production level should be achieved in each stand (Swedish National Board of Forestry 2005 a).

2.3 History of studies on growth models in Poland

Scots pine (*Pinus sylvestris*) is a major tree species in Polish forests, so the models for the growth of this tree species are the most developed. The studies on other trees followed the solutions for pine.

Poland has a long tradition in studies on trees' growth. Researches of Jedlinski, Grochowski and Plonski, from 1920s and 1930s, were the pioneer in this field. The first yield tables for pine were created by Jedlinski in 1932 and Plonski in 1937. The Jedlinski's tables were built using original methodology. The site classification was based on age and quadratic mean diameter (QMD). The data for building the model were collected on 180 sample plots. The plots were placed all over the country in pine stands of different age and site conditions (Zasada et al. 2004).

The Plonski's yield tables contain site index curves developed using a similar approach as in studies made previously by Schwappach (1908). The data to create the model were collected on permanent sample plots located mainly in eastern part of Poland, in predominantly unmanaged stands (Zasada et al. 2004).

A special place in history of growth studies in Poland have the research made by Schwappach. His tables for Scots pine and other species are based on data from permanent plots placed in central Europe. Height-age curves were drawn for each site classes using average height from each plot. The site classes were described by mean height in a given age (Zasada et al. 2004). The models based on the Schwappach's tables are still in use, because sample plots chosen by the researcher, since the end of Second World War, are situated in territory of Poland.

Szymkiewicz (1949) developed yield tables based on the Schwappach's ones and other previous studies. In his research, he discovered that, in Poland, there are stands, which grow faster than those described by the German forester. He added a new superior site index class to the Schwappach's tables by means of extrapolation (Zasada et al. 2004).

The work on modern growth models in Poland began in the 1970s. Contacts with the University of Minnesota initiated research on height growth function for Scots pine and growth model for Scots pine, MID1, similar to the one used in American FOREST programme (Bruchwald 1993). Individual tree based stand growth models were also described then.

Since the beginning of 21st century, the models for Scots pine, including various variants of thinnings, impact of industrial pollution and drainage on forest's growth were ready. In the same time, provisional growth models for birch, alder, aspen and larch stands were constructed.

Based on progressively collected data, full empirical models for commercially important species, like: English oak, common beech, Norway spruce, silver fir, Douglas fir, birch, European larch, black alder were built. In 1991 first growth model for mixed pine-spruce stands of north-eastern Poland was constructed by Siekierski (Zasada et al. 2004).

Nowadays, the studies on growth are focused on mixed and uneven aged stands (mixed mountain stands with beech, fir and spruce), and combinations of growth models with ecological, physiological, mechanistic and gap models of forest stands (Zasada et al. 2004).

Recently some parts of Polish growth model for Scots pine were included into European RotStand for root-rot prediction and its impact on pine stand development (Zasada et al. 2004).

In 1990s the information system LAS was built (Bruchwald& Siekierski 1992). The programme simulates the development of forest stands, estimates volume structure and optimizes the utilization of the resources on district or estate level. In 1992 the system included the models for pine stands, developed from the MDI-1 model (Bruchwald & Siekierski 1992). In the MDI-1, which is an individual tree model, different programmes of thinnings with various intensity, can be applied to the stands (Bruchwald 1993). The LAS is composed of several programmes performing the following operations: creation of a standard database, creation and correction of database for missing stands, forecasting the development of plantations, optimization of final cutting, correction of data, taking into account the forest exploitation, compilation of comprehensive information on a forest complex. The basic period for the forecast used in the system is 10 years. The system contains the ZREBY programme, which shows the stands mature for final felling in the next 20 years and plans the optimal cutting order. The user can accept the solution chosen by the programme or lower the amount of stands to cut. The LAS can be a helpful tool in preparation of management plans for forest districts, because the growth models included in the system give more accurate data about increment than growth and yield tables. As a scientific tool, the programme is very useful in analysing long term forecasts of forest growth (Bruchwald & Siekierski 1992).

Polish programmes of forest development are mainly growth models and were constructed to provide the aid for foresters in practical forestry, in inventories of forest resources. Computer growth models are used in the Information System of State Forest Holding as a part of the detailed annual planning process (determination of volume increment, planning of cuttings and amount of wood for final harvest use) for the districts (Zasada et al. 2004). The second main application of the models is preparation of management plans on the operational scale and ten-year management plans for forest district. For these applications, programmes of cuttings' optimization, like the LAS (Bruchwald &Siekierski 1992) and calculation of harvest scheduling are used.

The main directions of tree growth models' evolution include: further improvement of existing site index and height models, diameter growth algorithms, taper functions, weight and biomass calculations (Zasada et al. 2004). Majority of Polish models is based on individual tree measurement, so there is a need to develop stand programmes, which can be use in large scale prediction of forest growth and harvest scheduling (Zasada et al. 2004). Those models should be combined with GIS tools, to be a valuable aid for management planning offices and State Forest Holding. Future development of the growth models includes building reactions to various treatments and alternative silviculture (stands with low initial density, different site preparation, responses of stands fertilization or herbicide application) into models. In Poland, like in other countries, the climate changes and their influence on stands' growth as well as carbon sequestration are key issues nowadays. Future should bring international cooperation in this matter.

There is a lack of tools integrating tree growth predictions and development of economical features through time. It is not possible to compare multi-objective systems, like Forest Time Machine used in the study with similar ones created in Poland. In the past, those programmes were not needed. Now, taking into account the main directions of forest policy and status of State Forest Holding as unprofitable organization, the possibility of such applications is smaller than in Swedish forestry.

2.3.1 Description of Polish growth and yield tables

Tablice zasobnosci i przyrostu drzewostanow were created by Szymkiewicz in 1949. The fourth edition of the tables from 1971 was used in this work. The tables were constructed for main species of Polish forestry, like: Scots pine, fir, spruce, European larch, beech, oak, alder, birch, aspen and ash. The tables for Scots pine are divided into A and B tables. The first one is for management regimes with heavy thinnings, and the second one is used for the stands, where treatments with lower intensity are done. Table A is based on models created by Schwappach, with 5 site index classes and Ia class added by Szymkiewicz. Table B is based on tables created by Plonski. The tables for fir and spruce include five site index classes, and are also based on Schwappach's studies. The tables for European larch are taken from Schober's studies, and consist of the variables for five site index classes. The tables for beech and oak are divided into two management regimes, A and B, the same like for pine. For beech, they are constructed according to Schwappach's tables. For oak, Wimmenauer's tables, with four site index classes are used. In the work made by Szymkiewicz, there are two tables for birch, as well as for alder. For more productive stands of birch and alder, in eastern and north-eastern Poland, Tiurin's tables are recommended, when in other parts of the country foresters can use Schwappach' s tables. For aspen, three-class Tiurin's tables and for ash, two-class Schwappach's tables are applied. In *Tablice zasobnosci i przyrostu drzewostanow* all current volume's increments were corrected and adjusted to Polish conditions by Szymkiewicz.

