Large-scale Forest Inventory and Scenario Modeling

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Scenarios as Tools for Planning for the Future

Forestry is facing trends such as population growth, uncertainties such as climate change or market fluctuations, as well as major drivers of change such as new governmental policies or international agreements, new markets for forest products, or new harvesting technologies. There is increasing need to manage forests effectively to meet multiple requirements (including preservation of biodiversity) and changing conditions, and to show it to the customers and the surrounding society. Scenarios are tools for planning for changes and uncertain future. It is possible to derive expert scenarios without computerized models. In forestry, scenarios are usually based on the complex analysis of ecosystems and human behavior at the national, regional, and global level. In the analysis, large-scale forest inventory data and computerized scenario modeling are needed to explore resources and their alternative futures.

Scenario Approaches

Scenarios integrate information on what might happen based on drivers, the probabilities of future events, and the interests of different actors. There are four different scenario approaches: (1) vision; (2) projection; (3) pathway; and (4) alternative scenarios. The vision scenarios are based on subjective hopes. Projections are based on past trends and they predict how people expect the future to be. The pathway scenarios compare the present and desired future to assist in the design of strategies on how a certain future is achieved. The alternative scenarios map the possible futures based on anticipated changes.

Forestry Scenario Models and Forest Sector Models

Forestry scenario models are sometimes defined as computerized models used to make long-term projections of forest resources over a large geographical region (from a couple of hundred hectares to global level). They may be referred to as timber inventory projection models, timber supply models, timber assessment models, or long-term strategic planning tools.

Forestry scenario models cover natural processes of forests as well as management activities. There are different ways to classify forestry scenario models. A common classification is based on the forest growth prediction method (yield tables, stand models, or individual-tree models). Another classification distinguishes timber assessment and timber supply prediction models. Timber assessment models illustrate the effects of different harvest levels on the forest. Timber supply models predict supply, taking into account the forest structure and growth as well as the expected harvest.

Forestry scenario models are closely related to forest sector models. Forest sector models cover both forestry and the forest industry and they can be classified according to how they deal with spatial markets. There are two region nonspatial models, multiregion nonspatial price equilibrium models, spatial equilibrium models, trade flow and market share models, and transportation models.

Forestry Scenario Systems

Forestry scenario analysis is usually based on quantitative models covering natural processes (trees, other species, soil, etc.), products and services, human activities and their economy, and their interactions. For the analysis these models are integrated into software systems where appropriate data and models are integrated to mimic the real world and interaction of its components and processes.

The common components for most forestry scenario systems are: large-scale (national) forest inventory data as input, a simulation model for projections, and a method for the actual scenario generation corresponding to the defined assumptions. Depending on the method used in the generation of scenario, the models can be divided into optimization or iterative simulation models.

Examples of Forestry Scenario Models

Typically, a large-scale forestry scenario model has been designed for particular conditions and forestry-related problems. In northern Europe, national-level forest scenario models are available, for example, for Finland, Norway, and Sweden. In other parts of Europe, the models have been mainly designed for specific tasks and regions. In the USA, strategic planning software has been used for decades in the land management of public forests. New Zealand has utilized integrated simulation and optimization in the management of plantation forests.

In Finland, the MELA model of the Finnish Forest Research Institute is used for forestry modeling and analysis. MELA was designed in the 1970s for the regional and national analysis of timber production based on national forest inventory (NFI) sample plot data. MELA has two components: (1) a forest stand simulator based on individual-tree distance-independent models to generate automatically a number of feasible (sound and acceptable) management schedules for the stands over time; and (2) optimization software. In MELA, JLP software is used as the solver. In principle, JLP is a general linear programming (LP) package for solving Model I-type forest management planning and conventional LP problems. However, JLP is characterized by its outstanding capacity and speed in solving large-scale multilevel LP problems. This is due to the capability to utilize the specific problem structure where several management schedules are simulated for each stand. The structure of JLP makes it possible to solve both a production program for the whole forestry unit and the management of hundreds of thousands of stands simultaneously based on user-supplied goals. In MELA, hundreds of variables are available as optional decision criteria, combining the state of the forests, physical production, and economy. A typical analysis is based on the maximization of net present value. Three rounds of national analysis based on the NFI sample plot data have been carried out for the preparation of national forest programs since the 1980s.

