Swiss National Forest Inventory: Methods and Models of the Second Assessment

Edited by Peter Brassel and Heike Lischke

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WSL Swiss Federal Research Institute, CH-8903 Birmensdorf, 2001

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Abstract

Swiss National Forest Inventory: Methods and Models of the Second Assessment

The goal of the National Forest Inventory (NFI) is to record the current state and recent development of the Swiss forest in a representative and reproducible manner, using various data sources. To this end, in the second inventory (1993–1995) a combination of methods was used. Sampling followed a double sampling design: In the first phase aerial photos on a 0.5 x 0.5 km grid were used to estimate strata sizes, to identify forest plots and stocks outside the forest and to provide reference points for the field survey. In the second phase terrestrial sample plots on a 1.4 x 1.4 km grid were surveyed to record a number of variables to do with the individual trees and stands, young growth and damage by game, as well as features of the surrounding areas. The work and costs involved in the different steps of the terrestrial survey were recorded and evaluated. Ongoing training of the survey teams and control surveys ensured the data was of a high quality. Further information was obtained from interviewing the local forest services, from external data sources and models describing the site conditions, and from specially designed studies of forest transportation systems and the effects of game browsing on tree growth. The data were stored in a relational database and evaluated using statistical software developed specifically for this purpose. Static models were used for the evaluation of the following complex forest characteristics: the volume of standing and cut timber, tree growth, the work and cost involved in timber felling and extraction, the sustainability of forest regeneration, the protection provided by the forest against avalanches and rockfall, its recreational value, and the biotope values of the stands and forest edges. Furthermore, a dynamic model was developed which yields prognoses of the future development of each single tree depending on management scenarios. The models were supplemented by studies of error and uncertainty propagation to ensure good quality output variables. The raw and derived variables were comprehensively documented.

Keywords: multipurpose forest inventory, double sampling, terrestrial survey, aerial photography, growing stock, increment, forest growth model, sustainable regeneration, game browsing, forest functions

Foreword

The first Swiss forest inventory was compiled in the years 1983 to 1985. Before it started there were long discussions about its significance and field of applications. The federal authorities finally agreed to invest a considerable amount of money in an information system to support sustainable forest management. Timber volume was, of course, the primary target variable. Ten years later, when the second field campaign was launched, the world had changed. The issue of dying forests had made people aware of ecological risks. The conference of Rio de Janeiro in 1991 resulted in “biodiversity” becoming a popular term. Consequently, the Swiss Forest Inventory became an important tool for environmental monitoring. Hence, the methods had to be adapted and the list of parameters extended. The methodological changes, especially the statistical ones, were substantial: While the time series had to be maintained, adjustments to accommodate new fields of interest had to be implemented. This is one of the reasons why it has taken two years longer to publish the methods volume than it did to produce the survey results.

While this volume presents the methods used in the second inventory, the preparations for the third inventory are in full swing. We are fully aware that the objectives and methods will have to shift again. Maintaining the qualities of the time series will be a major challenge: In particular, we aim to provide an unbiased estimate of the variables influencing the state of our forests, giving the standard error of these variables and using well-defined methods that will allow comparisons with future investigations. Furthermore, the inventory has become a model-based tool for prediction. It has to predict both the quantity of timber and the quality of the environmental ecosystem.

The aim of this book is to give as comprehensive an account as possible of the sampling design, the methods of measurement and the statistical analysis used, as method design is one of the major tasks of WSL’s research efforts. This is a must for any validation and proper use of the data. While the state of Swiss forests is of little importance to the overall sustainability of the world’s forests, the methodology used in the inventory may be a valuable contribution to reliable forest monitoring. That is why we decided to have the report translated into English. The German version is, of course, also available.

We would like to express our thanks to the many people who contributed to this work, including WSL colleagues, the federal authorities who provided the funds, the many cantonal forest services who cooperated with us and numerous practitioners who provided valuable input. And finally we are very grateful to the translators who had to do an immense amount of work.

December 2001

Otto Wildi

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1 Introduction

Peter Brassel

1.1 The National Forest Inventory

The goal of the National Forest Inventory (NFI) is to record in detail the current state and changes within the Swiss forest in a representative and reproducible manner. The primary focus of the management report looks at the entire country, as well as the production regions: Jura, the Plateau, the Pre-Alps, the Alps, and the Southern Alps, which make up all of Switzerland. Depending on the problem task, other regions can be formed for evaluation.

The first NFI was realized between the years 1983 and 1985. At that time, about 11,000 forest sample plots were included in a kilometer grid and the results were published in 1988 (EAFV 1988). The data for the second NFI was collected between the years 1993 and 1995 and the results were published in 1999 (BRASSEL and BRÄNDLI 1999).

Both surveys were designed to be a multi-purpose inventory. This entails a high demand on the methods, flexibility in respect to the contents, inventory perimeter, and data analysis.

1.2 Goals and Contents of the Method Report

The method report presented here has two goals:

1. As a scientific publication it is designed to give a complete overview of the methods, so that the specialist is able to understand the second NFI.
2. In addition to the results of the second NFI (BRASSEL and BRÄNDLI 1999), it is intended to document the derivation of the adopted attributes. Thereby, it is possible to disentangle the result publication from comprehensive and detailed methodological explanation.

Most individual contributions within this book are published here for the first time. However, some subchapters have been summarized or synthesized from other publications.

1.3 Method Development in a Historic Overview

During the Swiss Forest and Wood Conference (1956), Professor A. Kurt, the director of the EAFV at that time, demanded the first National Forest Inventory. The goal of the inventory was to determine the production capacity of the Swiss forest, so that an objective base could support forest industry policies. In 1967, Kurt repeated this postulate at the Swiss Forest Directors' Conference. As a result, the National Forest Inventory was included in the guidelines of governmental policies. Therefore, it was possible to start developing methods for a comprehensive and permanently instituted inventory (WULLSCHLEGER 1985). Under the direction of Dr. P. Schmid-Haas, the research department, which was known at that time as "Inventory and Yield", started with the methodological preparation work. In 1973, the National Forest Inventory Research Department was finally founded. This new research department was entrusted to further develop these methods.

In the course of the policy preparation, the informational needs of the forest policy makers and the Cantonal Forest Service were clarified. The original idea of an inventory based on standing timber has been only superseded by the idea of a broader, multi-purpose inventory. Apart from the important forest management indicators, such as standing timber, growth increments, exploitation, tree species composition, and stand structure, the inventory is expected to also include information about the soil, forest vegetation, forest functions, and the conditions of enterprises (WULLSCHLEGER 1985).

According to this original plan, the cantons were to participate in the data collection process. Thus, they were to become part of the primary focus used to report the management results.

This original concept of a comprehensive survey, with the participation of the cantons, was abandoned in favor of a simpler, nationwide inventory with the primary focus only on the country and the regions. In the second stage, the intent was to intensify the grid for the cantons.

The development of these methods also involved the employment of aerial photography, so that the cost of the ground survey could be reduced. An important application of aerial photography lies in the classification of plot samples in forest and non-forest areas, thereby segregating the forest. This requires an objective and measurable forest definition, which is applicable in aerial photographs as well as on the ground. Apart from using the aerial photographs in the forest/non-forest decision process, the measurements taken were also intended to be used to enhance the precision of estimating the standing timber for the entire forest area.

The aerial photographs from the Swiss Federal Office of Topography are taken for the entire country in a six-year rotation. The employment of this high quality source of information for the National Forest Inventory seemed obvious. The first study dealt with the deployment of aerial photographs to determine the standing timber in open forest stands. The combined procedure for estimating the standing timber with regression estimators (ZOBEIRY 1972) turned out to have promising results for open forest stands. However, it was not possible to apply this method generally for all of the different forests within Switzerland. To assert the production capability of the Swiss forest, a technique was developed which allowed the estimation of the site class without ground surveys. This "simple site index key for forest stands in Switzerland" (KELLER 1978; KELLER 1979) can be applied for all sample plots throughout the NFI.

An important prerequisite for the NFI was to clearly define the attributes for the terrestrial inventory and the aerial photography interpretation. The definitions for the stand assessment used at that time in the cantonal forest management were heterogeneous and not comparable. The attributes had to be newly defined.

A declared goal of the first NFI was the assessment of the protective and recreational function of the forest. Nevertheless, these functions could only be determined if the surrounding areas of the forest were taken into account. Furthermore, it was not intended to extend the inventory perimeter into the non-forest area. As a result, the comprehensive evaluation of the forest function had to be relinquished.

In order to study the feasibility of the methods developed up to that point, a pilot inventory was conducted in the years of 1978–1979 in the canton of Nidwalden. The inventory design, inventory manual, aerial photography interpretation, vegetation survey and soils inventory, along with the workflow and equipment, were tested in the deployment of the operation. This pilot inventory gave valuable information and insight with respect to the definitions of the attributes, the size of the sample plots, the organization of the ground survey, the estimation of expenditures, and instructions for selecting the sample trees.

In 1981, the Swiss Federal Council decided to implement the first NFI and made the necessary funds available. The sizes of the sample plots were set to two concentric circular areas with two and five Aren (200 and 500 square meters), respectively. In addition, the sampling grid was defined. A grid with a mesh width of 1 km was intended for the terrestrial survey and a grid with a mesh width of 0.5 km was established for the aerial photography survey.

By the end of 1982, the last phase of the methods' development was completed. Very soon after the operational aerial photography interpretation had begun, it was realized that the amount of measurements taken for the standing timber estimation in the 0.5 km grid were too costly. The interpretation of the forest/non-forest decision had to be accelerated, since it had to precede the ground survey. The aerial photography was therefore only continued as a means in determining the forest area and to aid the terrestrial inventory by providing assistance for siting.

The forms used to collect data were later digitized. Data transfer was done with magnetic bands and punch cards. The development of software (FORTRAN) for the plausibility control, attribute derivation, file system and analysis was done on a batch-operating system at the computer center of the Federal Institute of Technology-Zurich (ETH-Zurich). At that time, the analysis software was designed to be flexible, so a large number of special analyses was possible.

During the analysis work of the first inventory, the methodological preparation for the second NFI started. At the time of the analysis and interpretation of the results, gaps of knowledge were identified which could only be closed with a second survey. Moreover, the change in the political climate, with new relevant questions emerging, led to changes in informational needs. Apart from the attributes collected in the first NFI, which consisted of timber production functions and non-wood goods and service functions, the second NFI gathered information for the ecological evaluation and protective functions, especially against falling rocks, avalanches and recreational functions. The area studied was extended from the forest to the forest edge and the "other" stocking outside the forest area.

Even though the need for information had increased, the amount of funding provided by the Federal government decreased. Therefore, a complete second inventory of all sample plots from the first survey was not possible. A decreased estimation in the precision of the target parameter was the consequence of these actions. Due to the double sampling design, it was possible to keep the loss of information about the country and the regions at a minimum. It was evident that reducing the terrestrial sampling plots by half meant a greater loss of information for smaller units.

In both inventories, great importance was attached to the illustration of the estimation error. The ordinary standard error of the target variable was used in the first, as well as in the second NFI. In the second NFI the area estimation error was also considered.

The workflow and the flow of data of the second NFI are presented in a simplified chart shown in Figure 1.

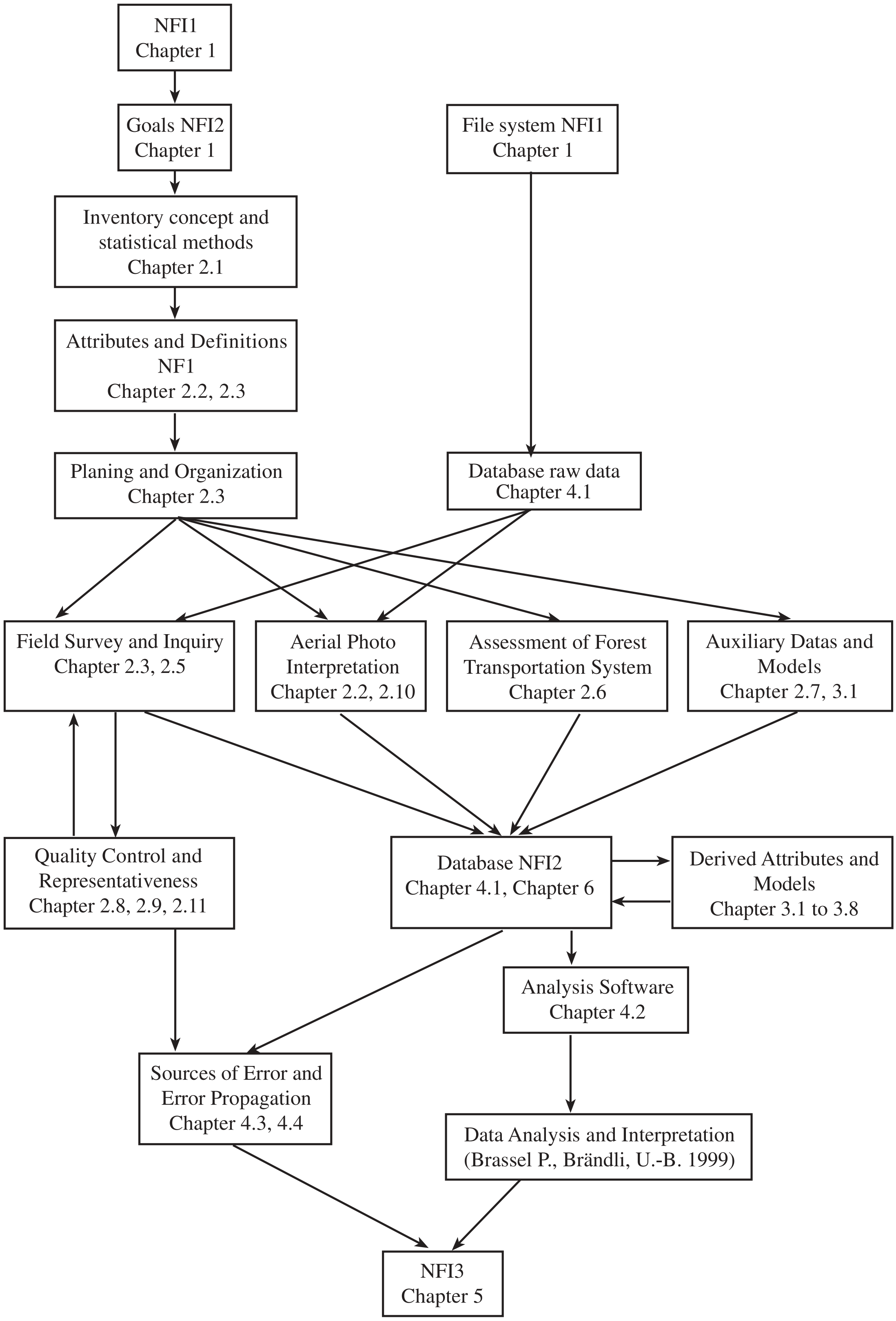

Figure 1. Flowchart NFI2.

1.4 Summary

Main Chapter 2 Methods documents the statistical design of the NFI, the derivation of the estimators, and the data sources. It also reports survey methods used on the ground in the forest, in aerial photography and on maps. It shows how the data quality is ensured and presents the results of the control surveys.

Chapter 2.1 Inventory Design NFI2 shows the statistical design of the inventory. Several alternative sample designs for repeated inventories are discussed. The main focus here is on the continuous forest inventory, sampling with partial replacement, and in particular on the combined multi-phase inventory designs. Among the multi-phase inventory designs, double sampling for stratification proved to be the most efficient one for the NFI.

The estimators for the current state and change of the target quantity's forest area, standing timber, basal area, and number of trees, as well as algorithms for calculating the estimation error are described. Special attention was paid to the cost efficiency, that is the accuracy optimization. The chapter Inventory Design NFI2 is a shortened version of the detailed original (KÖHL 1994).

Chapter 2.2 Aerial Photography documents the methods of the aerial photography interpretation in the second NFI. The data are analyzed using an analytic interpretation instrument in an absolute oriented stereo model. The most important attributes are forest area, which is quantified with the help of the forest/non-forest decision, and stratifying variables. The aerial photographs used in the second NFI have different dates, since the flights were conducted between 1988 and 1993. Due to this, the inventory interval for data measured using aerial photographs was between six and twelve years.

The catalog of attributes encompasses not only the forest area, but also includes the stand description, the forest edge presence, and measurements and counts of the stocking outside the forest area. In addition, orientation aids for the ground survey were measured.

Chapter 2.3 Terrestrial Inventory documents the planning, organization and workflow of the ground survey. Because the aerial photographs play a key role in the terrestrial inventory of both inventories, the general organizing is based on the flight plan of the Swiss Federal Office of Topography, while planning details and employment of the survey team depends on the forest district.

The terrestrial catalog of attributes is presented as an abbreviated version of the comprehensive guide for field surveys (STIERLIN *et al.* 1994).

Chapter 2.4 Expenditure of the Terrestrial Inventory introduces the results of the automated time keeping and special time studies. This chapter is an important foundation for planning subsequent national inventories and cantonal inventories.

The time consumption of the different work and survey phases is presented for the regions and for the whole country. The actual measurement and appraisal work consists of only about 50% of the total working time. The remaining time was used for driving, cruising, ensuring sample-plot centers and locations, instruction, training, etc. The chapter is an abbreviated version of the comprehensive original (ZINGGELER and HEROLD 1997).

Chapter 2.5 Game Browsing Damage Survey deals with an important side aspect of the terrestrial inventory. The recording of the browsing proved to be problematic in the first NFI since, at that time, the browsing of the terminal shoot in the current year was recorded and therefore, introduced a dependency on the time of recording. The second NFI tried to eliminate the time dependency by backdating the occurrence of browsing. Due to these circumstances it was not possible to compare both inventories directly. Both methods used to evaluate browsing were compared with each other, based on case studies. The chapter is an abbreviated version of the comprehensive original (SCHWYZER 2000)

Chapter 2.6 Forest Transportation System Survey describes the methods for evaluating the digitized forest road network. In cooperation with the forest service, the forest roads were continuously recorded in the first NFI at a scale of 1:25000. The road length was determined by the point intersection method and was converted into running meters per hectare. The continued recording of the forest road network, trafficked by trucks in the second NFI, was based on the same criteria and classification principle as were the 15 to 20 year old maps of the first inventory. In order to prevent larger problems in the continued recording, the whole forest road network was digitized for both inventory dates and connected with thematic attributes.

Chapter 2.7 External Data Sources documents the storage media and data, which were not calculated or collected during the NFI but were used for the analysis. With the help of these information sources, the information content of the inventory was increased, synergisms were used, and the specific inventory data was combined with other data.

Chapter 2.8 Criteria and Provisions for Quality Assurance discusses the foundation and conditions that ensure data quality. Important factors for inventory quality are: 1) careful recruitment and training for fieldwork personnel, 2) planning and preparation, 3) suitable material and documents, 4) control surveys of both the terrestrial inventory and the aerial photography interpretation and 5) repeated training courses for the survey teams.

Chapter 2.9 Control Survey of the Terrestrial Inventory shows results of the independent second survey from controlled sample plots and presents the methods of the data analysis. The goal of this control survey was to uncover distortion during the data gathering and to clarify the definition of the attributes, as well as to quantify the reproducibility of the terrestrial inventory. With the results of this control inventory, problems and uncertainties were discovered which were picked up and corrected later in repeated training of the survey teams.

Chapter 2.10 Control Survey of the Aerial Photography Interpretation discusses the reproducibility of the data assessed in aerial photographs. The goal of this control was to quantify the systematic differences between the first survey and the independent control survey, as well as between the different aerial photographic interpreters.

Chapter 2.11 Representativeness of the Sample Grid examines whether the sample grid is representative for the Swiss forest. The sample-plot centers were permanently marked in the NFI. These ensured points were marked with strong, visible blue paint. It is feasible that managers could be influenced by this fact. Systematic deviation would have serious consequences for the whole NFI. Among other things, a newly established terrestrial 4-km grid, with approximately 750 sample plots, was measured to investigate the representativeness. There was no significant difference between the target parameter, e.g., standing timber of the newly established grid and the original grid.

Main Chapter 3 Derived Quantities and Models describes all of the different derived attributes used in the NFI. The raw data could only sometimes be directly analyzed. In most cases they had to be transformed and combined.

Chapter 3.1 Site describes the models used for site index (KELLER 1978; KELLER 1979), altitudinal vegetation zones (BRÄNDLI and KELLER 1985) and the potential natural forest vegetation (BRZEZIECKI *et al.* 1993). The potential natural forest vegetation, represented by the forest communities (ELLENBERG and KLÖTZLI 1972), is modeled with different input values.

Chapter 3.2 Standing Timber, Increments and Utilization documents the calculation for some of the central target parameters of the NFI. One of the most important requirements for the calculation of the standing timber, increments, and utilization is the unbiased estimation of individual tree volume.

In order to calculate the volume for all trees based on the three-parameter volume function, a one-parameter volume function using the Diameter at Breast Height (DBH) as the input parameter (tariff) was derived. The increments were calculated for each individual tree. For ingrowth and utilized trees, an incremental tariff was used.