For all species, tables are divided into five parts. The first includes information about growing stock in the stand, like: average diameter and height, number of stems per ha, basal area, shape figure for: whole tree and merchantable timber, volume per ha for: merchantable and small-dimension timber. The second gives information about removed trees, like: volume of merchantable and small-dimension timber and volume of timber taken out from the stand in thinnings. In the third part, the volume of the timber from whole rotation, with the percentages of volumes taken out from the thinnings, is presented for all stands. The forth and fifth parts include increments: mean annual increment and current annual of whole volume for: merchantable and small-dimension timber. All those values are presented for five or ten year trees' age intervals. The tables for all species, except ash and Schwappach's tables for alder, include graphs of average height and current annual increment of merchantable timber of the individual tree.

Szymkiewicz's tables are old, but they are still in use in practical forestry for site index determination.

2.4 History of studies on programmes forecasting forest development in Sweden

National Forest Inventories (NFI) started in Sweden in 1923 (Andersson et al. 2005). Premier aim of them was to monitor forest resources. When studies on growth models began, the data gathered in inventories was used to construct programmes of forest development. HUGIN was one of the first programmes, constructed on the data from NFI. The work on HUGIN started in 1970s. The system utilizes sample plots of forest national survey for producing large-scale (regional and national) and long-term predictions of timber yield (Andersson et al. 2005). Two growth models were established within the project, one for stands with a dominant height below 8 m and for stands above. Both data from inventories and research plots were used for constructing models for single tree and stand development in HUGIN programme. HUGIN is still used today as a long-term forest management planning system at national level (Nyström 2001). In this programme growth functions developed by Ekö (1985) were used. Those functions are the base of ProdMod model of stand development.

The Forest Management Planning Package (FMPP) fulfils the needs of companies for forest growth and yield projections on small area of forest holding (Jonsson et al. 1993). Within the programme, there are more economical calculations, compared to HUGIN, but the same single tree model is used in both programmes (Andersson et al. 2005). HUGIN and FMPP are focused on wood production (Andersson et al. 2005).

FMPP predicts production possibilities of a forest holding. The programme's structure consists of models of tree growth and economic calculations, applied to various management regimes in all types of Swedish stands (Jonsson et al. 1993). The model in the programme is a single-tree, distance independent, growth model of basal area growth. Volume growth is estimated mainly by means of static form-height functions, based on diameter, age and site index (Jonsson et al. 1993). Factors which influence growth are e.g. climate zone, latitude, altitude, soil type, site index, thinning history, basal area per ha, diameter quotient (social position). Species mixture has to be specified. Internal factors (single tree) are described by species, diameter and age at the breast height.

Forest Management Planning Package, in prediction, focuses only on timber production. The stand development process is divided into two phases: the primary production, dealing with silvicultural treatments of the resources and having as an output mature tree ready for harvesting, and the secondary production process, where mature trees are considered as an input as well as resources for logging, transportation, storage and sales. The output is a timber product (Jonsson et al. 1993). Economic calculations are based on assumptions of costs in primary and secondary production. The revenues are assumed benefits from harvested trees (Jonsson et al. 1993). The deterministic approach to future prices was chosen in the FMPP to handle development of economic features through time.

Treatment options have to gain a high degree of utility, which is a compromise between high net present value and a reasonable distribution of net revenue over time (Jonsson et al. 1993). The decision-maker can choose desired profile by varying the rate of return and treatments' options. The role of the programme is to show the most favourable silviculture regime for area.

The FMPP has been used for analysis of a large number of forest holdings in Sweden (Jonsson et al. 1993). Practical application of it includes strategic planning, what is the optimal treatment and internal rate of return. The programme produces guidance of forest management for a company, in terms of potential future yield, its distribution over time and value of outcomes from forest operations.

Sallnäs presented in 1990, a growth model for Swedish forests different from the ones described above. The matrix model uses age class as a basic unit to predict development of forests on a big area on regional level. The yield model is different from the one created by Ekö (1985). It uses volume, not basal area, as an independent variable. The area of forest estate is placed in this matrix, divided in age and volume classes. Stands' input is compared to data collected in Swedish National Forest Inventories (FNS); the volume increment is calculated by comparing input to plots from FNS. The probability, that the stand will be transferred to other fragment of matrix is calculated using the data from country's network of sample plots (FNS). In the next period, the area of the stand is transited into the certain cells of the matrix. The matrix model was combined with SFanalys calculation sheets, to create the programme for forecasting trees' development and economical features for non-industrial forest estates.

The Forest Time Machine (FTM) was probably the first programme in Sweden to make integrated, multi-objective analysis of forest (Andersson et al. 2005). The work started in the beginning of the 1990s. It eventually evolved in to an object-oriented system, with modular components and a modern interface. There are models integrated in the system, which deal with growth of stands, amount of dead wood estimations, calculation of economic variables and harvesting volumes.

A similar system to FTM is under development nowadays. The Heureka research programme started at Swedish University of Agriculture Science in the year 2000 (Heureka 2005 a). In contrast to HUGIN and FMPP, Heureka aims on multi-purpose forestry and to analyze certain forest management regime’s implementation to defined forest land (Heureka 2005 b), and may replace previous programmes in the future. The vision of the Heureka is to build a bridge between analyses focused on timber utilization and environmental oriented planning (Heureka 2005 b). What is unique for Heureka is that the system is addressing various kinds of users. It can be a tool for national and regional authorities, forest organizations and environmental agencies to make long term and wide area prediction of forest cover development, concerning the idea of sustainable forestry, analyses of different scenarios for conservation targets’ development, carbon sequestration and issues connected with recreation in woodlands. For companies, the Heureka supports long term (more then 100 years) planning tool for managers, considering specific planning situations, such as high and sustainable economic yield. Operational planning for companies and private owners associations is also one of the applications in the system. Short-time planning (up to 3 years) is realized in terms of timber and forest fuel production, that is, production and income of various timber assortments, allocation of harvesting teams in time and space, transport and deliveries of timber and forest fuel. For small-scale, non-industrial private forest owners, the programme suggests more flexible and complex functions, analyzing their preferences and goals, than systems, which are currently in use (Heureka 2005 b).

In the Heureka project, growth models are mainly based on data from National Forest Inventories, and consist of sub-models for regeneration, growth and mortality. Changes in soils and nutrient supply, depend on management regime, are also studied. Output from different management regimes is evaluated due to the predicted consequences of the decisions, like spatial allocation of protected areas, timber supply, and social values of forest, moose populations, and influence of forest management on water quality.