In Norway, a similar approach to the Finnish MELA, based on integrated simulation and optimization, was adopted. The GAYA-JLP is a forest scenario model based on simulation of treatments for stands and linear programming (JLP) for solving management at forest level. The growth models are standwise. In addition to GAYA-JLP, the Avvirk simulation model is used for national and regional timber production analysis based on NFI sample plot data.

In Sweden, the Hugin simulation model has been used for long-term forecasts of timber yield and possible cut based on NFI sample plot data since the 1980s. Hugin is a deterministic simulation model with some built-in stochastic components. The growth models are based on individual trees.

In Germany, several models exist. For example, the FORCABSIM model is used to study the effects of management practices on the value of forest land and timber stock, as well as the stocks and fluxes of carbon. The FORSKA gap model uses forest inventory plot data to study the impact of projected climate change and alternative forest management strategies. In the Netherlands, the HOPSY model, based on singular stationary Markov processes, is used for wood forecasting.

In the strategic planning of US public forests, SPECTRUM was developed to replace FORPLAN, which has been used for Forest Service land management planning since the 1980s. FORPLAN was originally built for integrated resource planning of national forests. SPECTRUM was designed to incorporate new analytical capabilities to address ecosystem management issues. Both FORPLAN and SPECTRUM are general modeling tools applicable in different conditions.

In Minnesota, the DTRAN model has been used to analyze state-wide timber supply. DTRAN deals with interactions concerning timber supply within a region, taking into account the specific product requirements at specific market locations. In general, DTRAN is an optimization model that minimizes cost while meeting forest-wide production targets over the planning horizon. The advanced feature of DTRAN compared with other forestry scenario models is its ability to take into account transport costs.

In New Zealand, the IFS/FOLPI model has been used in forestry modeling. IFS is an interactive forest simulator used by the New Zealand Forest Service. FOLPI is a system based on LP. The system automatically translates the planning problem into an LP formulation, solves the problem using a standard LP package, and interprets the solution. The basic data for both IFS and FOLPI consist of tables of initial areas by crop type and age class.

In addition to national models, there are models covering larger regions. At the European level two approaches are used: the European Timber Trend Studies (ETTS) regularly carried out by the United Nations Economic Commission for Europe (ECE)/Food and Agriculture Organization are compiled from national estimates and the EFISCEN – developed from the former International Institute for Applied Systems Analysis (IIASA) timber assessment model – is a harmonized model based on NFI data. ETTS includes scenarios for the outlook for supply and demand of roundwood and forest products in Europe. In ETTS V the demand and supply forecasts are the results of econometric models, and the roundwood supply is based on the aggregates of national scenarios considered most likely by national experts.

The predecessor of EFISCEN, the original IIASA model, was developed in the late 1980s. The IIASA model is an area matrix model into which the management regimes are given exogenously. The EFISCEN matrix model uses NFI results, including area, volume, and net annual increment by age classes for more than 2500 forest types. The

EFISCEN has been used, for example, to study the impact of climate change on long-term growth and development of European forests.

Examples of Forest Sector Models

The most famous forest sector models are the Timber Assessment Market Model (TAMM), the Price Endogenous Linear Programming System (PELPS), the Global Trade Model (GTM), and the Timber Supply Model (TSM). Both TAMM and PELPS are mainly used at national level. GTM and TSM are designed for global analysis.

TAMM is a spatial model of the US solid wood and timber inventory. TAMM provides annual volumes and prices in the solid wood products and saw timber stumpage markets and estimates of total timber harvest and inventory by geographic region for periods up to 50 years. TAMM has been used to examine issues ranging from log export policies to the impact of carbon sequestration through tree planting.

PELPS was originally developed for the North American pulp and paper industry but PELPS III can be used for any sector to predict consumption, production, and capacity by technology, and trade within or among several regions or countries.