The target parameters of the standing timber, increments, and utilization were decomposed into timber assortments with a purely dimensional classification and without considering quality characteristics. With this, it was possible to describe the utilization of the standing timber.

Chapter 3.3 Prognosis and Utilization Scenario documents a simulation model which prognosticates future forest conditions and developments, standing timber and increments, the available amount of timber that can be utilized (utilization scenario) and its assortments, depending on the intensity and type of management intervention. This model was validated by both inventories.

Chapter 3.4 Sustainable Forest Regeneration deals with models which evaluate the regeneration situation in uniform high-forest and in structured, all-aged selection type stands (plenter forest). Apart from the definition of a "sustainable forest regeneration", in the sense of multifunctional forestry, this chapter presents: 1) the foundations and assumptions to calculate sustainable forest regeneration, 2) the minimum required number of trees and 3) the percentage of area with respect to the entire forest.

Chapter 3.5 Expenditure for Timber Felling and Removal explores the foundations, assumptions, and employed approximate values introduced to calculate the expenditure. By calculating the timber fell and removal expenditure with a unified method, it was possible to deduce comparable timber harvest costs for all of Switzerland, including all regions and cantons, independent of the regional conditions. The approximate values for timber felling and removal were either taken from the literature, particularly leaflets, or were based on practical experiences in forestry.

Chapter 3.6 Protection against Natural Hazards illustrates the methods for designating protective forests according to the NFI (NFI Protective Forest), and models that describe the effects of the forest. The designation of these protective forests takes into consideration avalanches and rockfall, as well as the potential hazards and the potential losses. The effects of the forest in respect to rockfall and avalanche fracture lines were quantified.

Chapter 3.7 Recreational Function documents the method that determines the recreational effects of the forest. The recreational requirement, as used in the NFI, is limited to short-term (daily) recreation only. The simple model for characterizing the recreational function, according to the NFI, was therefore limited to population density, with respect to the intensity of tourism. The recreational effects were characterized by the presence of roads, the infrastructure and the type of nature. The type of nature within the forest is determined through a combination and weighting of the stand structure attributes.

Chapter 3.8 Natural Protective Function describes the methods for the ecological assessment of the forest stands and the forest edges. For the assessment of the forest stands, the closeness to nature, the small wood diversity, and the structural diversity were considered. In this assessment, each of the three parameters was determined through the combination and weighting of different attributes, and finally aggregated to one entire evaluation. The ecotone value of the forest edge was established in a similar manner, based on the small wood diversity and the structural diversity.

The procedure for the ecological forest stand and edge evaluation stems from a combination of standard procedures and research work at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). With this, the instruments for an objective evaluation of the ecological values of the forest were provided, which were based on quantifiable parameters and were applicable to all areas of Switzerland.

Main Chapter 4 Data Analysis presents the foundations and instruments to analyze NFI data, examines the impact of errors taken from data gathered on the accuracy of derived attributes, and, finally, looks at the inventory results.

Chapter 4.1 Database gives an overview of the NFI database structure. The relational database is the foundation for all analysis within the NFI data and, therefore, one of the essential prerequisites for the entire NFI project. The database contains a collection of all raw data along with derived and external attributes.

Chapter 4.2 Analysis Software documents the user interface and the possible analysis of NFI data. The analysis software was implemented in SAS and made consistent analysis and database queries possible. Analysis could be parameterized and saved with standardized menus.

Chapter 4.3 Error Source and Its Influence on the Inventory Results discusses error propagation, starting with the measurements, in particular the classification in the forest and in the aerial photograph, followed by the derivation of attributes and concluding with the results. The sources of error were manifold and could arise by: 1) the selection of the sample plots, 2) measuring and describing the stand, 3) deriving the attributes and models and 4) calculating the estimator. The original title “An Assessment of some Nonsampling Errors in a National Survey Using an Error Budget” (GERTNER and KÖHL 1992) was published in 1992.

Chapter 4.4 Propagation of Data Uncertainty through Models investigates the influence of errors from input data on model results. The forest protection model, the models for the ecological assessment of the forest and the forest edges, as well as the model to assess the recreational quality of the forest all required different input variables, which were themselves full of uncertainties. These uncertainties of the input variables were known from control samples of the terrestrial inventory. Each individual uncertainty affected the model’s results and could influence the results of the assessment. The results of this work give important hints about the validity of the applied models in the second NFI.

Chapter 5 Outlook discusses the experiences and findings from the first and second NFI and draws conclusions for further successive inventories. Method development is turned into a permanent task through the constantly changing need for information, the development of remote sensing methods, such as digital photogrammetry and image processing, and in the development of inventory statistics.

Chapter 6 Appendix documents the cited literature, the index, and the list of variables used in the NFI database. The documentation of the variables with the detailed variable names indicates the information quality of the NFI.

1.5 Using the Methods and NFI Information

The methods (character definition, design, and models) and the tools (equipment, software, and database), which were used for the NFI are also suitable for similar inventories such as the densification of network in the cantons as well as for special inventories. The documentation of NFI methods presented here is intended to enable potential users to evaluate the suitability of the NFI inventory system for regional and special inventories. By using the NFI methods, an important contribution can be achieved to harmonize the database for forest development planning at the regional and cantonal levels.

The greatest value of the NFI lies in its information content. Only a small portion of this information was fully utilized from the results of second survey. The database and the analysis software are suitable for further data analysis of current problem tasks.

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2 Methods

2.1 Inventory Concept NFI2

Michael Köhl

2.1.1 Introduction

The inventory concept of the NFI links data that were assessed through field surveys, aerial photography interpretation, inquiries and map interpretation, and the informational needs, which were intended to be satisfied with the NFI. Inventory methods are subject to change, since informational needs and technical possibilities of data survey underwent a change through the course of time. In the first NFI, the main objective of the survey was to describe the state of the Swiss forests. This description, which has the nature of a snapshot, was also required in the second NFI. In addition, the changes had to be presented, which took place in the Swiss forest in the ten years between the first and successive inventories. These new problems made further development of the sampling concept of the NFI indispensable.

In the first NFI, only rough data on the Swiss forest (of which the reliability was partially unknown) was available for the method development. The method development for the second NFI was able to use the rich experience obtained during the conduction and data analysis of the first NFI. These experiences affected first, the inventory practice and second, the findings about the Swiss forest itself. The results of the first NFI survey allowed a better understanding and definition of the sample population (the Swiss forest) with respect to the variability and the spectrum of quantitative characteristics. With this information, it was possible to develop a more efficient method, which was better fit to the population.

Apart from the newly developed approach to describe change, the most important method modification affected the deployment of aerial photographs. In the first NFI, aerial photographs were used for the first time to cover the entire country of Switzerland in the framework of forest surveys. At that time, comparable surveys were only available for small (test) areas and applications at the regional or even on the national levels were hardly known. Aggravating for the employment of aerial photographs is the diversity of the Swiss forest, which is characterized through heterogeneous, small area structures and, consequently, was particularly demanding to the inventory methods. The second NFI was able to build on the experience of the deployment by completely covering aerial photographs in the first survey. Accordingly, by developing this method further, it became the pioneering role in Europe.

The efficiency of the NFI was significantly improved because of the intensive utilization of aerial photographs and the development of new methodological approaches that combined data derived from aerial photographs and forest samples. Especially attractive was the reduction in the number of forest samples by approximately 50 percent, while at the same time keeping the estimation precision of the first NFI for all of Switzerland and the five production regions. Due to the reduction in the field survey, each of the forest samples in the second NFI increased in weight. The reduction of the field survey was only possible because special analysis within the first NFI, along with the pilot inventory for the second NFI, revealed the high data quality of the field survey. A revised inventory manual (STIERLIN *et al.* 1994), an intensive training plan, and an independent control survey guaranteed high data quality in the second NFI (see Chapter 2.8 and 2.9). It also reduced the danger of one-sided error to a minimum. The high quality data that was guaranteed by the field survey formed the basis for efficiency improvement through the intensive aerial photograph deployment.

Even though the statistical methods fundamentally changed, the second NFI proceeded with high continuity from the first one. For example, the data sources of the first NFI were also kept in the second NFI, and the concentric sample plots and quadratic interpretation area of the field survey were not changed. In addition, the sample selection followed in accordance with the sample grid of the first NFI. All data from the first survey was used in the analysis of the second NFI.

The development method of the second NFI was guided by two important principles: The methods were only modified as far as it was absolutely needed, and the selection of the statistical methods, simplicity, and universal validity were ultimately given preference over more complex procedures, which would have only gained efficiency for a few characteristics. Many statistical approaches were tested during the development of these methods. For example, geostatistical methods (KÖHL and GERTNER 1992), Bayes estimators (KÖHL and GREEN 1991) and successive inventory designs with partial replacement of sample plots (SCOTT and KÖHL 1994). Under special conditions and for specific problems, these procedures led to more efficient estimates; however, they could not be combined into a universal valid sampling design for the second NFI. For the final determination of the sample designs of the second NFI, a more robust procedure was preferred, which was not only applicable to a few key characteristics such as timber volume or increment, but was also applicable to all conditions which could be encountered in the Swiss forest. That the procedure also led to immediately understandable results and additive tables was a nice concomitant.

In the following, an overview is given about successive inventory concepts and multi-phase sampling techniques to combine data observed from aerial photographs or on sample plots. Following, an account for the sampling concept of the second NFI and a discussion of the procedures to optimize the sampling design is given.

2.1.2 Sampling Procedure for Successive Inventories

The idea of describing the development of stands through permanent observations and thereby controlling the sustainable forest management was born in the last centennial in Europe. In Germany, permanent plots were already set up in 1860 (GRAVES 1906). In France, GURNAUD (1878) developed rules to use successive measurements to estimate increment, which are known as control method (Kontrollmethode, méthode du contrôle). BIOLLEY (1921) was the first to apply these rules. The forest of Couvet in the Swiss Jura, where the methods were developed, was measured ten times between 1890 and 1946 in intervals every six to seven years. Therefore, the permanent forest observation has been a 100-year tradition in Switzerland.

2.1.2.1 Continuous Forest Inventory (CFI)

In the United States, the idea of permanent observation became more important because of the economic recession between 1929 and 1950 (STOTT and SEMMES 1962), and thereby increased interest in primary production factors. Directly applying the European methods, which were based on recording all trees within a stand, especially the control method of GURNAUD (1878) and BIOLLEY (1921) was not possible. The vast areas of the North American forest would only allow the survey of a small part of the forest of interest. A solution to this dilemma was presented in the application of sampling methods that was rarely practiced at that time.

In the 1930's, sampling methods known as Continuous Forest Inventory (CFI), were developed which were based on repeated measurements of a set of sample plots (STOTT and RYAN 1939). STOTT and SEMMES (1962) give a historic overview of the CFI application. In the Midwest, between 1937 and 1938, a few hundred permanent sample plots in forests operated by the wood processing industry were established. In the Great Lakes and Central Plains States starting in 1939, approximately 3,700 permanent circular sample plots were set up in private, industrial and public forest enterprises. In 1948, the inventory of forests in Ohio and Wisconsin took place with about 1000 permanent sample plots. In 1952, the American Pulpwood Association (APA) became aware of the CFI and introduced it to their members. During the following years, a cooperation between the APA and the USDA Forest Service led to an extensive application of the CFI extending east of the Mississippi River. In 1962, approximately 50 enterprises associated with the wood processing industry managed 25 million acres using the CFI method.

In Germany in 1936, KRUTZSCH and LÖTSCH (1938) set up permanent sample plots for a continuous yield control. In Sweden, a similar concept was developed by PATTERSON (1950) and was applied in the forest yield research at the Swedish forest experimental station. In Switzerland, SCHMID (1967) introduced the CFI into forest management planning and advanced the classical control method to the continuous forest inventory. His intensive effort toward an applied survey method for permanent sample plots (SCHMID-HAAS *et al.* 1993) resulted in a wide acceptance of the method in Swiss forestry.

With the CFI method, all sample plots measured at the first occasion are measured again in successive inventories. The estimated mean of an attribute (e.g., growing stock, number of trees, basal area) and its variance are estimated as follows:

$$\hat{\bar{Y}} = \frac{\sum_{i=1}^{n} Y_i}{n} = \text{mean on second occasion} \tag{1}$$

$$\hat{\bar{X}} = \frac{\sum_{i=1}^{n} X_i}{n} = \text{mean on first occasion} \tag{2}$$

$$v(\hat{\bar{Y}}) = \frac{\sum_{i=1}^{n} (Y_i - \hat{\bar{Y}})^2}{n(n-1)} = \text{variance of } \hat{\bar{Y}} \tag{3}$$

$$v(\hat{\bar{X}}) = \frac{\sum_{i=1}^{n} (X_i - \hat{\bar{X}})^2}{n(n-1)} = \text{variance of } \hat{\bar{X}} \tag{4}$$

where

Y_i = observation on sample plot i (i = 1, ... n) on second occasion
X_i = observation on sample plot i (i = 1, ... n) on first occasion
n = number of sample plots ($n = n_1 = n_2$)

Changes between two occasions can be derived through the difference of both means.

$$\hat{\bar{G}} = \hat{\bar{Y}} - \hat{\bar{X}} \tag{5}$$

The change G (= growth) has the variance

$$v\left(\hat{\bar{G}}\right) = v\left(\hat{\bar{X}}\right) + v\left(\hat{\bar{Y}}\right) - 2\, r_{yx} \sqrt{v\left(\hat{\bar{X}}\right)} \sqrt{v\left(\hat{\bar{Y}}\right)} \tag{6}$$

where
r_{yx} = correlation coefficient between the observation on the second occasion and the first occasion.

The higher the correlation is between observations, the smaller the variance of the difference is. The value of the correlation coefficient r_{yx} decreases with increasing time intervals between observations. If completely independent sample plots are measured on both inventory occasions, the last term of (6) is dropped for calculating the variance. Consequently, the CFI estimator always produces a smaller variance than independent observations. This is also true when the correlation of the observed values is small on both occasions. The advantage of using the CFI method is clearly in the reduction of the variance of estimated change. The variance of the state estimation is not influenced.

Apart from the described advantages of the CFI method, it also contains the danger that the position of the permanent sample plots will be known and that the management of them is changed. It was not absolutely possible to assume hidden invisible NFI sample plots for several reasons: 1) Out of 11,000 NFI sample plots, 686 were visited annually for the national forest condition survey; 2) The position of the sample plot centers is visible by color markings; 3) A part of the NFI sample plots are used for the cantonal forest condition survey; 4) The sample plot centers correspond with the grid net of the topographic maps; 5) The position of the sample plots is known to the local forest service from the questionnaire accompanying the first NFI. The danger that visible permanent sample plots are not representative for the entire population through a changed management throughout the course of time has often been described; thus, according to SCHMID-HAAS (1983), there is "no guarantee that visible samples will remain representative." He believes that even the most experienced forester cannot be sure that he would not be influenced by the knowledge that his work might be subject to scrutiny. Consciously or unconsciously, it is possible that the sample areas are being treated differently than the rest of the standing timber. A sample plot inventory, which cannot reliably eliminate this danger, is not very suitable for planning purposes. From this conclusion, a clear requirement for an addition to the permanent samples through temporary sample plots can be drawn, so that systematic influences are quantifiable and make it possible to adjust the estimates. (See Chapter 2.10.)

2.1.2.2 Sampling with Partial Replacement of Sample Plots (SPR)

A sampling method for field survey that was introduced in the 1960's to the applied forest inventory is Sampling with Partial Replacement (SPR). With this method, portions of the sample plots that are measured in the first survey are replaced by new samples. For two occasions three types of sample plots can be considered:

- Sample plots, which are measured on the first occasion as well as on the second occasion (permanent sample plots, matched plots, n_{12} sample).
- Sample plots, which are only measured on the first occasion (unmatched plots, $n_{1\text{-}}$ samples).
- Sample plots, which are only measured on the second occasion (new plots, $n_{\text{-}2}$ samples).

If only the net change has to be estimated (e.g., volume growth), permanent sample plots are more cost efficient than two independent surveys. This means that for the same cost they lead to a smaller sample error. This seems obvious, since the difference between two independent observations is not only caused by change alone, but also through the variation within the two populations. If only current state is to be considered, temporary sample plots are often shown to be more cost effective than permanent plots, since the expenditures for marking the sample plot centers and the registration of sample tree coordinates do not exist. Combining both of these sample plots can therefore improve the cost efficiency, while at the same time, current state and change are to be estimated.

The estimators introduced in the following are calculated in four steps:

(1) At first the successive measurements on the second occasion are related through a simple linear regression with the values on the first occasion. Through this regression, the values of the sample plots that are not remeasured are updated. To describe the current state, two means are calculated: One mean is based on the measurements of the matched plots and the updated values of the unmatched plots. A second mean is derived from the new (temporary) sample plots.
(2) For both means the variance is calculated.
(3) Through weighting both means with their inverse variance, a combined estimator is derived. If the regression estimator has a larger variance, it receives a lower weight and vice versa.
(4) As the last step the variance of the combined estimator is calculated.

These steps can be used for the estimation of the current state, as well as for the estimation of the net change.

Apart from others, SUKHATME *et al.* (1984), COCHRAN (1977), and KISH (1965) also discuss the theory of sampling with partial replacement of sample plots. BICKFORD (1956) was the first to introduce the theory of SPR to the forest inventory applications. The first application of SPR was done in an inventory conducted by the USDA Forest Service in the northeastern United States. BICKFORD (1959) combined SPR with aerial photographs and applied this modified method in the Allegheny National Forest.

WARE (1960) examined the data of repeated measurements in the northeastern region of the United States and found that in six out of eight cases the variance was not the same at both inventory occasions. If the algorithm which calculates the SPR estimator ignores this fact it would result in biased estimates.

WARE and CUNIA (1962) decisively extended the applicability of SPR. Until the derivation of the theoretical framework, the application of SPR was limited to only a few special cases, since the sample theory for SPR requires either the equality of population variance, the same sample size of succeeding inventories, or the satisfaction of both requirements. The problem of the optimal strategy for replacing the sample units was only solved for the case of the estimation of one attribute. Furthermore, different survey costs for new and repeated measured sample plots were not accounted for.

SCOTT (1981; 1984) derived estimators from the sample values, which completely use the variance information of the permanent and temporary sampling units. He applied the variance estimator derived by MEIER (1953), which estimates the weights from the sample values, as well as the variance of the regression estimator for a two-phase sample. SCOTT and KÖHL (1994) extended SPR in the two-phase sampling for stratification at two and three occasions.

A detailed description of the work about SPR is found in KÖHL (1994), who additionally shows that the application of the SPR estimator has its problems. After more than two inventory occasions, the SPR estimator becomes very complex and unwieldy (SCOTT 1986; 1994). At the second inventory occasion, three different types of sample areas must be distinguished: permanent samples, new samples, and old samples. With three inventory occasions, there are already seven different types of sample plots. Therefore, the complexity increases with the number of observations in time.

Inventory results are not only needed for the entire population (i.e., the entire forest area of Switzerland), but also for thematic subunits, such as the forest area structured by property categories according to site quality. Out of these demands, results have been presented in table form. In the table margins, the total value for the thematic subunits of the columns and rows is found. In the case that the cell and marginal values of tables are estimated independently of each other, the cell values will not add up to the column and row sums (see Table 1). Non-additive tables are not a problem for the statistician. Nevertheless, they are hardly accepted by the users of the inventory results. Consequently, the non-additive tables have to be adjusted. Different methods were developed for adjusting the non-additive tables. These procedures are very complex and can result in biased results within individual cells.

Table 1a. Example for an additive table.
Forest area by type of ownership and site quality in 1000 ha.

	poor/moderate	good/ very good	Total
Public forest	404.1	408.0	812.1
Private forest	114.5	259.7	374.2
Total	518.6	667.7	1186.3

Source: EAFV 1988, page 81.

Table 1b: Example for a non-additive table.
Forest area by type of ownership and site quality in 1000 ha.

	Poor/moderate	good/ very good	Total
Public forest	409.1	407.0	824.9
Private forest	119.4	256.8	370.3
Total	503.1	671.9	1186.3

The application of the CFI method can also lead to problems. The inventory systems are dependent on whether the permanent samples are representative. This is especially true in managed forests or in the event of changing landuse. A change in the inventory objectives cannot be taken into account when changes of sample sizes or locations of sample plots are required to meet the new objectives. However, applying the CFI estimator results in additive tables.

The problem encountered with the application of the SPR method led some survey regions of the United States to replace the SPR method with alternative sampling designs (HAHN, SCOTT, personal communication).

In the Swiss National Forest Inventory, CFI as well as SPR estimators were used. During the second survey, only 50 percent of the forest samples from the first NFI were remeasured (permanent samples), and about 600 sample plots were newly set up (new samples). In order to estimate current state, only new and temporary samples were used. The estimation of change was based only on the permanent samples. Thus, the CFI estimator for the derivation of change, and the SPR estimator for the derivation of the current state were combined. The integration of both approaches in the two-phase NFI concept, which was based on aerial photography interpretation and terrestrial survey, is described in Chapter 2.1.4.