First prototype of a core Heureka system was available late in 2004 (Heureka 2005 b). It can support three various applications, for national and regional analysis, long term planning in forest companies and planning for non-industrial private forest owners (Heureka 2005 b).

Second phase of the research programme is proposed to run for four years, from October 2005 until September 2009. In this phase, forest development will be considered in landscape level, in areas dominated by forests.

Six different sub-programmes are concerned to be developed within the project (Heureka 2005 b). In ecosystem development sub-programme, non-tree vegetation models, and modules dealing with risk, will be included to models projecting tree cover's growth.

Second phase of Heureka will deal with actual problems, like: predicting non-industrial forest owners' preferences, importance of broadleaved species for biodiversity, forecasting the consequences of EU policy of afforestation of agriculture land, use of forest in reduction of CO_2 emissions, moose management and management in urban forests (Heureka 2005 b).

3 Description of the programmes used in the study

3.1 Forest Time Machine

Forest Time Machine (FTM) is a multi-oriented, forest decision support system, which simulates the development of a forest area (up to 25 000 ha) for a chosen management regime, in a specified time perspective. It is not a single model, but a complex interaction of different data and models (Andersson et al. 2005). The goal of the programme is to present several aspects in an integrated way and to have a multi-objective approach to the area. The system includes modules for tree growth, regeneration, mortality and decay of wood, forestry operations, economy, nutrient balances, and different indicators for biodiversity and recreation possibilities. FTM uses English as a language for communication with the user.

The output from the simulation depends on the description of the stand used as an input. An ordinary stand database, used in Swedish conditions, is the minimum required input to FTM. Location and altitude has to be known for the area and for each stand area, site index, age, volume and species composition are required. Optional, input, which gives more precise estimates, includes: tree height, number of trees per ha, basal area, average diameter at breast height, soil moisture, slope and ground structure (Andersson et al. 2005). Additional information is needed to analyze more detailed features, like nutrient balance in soil.

User specifies some details at the start: names of input and output, amount of years to run simulation and interest rate. The time step is 5 years.

The programme is integrated with a geographic information system (GIS). A digital map of the area, with indication of the stand borders, is needed to show spatial distribution of the stand development, different management regimes, and distribution of protected area and forest types. The spatial distribution of the results from FTM is possible to generate on the digital map.

In FTM, the decision maker can create management regimes, store them in the database and fit them to each stand. The management (regeneration, pre-commercial thinning, thinning, final felling, felling of seed/shelter trees) can be controlled by setting required tree species composition after each treatment, intensity of the treatment (user can decide, how many stems and basal area’s percentage should be removed in one operation) and the point in time (see Table 2).

Table 2. The input specified by user for creating stand management regimes in the FTM and variables (dependencies) which control stand management.
Adapted from Andersson et al. 2005.

Treatment	Dependencies
Regeneration:	Site index
Scarification method	tree species
Number of seedlings to be planted	
Species composition	
Pre-commercial thinning:	Stand age
Point in time	site index
Number of stems after treatment	tree species
Thinning:	Tree species
Time of thinning is specified in Swedish tables of thinning	site index
schedule	basal area
Thinning intensity (measured by removed percentage of basal	top height
area and stem number)	
Preferred species composition after treatment	
Final felling:	Tree species
Point in time	site index
Basal area, species composition of seed/shelter trees	
Stem number and preferred tree species for green tree retention	
Seed/shelter tree felling:	Years since final felling
Point in time	
Basal area and stem removal	

In practice, time of pre-commercial thinning and felling in rotation period can be determined by the user, but thinnings are made according to Swedish thinning regime tables. It means, when a stand achieves certain top height and basal area, the treatment is made.

FTM uses stand based growth models developed by Ekö (1985). Basal area growth and volume growth functions are based on empirical data from the Swedish National Survey (Andersson et al. 2005). For young stands (height below 8 m), instead of using basal area increment, time for the stand to reach 8 m height is calculated. When trees reach 8 m height, basal area (and volume) is calculated for the stand, by functions, which use site index, tree height and stem number as independent variables (Carbonnier, 1971 and 1975, Elfving and Hägglund, 1975, Eriksson, 1976). The growth simulator can be used for forecasting the growth and yield for stands with various species in different compositions. Self-thinning functions are included to calculate the mortality (Andersson et al. 2005). However for seed/ shelter and retention trees the mortality is calculated by using maximum age for species and temperate variable (Andersson et al. 2005).

In the regeneration phase, the number of naturally regenerated seedlings is also calculated, even when trees were planted on the plot. The amount of these seedlings is estimated by taking into account site conditions (soil preparation and moisture, shelter trees, site index), occurrence of different species' seedlings (based on present basal area, species composition in the stand and neighbouring stands and seeds' dispersal possibilities).

In calculations of amount of dead wood, three stages of decay are considered. The time, after a dead tree is moved to farther stage, depends on diameter of trunk and tree species.
Evaluation of biodiversity is not done by estimation the species' number, but it is connected with amount of dead wood in the stand, and it is made by using spatial analysis (digital map).
FTM includes economic evaluation of future operations in the studied area. It is not possible to make adjust calculations for long period of time. Only costs and benefits from forest operations are taken into account in the predictions. The costs are estimated using time and other units' prices. The income from wood is based on price list for assortments and calculated volume of harvested timber. For each period cash flow, net present value and rate of return are calculated (Andersson et al. 2005).

3.1.1 The output from FTM

As an output from Forest Time Machine, the user can get a description of the estate and each stand in every 5-year period, including percentage of species in the stand, basal area, volume, number of stems per ha in each stand, age of trees for: production, retention and shelter layer. The information about retention layer includes stem density per ha in species composition and diameter classes.

For each period, it is also possible to create data about dead wood in species composition, its volume and distribution in three decay classes.

From economical results, the user can get total net and NPV for entire simulation period. For 5-year period net value, costs and benefits of each operation and area of each treatment are calculated. Harvesting volume (timber in m^3 to, and pulpwood in m^3 fub) is presented in total and with division on wood from final felling and thinning.

The results for whole estate in simulation period include: standing volume m^3over bark per ha, growth m^3over bark per ha and year, area of forest types (ha) and age classes (ha), information about shelterwood (standing volume m^3 over bark per ha, age) and standing volume of old trees (m^3 over bark per ha).

3.2 ProdMod 2

The computer growth and yield model for stand development, ProdMod, was developed by Ekö. It predicts development of trees with dominant height above 8 m. Growth simulations are based on data from 17500 plots of Swedish National Forest Survey.