GTM is a partial market-equilibrium economic model originally developed at IIASA to predict future world trends in forest product consumption and production, timber supply, and global trade. The model finds, at any time period, the market equilibrium solution for all regions and all forest products such that demand and supply are equal for each forest product in each region. National versions of GTM have been used, for example, in Finland (SF-GTM).

The Center for International Trade in Forest Products (CINTRAFOR) has extensively revised the original GTM into CGTM. CGTM has been used to assess the economic impacts of climate change on the global forest sector, impacts of US carbon mitigation strategies on US and global carbon accounts, impacts of timber supply shortage on land-use allocation, and impacts of supply constraints and trade policies on global tropical forests. In addition, the model has been utilized in studies on the development of tropical hardwood markets, effective trade policies on tropical deforestation, and on market distortions and their impacts on the forest sector in Latin America.

TAMM and GTM are static simulation models. A static simulation model utilizes econometrically estimated functions of supply and demand to determine the single period equilibrium price and harvest level. Both models simulate the supply as price changes and growing stock adjusts through growth and harvest of timber. The solutions in many periods are linked together to project market behavior over time. Supply and demand relationships derived from historic data may or may not hold up during the projections.

TSM is an optimal control model that uses dynamic optimization to determine (solve endogenously) the path of price, harvest, and management that maximizes the net present value of consumers' plus producers' surplus over all time periods in the future. In TSM timber supply is a function of price and the amount of harvestable age classes. In forest sector models, the control theory may be more suitable than static simulation for long-term analysis because it provides the theory for predicting harvest behavior in the future when econometric relationships may not be valid.

TSM has been used, for example, to analyze the economic impact of climate change on global timber markets. In addition, TSM has been used to forecast the likely response of industrial wood producers to increased or decreased demand for fiber over the long term, and to analyze the effects of further set-aside or the adoption of more costly forest management or harvesting systems on timber supply.

In the USA, two different model sets have been used to analyze US private timber resources: the TAMM/NAPAP/ATLAS/AREACHANGE (TNAA) system and the Forest and Agriculture Sector Optimization Model (FASOM). The TNAA system consists of four linked models: TAMM, The North American Pulp and Paper (NAPAP) model, the Aggregate Timber Land Assessment System (ATLAS), and the AREACHANGE model. The AREACHANGE model projects the shifting of timberland between forest and nonforest uses and among forest cover types. NAPAP is a static, price-endogenous, spatial equilibrium model – like TAMM. NAPAP projects consumption, production, prices, and trade in pulp, paper, paperboard, and fiber markets. TAMM deals with solid wood and provides an interface with the timber resource model ATLAS. The TNAA system has been used for more than 20 years, especially in US Resource Planning Act (RPA) timber assessments and updates. The RPA assessment is the evaluation of the supply and demand situation for timber in the USA mandated by Congress and carried out by the US Department of Agriculture (USDA) Forest Service. The purpose of RPA is to analyze the timber resource situation to understand the implications for future cost and availability of timber products. The basic set of models has also been used in regional studies, for example in the south.

FASOM is a spatial, intertemporal optimization model which links the US forest and agriculture sector. FASOM was originally developed to examine forest and agricultural carbon sequestration policies. The Office of Economy and Environment in the Environmental Protection Agency (EPA) initiated the development of a dynamic model of the joined forest and agriculture sectors to be able to model the competition for the land. In FASOM the management investments and land use options are endogenous. The model employs a joint objective function, maximizing the present value of producers' and consumers' surpluses in the markets of the two sectors, subject to restrictions on the disposition of the land base that is suitable for use in either sector.

Forestry Scenario Analysis

A typical forestry scenario analysis includes several steps. First, the scenario assumptions are outlined. Second, the appropriate data and model or models are selected and preprocessed to be compatible with each other and the assumptions, if necessary.

Scenarios are usually based on the existing forest inventory data. Sometimes problems arise due to incompatibility of the inventory (designed perhaps to serve other purposes) and the selected model. It is possible to select the model according to the data available (bottom–up) or synchronize data with the selected model (top–down) using other models. The complex chain of models may cause additional errors to the scenarios. Therefore a careful validation of the model integration should be included in the selection process.