2.1.3 Combined Inventory Procedures

If sample plots lie far apart from one another and can only be reached at great expense, it could be very costly to survey the inventory area through randomly or systematically distributed terrestrial sampling units. In the statistical literature, sampling methods can be found which can dramatically increase the efficiency of a survey by utilizing information from several different data sources. If these procedures are applied to forest surveys, it is suitable to combine terrestrial measurements and interpretation of aerial photograph or satellite data. Combined surveys utilizing aerial photography and field assessments were already intensively studied in the 1950's (HILDEBRANDT 1961, 1962). HILDEBRANDT gives an overview of the state-of-the-art research and applications of combined forest surveys at that time.

The production of maps showing the distribution of forests has always played an important role in the employment of aerial photography in forest management. Today, capturing the forest area dynamics in densely populated areas and in regions of the tropical rainforest or boreal forests is of the utmost importance. The suitability of aerial photography and digital remote sensing data to monitor forest area change has been intensely studied (see for example ITTEN *et al.* 1985; KUSHWAHA 1990) and is in some countries, such as India (UNNI 1990), an already routinely applied standard forest area monitoring method. Nevertheless, this aspect of applied remote sensing methods shall not be discussed any further here.

The following discussion focuses mainly on the application of aerial photography for the growing stock estimation. The following three conceivable groups of sampling designs for combined forest inventories are illustrated further:

1. Stratified sampling
2. Multi-stage sampling
3. Multi-phase sampling/double sampling

The multi-phase/double sampling group can be further divided into:

3a. Double sampling with regression estimators
3b. Double sampling for stratification
3c. Double sampling for stratification with regression estimators

Stratified sampling is based on the partition of a population into several homogenous non-overlapping subunits – so called strata. Because of the decomposition of the total variance into the variance within the strata and between the strata, the sampling error is smaller than compared to a simple random sample of the same sample size. A prerequisite for the application of stratified sampling is that the size of the strata must be known. Aerial photography can be used with the stratified sampling design to determine the size of each individual stratum. The boundaries of areas with homogenous structure are hereby recorded (delineated), and each area (parcel) is assigned to a stratum. Subsequently, the size of the individual strata is calculated by adding the parcels together. High labor and time expenditure for implementing stratified sampling is inevitable because of the necessity to delineate the strata and the subsequent area calculation that follows. The application of a stratified sampling design does not seem appropriate for large-scale inventories when aerial photography is used for stratification.

A clearly organized illustration of multistage sampling designs for forest inventories can be found at BOWDEN et al.(1979) and JOHNSTON (1982). They give examples of up to four stages by employing terrestrial surveys, samples on aerial photographs and classification of digital satellite data. LANGLEY (1975) showed the application of multistage sampling designs with unequal selection probabilities. He gives different inventory examples with up to five stages and combines terrestrial measurements, aerial photography, and space images from Apollo 9.

In a double sampling design, the auxiliary variable is assessed in the first phase (survey stage), while in the second phase the variable of interest is assessed. The auxiliary variables should be easier and more cost efficient to be assessed than the target variable, since more samples are taken in the first phase than in the second one. Usually, the double sampling design permits a more cost efficient assessment of the variables of interest than the simple terrestrial survey for the same level of precision.

For combined inventories to estimate the growing stock, remotely sensed information (e.g. from aerial photographs) is utilized in the first phase. In the second phase, the survey of timber volume takes place by measuring individual trees on forest plots.

The term “double sampling with regression estimators” applies when the growing timber is estimated e.g. in aerial photographs, or when variables are estimated which are correlated with the growing stock and are further related to the measured standing timber in the forest sample plots via a regression estimation. The interpretation of aerial photography can also serve to determine the size of the strata and can be used for the derivation of the measured growing stock for each individual stratum. This procedure is called “double sampling with stratification”, whereby poststratification is applied. A multitude of publications exist which deal with estimating growing stock with double sampling designs. In German speaking regions, double sampling with regression estimators was mainly studied.

The applications of combined inventories described in the literature are dominated by double sampling with regression estimator. The suitability of the procedure is usually investigated in smaller regions (e.g., southern Black Forest, Lüneburg Heath, or Harz), in homogenous forest areas, or with the help of large-scale aerial photographs (1:3000 to 1:10000). The variable of interest is nearly always timber volume. Applications of the double sampling for stratification are also found to be used for large scale surveys in such regions as Lappland (POSO 1972), North America (BICKFORD *et al.* 1963) or India (KÖHL 1991).

There could be several reasons for the hesitant application of the double sampling with regression estimators outside of special studies. The efficiency of this procedure depends on the cost relationship between the assessment in the first and second phase, and it also depends on how tightly the relationship is between the variable of interest and the auxiliary variable. In large areas or in forests with a large spatial variability, R^2 values of 0.4 seem to be realistic, while in homogenous or small-scale forest areas, a relatively high R^2 value can be obtained. R^2 values larger than 0.9 nevertheless seem questionable and are very often the result of transformation or of regression through the origin. The interpretation of R^2 values in these cases is critical.

Attributes measurable in aerial photographs such as tree height, crown diameter, or the number of trees within a defined area could be used as independent variables in a regression function to estimate the growing stock. These regression functions have the distinct disadvantage that the independent variables can only be determined in the aerial photography under sometimes unrealistic conditions. Apart from a suitable aerial photographic scale – SCHADE (1980) believes that a scale of 1:10,000 is too small to determine the crown diameter –

the stand conditions must allow for the measurement of the variables. In dense, multilayer forests, the assessment of the number of trees or the crown diameter is difficult, and in fully stocked stands the direct measurement of tree heights is impossible. Consequently, a double sampling design, where the auxiliary variable is based on volume functions derived from measurements in aerial photographs, is for many practical applications not feasible.

The quantification of the entire growing stock for large-scale forest inventories is usually only one of many attributes to be assessed. Detailed representation, in respect to the growing stock (for example, ordered by development stages and tree species) requires the evaluation of subunits, which are summarized in tables. For each of the subunits, a new regression relationship has to be derived independent from each other, which – similar to the problem with SPR – leads to non-additive tables. The necessity to derive such a multitude of regression relationships and the adjustment of the tables, as well as the demand for detailed results of forest inventories, result in the analysis of double sampling methods with regression estimators becoming very complex and awkward. Since regression analysis depends on certain assumptions, not all target variables can be analyzed. This is especially true for variables on a nominal or ordinal scale. Double sampling with regression estimators is, therefore, only applicable to the analysis of very few requested attributes of interest for a forest inventory.

An implicit requirement for the application of regression analysis is the assessment of the variable of interest and the auxiliary variable on the same object, and results in the constraint that the sample plot centers of aerial photographs and terrestrial plots must coincide.

Studies of the position accuracy in the NFI have found that the center of the aerial photo plots and the terrestrial sample plots are, on average, five meters apart. Since the terrestrial samples in the first NFI were located with high expenditures, it is reasonable to assume that the distance achieved here is the lowest limit possible under practical conditions. Further distances should be expected, especially in inaccessible forests. In tropical forests these sample plot centers rarely coincide. A tight relationship between the auxiliary and target variable cannot be expected because of the forest's large-scale homogenous structure and highly variable structures in small areas.

The method of double sampling for stratification utilizes an auxiliary variable, which serves to estimate the strata size. Measurements in aerial photographs can be simplified, so that the cost for the first phase sample can decisively be reduced, as compared to double sampling with regression estimators. No regression functions have to be derived; the analysis of subunits leads to additive tables. Consequently, the estimation procedure is considerably more simple than for double sampling with regression estimators and is generally applicable.

Samples do not necessarily have to coincide, as long as the samples from the first phase and the samples for the second phase are ensured to be in the same stratum. Errors in the interpretation do not lead to biased results, but to a higher variance within the strata and, thereby, to a higher sampling error. If the interpretation of the auxiliary variable includes a class "non-forest", the results of the photography interpretation can directly be used for area estimation.

When the growing stock is estimated, the efficiency of the double sampling for stratification design could be smaller than the double sampling with regression estimators' design. Because the analysis algorithms are far easier to manage, the applicability for continuous and non-continuous data is warranted, and the implementation of the method is also possible under difficult, practical conditions, double sampling for stratification can be considered a robust procedure. It is preferred for large-scale, multi-resource inventories with a multitude of objectives.

2.1.4 Statistical Design of the Second NFI

Before the statistical aspects of the NFI sampling concept are described (detailed account in KÖHL 1994), the notation used in the following is briefly introduced. For periodical surveys, the number of sample plots which are measured on different inventory occasions are termed as follows:

First occasion:
n_1 = Number of sample plots that are measured on the first occasion.
Second occasion:
n_{1-} = Number of sample plots that are measured on the first occasion.
n_{-2} = Number of sample plots that are measured on the second occasion (new samples).
n_{12} = Number of sample plots that are measured on both occasions (permanent samples).

The minus sign indicates that a sample plot was not surveyed at any particular point in time. From this notation, it is clearly obvious when a sample plot was surveyed for the first time. Figure 1 illustrates the different types of sample plots.

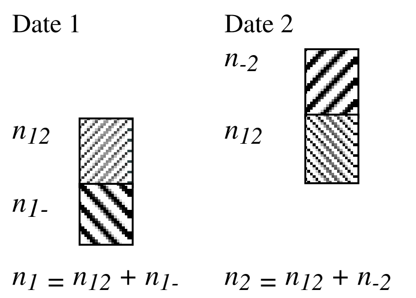

Figure 1. Types of sample plots for two inventory occasions.

Attributes, which refer to the entire population (all trees in the Swiss forest) are noted with capital letters, or rather Greek letters. Estimators derived on the basis of samples are represented by small letters, or with the symbol “^”. Different capital letters distinguish different attributes accordingly. Occasions are also distinguished when these attributes are measured. The index *i* refers to sample plots. Index *j* refers to individual trees.

2.1.4.1 Area Estimation

Information about the area and area proportion presents a central result of forest inventories and is important for the following three topics:
1. The area itself is an important target parameter for forest inventories. Apart from the quantification of the entire forest area, detailed accounts of the areas size are necessary (i.e., the size of forest types, tree species or age classes).
2. Many estimators of forest inventories are area related, such as the growing stock per hectare.
3. Quantifying the forest area change is of the utmost interest in regions with strong forest area dynamics.

Area estimations have basically two different target parameters: the amount of area (i.e., forest area proportion) and the absolute area (e.g., forest area). The absolute area calculated by dot grids depends on the number of dots that fall into the appropriate category. The area proportion always has to be seen in relation to the total area. The estimation of proportions with random points is statistically very easy. The localization of one point corresponds to a Bernoulli experiment with the possible values of non-forest and forest. The Binomial distribution describes the sampling design completely: If n_W out of n random points are found in the forest, $p= n_W/n$ is an unbiased estimator for the true forest proportion p. In the estimation of the total area, the sample points are realizations of a Poisson process with a density λ, where each point represents on average an area of $1/\lambda$. An estimator for the area F is given by $F=n/\lambda$. For additional information see KÖHL 1994.

For the NFI, the forest area and the forest area proportion was estimated from aerial photographs. A careful illustration of the aerial photography interpretation, as well as the forest definition of the NFI, can be found in Chapter 2.2. On a sample grid with a mesh width of 500 meters, aerial photo samples were distributed over the entire country, and each sample point was decided to be either forest or non-forest. On the basis of this dot grid, the total forest area and the forest area proportion were assessed. The forest area proportion is estimated according to COCHRAN (pp. 50-- 1977) by:

$$p = \frac{n_w}{n} \tag{7}$$

$$v(p) = s_p^2 \approx \frac{pq}{n} \tag{8}$$

$$s_p = \sqrt{v(p)} \tag{9}$$

where

p = Forest area proportion.
q = $1-p$ = Proportion of non-forest area.
$v(p)$ = Variance of p.
s_p = Standard error of p.
n = Number of all dots on the dot grid.
n_W = Number of forest dots on the dot grid.

The total forest area $\hat{A}_w$ is estimated by multiplying the (known) total area A with the forest area proportion p.

$$\hat{A}_w = \frac{n_w}{n} A = pA \tag{10}$$

with the variance $v(\hat{A}_w)$ and the standard error $s(\hat{A}_w)$

$$v(\hat{A}_w) = A^2 s_p^2 \tag{11}$$

$$s(\hat{A}_w) = \sqrt{v(\hat{A}_w)} \tag{12}$$

If the estimation equations shown above are used for a systematic dot grid, the standard error is generally overestimated. The form and the spatial distribution pattern of the forest areas also influence the amount of overestimation. Nevertheless, experience shows that the binomial distribution gives acceptable results for larger areas such as production regions, as long as the areas are small compared to the sample grid, and as long as they are irregularly distributed (TRACHSLER *et al.* 1980). KLEINN (pg. 26/27,1991) shows by using systematically distributed points, that the difference between the sampling error of the area estimate and the true sampling error depends on the forest distribution and is moderately low for small-scale, fragmented forest areas. Since the forest areas in Switzerland mainly consist of small-scale structures and are characterized by heterogeneous distribution patterns, it seems justified to apply these estimation equations. However, for smaller units like forest districts, the use of empirical methods should be considered, which allows for a more precise estimation of the sampling error.

2.1.4.2 Aggregation of Individual Tree Data into Sample Area Values

The NFI uses concentric sample plots as sampling units. Trees with a DBH between 12 cm and 35 cm are tallied in an area of 0.02 hectare. Trees with a DBH over 35 cm are tallied in an area of 0.05 hectare. Since the only plots selected are those with their center in the forest, the selection probability of individual trees is determined in the NFI by two factors: first, the DBH and with that the plot size (0.02 ha or 0.05 ha) and, second, the distance of a tree to the forest edge.

For trees whose distance to the forest edge is larger or equal then the radius of the appropriate sample plot (r=12.62 m for DBH<35 cm or r=7.98 m for 12 cm ≤ DBH ≤ 35 cm), the selection probability only depends on the DBH. For trees whose distance to the forest edge is smaller than the appropriate sample plot radius, the selection probability decreases with increas-ing proximity to the forest stand edge. These different selection probabilities have to be corrected through expansion factors.

The statistical approach of the NFI assumes that the sample plots represent the smallest sample unit. Thus, individual tree values have to be aggregated for each sample plot. The aggregation is accomplished by weighting each single tree attribute Y_{ij} with the weight

$$w_{ij} = A/\ a_{ij} = 1\text{ha}/a_{ij} \tag{13}$$

where *ij* represents the *j*-th tree on the *i*-th sample plot. a_{ij} denotes the area in hectares, which one tree represents, and allows taking different selection probabilities of individual trees for the derivation of estimators into consideration. Due to this type of weighting, the attributes of each individual tree $w_{ij} \cdot Y_{ij}$ are related to an area of size one hectare, that is they obtain the unit $[Y_{ij}]/\text{ha}$.

For sample plots which do not extend past the forest edge, the weights w_{ij} are constant for the 0.05 hectare or 0.02, respectively.

$$w_{ij} = w_{0.05} = \frac{A}{a_{ij}} = \frac{1\text{ ha}}{0.05\text{ ha}} = 20, \text{ for trees on a 0.05 hectare sample plot } i.$$

$$w_{ij} = w_{0.02} = \frac{A}{a_{ij}} = \frac{1\text{ha}}{0.02\text{ ha}} = 50, \text{ for trees on a 0.02 hectare sample plot } i.$$

Since the trees can be categorized as one of the two concentric sample plots, depending on the DBH, the projection factor can also be equivalently written in terms of the appropriate diameter range of the concentric samples. For the NFI, this results in:

$$w_{ij} = w_{0.05} = \frac{A}{a_{ij}} = \frac{1\text{ha}}{0.05\text{ ha}} = 20, \text{ for trees with } d_{1.3} > 35 \text{ cm.}$$

$$w_{ij} = w_{0.02} = \frac{A}{a_{ij}} = \frac{1\text{ha}}{0.02\text{ ha}} = 50, \text{ for trees with } 12 \text{ cm} \le d_{1.3} \le 35 \text{ cm.}$$

The weight w_{ij} must be increased for trees that are standing on forest edge sample plots. For direct weighting, the proportion of sample area that is located in the forest area has to be determined for each of the two concentric samples. Both weights are then determined. This method leads to biased results, since the weight for all trees remains constant for either concentric sample plots, and because the individual selection probabilities are not corrected.

The different selection probabilities of the boundary trees can be accounted for by calculating the individual weight $w_{ij}=A/a_{ij}$ for each tree, which depends on the distance of each tree to the forest edge. This kind of method is called “tree concentric method” and leads to unbiased estimates. KÖHL (1994) discussed other possibilities to treat sample plots on the forest edge.

If the individual trees Y_{ij} are related to one hectare, the values can be summarized to one value Y_i for the i^{th} sample plot.

$$Y_i = \sum Y_{ij} w_{ij} \tag{14}$$

2.1.4.3 Derivation of Total Values

For the derivation of means or totals (i.e., total growing stock), the values of the sample plots Y_i have to be summarized. For one-phase sampling designs, which were used in the first NFI, the mean $\hat{\bar{Y}}$ and its variance $v(\hat{\bar{Y}})$ can be calculated according to:

$$\hat{\bar{Y}} = \frac{\sum Y_i}{n} \tag{15}$$

$$v\left(\hat{\bar{Y}}\right) = \frac{\sum_{i=1}^{n}\left(Y_i - \hat{\bar{Y}}\right)^2}{n(n-1)} \tag{16}$$

If the area of the assessment unit A is assessed without error and is known, the total $\hat{\bar{Y}}$ and the variance of the total $v(\hat{\bar{Y}})$ can be calculated according to the following:

$$\hat{Y} = A \cdot \hat{\bar{Y}} \tag{17}$$

$$v(\hat{Y}) = A^2 \cdot v(\hat{\bar{Y}}) \tag{18}$$

If the area of the unit of reference has to be estimated by an independent sample, the sampling error of area estimation must be taken into consideration for calculating the variance of the total $v(\hat{Y})$.

$$\hat{Y} = \hat{A} \cdot \hat{\bar{Y}} \tag{19}$$

$$v(\hat{Y}) = \hat{A}^2 \cdot v(\hat{\bar{Y}}) + \hat{\bar{Y}}^2 v(\hat{A}) \tag{20}$$

where

$\hat{A}$ = estimated area of the unit of reference.

$v(\hat{A})$ = Variance of area estimation.

In the first NFI, the error of area estimation was not considered for calculating the results, even though the area was estimated by a dot grid of aerial photo samples. Due to this the sampling error for all area dependent values was underestimated.

Through the application of stratification, the efficiency of the sampling survey can be increased, as compared to the one-phase method. In stratified sampling, the population is at first divided up into non-overlapping subunits (strata). Therefore, each element can clearly be assigned to one, and only one, stratum. For the application of stratified sampling, the exact strata sizes have to be known. The selection of the elements takes place independently within the individual strata. The reasons for the application of the stratified sampling method are manifold. The desire to obtain information about the different subunits of the total population, e.g. for different production regions, could suggest the stratification. A significant advantage is the increase in efficiency that can be gained with a stratified sampling design. If a population is partitioned into several homogenous subunits, the estimation for a given sample size is more precise in comparison to a simple random sampling. The efficiency of stratified sampling is based on the decomposition of the variances. The variation within the strata has to be as homogenous as possible, while the variation between the strata should be high. The efficiency of the procedure depends on the ratio of both the variation portions.

For combined forest inventories, the stratification is carried out with data obtained by remote sensing. If aerial photographs are utilized, the stratification is executed through delineating the strata on the basis of visible features, such as mixture portion or crown coverage. After the delineation, the areas of the strata are derived planimetricly or with the help of other methods to determine the area. As it is necessary to delineate the strata and to subsequently determine the area, the high rate of work and time expenditure to conduct these methods is an unavoidable consequence. The application of stratified sampling design utilizing aerial photography appeared not to be anymore reasonable when applied to large-scale inventories. This is the main reason, in practical application, for conducting combined inventories on the basis of multistage or multiphase sampling designs.

In double sampling inventories, auxiliary variables are included in the first phase (assessment level), while in the second phase, the variable of interest is measured. An example of both of these phases is the crown diameter as the auxiliary variable and the individual tree volume as the target variable. The auxiliary variable should be easier and more cost effective to measure than the variable of interest, since more samples are taken in the first phase than in the second phase. At the same precision, double sampling usually allows a more cost-effective way of obtaining the desired results as compared to terrestrial surveys.

At double sampling for stratification, the auxiliary variable is used to assign the sample to a stratum. This sampling method is very similar to stratified sampling, but differs in that the strata sizes are estimated in comparison to the actual known strata size. However, the error, which arises in estimating the strata, has to be considered in the derivation of the sample error.