The computer model uses functions of basal area growth per hectare and year. At the end of each period, basal area is transformed to volume by means of functions for stand form height or volume per hectare. Volume growth is generated as a difference between two volumes (Hägglund 1981).

All the steps in the model can be controlled by the user, who decides about the intensity (measured by percentage of removed stems and basal area) and time of thinning.

The model is built of 42 different basal area growth functions (Hägglund 1981), which are defined by: geographical location (latitude and altitude), climate zone in Sweden, history of the operations made in the plot (never thinned, thinned more then 5 years ago, thinned within last 5 years), and species (Scots pine, Norway spruce, birch, beech, oak and other broadleaves). Those functions contains independent variables, like: basal area per ha per species projected, for other species, diameter of stem of mean basal area, calculated on the basis of the trees larger than 5 cm DBH, average age at the breast height for the two largest trees per species, proportion of total basal area consisting of diseased trees, site index, altitude, latitude, ground vegetation type, soil moisture, local climate (maritime and others). There are 14 functions for volume development, containing independent variables, like information about the history of treatments in the stand (thinned more than 5 years ago, thinned within last 5 years, unthinned) and the variables described above, used also in basal area functions (Hägglund 1981). Input sheets to ProdMod are in Swedish.

ProdMod is used in Forest Time Machine- multi-objective system of forest development as a model for predicting tree growth.

3.2.1 The output from ProdMod

From basal area per ha for the species, number of stems per 1 ha, age on the breast height and site index, programme calculates volume, diameter corresponding to basal area (DBH>5cm), top height and annual increment for each 5-year period. Also the biomass in tons per ha is calculated for each tree species in the periods.

3.3 Matrix model and SFanalys

The concept of matrix model enables constructing the predictions about forest cover development on big area of regional level. An early version of the model was presented in 1985. One of the advantages of the model is that the calculations can be quickly handled by the computer (Sallnäs, 1990).

The model consists of three parts: matrix of forest area, a set of transition probabilities, which determinates the development of the stands' area, under different treatments, and set of activities (Sallnäs, 1990).

The basic information about forest area consists of variables describing: geographical region, owner category, site quality, species composition, thinning status, age and volume of trees (Sallnäs, 1990). Young stands in the model are defined as a bare land or forests with an average height of less than 6m. There is no volume and species composition defined for the trees in this stage (Sallnäs, 1990).

Specific forest types are described by age and volume (Nilsson et al., 1992). These two features are divided into intervals and placed in the matrix. The area of forest estate is placed in this matrix, divided in age and volume classes. Stands' input is compared to data collected in Swedish National Forest Inventories (FNS); the volume increment is calculated by comparing input to plots from FNS. The probability, that the stand will be transferred to other fragment of matrix is calculated using the data from country's network of sample plots (FNS). In the next period, the area of the stand is transited into the certain cells in the matrix area.

Thinning in the model is expressed as the fraction of area from the matrix's cell that is thinned. This area is moved one step down in volume cells. The area of clear-cut is moved to the bare land cell (Nilsson et al.1992).

In the matrix model, the management activities are controlled in two levels: basic management programme, defined for each forest type, and second management programme for estate, which does not correspond to ideal management. In ideal management, thinning is expressed as a percent of growth in each forecast period. The management regime in the model can be controlled by the user. For Swedish conditions treatment's intensity was extracted from Swedish yield tables and depended on age, species, and site. Point in time for final felling was estimated by age of the trees as a main criterion for harvest (Nilsson et al.1992).

The input data for the matrix model projecting future volume growth for an area must include a number of variables:

- area of each stand,
- trees' age,
- site index,
- volume per ha,

- next expected treatment
- species composition.

The species composition is given as a percentage (the tree species are limited to pine, spruce, oak, beech and other broadleaves).

Before running the model, a decision-maker should specify the region in Sweden where the area is situated.

The functions for growth and yield of trees were used with SFanalys programme (version 1.3, 1990), where the silvicultural methods are optimized and fit to traditional Swedish management. The management regime can not be modified by the user. SFanalys was applied to estimate economical figures: cost of forest operations and benefits from harvested volume of wood. The rate of return is chosen by the user. Costs per each treatment were presented per hour, per 1000 seedlings of planting material and expenditure of equipment.

The prices per each assortment of saw timber, and pulpwood with distinction between tree species is needed for the programme. The smallest diameter for pulpwood and saw timber, percentage of the most valuable wood in thinning and final felling should be specified by the user.

SFanalys's input files are in Swedish, what can cause difficulties in using the programme.

3.3.1 The output from SFanalys

As an output from the programme, the user can get economical results: costs and benefits from the treatments for each period. SFanalys calculate the area for each activity and the harvested volume. It is not possible to create the information about each stand development, because the estate's area is divided into trees' age classes. The user receives the data about each class and treatments are also implemented to this unit.

4 Comparison of volume and estimations between computer simulations with FTM, ProdMod and Polish growth and yield tables

4.1 Materials and Methods

4.1.1 Description of the district

The Gostynin forest district is situated in central of Poland, in Ziemia Gostyninska, the central point of Mazowsze Centralne (52º27'N, 19 29'E). Those lowlands have the lowest proportion of forest land in Poland (Sikorska 2002). The district occupies an area of 16 128 ha (2002), with 15 460 ha of forest stands. Productive woodlands are estimated to cover 9 901 ha.

The other forests belong to reserves (476 ha), and have the status of protective forests (5 083 ha, forests protecting: soils, water, forests around the cities).

Average age of trees is 55 years, mean volume is 209 m^3 per ha with growth of 3.81 m^3 per ha and yr. The growth is low compared to the average of SFH, 6.58m^3 per ha and yr (State Forest-National Forest Holding 2005 a). The Gostynin district is situated outside the natural range of beech (*Fagus sylvestris*), spruce (*Picea abies*) and fir (*Abies alba*) (Jaworski 1995, Tomanek 1997), so tree species composition is poor and typical for this region, with dominancy of pine (*Pinus sylvestris*), 93.81%. The big proportion of black alder (*Alnus glutinosa*) 3.10%, is common for the region (Sikorska 2002). The district is characterized by large proportion of wet stands, 4% and includes several lakes.

After pine and black alder, birch (*Betula pendula*) and oak (*Quercus robur, Quercus petrea*) are the most abundant in the area (together 2.5%). Other tree species (spruce, hornbeam *Carpinus betulus* and larch *Larix decidua*) are together accounting for 0.5% of forest area. The structure of stands is dominated by fresh mixed pine forests (83.2% of woodland area).

The climate of the region, with continental influence, has an impact on species composition. Precipitation is one of the lowest in Poland (below 500 mm per year). Mean annual temperature is 7 to 8° C. The vegetation period is 200-210 days (Gil et al. 1999).