The choice of model type should depend on the problem in question. In the analysis, any number of input assumptions and structural relationships are manipulated. Most models are different in the model theory, model scope, and exogenous assumptions applied and therefore their ability for analysis varies. The utilization of forest sector models in the analysis of timber supply is often limited because the simple and aggregated forestry submodel does not allow modeling options for forest management regimes. Forestry scenario models usually provide more detailed analysis of forest management. However, forestry scenario models fail to solve the optimal management of forests under market economy because they cannot model the balance between supply and demand through prices. A popular solution is to use iteratively a forest sector and timber assessment model. By linking different models it is also possible to cover a larger range of social, environmental, and economic measures from the local to the global level. The outputs from one model are used as (exogenous) input assumptions in the other model.

Third, the assumptions are transformed into scenario parameters relevant for the data and model or models selected. Fourth, actual scenario runs are carried out and the results interpreted. Sometimes it is necessary to iterate between steps 1 and 4 several times – either for the actual study or for sensitivity analysis.

Future Challenges of Large-Scale Forest Inventory and Scenario Modeling

Forestry scenario modeling is needed, for example, to solve ecologically, economically, and socially sustainable use of forest resources for national forest programs. In economic and environmental policy analysis, scenarios may be conditional predictions on what will be the carbon sequestration of forests if the amount of harvested wood is decreased or increased, or studies on how forestry should adapt to and mitigate the effects of climate change.

Due to globalization it is important to incorporate a global scope and trade into the analysis to understand how, for example, plantation establishment or aging in the emerging region, environmental pressure to reduce harvesting in certain regions, and technological change affect global, national, or regional timber markets. In these trade-off studies, the model should be able to describe simultaneously the quality differences and resulting price differences among wood producers and between wood and nonwood, the price adjustment when matching demand and supply, as well as how wood producers change their investment, management, and harvest decisions in response to changes in relative prices. The models should cover all the relevant phenomena. For example, when solving forest management endogenously, models for nontimber products and services, damages, biomass, carbon, and different ecological/landscape considerations may be needed.

In scenario analysis, the magnitude of relative differences between different scenarios is important. Sometimes the uncertainty due to the models used is greater than the difference between scenarios. Because errors and uncertainty are rarely incorporated into the models, the interpretation of results is often difficult.

In the future, research and development should pay more attention to the optimal choice and integration of data and models, as well as modeling stochastic phenomena and errors explicitly.

See also: **Inventory**: Forest Inventory and Monitoring; Modeling. **Mensuration**: Forest Measurements; Yield Tables, Forecasting, Modeling and Simulation.

Further Reading

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Multipurpose Resource Inventories

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Introduction

Resource inventories are often functionally oriented and confined to areas where resource management opportunities are the highest (e.g., timber inventories were only conducted as commercial forest land). However, many lands are now managed for a variety of benefits, including water, forage, wildlife habitat, wood, recreation, wilderness, and minerals. International agreements and recent legislation often require that we take an integrated approach in our decision-making, resource planning, and inventories. In order to address increasing concerns about the environment and sustainable development and to reduce costs, we are finding we need more information than we normally collect in traditional timber inventories. Faced with new information requirements and decreasing budgets, many resource inventories in the future will have to change from the traditional functional inventories we conduct now. They will have to meet more needs with less funding. Future inventories will need to concentrate on measuring basic resource attributes in a manner that will permit multiple use interpretations. The inventories must be comparable across forests, states, and regions. They must also promote a continuity of information and direction between major decision levels. Lastly, future inventories must link to the past, provide a basis for monitoring plan implementation, and provide information on changes and trends.

Multipurpose resource inventories (MRIs) help meet our needs. MRIs are data collection efforts designed to meet two or more needs. Integrated, coordinated, and multiple resource inventories are forms of multipurpose inventories. Such inventories help meet the new information requirements. Fundamental to the successful development and implementation of MRIs are information needs assessments,