If the area of the inventory region A is assumed to be known, the total of an attribute $\hat{Y}_{ds}$ can be calculated through the means of the sample plot $\hat{\bar{Y}}_{ds}$. According to RAO (1973), it follows that:

$$\hat{\bar{Y}}_{ds} = \sum_{h=1}^{L} \frac{n'_h}{n'} \hat{\bar{Y}}_h \tag{21}$$

$$v(\hat{\bar{Y}}_{ds}) = \sum_{h=1}^{L} \frac{n'_h - 1}{n' - 1} \frac{n'_h}{n'} v(\hat{\bar{Y}}_h) + \sum_{h=1}^{L} \frac{1}{n' - 1} \frac{n'_h}{n'} (\hat{\bar{Y}}_h - \hat{\bar{Y}}_{ds})^2 \tag{22}$$

$$\hat{Y}_{ds} = A \cdot \hat{\bar{Y}}_{ds} \tag{23}$$

$$v(\hat{Y}_{ds}) = A^2 \cdot v(\hat{\bar{Y}}_{ds}) \tag{24}$$

where

$\hat{\bar{Y}}_h$ = mean in stratum $h = \dfrac{\sum Y_{hi}}{n_h}$, $h=1,...,L$.

$v(\hat{\bar{Y}}_h)$ variance of $\hat{\bar{Y}}_h$, $h=1,...,L$.

$v(\hat{\bar{Y}}_{ds})$ variance of $\hat{\bar{Y}}_{ds}$.

$v(\hat{Y}_{ds})$ variance of $\hat{Y}_{ds}$.

n'_h = number of aerial photographic samples in stratum h, $h=1,...,L$.

n' = number of all aerial photo samples $= \sum n'_h$.

n_h = number of terrestrial samples in stratum *h, h=1,...,L.*

Y_{hi} = sum of all attributes of all individual trees Y_{ij} on the i^{th} sample plot in stratum *h.*

L = number of strata.

The importance of stratification lies in the reduction of the sampling error, which results from breaking down the total variation into the variation within and the variation between the strata. The way the strata are formed has a considerable influence on the size of the reduction and is, therefore, not oriented on subunits which might be useful in the derivation of inventory results, but in the decomposition of the total variance, so that the variance within the strata is minimized. Since the stratification is carried out in aerial photographs, attention must be paid in order for these strata to be clearly identified and consistently recorded in the aerial photographs.

In addition to forest strata, a non-forest stratum must be included where a null value is assigned to all attributes. The error for the area estimation is thereby included in the derivation of the totals. The area of the entire forest and non-forest area of the unit of reference (productive region) is substituted for *A*, which is assumed to be known without any error.

The equations 21 to 24 shown above are also used for area estimation. The attribute for the area estimation is denoted by X and has two possible values:

$$X = \begin{cases} 1 & \text{if sample plot i is within the unit of interest} \\ 0 & \text{otherwise} \end{cases}$$

The area of the unit of interest $\hat{X}_{ds}$ and its variance $v(\hat{X}_{ds})$ are calculated as follows:

$$\hat{X}_{ds} = A\sum_{h=1}^{L}\frac{n'_h}{n'}\hat{\bar{X}}_h = A\hat{\bar{X}}_{ds} \tag{25}$$

$$v(\hat{X}_{ds}) = A^2 v(\hat{\bar{X}}_{ds}) \tag{26}$$

The terms of these equations are calculated by substituting *Y* with X in the equations presented above (15, 16, 21, and 22).

2.1.4.4 Ratio Estimator for Area Related Results

With the relationships shown up to this point, it is possible to derive totals for attributes and areas. If results are to be given in relation to unit area (e.g. per hectare), they have to be calculated by forming ratios while using total values.

For one-phase sampling designs, a ratio $\hat{R}$ of two estimates, $\hat{Y}$ and $\hat{X}$, and its variance $v(\hat{R})$ according to COCHRAN (pp. 150 seqq. 1977) is generally derived as follows:

$$\hat{R} = \frac{\hat{\bar{Y}}}{\hat{\bar{X}}} = \frac{\bar{Y}}{\bar{X}} \tag{27}$$

and (LOETSCH and HALLER, 1964)

$$v(\hat{R}) = \hat{R}^2\left\{\frac{v(\hat{\bar{X}})}{\hat{\bar{X}}^2} + \frac{v(\hat{\bar{Y}})}{\hat{\bar{Y}}^2} - 2\frac{s_{YX}}{n\hat{\bar{X}}\hat{\bar{Y}}}\right\} \tag{28}$$

where

$$\hat{\bar{Y}} = \sum_{i=1}^{n} \frac{Y_i}{n}$$

$$\hat{Y} = \sum_{i=1}^{n} Y_i$$

$$\hat{\bar{X}} = \sum_{i=1}^{n} \frac{X_i}{n}$$

$$\hat{X} = \sum_{i=1}^{n} X_i$$

s_{YX} = covariance term

n = Number of terrestrial sample plots
(See also pp. 79–87, KÖHL 1994.)

In the NFI2, area-based inferences are consistently derived through combined ratio estimators (pp. 165, COCHRAN 1977; pp. 84, KÖHL 1994). Means of ratios are not computed, since they are biased even when large sample sizes are taken (COCHRAN 1977; SUKHATME *et al.* 1984). For inference in an area-based frame, a combined ratio estimator is used within the NFI. The ratio estimator, $\hat{R}_{ds}$, and its variance, $v(\hat{R}_{ds})$ in a double phase sampling design is calculated according to:

$$\hat{R}_{ds} = \frac{\hat{Y}_{ds}}{\hat{X}_{ds}} = \frac{\hat{\bar{Y}}_{ds}}{\hat{\bar{X}}_{ds}} \tag{29}$$

$$v\left(\hat{R}_{ds}\right) = \hat{R}_{ds}^2 \left\{ \frac{v\left(\hat{\bar{X}}_{ds}\right)}{\hat{\bar{X}}_{ds}^2} + \frac{v\left(\hat{\bar{Y}}_{ds}\right)}{\hat{\bar{Y}}_{ds}^2} - 2\frac{s_{YXds}}{n \cdot \hat{\bar{X}}_{ds} \cdot \hat{\bar{Y}}_{ds}} \right\} \tag{30}$$

$\hat{X}_{ds}, \hat{\bar{X}}_{ds}, v(\hat{\bar{X}}_{ds})$ are computed analogous to $\hat{Y}_{ds}, \hat{\bar{Y}}_{ds}, v(\hat{\bar{Y}}_{ds})$ (equation 21–23), the covariance term s_{YXds} according to.

$$s_{YXds} = \left[\frac{1}{n'^2 - n'} \sum_{h=1}^{L} \left\{ \left(n_h'^2 - n_h'\right) s_{YXh} + n_h' \hat{\bar{Y}}_h \hat{\bar{X}}_h \right\}\right] - \left[\frac{1}{n' - 1} \hat{\bar{Y}}_{ds} \hat{\bar{X}}_{ds}\right]$$

where

$$s_{YXh} = \frac{\sum_{i=1}^{n_h} (Y_{hi} - \hat{\bar{Y}}_h)(X_{hi} - \hat{\bar{X}}_h)}{n_h - 1}$$

2.1.4.5 Assigning Area Related Information to Sample Points

Assigning area and stand data to sample plots can be done either by a point decision or by an area decision. For a *point decision,* the position of the sample plot center plays a prominent role in relating area or stand related attributes to sample plots. If one sample plot covers more than one class of an attribute, the attribute class in which the sample plot center is located is assigned to the sample plot, and is independent of the actual situation. Thus, an implausible situation could result from this. Another example of this can be seen in a sample plot that is covered partially by both young and mature growth forest, and assigned to the category of young growth forest if the sample plot center falls into the young growth forest area. Because trees in a young growth forest cannot come up to the calipering limit of 12 cm, the volume of the standing timber should be zero. In the example above, it is possible that individual trees of the mature forest result in a sizeable volume which, with a point decision, is ascribed to the young growth forest. This procedure blurs the traditional forestry definition, but does not provide any difficulties for the interpretation of the results, as long as the assignment criteria are taken into consideration. In the first NFI, the stand and area related data are assigned to the individual sample plots by means of a point decision. The results of the analysis, according to stand and area related data, were never criticized (BRÄNDLI, oral communication).

In the *area decision,* the sample plot area is subdivided into different area parcels. The total of these parcels adds up to the number of area and stand categories, which can be found on the sample plots. It then follows that sample plots on stand borders are treated as two or more virtual sample plots. Each of these virtual sample plots counts as an observation and is entered separately in the database. The advantage of this procedure is that stand and area data can clearly be attributed to individual trees. The disadvantage, nowever, is the necessity to measure accurately the stand borders. The measurement is time consuming – in the NFI about thirty percent of the sample plots have forest or stand borders – and is not free from subjective influences when the borderline is defined. For successive inventories, the problem of the permanence of stand borders arises.

The assignment of stand and area related data is carried out in the second NFI analogous to the first NFI by means of point decision. The influences on the results are small and previous experience shows they are tolerated without any problems. Furthermore, the time consuming measurements of the stand borders can be dropped.

2.1.4.6 Derivation of Results for the Production Regions and Switzerland

During the derivation of the results, the characteristics which were measured on individual trees or sample plots, should be summarized in the NFI in such a way that the results are shown for units of reference that are unmistakably defined with respect to the spatial and thematic aspects.

The smallest units of reference for which the NFI provides results are the five production regions: Jura, Plateau, Pre-Alps, Alps and Southern Alps. Within these units of reference it is possible to construct thematic units with the help of variables that can be used to form classes such as tree species, stage of development, or type of ownership. In the following, spatial units are referred to as units used to report management results – in short unit of reference, while thematic units are called assessment units. The algorithm shown above can be used for either the estimator derivation of the units of reference or of the assessment units.

For data analyses, the five production regions are treated as independent populations. Therefore, from a statistical point of view, Switzerland is not covered by just one sample survey, but by five independent surveys. The results for the unit of reference "Switzerland" are derived by summarizing the results from the five production regions; that is through combining the independent surveys of the five production regions. The advantage of this procedure is that both the total values and their variances are additive. Results for the whole of Switzerland are calculated by summarizing the estimates of the five production regions. As thematically related units of reference are usually given in table form, the summaries were done independently for each table cell (=unit of reference). The following further illustrates the calculation of table values, the different types of tables, and the summaries of tables for the derivation of the results for the unit of reference “Switzerland”.

The derivation of estimates in tables is achieved independently for individual cells, the row and column margins, as well as the total sum of the table and is performed with identical algorithms. For the analysis, it is important to note that each cell can be subdivided in h strata and that the estimates for $\hat{\hat{Y}}$, $v(\hat{\hat{Y}})$, $\hat{X}$ and $v(\hat{X})$ are derived by the equations of the double sampling for stratification design. From this the analysis for the hierarchy presented in Figure 2 follows.

The number of aerial photo samples n', as well as the number of terrestrial samples n, are given by the sampling design and are constant for all cells. The number of aerial photo samples in the individual strata n_h', as well as the values of the attribute Y_i, are random variables and have to be taken into account for variance calculations. The random variable Y_i takes on the value zero in the case that the terrestrial sampling plot is not in the considered unit of reference. The consequence for calculating the cell values is that the strata weight n_h'/n' and the number of terrestrial observations n and n_h are the same for each cell. This is independent of the subunit (i.e., row and column combination), which should be analyzed. For the calculation of the total values (equation 23 to 26), A is substituted by the area of the production region. Since the stratification of the entire country was partitioned into forest and non-forest, A is the sum of all forest and non-forest areas in the production regions.

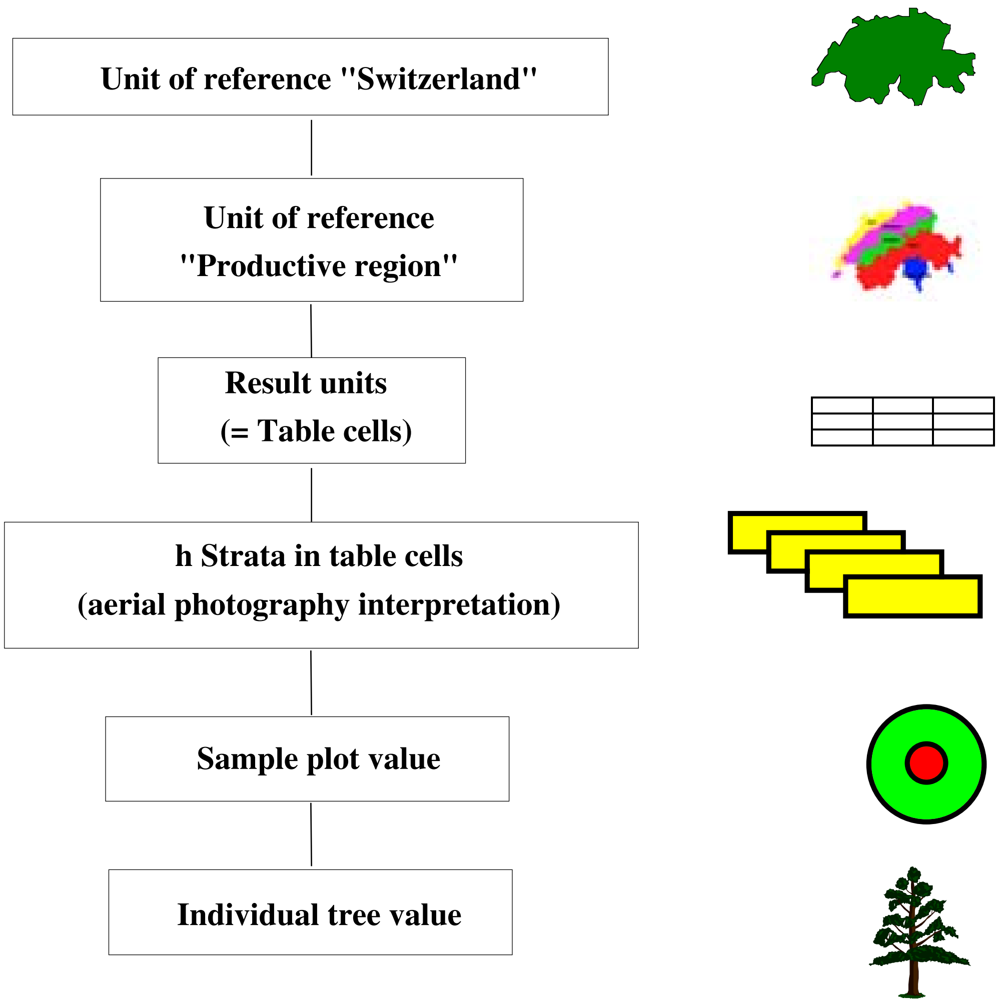

Figure 2. Hierarchy during the data analysis.

For the analysis, three types of tables have to be differentiated: attribute tables, reference tables, and ratio tables (Figure 3). These tables are similar in their structure (i.e., they represent the same thematic units in the rows and columns). In the attribute table the estimates of the attributes from the sample plots are combined. This can include measurable variables such as number of trees, basal area, standing timber, or the increment. It can be comprised of area-based measures as stand type, stage of development, or types of ownership. For area-based attributes, the area that is taken up by the sample plot of the corresponding category has to be estimated. The estimates that are derived for the individual attributes for each cell are the total $\hat{Y}$ and the variance of the total $v(\hat{Y})$.

The reference tables are also the denominators of the ratio estimator. They can, for example, encompass an area of area-based attributes such as the number of trees per hectare, the number of trees for the number of tree proportions, or the basal area for the basal area proportion. In the following, the attention is mainly drawn to the area tables as reference tables, since these are by far the most frequently used applications in the NFI.

Within the area tables, the total area $\hat{X}$ and its variance $v(\hat{X})$ are presented for each table cell. With the help of the area tables, it is possible to transform the attribute tables into ratio tables (i.e., tables with a unit area). The area tables only have to be derived once for all subunits (cells) and can then be employed for all attribute tables with the same row and column categories. The estimates of the cells in the ratio tables are taken from the ratio $\hat{R}$, which is formed by taking the ratio of the sum of the attribute $\hat{Y}$ and the sum of the area $\hat{X}$. For the calculation of the variance for the ratio, the variance of the individual cell $v(\hat{Y})$ and $v(\hat{X})$, as well as the covariances, are used.

For the derivation of area tables, it is important to pay attention to which area definition should be used in the analysis. For example, the area-related standing timber volume of spruce can be calculated either for the entire region, the forested area, or for the area with spruce forest.

Up to this point, the analysis of the five production regions has been described. For each of the production regions in their thematic subdivisions, identical attributes, areas and ratio tables are calculated. For the derivation of the results for the unit of reference "Switzerland", these tables must be combined.

The total of an attribute for the unit of reference "Switzerland" is calculated by summing up the totals of the tables.

$$\hat{Y}_{CH} = \sum_{k=1}^{5} \hat{Y}_k \tag{31}$$

$$\hat{X}_{CH} = \sum_{k=1}^{5} \hat{X}_k \tag{32}$$

Since this is the sum of five random variables, the variance of the totals can be calculated according to:

$$v\left(\hat{Y}_{CH}\right) = \sum_{k=1}^{5} v\left(\hat{Y}_k\right) = \sum_{k=1}^{5} A_k^2 v\left(\hat{\bar{Y}}_k\right) \tag{33}$$

$$v\left(\hat{X}_{CH}\right) = \sum_{k=1}^{5} v\left(\hat{X}_k\right) = \sum_{k=1}^{5} A_k^2 v\left(\hat{\bar{X}}_k\right) \tag{34}$$

Results related to unit area are derived analogously to the procedure in the individual production regions (equation 27 and 28), by utilizing the tables, which are obtained through summation for the unit of reference Switzerland.

$$\hat{R}_{CH} = \frac{\hat{Y}_{CH}}{\hat{X}_{CH}} \tag{35}$$

$$v(\hat{R}_{CH}) = \frac{v(\hat{Y}_{CH}) + \hat{R}_{CH}^2 v(\hat{X}_{CH}) - 2\hat{R}_{CH} s_{YXCH} / n}{\hat{X}_{CH}^2} \tag{36}$$

where

$$s_{YXCH} = \sum_{k=1}^{5} A_k^2 s_{YXk} \tag{37}$$

These estimates are derived for the individual cells. Thus, for each cell of the ratio table of the unit of reference “Switzerland”, five estimators are applied: $\hat{Y}_k, \hat{X}_k, v(\hat{Y}_k), v(\hat{X}_k)$, and s_{YXk}. Since the tables are additive, the estimates for the individual cells do not have to be adjusted. Therefore, table totals for an individual attribute presented in several tables with different thematic units of reference (i.e., column and row headers) are identical.

Attribute table
Total ($\hat{Y}$)

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

V [m^3]

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

G [m^2]

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

N [n]

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

I [m^3]

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

Young growth [ha]

$\hat{Y}_{11}$	$\hat{Y}_{21}$	$\hat{Y}_{31}$
$\hat{Y}_{12}$	$\hat{Y}_{22}$	$\hat{Y}_{32}$
$\hat{Y}_{13}$	$\hat{Y}_{23}$	$\hat{Y}_{33}$

Pole wood [ha]

Reference table
Area ($\hat{X}$)

$\hat{X}_{11}$	$\hat{X}_{21}$	$\hat{X}_{31}$
$\hat{X}_{12}$	$\hat{X}_{22}$	$\hat{X}_{32}$
$\hat{X}_{13}$	$\hat{X}_{23}$	$\hat{X}_{33}$

[ha]

Ratio table
Area base ($\hat{R}$)

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

V [m^3/ha]

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

G [m^2/ha]

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

N [n/ha]

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

I [m^3/ha]

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

Young growth [proportion]

$\hat{R}_{11}$	$\hat{R}_{21}$	$\hat{R}_{31}$
$\hat{R}_{12}$	$\hat{R}_{22}$	$\hat{R}_{32}$
$\hat{R}_{13}$	$\hat{R}_{23}$	$\hat{R}_{33}$

Pole wood [proportion]

Figure 3. Types of tables[1].

[1] The thematic units of the rows and columns are for all tables identical. Columns could, for example, represent a subdivision in “private forest,” “public forest,” and “total;” rows could represent a partition into “conifers,” “broadleaf,” and “total.” For such a partition, the total of the reference unit would be written in the lower right cell (index 33).

2.1.4.7 Estimation of Current Values and Change

Apart from recording the current values of forests, the second NFI serves as the first remeasurement as a way to assess change. The statistical approaches shown above are derived primarily to estimate current values. They can also be applied to estimate change provided that two conventions are introduced for analysis.

The first convention is concerned with the change that is observed on individual trees or is derived from data collected from individual trees. Standing timber falls into this category. If each individual tree is associated with some attributes which quantify the change between the first and the second survey, the change can be analyzed just as current values. For the volume increment, each individual tree is assigned an attribute that represents the change between NFI1 and NFI2. The increment is derived similarly to the individual tree volume via functions (see Chapter 2.1). By doing so, changes can be treated as individual tree attributes.

The second convention is concerned with the number of sample plots that are used to estimate the current values and change. As described above, SPR does not result in additive tables. This is the main reason to drop the SPR estimators in favor of the CFI estimators, and to choose two different sample sizes to estimate current values and change. For estimating change, only permanent sample plots were used; that is only those plots which were included in the first as well as the second inventory. The respective sample sizes are compiled in Table 1.

Table 1. Sample size in NFI2.