4.1.2 Adaptation of stand data to programmes' input requirements

The Swedish programmes' requirements on input data means that, so not all stands from the Lucien sub-district in the Gostynin district could be used as input for the programmes. Since, the sample should only include even-aged stands and species were limited to spruce, pine, birch, oak and beech, so alder in the simulations was treated like birch. Therefore the stands in the reserve could not be used, because they have many tree species of different age in each stand.

Thirty stands suitable for this study (see Table 3) from the Lucien sub-district in the Gostynin forest district (Regional Directorate of State Forests-National Forest Holding in Lodz) were selected on the 6th of January 2005 from SILP database of State Forest Holding (Information System of SFH) as input to the programmes.

Table 3. Description of stand used in the study. P-Scots pine, S-Norway spruce, B-common birch, A-black alder, O-oak

Id	Protection category	Area (ha)	Age	SI (Polish)	SI	Vol/ha (m3)	Total vol. (m3)	Species part.(10%)
604003002	production	7,71	109	I	T29	418	3223	10P
604003007	production	3,25	109	II	T25	238	774	10P
604003047	production	10,75	118	I	T29	377	4053	10P
604003080	production	1,77	119	II	T25	407	720	10P
604003105	production	5,82	114	I	T29	344	2002	10P
604003107	production	5,26	114	I	T29	523	2751	10P
604003198	production	0,44	28	IA	T32	186	82	10P
604003200	production	0,52	28	IA	T32	189	98	10P
604003215	production	2,63	109	IA	T32	469	1234	10P
604003226	production	3,15	114	I	T29	439	1383	10P
604003237	production	26,37	114	I	T29	419	11049	10P
604003248	production	15,00	114	I	T29	449	6735	10P
604003403	production	8,46	104	I	T29	471	3985	10P
604003407	production	7,40	104	I	T29	418	3093	10P
604003411	production	1,02	104	I	T29	524	534	10P
604003463	production	1,77	6	I,II,II,II,II	G31	0	0	1P,1S,5B,1O
604003457	production	1,65	79	IA	T32	316	521	10P
604003487	water protection	0,25	54	II	G27	368	92	10A
604003496	water protection	0,62	26	II	G27	137	85	10A
604003498	water protection	0,58	49	I,II	G27	46	27	2B,8A
604003500	water protection	0,34	64	II	G27	295	100	10A
604003529	water protection	1,70	139	II,III	T25	346	588	9P,1O
604003574	water protection	0,48	26	II	G27	116	56	10A
604003581	water protection	0,24	7	II,II,II	G27	0	0	4B,6O
604003585	water protection	1,35	24	I	T29	112	151	10P

Id	Protection category	Area (ha)	Age	SI (Polish)	SI	Vol/ha (m3)	Total vol. (m3)	Species part. (10%)
604003171	water protection	3,84	8	IA,I,II	T32	0	0	7P,1B,2O
604003152	water protection	0,77	44	II	T25	140	108	10P
604003156	water protection	1,65	38	I	T29	147	243	10P
604003173	water protection	1,57	25	I,II	G28	88	138	2P,8B
604003452	water protection	0,05	81	III	G27	193	10	10A

Since the SILP database does not include stem number and basal area, these variables were taken from *Volume and growth tables* (Szymkiewicz 1971). Also, Polish site index, based on age and mean height of the stand, had to be transformed into Swedish site index, which is defined as dominant height of a stand at a prefixed reference age (total age of the stand). Dominant height is defined as the arithmetic mean height of the 100 largest (by diameter) trees per 1 ha. The stand refers to an ideal, even-aged, managed stand of a single species. The estimation of site index should be objective (Hägglund, 1981). Site indexes for different species in Swedish conditions can be compared by using formulas (see below):

$H_{50\ birch}$ => $H_{100\ Spruce} = 1.15 * H_{50\ birch} - 1$

$H_{100\ oak}$ => $H_{100\ Spruce} = 0.6 * H_{100\ oak} + 15.$

To make the translation site index, Polish growth and yield tables by Szymkiewicz and Swedish site index tables (Ståndortsindex) were used. For each Polish site index maximal mean annual increment (MAI) and the age of the tree corresponding to this MAI, was selected from Szymkiewicz's tables. For the stands, where the function is production, the data from tables for heavy treatments and for water protecting stands, the variables from tables for light treatments (see sub-chapter 2.3.1) were chosen (see Table 4 and 5)

Table 4. Heavy treatments

Species	Polish site index	Max MAI merchantable timber m^3/ha according to Polish tables	Year of max MAI according to Polish tables	Swedish MAI: 'bonitetklass' m^3sk/ha and year	Swedish site index 'ståndortsindex'
Pine	IA	9.9	60-70	9.9	T 32
	I	8.1	60-80	8.3	T 29
	II	6.5	70-95	6.4	T 25
	III	5.3	75-90	5.1	T 22
Spruce	II	10.6	95-105	10.7	G 31
Birch	I	7.3	50	7.3	Birch 25= G 28
	II	5.8	40-50	5.9	Birch 23= G 25
Oak	II	6.2	80-105	6.3	Oak 29= G 32
	III	4.7	100-130	4.6	Oak 24= G 29

Table 5. Light treatments

Species	Site index	Max MAI merchantable timber m^3/ha according to Polish tables	Year of max MAI according to Polish tables	Swedish MAI: 'bonitetklass' m^3sk/ha and year	Swedish site index 'ståndortsindex'
Pine	IA	10.0	75-90	9.9	T 32
	I	8.6	85	8.8	T 30
	II	7.1	80-90	7.4	T 27
	III	5.7	90	5.9	T 24
Oak	II	6.1	95-140	6.3	Oak 29= G 32
	III	4.8	115-160	4.9	Oak 25= G 30

The MAI from Polish tables was compared with MAI (bonitetsklass) from Swedish site index tables (Ståndortsindex). This comparison was a basis for estimations of site index for each stand.

4.1.3 Adaptation of Polish costs and benefits' structure to SFanalys requirements for economic figures' calculations

The structure of operational costs in Polish forestry was studied in terms of how well it fit to the input sheets from SFanalys programme. The input required the costs' structure per one hour, but in Polish State Forest Holding, the costs are calculated per unit of the area (treatments, like soil scarification, planting, cleaning, and early thinning) and per $1m^3$ of harvested timber in late thinnings and final fellings. The second limitation is that manual cutting still dominate in Polish forestry and the programme calculates all the figures based on the costs of mechanized operations in thinning and final-felling.

State Forest Holding has contractors, private enterprises, which are making all the treatments in the forests, so the costs of the operations are accounted as the amount of money paid to the companies. The costs' lists very often include costs for groups of the treatments, not for a particular operation, so the list for the SFanalys can not be fulfilled very precisely.

The assortments classification of wood in Poland is different from this required by the programme. The generalization of the timber prices was essential to make the forecast.

4.2 Methodology

Forest Time Machine was applied for 200 years, for all thirty stands chosen to make the study. Three management programmes (for pure pine, pure birch and mixed, pine with birch stands) were constructed. The stands with alder were treated like birch stands. The programmes were made according to the traditional Polish silviculture regimes (Murat 1999). The number of planted seedlings used in the simulations was:

a) for pine 8000
b) for oak 8000
c) for birch 5000
d) for spruce 4000
e) for alder 5000

In birch stands one pre-commercial thinning was planned and in pine stands two. Early thinnings were made from below; late thinnings were from above (Murat 1999). The first thinning in pine stands was made at the age of 25, in birch stands at the age of 20. The percentage of basal area and number of stems per ha removed was estimated from Polish growth and yield tables (Szymkiewicz 1971). The percentage of basal area taken out in the early thinnings was from 15 to 20%, in the late ones it was about 10%. In the management programmes, rotation age for pine was 100 years and for birch 80 years.

Four stands (604003200, 604003152, 604003457, and 604003407) were chosen for the calculation in Prod Mod. Those stands were pine stands, in age of 28, 44, 79 and 104. The characteristic of them can be found in the table 3. The development of the stands was predicted until the end of the rotation, which is 110 years for pine in the Gostynin district. The management programmes were planned to be very similar to the regimes applied to Forest Time Machine.

The simulations in SFanalys were made for six periods for the entire thirty stands. The costs of forest operations for 1 m^3 or 1 ha and seedlings prices were taken from real costs paid by the Gostynin district for each operation and production of seedlings (price for production of 1000 seedlings in 2005 for tree species). The costs of harvesting were estimated from the publication of Moskalik, 2004. The costs from zloty were translated into SEK (the course was 0.45 zloty per 1 SEK). The matrix model, which is connected with SFanalys, forecasted the stands' distribution in volume and age classes for the periods of simulation.

The results part includes the comparison of the volume output at the end of the rotation (100-110 years for pine) for selected stands from FTM and ProdMod with the figures from Polish growth and yield tables.

4.3 The Results

4.3.1 Comparison of volume between output from the programmes (FTM, ProdMod) and Polish growth and yield tables

The volumes of each stand from both programmes were similar, but they varied a lot form the figures from Polish volume tables (see table 6). The results for pine stand of 28 years old varied only 15 m^3 per ha between the FTM and ProdMod. In older stands, to some extent, the difference was more significant. The figures from FTM for 79 years old stand were 71 m^3 per ha bigger than from ProdMod, but for 104 years old stand the difference was only 28 m^3 per ha. The first and the third stand presented in the table 6 had the same site index and volume according to Polish tables, but the volumes, from both programmes were different.

The site index of pine 104 was higher than site index of pine 44, but volume at the end of the rotation was lower from the programmes as well as from the tables.

Table 6. Comparison of the volume at the end of the rotation between the programmes (Forest Time Machine, ProdMod) and Polish volume and yield tables

No. of the stand	**Stand description**	**FTM m^3 over bark per ha**	**ProdMod m^3 over bark per ha**	**Polish tables m^3 sk per ha of merchantable timber**
604003200	Pine 28	360	375	506
604003152	Pine 44	305	329	463
604003457	Pine 79	395	324	506
604003407	Pine 104	322	294	441

5 Discussion

5.1 The method and the results

In the work I focused on analyzing the input: stands' description as well as economical figures, and the output from the programmes, to check how strongly the modification and generalization of the input influence on the possibilities of programmes' application to Polish conditions.

There might be three reasons for the differences in the results. First of all, the volume assumptions from the tables are not accurate for present conditions in Polish forestry and for evaluation of programmes' final output.

The volumes from the tables were dissimilar to the programmes' output as well as to real data taken to the study (see table 7). The volume of pine 79 stand (316m^3 per ha) from the database was 146 m^3 per ha lower than the volume from the tables (462 m^3 per ha in a stand of 80 years). When comparing the volume of pine 79 stand with the output estimations in year 80 from Forest Time Machine and ProdMod for the pine 28 stand, with the same site index, the differences were smaller than when comparing those results with Polish growth and yield tables (see table 7). The differences between programmes' output and real data were very small. From analysis of volume assumptions, the answer on the question, if programmes give reliable volume predictions can not be formulated. The tables by Szymkiewicz were constructed long time ago. Despite of they are still in use in practice, the data are not accurate, because of changes in management, like reduction of number of seedlings planted per hectare. This is another cause, why Polish tables used in the study are not the only ones the output from the programmes should be compared with. To make the evaluation of the output, modern growth models, more adjusted to the situation in forests nowadays, should be used.

Table 7. Comparison of the volume of pine 79 stand from the database with the volume output from the programmes of pine 28 stand in year 80 and the figure from the Polish tables for the 80 years old stand

No. of the stand	Stand description	Volume from database m^3 sk per ha	FTM m^3 over bark per ha	ProdMod m^3 over bark per ha	Polish tables m^3 sk per ha of merchantable timber
604003457	Pine 79	**316**			462
604003200	Pine 28		310	324	462

The second reason of the differences in the results could be that components of the programmes were made from the data collected in Sweden, so they might not give the accurate prediction for Polish stands, as for Swedish ones. Swedish growth models are mainly stand based models, which use data from NFI to forecast forest development (Hägglund 1981, Sallnäs 1990, Andersson et al. 2005). The differences in the output from Polish and Swedish sources might appear because of climate's varieties between Sweden and Poland and dissimilar tree growth patterns.

The third thing is that the modifications of the data from the Gostynin district, like translation of site index, using number of stems and basal area from the tables, could influence on the results.

The management regime, which was formulated using general requirements, influenced on the difference in output between programmes. ProdMod and FTM are based on the same growth model, but the regimes applied to both programmes were similar, but not identical.

The costs of translation of the programmes from English and Swedish and adaptation to Polish conditions should be borne when the results are needed. There is a lack of multi-objective systems in Polish forestry, but the work on tree growth models is advanced (Zasada et al. 2004), so the prediction of the growth, harvesting level connected with economical calculation is required more than pure models of trees' yield. Economical and harvest level forecasts can be useful aid for State Forest Holding especially now, when the company is searching for new sources of income to fulfil protective and social functions of forests (Tomaszewski 2001).