	Estimation of Current Values	Estimation of Change
Aerial Photo samples	165'190	40'000
Permanent samples[1]	23'227	23'227
Temporary samples[1]	2'400	–

[1]Forest and Non-Forest Samples

A departure from this concept affects the estimation of those attributes where change is derived from a model. In this case, change can also be reported for temporary sample plots so that the sample size for estimating change is accordingly higher. In essence, this affects the estimation of increment that is described in Chapter 3.2.

2.1.5 Optimization

The goal of the inventory planning is the development of an “optimal” sampling design, which allows for a given budget to estimate the desired characteristics with a sampling error as small as possible. Apart from the cost, which is the strongest constraint, the inventory planning must consider the tolerable range of error, the characteristic of the forest to be surveyed, the available personnel, and the geographic or thematic units of reference.

During the planning of the second NFI it did not suddenly happen that one inventory design was the only suitable method. Instead, several possible methods were developed. Based on objective decision rules, the procedure that was best suited for the goal of the second NFI was chosen. Because the development of each sampling design variation is a time consuming process, the mistake of committing very early to only one single design is made for many inventories in the preparation phase. After that phase, it is often not clear why a certain design was chosen, and the choice of one method over another is not solely justified by the optimization objective alone.

The goal of the sample design optimization is to increase cost efficiency. The cost efficiency is described as the relative efficiency between two design alternatives. The relative efficiency of design A versus design B at a given cost is the ratio of the variance of both alternatives $\frac{\sigma_B^2}{\sigma_A^2}$ (p.

103, COCHRAN 1977). Therefore, it is necessary to obtain information about the cost as well as the variances in order to be able to compare both design alternatives.

In the comparisons between the sampling design variations, only such costs should be considered which vary with the sample size. Fixed costs, which are the same for all variations and do not change the sample size, should be excluded (WÖHE 1981). A general cost function for the double sampling design for stratification at both inventory occasions is:

$$C = C_p n' + C_{12}\, n_{12} + C_{-2}\, n_{-2}$$

where

C = Total variable costs.
C_p = Costs for the interpretation of one aerial photo sample plot.
C_{12} = Costs for the survey of one permanent, terrestrial sample plot.
C_{-2} = Costs for the survey of one new (temporary), terrestrial sample plot.
n' = Number of aerial photo sampling units.
n_{12} = Number of permanent sample plots
n_{-2} = Number of temporary sample plots

For each alternative there exists an optimal combination of sample sizes. This combination must be compared against the other alternatives. The optimum can be determined in two different ways:
– Minimizing cost for a predetermined precision
– Minimizing the errors for given cost

The above problem is a standard form of an optimization problem: The minimization of a target function under certain defined constraints. COCHRAN (1977) presents solutions for double sampling for stratification. WARE and CUNIA (1962) show SPR solutions for two different occasions. BICKFORD *et al.* (1963) derive solutions for double sampling for stratification combined with SPR for two different occasions.

In complex cases, numerical methods have to be applied. The classical method is the linear programming method, where the target function with linear equality and inequality conditions is linear (HILLIER and LIEBERMAN 1974). This method is limited in its application, since for many optimization problems either the target function or the conditions are not linear, or solutions with integer values are required.

SCOTT and KÖHL (1993) discussed the application of the m-neighborhood-method (GARFINKEL and NEMHAUSER 1972), an integer non-linear programming method, in the context of forest inventories. With this method, all possible combinations of m starting points above and below some initial sample sizes of each variable are tested for the combination that minimizes the optimization function the most. The predetermined settings are varied until no further improvements can be achieved. The m-neighborhood-method does not guarantee that the global optimum can be found. Nevertheless, it ensures an improvement over the preset starting point.

During the preparation of the second NFI, SCOTT and KÖHL (1993) developed a special program (SIZE) for the optimization of sampling procedures. The procedure is based on the m-neighborhood-method and makes it possible to derive the optimal sample size for three different sampling methods (simple random sampling, stratified sampling, and double sampling for stratification) with one, two or three different successive inventories. SPR as well as CFI estimators can be compared. The program requires some details about the population, the cost coefficients, and about the variability of the variables of interest. This approach also allows, apart from the simple comparison of different design alternatives, a sensitivity analysis to be conducted. By varying the input parameters it is possible to investigate the consequences in respect to cost efficiency. With this, it is possible to find design alternatives which represent an optimal solution only under the most restricted circumstances. For inventory purposes, solutions should be preferred that are robust against changes in the input parameters over a wide range, so that they do not differ too much in respect to the optimal solution but are still cost efficient.

In contrast to aerial photography interpretation, the cost for the field survey is not constant over the entire country of Switzerland. It differs depending on the accessibility and topography, and for permanent and temporary sample plots as well.

For the optimization of the NFI, several different sampling designs were investigated. As examples, three different alternatives are presented:

a) One-phase sampling design:
   This procedure does not include stratification based on aerial photographs and corresponds with the statistical design of the first NFI. The variables of interest are measured on terrestrial sample plots. Aerial photography is exclusively used to determine forested area and forest area proportions.
b) Double sampling for stratification (DSS) design with permanent samples:
   Here, aerial photo samples are used to estimate the strata size, and the permanent sample plots from the first NFI are used. If more than six million Swiss Francs (CHF) would be available for the field survey and the interpretation of aerial photographs, additional new (temporary) sample plots should be included.
c) Double sampling for stratification design with permanent and new samples:
   The number of new sample plots is given first. Starting at a certain cost threshold it is possible to raise the number of permanent sample plots similar to alternative b, until the total expenses are reached.

In Figures 4 and 5, the standard errors in percent for the estimation of the standing volume (Figure 4) and the estimation of the number of trees (Figure 5) are plotted against the cost for the three sampling design alternatives. For the same cost, the standard error is smaller for the standing timber than for the number of trees. Nevertheless, the trend of the curves is similar for both features. The curves for all double sampling design alternatives merge for expenses costing more than six million CHF. The reason for this is that with these expenses not only all 11,000 permanent samples of the first NFI are measured, but new sample plots are included as well.

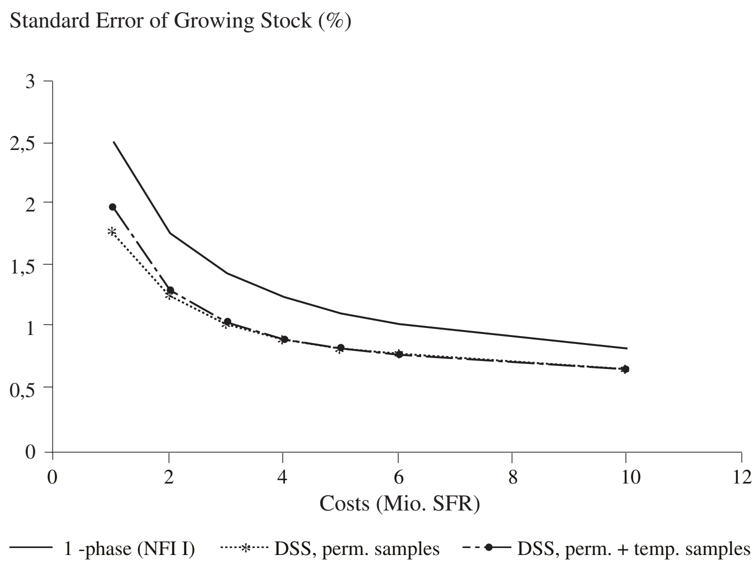

Figure 4. Standard error of the timber volume.

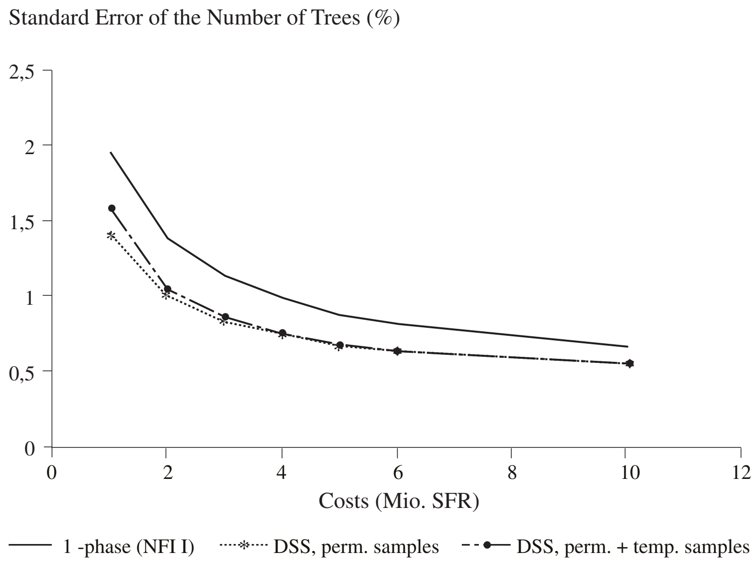

Figure 5. Standard error of the stem number.

With the one-phase sampling design (alternative a), a relatively high standard error results. The double sampling designs are, in all situations, more cost efficient. The survey of a permanent sample plot is less expensive than establishing a new sample plot. Therefore, it is possible to survey a larger number of sample plots with alternative b (DSS, permanent samples) at the same cost than for alternative c. For the estimation of current state, only measurements from the second occasion are applied. The values of the first occasions have not been updated. For this reason, the number of surveyed forest sample plots at the second occasion directly affects the size of the standard error and, therefore, alternative b is more cost efficient for expenses less than six million CHF.

Another important aspect of the sampling design planning is apparent in Figures 4 and 5. Higher expenses do not result in a constant reduction of the standard error. Increasing the budget at lower expenses results in a large reduction of standard errors, while the curve for the standard errors flattens with increasing expenses. This means increasing the budget when it is already at a high level results in a smaller reduction of the sampling error. For the second NFI, about three million CHF were available for the variable cost, which is approximately the range in which the cost efficiency is at its optimum. Increasing the budget would by far influence the standard errors less than cutting the budget. For expenses over four million CHF, it is questionable whether the financial resources can effectively be used. Instead of increasing the number of forest sample plots, it seems more reasonable to measure additional characteristics such as data for vegetation, soil, or non-wood goods and services.

The decision for a specific alternative for the second NFI was made in favor of the double sampling design. In addition to the survey of the forest sample plots, aerial photo plots were interpreted in order to estimate strata sizes. The double sampling alternative without new samples was more cost efficient in respect to the estimation of current values. However, the difference in cost efficiency with the available funds was very small. Since new samples allowed the sample plots to be investigated with respect to their representativeness, new terrestrial samples were measured for the second NFI, even though this meant a slight decrease in cost efficiency.

The optimization for the given budget led to surveys in three different grids:

- Aerial photo interpretation in a 500 x 500 meter grid with 165,190 aerial photo samples.
- Survey of permanent samples in a 1.4 x 1.4 km grid with 23,227 forest and non-forest samples (5513 of them permanent forest sample plots).
- Survey of new samples on a subsample of the 500 x 500 meter grid with 2,400 new (temporary) forest and non-forest samples, where approximately 670 of them were forest samples.

2.1.6 Discussion

The demands on the possible analysis of the second NFI were determined by the published results of the first NFI (EAFV 1988). Additionally, the second NFI had to provide information about changes. The attributes used in the NFI can be divided into two groups: qualitative variables and quantitative variables. Both variable groups can be analyzed with the previously introduced method of ratio estimation. However, the qualitative variables are treated as ratio estimates.

For the calculation of statistical parameters related to unit area by ratio estimators, attribute data and area data must be linked. The calculation of standard errors of a ratio requires the derivation of the variance of the attribute of interest, the variance of the respective area, and the covariance. Total values and means based on measurements of the sample plots have to be independently derived.

The analysis of the inventory data can be interpreted as associating tables with each other. On the one hand, there are tables of attributes and, on the other hand, there are tables of area data. The table cells are determined by several different categorical variables. In the table cells, records of total values, means and variances can be found. For calculating tables which present results in unit area (e.g. volume in m^3/ha), the same area table can be utilized for several attributes, as long as the thematic separation of rows and columns (i.e., the units of reference represented by each table cell) are the same. For calculation of the standard errors, it is only necessary to derive the covariance in addition to the variances. This approach reduces the required calculations to a minimum while, at the same time, ensuring the flexibility of the analysis system. It is possible to use only a few standard modules (e.g. the variance or covariance calculation), and allows for extensive use of standard software. In addition, the analysis concept can be integrated into a databank concept – an aspect which SCOTT (1986) doubted was possible for the application of SPR. The integration of standard software also reduced the efforts needed to validate the software system prepared for the analysis, as well as the required time for the programming.

By using CFI estimators, the problem of non-additive tables can be avoided. The analysis can therefore be carried out for any unit of reference without having problems with the compatibility of the results with other units of reference. The grand total of tables with different row and column settings will agree without any additional adjustments.

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2.2 Aerial Photography

Markus Keller

2.2.1 Introduction

From the beginning, aerial photography was incorporated into the inventory design of the NFI as one of its most important data sources. While aerial photography mainly served to determine the forest area and to measure reference point data for the terrestrial survey in the NFI1, the NFI2 extended the catalog of attributes measured in aerial photographs. Apart from area data, stand data, and tree data, new attributes were added that refer to areas outside of the actual forest (Chapter 2.2.6).

The most striking difference between the NFI1 and NFI2 is the extent of the airphoto interpretation. The NFI2 was designed as a double sampling inventory (Chapter 1.1.3). Auxiliary variables were measured in the first phase (airphoto interpretation). In the second (terrestrial survey), the actual variables of interest were measured. Compared to the NFI1, the number of field samples was reduced by half to approximately 6,600, and the number of aerial photo samples quadrupled to a total of about 165,000. Because of this the precision in the forest area estimation increased. Due to this fact, and due to the stratification in aerial photographs, it was possible to obtain similar standard error values, such as for the estimation of the standing volume, as compared to the NFI1 (Chapter 1.1.4).

For the aerial photo sample plots, a square sample grid with a 0.5 km mesh width (0.5-km-grid) was chosen. For the terrestrial sample plots a coarser grid with 1.4 km (= $\sqrt{2}$ km) mesh width (1.4-km-grid) was chosen. The 1.4-km-grid and the 1.0-km-grid of the NFI1 are subsets of the 0.5-km-grid (Figure 1). The second terrestrial grid – a 4.0-km-grid shifted by 0.5 km – was taken as an independent sample in order to verify the representativeness of the NFI2 sample plots.

2.2.2 Goals

The following goals were set for the airphoto interpretation:

1. **To identify forest area:** Each aerial photo sample plot was classified according to defined assignment rules: the so-called “Forest/Non-Forest Decision.”
2. **To measure reference points:** The coordinates of reference points were measured to help the field survey team determine where to locate the sample plot centers by using these measurements.
3. **To prepare for stratification:** Stand attributes were measured and were used as stratifying variables for the statistical analysis of the field data.
4. **To assess stocking outside the forest area according to NFI:** In all of the aerial photo sample plots, stocking and individual trees were recorded independently from the “Forest/Non-Forest Decision.”

The NFI1, as well as the NFI2, were primarily designed to record the current state of the forest. In addition, the NFI2 was also designed to record changes. Therefore, Goals 1, 2, and 3 were the principal focus of the airphoto interpretation. Goal 4 was formulated to meet the needs for data concerning occurrence, type, and distribution of small wooded areas, hedges, and individual trees outside the actual forest area, according to NFI forest definition. In Switzerland, the information about these types of stockings is in demand because of the important role they play as ecological islands in a landscape formed by strong anthropogenic influences. Furthermore, this information is also taken into account in international statistics to estimate the total biomass of a country.

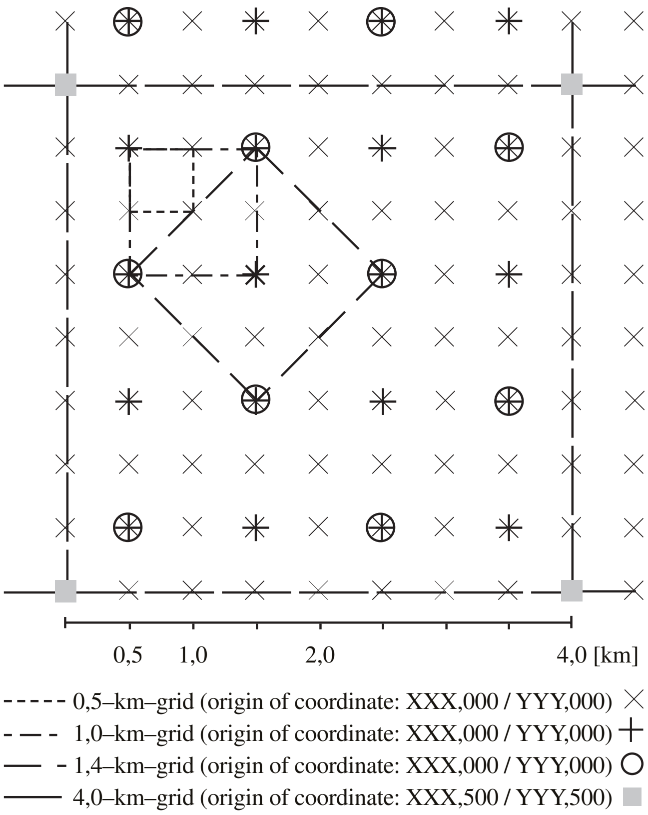


Figure 1. Sample Plot Grids for the National Forest Inventory.

2.2.3 Airphoto Interpretation

The airphoto interpretation in the NFI is based on the application of photogrammetric procedures with analytic plotters. During the analysis, pairs of aerial photographs with stereoscopic overlap areas (stereopairs), are studied as three-dimensional images that are photogrammetricly analyzed and interpreted.

2.2.3.1 Aerial Photographs

As with the NFI1, the NFI2 employed aerial photographs from the Swiss Federal Office of Topography's regular flight program to update the national maps of Switzerland. Every year about one-sixth of Switzerland is photographed in black and white from the air. Figure 2 gives an overview about the flight years of the aerial photographs interpreted for the NFI2 and provides an account of how current their information is.

In the regions north of the line Murtensee – Zugersee – Walensee, in the southern part of the Walliser Alps, and in the Southern Alps, the time span between the aerial photographs and the field survey in the NFI2 took four to six years longer than in the NFI1. In western Switzerland the time span was about the same as in the NFI1. In the remaining alpine regions of the cantons Valais, Berne and Grisons the time span was one to two years shorter.

The reasons for these differences are found to be: (1) slightly altered flight plans and (2) extended airphoto interpretation which took more time than anticipated. Due to logistical reasons the interpretation always had to be finished before the field surveys, thus it was not possible to employ the newest aerial photographs in all regions. Chapter 3.2 explains how the regions different time intervals between the first and second survey were considered during the analysis.

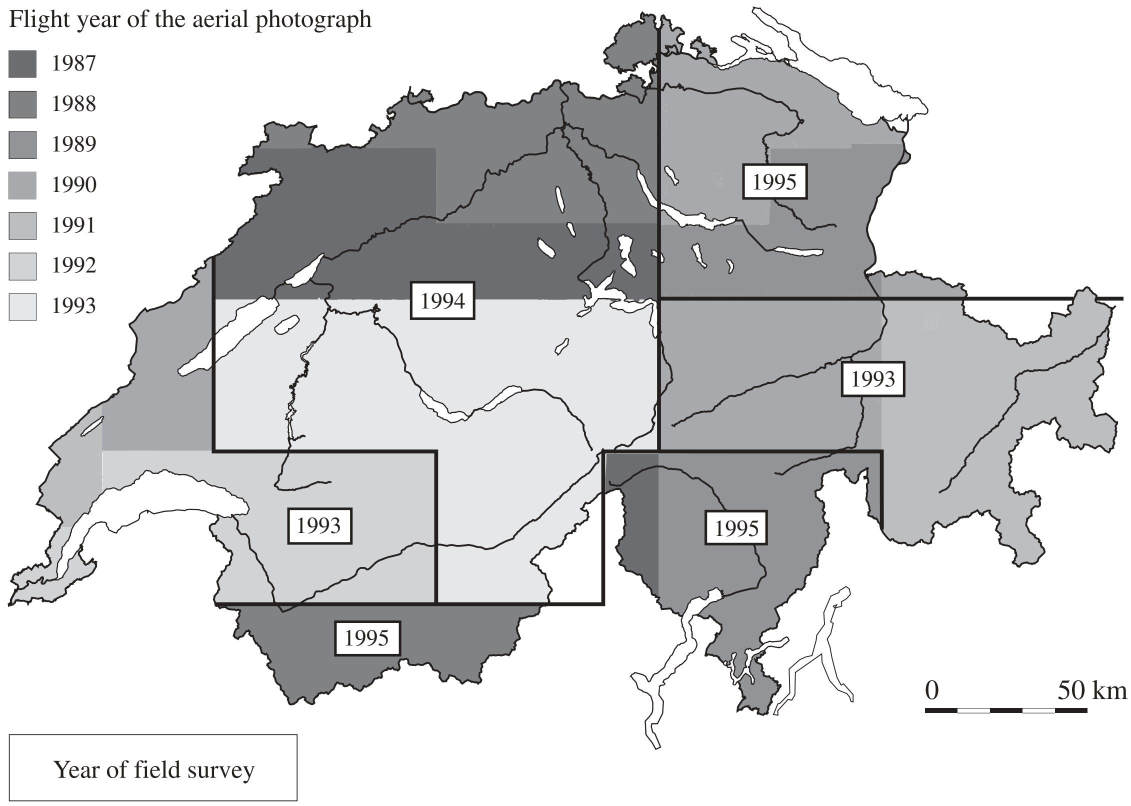


Figure 2. Flight Years of the Swiss Federal Office of Topography.

The aerial photographs employed for the NFI1 and NFI2 did not only differ with respects to their current information, but also in part with respect to their scale. The NFI1 aerial photographs were available with a scale of 1:25,000, while the NFI2 aerial photographs were interpreted at a scale of 1:30,000. This affected the aerial photographs that were taken with the mapping cameras from type “Leica RC-20” and “Leica RC-30.” Both cameras were equipped with a device to compensate for the blurring effects caused by aircraft motion in flight direction during the time the photograph was taken (FMC = Forward Motion Compensation). Aerial photographs that are taken with these types of cameras usually have a sharper image than older aerial photographs and make it easier to measure small objects. Consequently, it cannot be ruled out that in individual cases, as a result of better image quality, airphoto interpretation leads to different results as compared to aerial photographs that were taken with an older camera type (i.e., “Leica RC-10”).

2.2.3.2 Photogrammetrical Analysis Instruments

The airphoto interpretation was done on two workstations equipped with an analytic stereoplotter (“Leica DSR-1/15” or “Leica DSR-15”). A precision drawing table “Kern-GP1” was available for the output of digital measured values onto engraving foil or paper. Both instruments were controlled by a DEC-computer (“Microvax-3900” or “Microvax-3400 operating system VAX/VMS 5.2). In addition, two analog stereoplotters “Wild-APT1” were available for comparison with aerial photographs from the first inventory. A conventional 35 mm camera can be mounted on these instruments to reproduce details from aerial photographs.

All photogrammetric instruments are equipped with a second ocular that allows two people to look at the same stereo model simultaneously. This way it is possible to control and improve the reliability and quality of the interpretation through direct observation. Chapter 2.10 “Control Survey of the Aerial Photography Interpretation” examines the reproducibility of the aerial photography interpretation.

2.2.3.3 Workflow

The airphoto interpretation was carried out in four steps (Figure 3):
1. Data preparation
2. Orientation
3. Interpretation
4. Storing of the analyzed data within the database

2.2.4 Orientation of the Pair of Aerial Photographs

According to HILDEBRANDT (1996), “one understands that by the orientation of an aerial photo pair first of all the mutual orientation of the images in a way that all homologous rays intersect. With that the rays of both images are restored in their correct orientation to each other.” If, in addition to this, the lateral and longitudinal inclinations of the aerial photographs are also considered, it is then called “relative orientation.” Nevertheless, the relative oriented model is not determined with respect to its position in space. Only the absolute orientation establishes the reference of the relative oriented model to the terrain coordinate system.

The following briefly describes the steps that lead to an absolute orientation, and the established precision standards for the NFI are stated. Further information about the theory and mathematical derivations of the individual steps are described in detail in well-known standard books, like KRAUS (1990) or HILDEBRANDT (1996).

2.2.4.1 Data Preparation

For the orientation of stereopairs, the appropriate set of base data has to be available. To these data belong specifications about the mapping cameras and lenses used during the flight; the data from the data strip on aerial photographs, along with information about the photographed terrain section. Information about the photographed terrain section was taken from the national maps with a scale of 1:25,000. These essential data were directly needed for the orientation, as well as to identify the stereo model. These data were stored following the first orientation together with the orientation parameters in the data bank. For all further interpretations of one stereopair, such as to examine the reproducibility of attributes, it was sufficient to perform the interior orientation (see below) and to extract the other orientation parameters from the data bank.

Ground control point and reference point data also belong to this data basis. In the NFI1 they were measured for the orientation of the aerial photographs and the terrestrial location of the sample plot center. They were also used for the orientation of the new aerial photographs in the NFI2.

2.2.4.2 Interior Orientation

In a mapping camera – in contrast to a normal, non-calibrated camera – the relationships between the incoming bundle of rays and the created aerial photograph is determined through calibration. The values of the “interior orientation” of a mapping camera are recorded in the calibration protocol. For the interior orientation of a mapping camera, the calibrated focal length, the position of the principal point, and the parameters used to compensate for optical inaccuracies like distortion or chromatic aberration, have to be known. The parameters specific to each camera are taken from the calibration protocol, and the position of the principal point is then calculated from measurements of the fiducial marks on the aerial photograph.

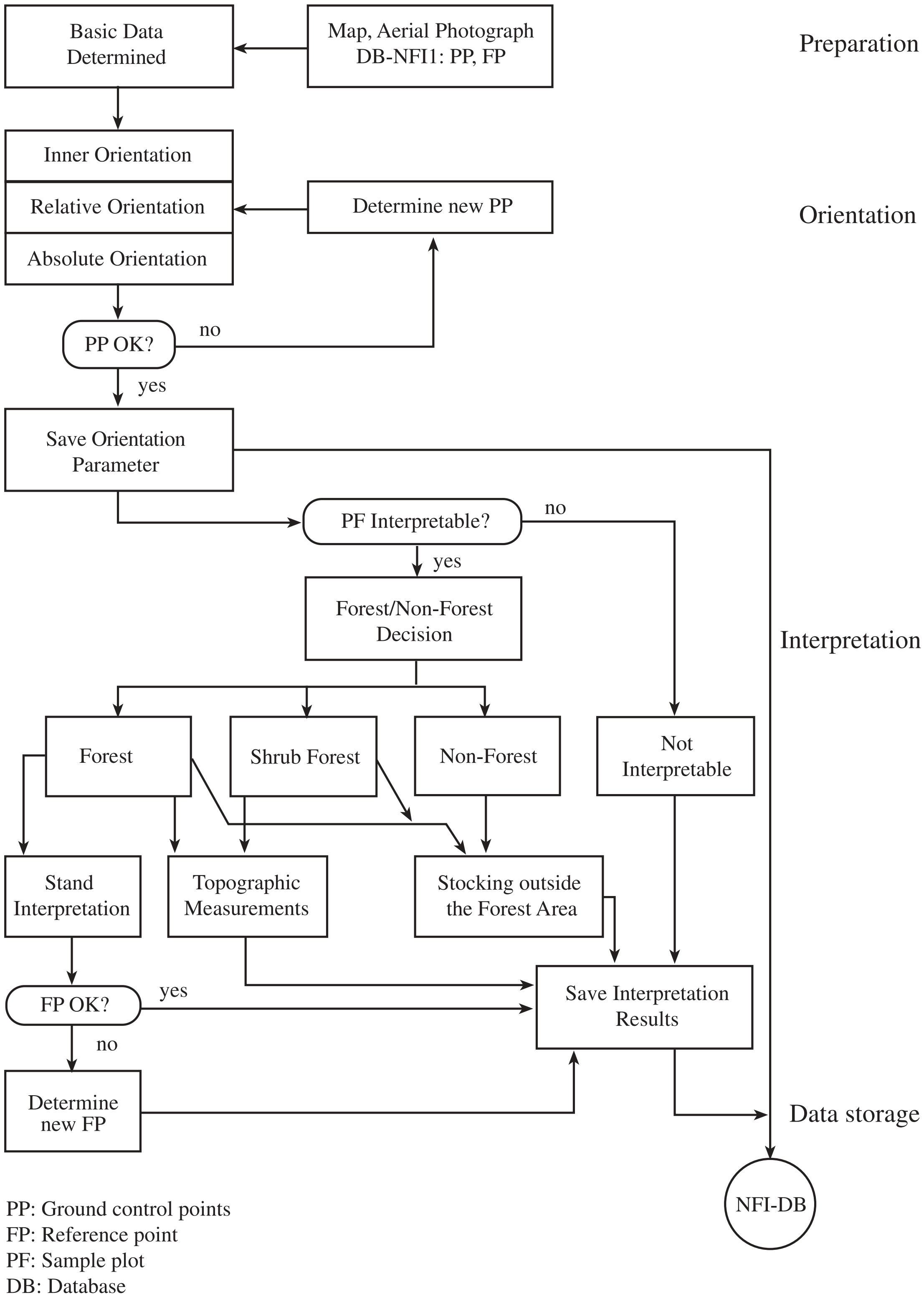


Figure 3. Process of the Airphoto Interpretation.

The analytical stereoplotter is equipped with a double-image carrier, which is free to move in the plane and onto which aerial photographs can be fixed. In each aerial photograph the interpreter measures the position of the four fiducial marks. The actual value of the fiducial mark coordinates is compared to the desired values from the calibration protocol of the mapping camera, and the resulting measurement error is calculated. The residuals for the x- as well as the y- coordinates are not allowed to exceed 10 μm.

2.2.4.3 Relative Orientation

During the relative orientation, the spatial position of the image plane at the time the image was taken is reconstructed. By reconstructing the heading, roll, and pitch angle, each aerial photograph of a stereopair is brought mathematically into the same spatial position relative to the earth's surface as it was at the time of exposure. Simply stated, by shifting both photographs of a stereopair, they are brought into a position in which the observer can perceive them as a three dimensional model.

In order to accomplish this, the interpreter selects in the stereoscopic overlap area of the stereopair eight evenly distributed tie points, which are well visible both in the left and in the right image. Both aerial photographs are shifted against each other until all eight tie points in the left aerial photograph line up as precisely as possible with the ones in the right aerial photograph. Ideally, from these measurements the computer of the analytical stereoplotter calculates a parallax free stereo model. With this, the stereopair is "relatively oriented" and can be seen by the interpreter as a three dimensional image.

As compared with the normal procedure according to GRUBER (KRAUS 1990), which uses six tie points, the eight tie points produce a better result for analytic stereoplotter (ZUTTER, oral communication). This statement was examined and confirmed in the course of the pilot inventory for the NFI2. Figure 4 shows the distribution of the eight tie points in the stereo model.

The relative orientation is stepwise optimized until the position error of the x- and y- coordinates for each individual control point is at most ±7 µm.

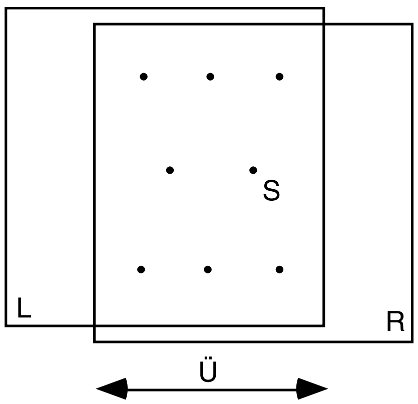


Figure 4. Layout of the Control Points in the Stereo Model.

L: Left airphoto R: Right airphoto
Ü: Overlap area S: Tie point

2.2.4.4 Absolute Orientation

The absolute orientation finally permits the fitting of the parallax free stereo model into the kilometer-coordinate system of the national map by utilizing ground control points, whose ground coordinates (from a map) and image coordinates (from an aerial photograph) are known. In the absolute oriented stereo model it is possible to give the x-, y-, and z-coordinates for any point.

Triangulation points or spot height from the national map 1:25,000 are used as ground control points for the absolute orientation. In the NFI1 the x- and y- coordinates were measured at the digitizing table. The value of the respective elevation information from the map was accepted for the z- coordinate. The measurement error for the x- and y- coordinates of the ground control points in the NFI1 amount to about 2.5 m (BRASSEL, oral communication). In the NFI2 new ground control points were measured from the map with the help of a line glass, so that the measuring error had about the same magnitude.

Reference points are exactly defined points from prominent objects, e.g., the north corner of a house whose three dimensional coordinates are usually determined from an absolute oriented stereo model. They should be clearly identifiable in the aerial photograph or on the map as well as on the ground. A reference point, apart from the x-, y-, and z- coordinates, consists of a description of the reference point and, depending on the type of reference point, the appropriate description of the direction. Reference points assist the field survey team as potential starting points using measurements to locate the sample plot center. The measurement of reference points is described in detail in Chapter 2.2.6.4.

An absolute orientation has to be based on at least four ground control points if it is important to know how accurate the orientation has been. KRAUS (1990) recommends using six to eight ground control points if the precision of an absolute orientation is required to be even more accurate.

In the NFI at least six ground control points were used. However, for most of the regions, with the exception of remote areas in the mountains, about fifteen to twenty ground control points per stereo model were available from the data bank. If it turned out that fewer than six were suitable, new ground control points were measured from the national map. If possible, those ground control points and reference points were used for the absolute orientation, which were already used in the NFI1. The intent in doing this was to achieve a reconstruction of the position of the sample plot centers as closely as possible to the position they were measured in the NFI1. This also includes the position error at that time. Consequently, only the height measurements were corrected for the reference points, while the x/y- coordinate measurements were retained. If the residuals of the reference point coordinates in the x- and y- direction were too high, the control points in the stereo model were repositioned. The residuals of the x- and y- coordinates and the residual of the z- coordinate for each point were allowed to be only ± 2.5 m and ± 1.0 m respectively.

2.2.5 Forest Definition for the Forest/Non-Forest Decision

The discrimination of forest and non-forest areas in aerial photographs requires an unambiguous reproducible forest definition. MAHRER (pp. 40, EAFV 1988) describes the forest definition used in the NFI in the following way: “With the NFI forest definition, the aspect of a stocking is evaluated by the following stand criteria that can be measured in the aerial photograph: width, crown coverage and dominant stand height.”

The NFI2 adopted the forest definition without any changes from the NFI1. It is the most important basis for the thematic airphoto interpretation and is therefore described here (STIERLIN *et al.* 1994). Figure 5 shows the critical thresholds of the stand attributes which are used to reach the forest/non-forest decision.

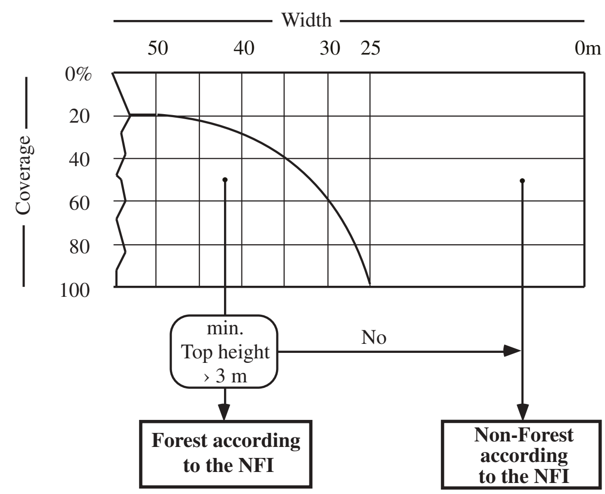


Figure 5. Forest Definition According to NFI.

- **Width**: The width of the stocked part of the interpretation area is at least 25 m. The shortest distance across the sample plot center is measured between one forest boundary line to another forest boundary line. The forest boundary line separates the forest area from the non-forest area. It encompasses all stocking elements. (Stocking elements are defined as trees and shrubs which, according to the NFI tree species list, are at least 3 m high and less then 25 m apart.)
- **Crown coverage**: The crown coverage of the stocked part of the interpretation area has to be larger than or equal to 20%. (Exceptions to this rule include: afforestation, regeneration, burned, cut, or storm damaged areas.)
- **Dominant stand height**: The stocking has to have a dominant stand height of 3 m. (Exceptions to this rule include: afforestation, regeneration, burned, cut, or storm damaged areas as well as shrub forest consisting of dwarf pine (*Pinus mugo prostata*) and alpine alder (*Alnus viridis*).

For positive forest decisions the following conditions apply: The minimum width is 25 m with a crown coverage of 100% and the required dominant stand height. With increasing width the minimum crown coverage is allowed to decrease. The smallest acceptable threshold for the crown coverage is 20% at a minimum width of 50 m.

MAHRER (1976) gives the following considerations as arguments that led to the choice of exactly these discrimination criteria for the NFI forest definition:
- When the threshold standard for the criteria of the forest definition was established, close attention was paid so that areas designated as “forest” had a forest character.
- The chosen minimum width of 25 m corresponds to approximately the length of one tree. Individual trees in a row or hedges can therefore not be designated as forest.
- The crown coverage (the ratio of the crown projection area under the canopy to the total area) must amount to at least 0.2. A crown diameter of 12 m corresponds to an average tree distance of 25 m. This in turn implies approximately one tree length. Individual stocking elements still influence each other. They are part of a larger collective of woody plant species that is perceived as “forest.”
- For the minimum required dominant tree height of 3 m an extensive inclusion of forest area was assumed. Exceptions are the alpine alder and dwarf pine stands, as well as the above mentioned special cases.

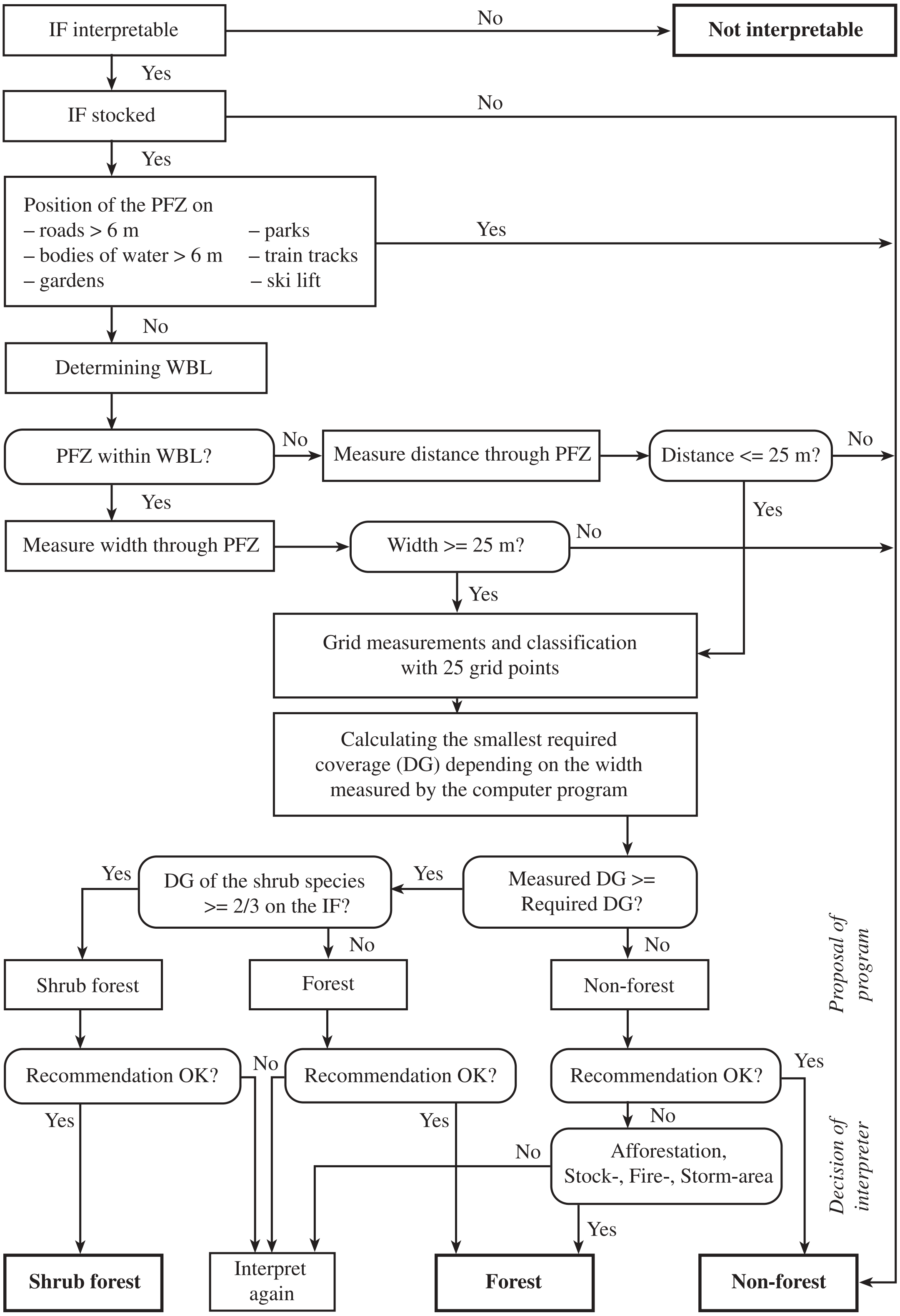
2.2.6 Measurements in the Stereo Model

A NFI sample plot consists of two concentric circular plots of 200 m^2 and 500 m^2 within a square interpretation area with a side length of 50 m. For the airphoto interpretation, all measurements and interpretations – apart from recording stand borders and forest edges – refer to this square interpretation area. The circular areas are only used for the terrestrial survey of the tree data.

Building upon the standard software (LEICA 1991) for the analytical plotter, a menu controlled interpretation program was developed for the airphoto interpretation. This program takes the interpreter sequentially through the individual measurements and interpretations. The sample plots of the terrestrial sample grid were interpreted using this program. (To compare the definition of sample grids in the NFI2, see Chapter 2.1 “Inventory Concept NFI2.”) For the analysis of the interpretation area in the 0.5-km-grid for which no field survey was conducted, a simplified program version was used. The differences in the program versions are specified in Chapter 2.2.7.