On the other hand, SFanalys can not be used for detailed prediction of future benefits, because the input requirements for the programme are different compared to Polish costs structure. The data need a lot of generalization, which influence the credibility of the output. Moreover, the management regime can not be changed and it is focused on economical optimization of harvesting, contrary to less intensive management used in Polish forests.

5.2 The limitations in applying the programmes to Polish conditions

5.2.1 Requirement for the input

The tools used in the study need precise data to make the output valuable for the decision maker (Andersson et al. 2005). When considering the application of Swedish programmes to other countries' forestry, first of all the ability of the input should be considered. The guesses and assumptions of the variables lead to less reliable output from the programme. In my studies a lot of input generalizations were made. The data from the Gostynin forest district included different stand descriptions than was required as an input. Lack of number of stems per hectare and basal area of the stand made the data less precise. Transformation of site index can cause some mistakes, because the average growth in Poland is higher and Swedish tables (Ståndortsindex) do not include higher growth rate for pine stands than a yield of more than 8.8 m^3 per ha and year and 8.0 for birch. What is more, there are differences in calculation of mean annual increment of trees.

Costs of operations were transformed and additional calculations were made to get valuable input for the programme. All generalizations made to the variables could influence on the output.

Taking into account the limitations mentioned above, to make the programmes useful in practice, the required data should be collected or the input sheets have to be transformed to more adequate to Polish conditions (like measuring of operation's intensity by percentage of volume). In both situations the costs of those transformations should be estimated, and the costs of work on the programmes, on one side, the costs of changing the inventory system in Poland, on the other.

Nowadays the programmes can be used in scientific research in forecasting trees' development in the stands, where basal area and number of stems per hectare are measured. The second solution is to use those figures from the tables.

In economical calculations, general data, from the research in the region, or type of the equipment can be used.

5.2.2 Growth models

ProdMod and the matrix model are growth models constructed on data collected from the territory of Sweden. Forest Time Machine includes sub-model of forest growth based on ProdMod. The data from Polish inventories should be integrated into the programmes to make the predictions more credible. However nowadays reliable data from the inventories of Polish forest on large scale can not provided. Poland is already starting with the project of national forest inventories (Borecki and Zajaczkowski 1998).

The stands, which the growth models are based on, are managed in quite dissimilar way than the Polish ones. It can not be enough to use Polish data and Swedish growth models, but to have more reliable forecasts of forest yield, Polish growth models and management regimes should be included into multi-objective systems, like Forest Time Machine. On the other hand, the volume assumptions from Polish tables are not adequate for evaluation of the programmes' output. Further researches are needed to compare the volume output from studied programmes with modern growth models constructed in Poland.

5.2.3 Management regime

The tradition of managing forests is linked with policy and the importance of this branch in the country's economy. Sweden and Poland are quite dissimilar in this field. Management regimes used in Sweden do not fit to Polish forestry, because of different labour costs, species composition and general aims of management. SFanalys contains management programme focused on optimization of timber harvesting and can not be changed to the regime more accurate for the data from Gostynin.

In Forest Time Machine the management can be created by the user, in terms of operations' intensity, but the time of thinnings is limited by the system. Furthermore, Polish management is more difficult to define than Swedish, because the intensity of the treatments is measured by percentage of volume taking out from the stand.

There is lack of management proposal for some of the tree species, like alder, which has economic importance in Poland. Other species, like fir needs more complicated cutting methods, difficult to create within a computer programme.

5.2.4 Differences in forest policy between Poland and Sweden

The programmes predicting forest development were constructed in Sweden to study the timber supply possibilities of Swedish forests in the future (Eriksson and Sallnäs 1987, Jonsson et al. 1993, Nyström, 2001, Lämås and Eriksson 2003, Andersson et al. 2005). Multi-objective systems deal not only with wood supply, but with forest as a part of the landscape (Andersson et al. 2005). All those programmes are created for Swedish conditions and traditions in forestry. In new ones, like Forest Time Machine, the management can be, to some extent, controlled by the decision-maker. The output from the programmes includes the variables common for Swedish conditions, but less required in Polish forestry, like dead wood calculations.

Differences in forestry included various species composition and structure of stands in Poland and Sweden. The intensity of operations, size of clear cuts is diverse in both countries. Everything affects the utilization of those tools outside the place, where they were constructed. The difference between the countries in forest policy is big, so the input needs a lot of generalizations and the output from the programmes is less valid. Application of them to more similar conditions could give more satisfactory results.

5.3 Possibilities of application

Polish programmes of forest development are constructed mainly to provide the aid for foresters in practical forestry, in inventories of forest resources. Growth models are used in

Information System of State Forest Holding as a part of detailed annual planning process (determination of volume increment, planning of cuttings and amount of wood for final harvest use) for the districts (Zasada et al. 2004). The second main application of the models is preparation of management plans on the operational scale and ten-year management plans for forest district.

The studied programmes: Forest Time Machine, ProdMod and SFanalys are new tools of planning, used in practice and on the field of science in Sweden (Jonsson et al. 1993, Nyström, 2001, Lämås and Eriksson 2003, Andersson et al. 2005). In management planning, the most important levels of forest production are single stand, an estate or a forest holding and the landscape. There are differences between industrial and non-industrial, family forestry (Andersson 2002). The studied programmes can be applied in all of those fields.

ProdMod is a growth model on stand level, which is used as a part of Forest Time Machine, multi-objective system forecasting forest development. It gives information about the growth through the whole rotation. Each step is controlled by the decision-maker, so impact of various management regimes on growth in particular stand can be tested. The model can be useful tool in predicting harvesting level and constructing selling plans. It should be applied to each stand, what takes a lot of time, so integration with more complicated systems gives better utilization of this model.

In the matrix model, the large area's growth predictions can be easily handled (Sallnäs, 1990). The model enables constructing forest growth predictions on regional level. In the study, it was connected with SFanalys calculation sheets. The economical programme was constructed for small scale forest owner to give him integrated analysis of the estate, in terms of harvesting level, intensity of operations, benefits from timber, as well as costs of each treatment planned in the period. That information can be used in constructing economical and selling plans for the holding. Based on the results from the predictions, work programmes, budget of costs and revenues can be added to management plan.

Forest Time Machine gives much wider possibilities for the user than the programmes mentioned above. According to Anderson et al. (2005), the system can be used for several studies on long time planning in the landscape. Different management strategies and their influence on biodiversity, as well as social values of forests, harvesting levels and economical figures, can be tested in long-time perspective. This is a tool for non-governmental agencies, like Swedish Environmental Agency (Andersson et al. 2005), or Forest Service for studying the impact of various management strategies on nature conservation and economical revenues from the forest. Forest Time Machine was used to test different management strategies for increasing the proportion of deciduous trees in the landscape of southern Sweden, research on management's impact on nutrients balance in soil, biodiversity, water quality and economy (Anderson et al. 2005). The programme can be applied when the management's goals of forest owner are clearly formulated. The FSC certification requires a minimum of 5 % of forest to set aside for nature conservation and the amount of deciduous trees should be on certain level (Swedish FSC Standard for Forest Certification 2003). The influence of changes in management according to certification process can be tested in long-time perspective by the programme. The user can determine regime for each stand and plan the situation of conservation areas on the digital map integrated with FTM.

Possibilities of programmes' application to Polish forestry are fewer compared to Swedish conditions. Forest legislation is not so liberal like Swedish, and management in forest is regulated in details, in sense of species composition in the stand and functions of forests. In reality, for each tree species a specific felling method should be applied. Particular soil condition and region require specific species composition to be planted (State Forest-National Forest Holding 2005 g).

It means that planting the most economical tree species is possible only in some areas. The forest policy makes State Forest Holding the major actor in this field and private sector is of marginal importance. In the future, private owners of forest may need this kind of tools in management to create economical plans and determine harvesting levels for their estates, but now the only use for the programme is science and practical forestry, represented by State Forests and management planning offices.

5.3.1 Scientific application

The programmes can be useful tools for the researchers as well as for students in forest education. The growth models, like ProdMod and matrix model can be applied to the research on growth in sample stands all over the country, including study on pollution influence on trees' yield. Impact of different management strategies on stand growth, species composition, amount of timber, biodiversity and nature conservation aspects, in long-time planning, can be tested. Forest Time Machine could be used in choosing the best management regime for area under pollution influence, urban forests, the area of protective and nature conservation as a major function. Different strategies can be studied for mountains and other sensitive areas, the regions, where nature conservation measurements are planned, with presenting them on the digital map.

One of the applications includes preparation of management plans and strategies of protection in Promotional Complexes of State Forest Holding, which are special units, where sustainable management is promoted.

The matrix model can be a tool for projection growth, age and volume structure of forest in the whole country. This forecast can say a lot about timber resources and can be useful aid for the decision-makers to create the forest policy and harvesting levels in State owned forests.

Application of SFanalys can give the information about profitability of management and particular operations. Different scenarios can be tested with different costs and timber prices. Lowering rotation age can be studied in terms of economical factors and biodiversity (amount of dead wood).

For nature conservation studies, dead wood simulations can be used in the researches on beetles and other organisms living in this substrate. The impact of different management regimes in FTM on amount of dead wood can be tested.

5.3.2 Practical application

There are two major users for the programmes in practical forestry nowadays. One of them is State Forest Holding and the other group consists of management planning offices, which prepare management plans for all categories of forest owners.

The growth model, especially ProdMod can be used, analogously to Polish growth models (Zasada et al. 2004) in Information System of State Forest Holding and for actualization of databases on district level. It can be, as well as Forest Time Machine, an aid for management planning offices in preparing 10-year management plans for forest districts. All the programmes can be applied for testing different regimes' impact on economical results of the districts and for planning spatial and temporal allocation of harvesting and other treatments. Matrix model can easily handle the data from large areas, so adaptation to regional inventories of forest resources should be possible.

Forest Time Machine is integrated with GIS tools, so spatial allocation of management regime or facilities for tourists can be one of the applications. Especially, it is important in urban areas, where forest is visited by many people (Promotional Complexes, forests around cities). Analysis made by those tools can enable foresters to locate the stream of visitors, in way to make it less harmful for the nature. Economical aspects of pro-social management in this forest are possible to study within the programmes.

SFanalys and economical calculations from FTM can be applied in operational planning in forest district, as well as additional aid to management plans. The possible application includes constructing economical plans for 10-year period.

Nowadays there is a lack of this type of tools in Poland, because economical analysis of costs and profits in forest districts and planning the budget is done only for short period of time. For scientists and foresters the need of programmes predicting future economical balance of forest, integrated with harvesting level, is more obvious now than it was some years ago, but still social acceptance and protection of forest ecosystems are the major roles of planning the management in Polish forests (Paschalis 1996 and 1997, State Forest National Forest Holding 2005 g).

6 Conclusion and recommendations

In the literature, the multi-objective planning tools are presented as required in modern Polish forestry (Bruchwald 1993, Zasada et al. 2004) but the development of this kind of programmes is not as advanced as in Sweden.

The programmes required modifications of input, like transformation of site index. Species composition is a limiting factor in application, as well as uneven age distribution of the trees in the stand. The data from the Gostynin district did not include some variables describing the stands essential for the programmes. Forest Time Machine for example, needs stem density and basal area of each stand, which had to be estimated from growth and yield tables.

The input for SFanalys is different to Polish cost and wood assortment structure.

The output from the programmes differs. FTM is multi-objective system predicting forest development (Andersson et al. 2005); SFanalys focuses on economic balances of an area. ProdMod is similar to Polish growth and yield tables, because it predicts tree growth on stand level.

The volume output from the programmes is lower compared to the results from Polish tables. There might be three reasons for the differences in the results: 1) volume assumptions from the tables are not accurate for situation in Polish forestry nowadays, 2) the programmes were constructed for Swedish stands and they might be unsuitable for other country's conditions, 3) and the modifications of the input data influenced on the programmes' output.

To decide about the utility of the Swedish programmes further studies are needed, like the comparison of the estimations with modern Polish growth models.

The growth models included in the studied programmes are mainly constructed on the data from National Forest Inventories in Sweden and based on traditional Swedish management regimes. There is a need to add the data from Polish inventories to the growth models. It can be not enough to use Polish data to Swedish models, but to have more credible forecasts of forest yield, Polish growth models should be included into multi-objective systems, like Forest Time Machine.

The input structure of the programmes should be more adjusted to Polish conditions, including stand description, definition of treatment intensity, assortments and cost structure. Management regime must be more flexible in terms of species composition, thinning intensity, longer rotation age, higher number of seedling planted per ha, and different labour costs. The user should have the possibility to create and change management regime, like in ProdMod and Forest Time Machine. In Poland, different treatments are often applied in one stand at the same time. According to management principles (State Forest-National Forest Holding 2005 g), clear felling is limited to 6 ha, so the area of the operation does not cover an entire stand. The stand is divided into operational plots, which are utilized one after other. The programmes modelling forest development should enable the application of more than one regime to a particular stand.

Studied programmes can not be used in Polish forestry without necessary changes, like translation to Polish, if they are going to be used by foresters in practical forestry. The possibilities to use the programmes' are similar in both countries, but in Poland nowadays three main applications of the programmes seem likely: scientific research, as an aid for the decision-makers, and for managers of forest districts in the preparation of management plans.

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