2.2.6.1 Forest/Non-Forest Decision

The aerial photo sample plots that are within a stereo model are dealt with one after the other within the interpretation program. Thanks to the absolute orientation, the floating mark of the analytical plotter automatically moves to the position with the coordinates of the first sample plot center in the chosen sector. Figure 6 gives an overview over all measurements and interpretations that lead to the forest/non-forest decision.



IF: Interpretation area
WBL: Forest boundary line
PFZ: Sample plot center
DG: Crown cover

Figure 6. Flow Chart of the Forest/Non-Forest Decision.

The airphoto interpretation begins with the measurements and interpretations for the forest/ non-forest decision. For unmistakable non-forest samples, the interpreter can skip the measurements in the forest (distance and width) and continue with the measurements of the stocking outside the forested area (Chapter 2.2.6.5). If these stockings are missing, only the elevation of the sample plot center is measured and the next aerial photo sample is used. In all other cases the interpreter determines the forest boundary line.

The forest boundary line is clearly visible for the majority of the stands. If the canopy cover is low and the stand has larger openings or turns into a sparsely stocked stand, the determination of the forest boundary line becomes time consuming and demanding. In this case the distance of each individual stocking element (STIERLIN ET AL. 1994) to all its neighbors has to be measured, while considering at the same time the minimum required dominant stand height. Such stands can often be seen in regions near the timberline.

If the course of the forest boundary line is determined, the interpreter specifies the position of the sample plot center relative to the stocked area. If this is **outside** of the forest boundary line (e.g., in the case of forest edge indentation into a field or a meadow), the **distance** between elements is measured. If the sample plot center is **inside** of the forest boundary line, the **width** is measured in a next step.

Measurement of the Width

The width (Figure 7) of a stocking is the shortest distance from one forest boundary line to another and across the sample plot center if the sample plot center is **within** the forest boundary line (p.38, STIERLIN ET AL. 1994). The width has to be at least 25 m. For critical distances the width is measured at least three times and the arithmetic mean from these measurements is calculated. If the width criterion is fulfilled, the dot grid measurements are applied next; otherwise, the sample is non-forest.

Measurement of the Distance

The distance (Figure 7) is the shortest distance from one forest boundary line to another and across the sample plot center if the sample plot center is **outside** of the forest boundary line (p.39, STIERLIN ET AL. 1994). If this distance is less than 25 m, it is possible that this represents a forest sample, and the dot grid measurements are continued in order to determine the crown coverage. Otherwise, this is a non-forest sample.

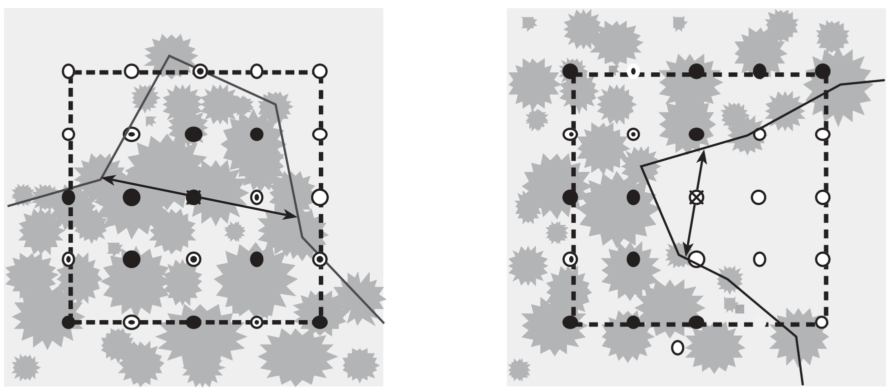


Figure 7. Measuring the width of the stocking and distance of the forest boundary line in the aerial photograph.

Dot Grid Measurement

The attributes "crown coverage" and "dominant stand height" needed for the forest/non-forest decision are estimated with the help of dot grid measurements. This encompasses the measurement on 25 dot grid points (see Figure 7), which are distributed over the interpretation area of 50 m x 50 m in a grid with a mesh width of 12.5 m. The midpoint of the grid coincides with the sample plot center.

The interpretation program moves the floating mark successively to all 25 positions of the dot grid points. The interpreter measures the height of the respective object at that point (see also measurements at corner height of an interpretation area) and classifies each dot grid point into one of eight classes (Table 1). The following classes are distinguished accordingly:

Table 1. Forest and Non-Forest Classes.

Classes	Forest/Non-Forest Decision according to NFI
Non-Forest	Non-Forest
Forest road with maximum width of 6 m	…
Ground stockable	
Ground not stockable (e.g., rock, scree)	Forest
Conifer	
Broadleaf tree	
Larch	
Shrub	Shrub forest

For the classes with stockings ("conifer," "broadleaf tree," "larch," and "shrub"), the minimum dominant tree height of 3 m generally applies. The only exception is the class "shrub" for which the shrub species "dwarf pine" and "alpine alder" do not have to fulfill this requirement. Trees and other shrub species that are smaller than 3 m in height are classified as the "ground stockable" class. For temporarily unstocked areas, special regulations apply. (See also program recommendation and interpretation decision.)

From the dot grid measurements the attributes "crown coverage" and "stand profile height" are derived:

The **crown coverage** is calculated from the proportional part of the dot grid points with stocking on that part of the interpretation area which is within the forest boundary line and thus fulfills the width criterion (see Figure 7). Dot grid points that fall into the class "non-forest" are not considered in determining the crown coverage.

The **stand profile height** is the same as the mean object height of all dot grid points, which are within the forest boundary line of an aerial photo sample plot. This should not be confused with the tree height or the average dominant stand height (Chapter 2.2.6.2). The stand profile height takes on high values if the entire interpretation area consists of a compact and complete stocked stand with high trees. It is used as a stratifying variable for the growing stock determination.

Program Recommendation and Interpretation Decision

Based on the measurements of width and crown coverage, the interpretation program gives the interpreter a recommendation: forest, non-forest, or shrub forest. The interpreter can accept or reject the recommendation. Usually the recommendation is accepted. Nevertheless, there are cases in which the recommendation has to be rejected. For example, the interpretation program will always recommend unstocked areas as "non-forest," because the minimum required crown coverage has not been realized. By comparing this area in aerial photographs from the NFI1 or with maps, it is possible to determine if the area is only temporarily or permanently unstocked. Afforestation, regeneration, cut, burned or damaged areas, such as windthrow, snow pressure, and avalanches, are considered as "temporarily unstocked areas." Permanently unstocked areas for example, are roads with a width between 3–6 m, creeks with a streambed width between 3–6 m, wood storage areas, and recreational facilities.

"Shrub forest" is recommended in all those cases where the criteria width and crown coverage is sufficient for a positive forest recommendation and when more than two thirds of the grid points within the forest area are classified as "shrubs." If the recommendation shrub forest is accepted, the attributes "shrub species " and "shrub forest type" are also assessed.

The following **shrub species** are distinguished as:
– Alpine alder (*Alnus viridis*)
– Dwarf pine (*Pinus mugo prostrata*)
– Non-identifiable shrubs

Shrub forests are arranged according to the following **shrub forest types**:
– Pure shrub forest
– Shrub forest with forest trees

2.2.6.2 Measurements of the Topography

Apart from measurements in the forest stands and on trees, aerial photographs are also used to measure the topography and to evaluate the ground surface of the interpretation area.

Elevation Measurements of the Sample Plot Center
The height of the sample plot center, according to the elevation model RIMINI (Chapter 2.7 "External Data Sources"), is taken as an initial value for the z- coordinate of the sample plot center and is recommended to the interpreter. Since this value can differ significantly from the elevation value in the absolute oriented stereo model, the recommended ground level of the sample plot center is corrected and replaced by the quantity measured in the stereo model. This measurement is done in all aerial photographs with a ground elevation of less then 2,500 m above sea level, even for obvious non-forest samples. Aerial photo samples with ground levels of 2,500 m above sea level or more are not interpreted in the aerial photographs. They are declared *a priori* as non-forest areas, since the probability is very small to detect any kind of stocking elements in these regions.

Corner Elevation of the Interpretation Area
Whenever possible, the elevation of the four corner points of the interpretation area are directly measured at the ground surface. Under adverse visible conditions in the stereo model and in dense stands without direct view of the ground, the corner elevation can also be measured at the dominant stand height if the elevation of the sample plot center is also measured at the dominant stand height. For this, a program option is available so that the average dominant stand height can be calculated in the proximity of the interpretation area. This is accomplished by calculating the arithmetic mean of several tree height measurements. After the last corner elevation is measured, the amount of the average dominant stand height is subtracted from all elevation measurements; that is to say, the four corner elevations as well as the sample plot center elevation.

With the help of the corner elevations and the elevation of the sample plot center, the ground surface profile of the interpretation area can be calculated. The measurements of the object's elevation in the 25-dot-grid refer to this ground surface model. It is therefore sufficient to take only one single measurement at the highest point of an object in order to calculate the total height of this object (e.g., the tree height). A second measurement at the stem base can be omitted.

Slope and Aspect of the Interpretation Area
Within the interpretation area, the slope gradient can be determined by measuring the gradient vector. The ground elevation is hereby measured from two points, which are generally in the

slope line of 15 m above and 15 m below the sample plot center. From heading of the gradient vector, the interpretation program calculates the aspect of the interpretation area for forest sample plots and puts them into the classes N, NE, E, SE, S, SW, W, NW, and unknown. The interpreter can correct the aspect recommendation if necessary.

Relief

Similar to the terrestrial samples, the relief of the aerial photo samples is characterized in the proximity of the interpretation area and is subdivided into seven classes:

– Plain: surface with slope <10%
– Hilltop: upper hillside, ridge
– Middle hillside: hill slope 10–70%
– Base of hill: syncline, trench
– Steep hill: hill slope >70%
– Undefined (i.e., none of the above options)
– Undefinable (i.e., not clearly visible in areas such as shade)

2.2.6.3 Stand Description

Stand descriptions are suitable for collecting stratifying variables, which can be used during the analysis to estimate the strata size. One example is the stand profile height. Stand descriptions refer to the reference stand; that is the stand in which the sample plot center is located. The following attributes are a part of the stand description:

– Stand profile height
– Development stage
– Crown closure
– Stand size

Development Stage

The stand attribute "development stage" is estimated in aerial photographs with the attribute "development stage AP (aerial photograph)" as well as during the field survey but is based on different criteria. The terrestrial derived "development stage" is a function of the dominant diameter at breast height (p.146, STIERLIN *et al.* 1994). This diameter cannot be measured directly in aerial photographs. Instead, it is possible to measure the object's height and distances. The estimation of the development stage AP in aerial photographs is based on an expert opinion, which apart from the dominant stand height also takes other factors into account. These other factors are crown diameter, canopy cover density, tree species composition, production region, elevation, slope gradient, and aspect of the stand. Six different development stages are differentiated as follows:

– Young growth/thicket
– Pole wood
– Young/medium timber
– Old timber
– Mixed
– Undeterminable

Table 2 shows the relationship between the dominant stand height (in meters) and the development stage AP. The average dominant stand height at the development stage AP, young growth, pole wood, young/medium timber, and old timber are shown below.

Table 2. Development Stages (AP).
* The average dominant stand height is not a discriminatory variable for the attribute development stage (AP). While considering the above mentioned other factors, the classification in the endlapping range is a discretionary matter of the interpreter.

Altitudinal Zone	Crown closure	Development Stage (AP)			
		Young Growth*	Pole Wood*	Young/Medium Timber*	Old Timber*
Colline/Submontane	Sparse – Normal	up to 8 m	8–20 m		
	Crowded	8–12 m	12–25 m		
	All			20–30 m	from 25 m
Lower and Upper Montane	Sparse – Normal	up to 8 m	8–20 m		
	Crowded	8–10 m	10–20 m		
	All			20–30 m	from 25 m
Lower and Upper Subalpine	All	up to 8 m	8–20 m	20–25 m	from 25 m

Crown closure

With the attribute crown closure, which is derived by way of an expert opinion, a measure of tree crown competition is found (Figure 8 to Figure 16). This attribute is quantified during the field survey, as well as during the aerial photography interpretation, according to the instructions of the NFI inventory manual (STIERLIN ET AL. 1994). In addition, mountain forest canopy cover known as “lamellar grouped” is also quantified in aerial photographs.

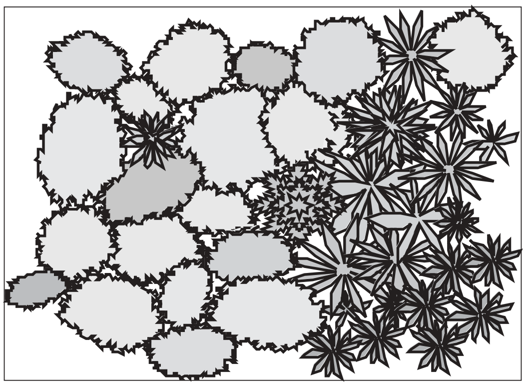


Figure 8. Crown closure crowded.
The tree crowns are competing with each other. Strong contact leads to deformation and partially to asymmetric crown shapes.

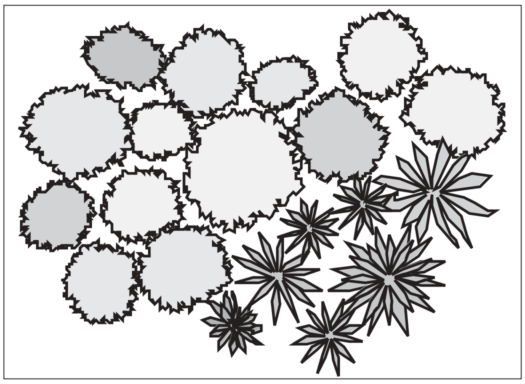


Figure 9. Crown closure normal.
The tree crowns touch each other slightly but are able to develop normally and have a good shape.

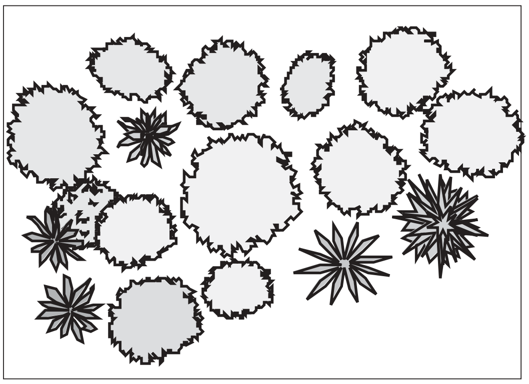


Figure 10. Crown closure open.
The trees are loosely spaced for the most part without any contact. The stand has small gaps in which no other crowns move in.

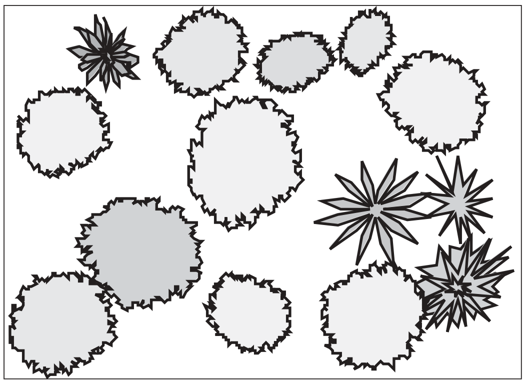


Figure 11. Crown closure open/sparse.
Stands with gaps in which individual tree crowns could be added.

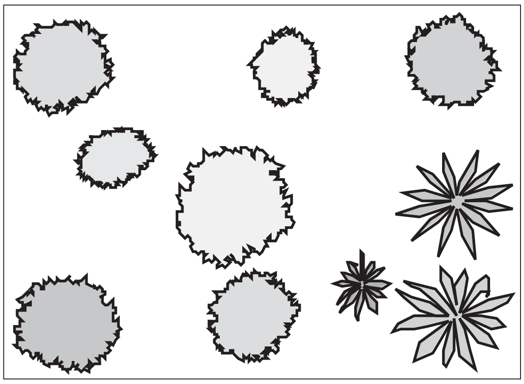


Figure 12. Crown closure sparse.
Stands with large gaps in which several tree crowns would fit.

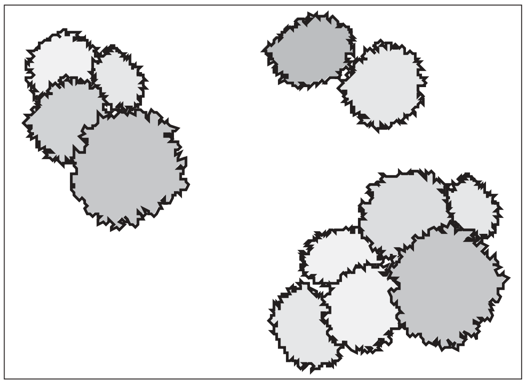


Figure 13. Crown closure grouped/crowded.
Compact groups of trees with crowded crown closure. The tree crowns strongly compete with each other (e.g., clusters in the mountains).

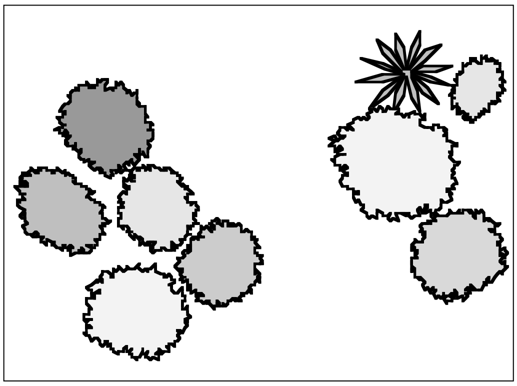


Figure 14. Crown closure grouped/normal.
Small, clearly separate groups of trees with normal crown closure. The tree crowns touch each other slightly but have a good shape and develop normally.

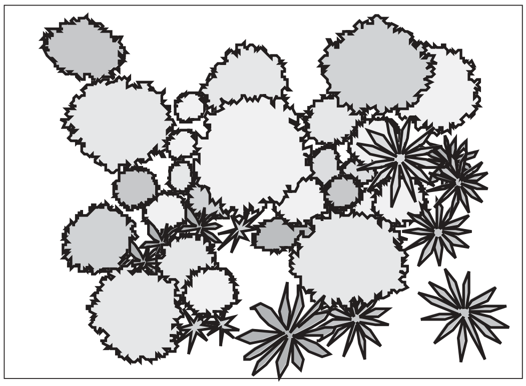
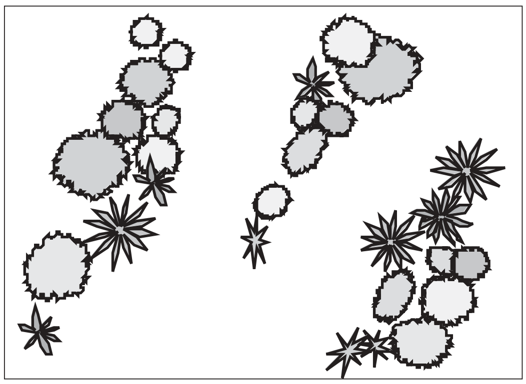


Figure 15. Crown closure complete.
Stands have a layer structure. The tree crowns overlap each other (vertical competition). This can especially be seen in all-aged, selection type stands.

Figure 16. Crown closure grouped with lamellar structure.
Special type on steep slopes in the mountains with staggered arranged tree groups in a “flame-like” shape, which are separated from each other by trenches (avalanches, wind, and erosion material).



Stand size

The stand size indicates the spatial extent of the reference stand. The size does not refer to the square interpretation area with the side width of 50 m and can therefore exceed the size of the interpretation area. With the help of the floating mark, the course of the stand boundary is digitized as a closed polygon, and the size of the enclosed area is calculated. The stand boundary separates tree collectives, which differ in one or many of the following attributes: tree species composition, age, stage of development, canopy cover density, and structure.

Stand Boundary and Forest Edge

The stand boundaries are measured if they intersect with the 500 m^2 circle of the sample plot area. Forest edges are always recorded in aerial photographs if the shortest distance from the sample plot center to the forest edge is less than 25 m. Both of these measurements serve as auxiliary information for the field survey team, in order to find the sample plot in the field and for the terrestrial assessment of the forest edge. These measurements permit a better estimation of the expected work expenditure and contribute to the optimization of the operations scheduling.

2.2.6.4 Reference Points

An important task of the airphoto interpretation is the measurement and description of reference points, which are needed by the field survey team to locate the sample plot center. Reference points have to be clearly identified in aerial photographs as well as on the ground. Whenever possible the same reference points should be measured that were already measured during the first NFI survey. Because a long period can pass between the date when aerial photographs are taken and the date when the field survey is conducted, reference points can disappear or change position as frequently happened in the NFI2 (e.g., an intersection of two roads was reconstructed). In each aerial photo sample, two to three reference points are measured so that the field survey team can choose for themselves the most suitable one. In case the reference points are not well chosen, or cannot clearly be identified, the field survey team measures suitable reference points with the help of the line glass from the map.

In respect to position accuracy, reference points measured from the map are comparable to the ones measured in aerial photographs. However, less potential points are available than in aerial photographs, since each point has to have a measurement for the x-, y- and z- coordinates. This requirement is only fulfilled for a few points on the map, and these are usually triangulation points or spot heights. However, in the absolute oriented stereo model, the three dimensional coordinates of any arbitrary point can be measured. Therefore, any visible object becomes a potential reference point, such as a prominent tree, every visible building, a pylon of a power line, etc.

In aerial photographs, reference points can be selected that are closer to the sample plot center of interest. Due to this, the time consumption to locate the sample plot center from the reference points in the field is significantly reduced. A study from the first NFI showed that the average time to locate the sample plot center with reference points originating from aerial photography (8055 measurements) and reference points taken from the map was 22.9 minutes and 33.5 minutes respectively.

Reference Point Selections and Reference Point Measurements

The following objects are permissible reference points:

1. Building
2. Rocks/stone
3. Bridge
4. Road curve
5. Support structure
6. Avalanche control structure
7. Conifer tree
8. Broadleaf tree
9. Well
10. Shaft
11. Pole, pylon
12. Road/road intersection
13. Road/trench intersection
14. Road/creek intersection
15. Creek/creek intersection
16. Stand border/road intersection
17. Sample plot center elevation/trench intersection

Reference points on objects with a spatial extent are complemented with the measurements of the object's elevation, and by the indication of the direction (e.g. a house with the reference point corresponding with its SW corner). The cardinal point of the object's corner at which the reference point is measured is specified relative to the center of the object.

For solitary trees the object's height is a good characteristic to distinguish them from other trees in the field.

2.2.6.5 Stocking Outside the Forest Area

In the NFI2, stocking outside the forest, according to the NFI definition, was quantified in all aerial photo samples of the 1.4-km-grid with a partial or complete non-forest portion on the interpretation area. The attribute "type of stocking" records whether the stockings are individual trees, woody plants, or groups of brushes, which did not fulfill the criteria of the NFI forest definition.

Woody Plants
If there are any woody plant formations on the interpretation area, the length and the type of the woody plants are recorded. The largest distance within a woody plant is measured and referred to as the width of the woody plant. For example, in a rectangular woody plant with the dimensions of 10 m by 20 m its length measures 22.4 m. If there are several woody plants in the same interpretation area, or if a woody plant consists of several sections, the sum of all the diameters is used.

The attribute "woody plant type" is divided into the following classes:
- Hedge/agricultural shrub
- Hedge/agricultural woody plant
- Creek/bank shrub
- Creek/bank woody plant
- Shelter-belt (artificially planted woody plant belt with protective effects, e.g., wind protection, visual protection, or noise protection belt)
- High-altitude woody plants (woody plant formations in the mountains)
- High-altitude cluster (cluster formation in the mountains)
- Woody plants in parks (woody plants without economical utilization that are often found around walkways, grassy areas, etc.)
- Forest corner (a forested area connected to a larger forest complex which does not have the minimal width of 25 m and is therefore counted as non-forest)

In the NFI, the term "shrubs" also refers to stockings, which consists of bush and shrub types (according to NFI species coding), while "woody plants" also include tree species.

Solitary Trees
For solitary trees on the interpretation area, the tree type is determined and the number of trees is counted.

The following tree types are distinguished:
- Forest trees
- Park trees (solitary trees in gardens or parks)
- Standard fruit trees
- Dwarf fruit trees
- Avenue trees
- Solitary shrubs
- Mixed

Knowledge about these types of important ecological parameters is interesting for two reasons: It provides information about the occurrence, type, and distribution of stocking outside of the forest according to NFI, and it serves as an input variable in international or global statistics, e.g., UN-ECE/FAO, 1990 Forest Resource Assessment. Furthermore, it allows comprehensive estimations of the total stocked area of a country and thereby simplifies the comparison of national forest area quantities, even though they are based on different forest definitions.

2.2.6.6 Terrestrial Clarification

Aerial photographs, which could not be clearly labeled as class “forest,” “brushwood forest,” or “non-forest“ were specially marked. In this case, the field survey team had the task of clarifying the forest/non-forest decision in the field.

It is difficult to interpret aerial photographs on steep shaded hillsides in the mountains. This is especially true in cases where nearby bright parts of rocks or snowfields cause a high contrast in aerial photographs. The development process of the aerial photographs is tailored to the needs of the Swiss Federal Office of Topography. The same process is not sufficient for the NFI measurements, especially in the already darker parts of the forest. The same is true for aerial photo samples that were covered with clouds. Nevertheless, this is rarely the case overall.

Far more often are those cases in which the measured forest width or the distance between trees is close to the critical threshold of 25 m. It is also difficult to evaluate in aerial photographs exactly where the relevant forest boundary line is located along forest edges with a high percentage of broadleaf wood, because the crowns are usually asymmetric. If the sample plot center is less then 2 m away from such a forest boundary line; it is clarified in the field.

Airphoto interpretation is also more difficult when aerial photographs are taken during the spring, since they have to be measured when the trees and stands are leafless.

Another reason for the terrestrial clarification is given when it is not possible to clearly distinguish in the aerial photograph between shrub and forest type (e.g., *Alnus viridis/Alnus incana*), leaving to speculation whether the sample is a brushwood forest or a forest. On the south side of the Alps, with its extensive coppice forest and brushwood forest, a clear separation is often impossible.

2.2.6.7 Combined Forest/Non-Forest Decision

The forest/non-forest decision is mainly reached in the NFI through airphoto interpretation in the first inventory phase. In some cases this is not enough, so that in the second inventory phase (the field survey) a forest/non-forest decision also has to be reached. From the combination of both decisions, the final valid decision (the so-called “combined forest/non-forest decision”) is derived.

In most cases the combined forest/non-forest decision is identical to the one derived from the aerial photographs. If the forest/non-forest decision is clarified on the ground, it then replaces the decision from the aerial photographs with one exception: If sample plots are not passable or not accessible, the decision of the airphoto interpretation prevails, since it is not possible to verify it on the ground.

A terrestrial forest/non-forest decision is performed if:
- A terrestrial clarification is requested. In this case the sample plot area is newly located.
- The field survey team finds a situation that does not fit the result from the aerial photography interpretation.

Up to eight years elapsed between the dates that aerial photographs were taken and the field survey was conducted. Due to natural or anthropogenic influences taking place during this time lapse, it was possible for significant changes to occur at the sample plot, which would have resulted in a different airphoto interpretation. Even though changes can occur when a sample plot is located next to a steep mountainside and disappears because of the erosion process, it is the exception. It is human activities, like the construction of roads or development of new regions in mountainous areas for tourist use, which are the main reasons for significant changes. At the same time there are several areas that did not meet the criteria for a positive forest/non-forest decision at the time the aerial photographs was taken but in the meantime “grew in.” In all of Switzerland, the forest area increased by 4% since the first NFI.

2.2.7 Analysis in the 0.5-km-grid

The analysis described in Chapter 2.2.6 refers to the terrestrial grid (1.4-km-grid or the 4.0-km-grid shifted by 0.5 km). For aerial photo samples in the 0.5-km-grid, for which no field survey was conducted, a simplified variation of the analysis software was applied that did not quantify the following attributes:
- Stand size
- Stand boundary
- Forest edge
- Reference point measurement
- Quantification of woody plants and trees outside of the forest area

2.2.8 Discussion and Outlook

The most important goal of the airphoto interpretation was achieved: The distinction between forest and non-forest areas for all of Switzerland with a consistent forest/non-forest decision and a given estimation error. Chapter 2.10 demonstrates that the reproducibility of the forest/non-forest is very good. Improvements are possible for attributes which are derived from expert opinions, for example stand size or lamella structure, by replacing categorical attributes with measurable quantities.

Quantification of changes is only meaningful if the same object – namely the NFI sample plots – is referenced to when discussing any changes. For the orientation of the aerial photographs in the NFI2, ground control points and reference points from the NFI1 were also employed, so that the orientation of the aerial photographs used in NFI2 approximated the one in the first NFI. Since it is not reasonable to repeat the positional error of the NFI1 in all succeeding inventories, a new method has to be found for the NFI3, to make sure that the same object as in the proceeding inventories is addressed, while at the same time the true coordinates can be determined.

The importance of remote sensing for large-scale inventories is increasing. Remotely sensed data will also be one of the most important sources of data for the NFI3. At this time, it is not possible to make a final statement about the employment of remote sensing methods, since this depends decisively on the inventory goals of the NFI3 which are currently unknown.

Photogrammetry is coming into a new age. Digital photogrammetry is advancing and will most likely supersede the classical photogrammetry in the near future with its analytic plotters. Digital aerial photographs are already available today for the entire Swiss market and the Swiss Federal Office of Topography intends to update the national maps of Switzerland digitally in the future.

It is very likely that the NFI3 will employ digital data. This data will allow the employment of modern image analysis methods and can be partially automated. In addition, digital data offers the advantage of achieving reproducible and consistent results. With this an analysis over the entire area of individual attributes is within the range of possibilities.

In spite of that, it is unrealistic to assume that remotely sensed data will be analyzed completely through automation in the NFI3. Even in the future, well-trained interpreters, who are familiar with the criteria of the measured attributes from the first two national forest inventories, will still be needed. It is therefore important to maintain the continuity of the existing attributes. Improvements can be expected in areas where it is possible to replace or supplement quantities based on expert opinions, subjective interpretations, or estimations with measurable quantities.

2.2.9 Acknowledgments

The following people have worked successfully to make airphoto interpretation a reality in the second NFI. Michael Köhl developed the inventory methods; Robert Sutter was responsible for airphoto interpretation in general, training of the interpreters, and the photogrammetric sides of the aerial photography interpretation; and Rüdiger Jensen was responsible for programming and implementing the interpretation instructions.

2.2.10 Literature

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2.3 Terrestrial Inventory

Hans Rudolf Stierlin, Jürg Zinggeler

2.3.1 Introduction

The terrestrial inventory is the most important source of data for the National Forest Inventory. Within the forest, and along the forest edges, approximately 100 different attributes are recorded. These attributes are the basis for most of the 400 derived attributes, such as growing stock, increment, and utilization. They are also the basis for measures which quantify forest functions or the ecological importance of the forest. The "Manual for the Field Survey of the Inventory 1993–1995" (STIERLIN *et al.* 1994) was the most important document of the terrestrial inventory. In it the definition and the survey instructions for the individual attributes; the organization and the flow of operation while recording sample plots; as well as the equipment used and documents are described in detail. The "NFI2 manual" sets the standard for the terrestrial survey at the sample plots and for the forest service's inquiry. This standard had to be followed exactly and was ensured through the schooling and training of the survey team. Changes and refinements of the manual were given to the survey team in writing. These refinements were collected in a folder, which each team carried together with the manual. The only permitted changes of the manual were contained in the folder.

2.3.2 Preparation and Implementation of the Field Survey

2.3.2.1 Pilot Inventory

A pilot inventory of 1992 was the main test for the terrestrial inventory. Several different new survey attributes, which were defined before in some method tests, were checked in the pilot inventory and partially included as a useful addition to the catalog of attributes. Even the first NFI was not solely concerned with the production function of the forest. Since that time the information required about the other functions of the forest has increased immensely. The main focus in mountainous regions was the protective function of the forest. It was also intended to describe and evaluate the forest as an important, near-natural habitat for animals and plants, as well as for recreation (BRÄNDLI 1992).

Important new elements were: the evaluation of forest edges and the quantification of ecological parameters such as dead wood, dry or humid sites, recreational facilities, and gaps in the forest. The objectives of the pilot inventory were: to develop survey instructions for the field survey, examine their practicality in the field, evaluate the measuring instruments and tools, and optimize the flow of work. Time studies for the different working phases provided valuable information for planning the field survey of the second NFI. The pilot inventory was conducted in five test areas, which represented the different conditions within the five regions of Switzerland.

An important goal of the pilot study was the selection of a suitable field computer. The American product "PARAVANT" turned out to be the one selected (see also Chapter 2.3.4). The program for the data collection had to be adjusted to the work routine of the terrestrial sample survey and for the forest service's inquiry. The flow of data from the WSL to the survey teams and back was developed in the pilot study.

2.3.2.2 Planning the Field Survey

The planning of the field survey was primarily based on the first NFI. At that time the NFI survey conformed to the flight plan of the Swiss Federal Office of Topography, so that the forest/non-forest decision could be accomplished using the most recent aerial photographs. This resulted in a three-year task with regions divided schematically according to sheets of the national map. These regions were also used for the second NFI (Figure 1).

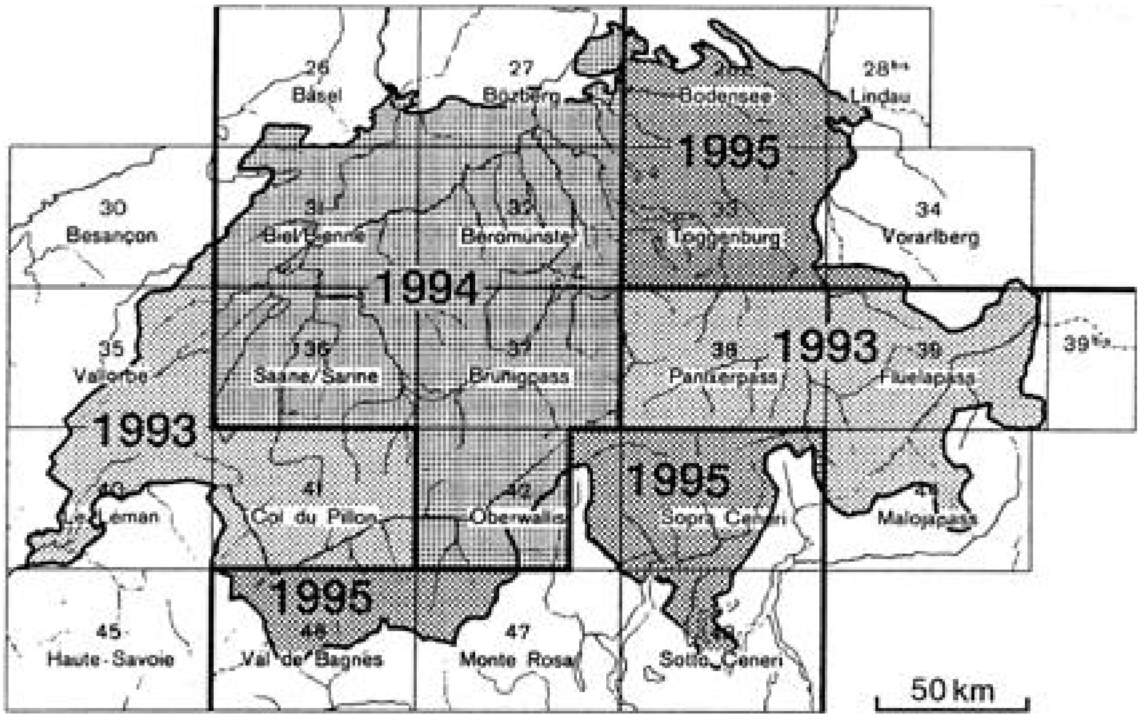


Figure 1. Survey years of the second NFI. Planned time frame for the data gathering in the forest.

For the estimation of the total expenditure and the number of survey teams needed, several different bases and empirical figures were available. From the first NFI survey the number of permanent sample plots were known. Due to decreased funding, only half of the permanent sample plots could be measured in the field for the second NFI. Besides the sample plots that were measured from the first NFI, an additional 10% were measured, which helped in the study of the representativeness of the sample grid, and up to 13% of the sample plots were newly interpreted in the aerial photograph as forest. The planning of details depended on the cantonal forest districts. For each forest district the number of sample plots was estimated. From the expenditure of time per sample plot, which was estimated based on the empirical numbers from the first NFI and the pilot inventory, as well as the number of sample plots, the expenditure of work per forest district was calculated. As a rule, only one survey team worked in a forest district. This team was responsible for measuring all sample plots in the forest district and for the forest service's inquiry. The next step was to put the sequence of forest districts for each survey team together in a way that the teams would start in March/April with their work in the lowland, continue in the summer months in the mountains, and return to work again in the lowland forest districts during the autumn (Table 1, Figure 2).

Table 1. Process of the field survey – example of the workload of a group. Field survey of 1994 – group 13.

Forest district	Number of sample plots	Survey data
Basel-city / Basel-county 1	23	7.3. to 20.3.
Zurich 8	9	21.3. to 23.3.
Zurich 7	42	24.3. to 26.4.
Solothurn 4	38	27.4. to 24.5.
Bern 16	39	25.5. to 17.6.
Wallis 2	69	20.6. to 15.8.
Bern 20	43	16.8. to 16.9.
Jura 4	33	19.9. to 10.10.
Bern 8	71	11.10. to 25.11.
Total	367	

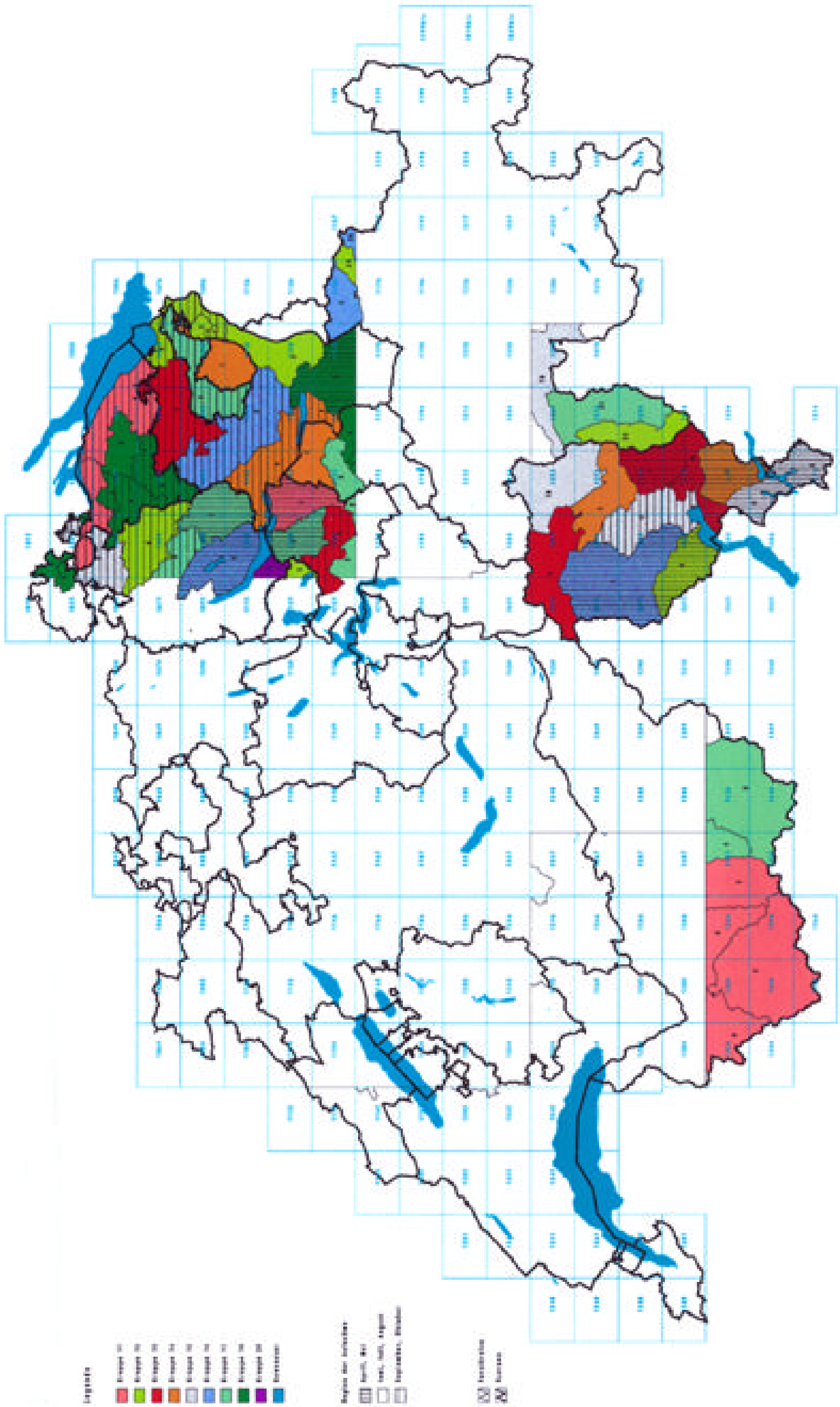


Figure 2. Employment plan for the field survey NFI, 1994.

2.3.2.3 Survey Administration and Organization

The field survey for the second NFI was planned, organized, and carried out by the board at the WSL. This board consisted of one supervisor and three assistants. The board was responsible for instruction and training, equipment, optimal employment of the survey teams, and to act as the contact between the WSL and the teams.

Apart from the above mentioned tasks, the board was also in charge of updating the forest roads on the national map, digitizing the forest road network (Chapter 2.6), as well as transferring the data between the data bank and the field (Chapter 2.3.4).

2.3.2.4 Survey Team

A forest engineer, usually coming straight from a forestry college as a team leader, and a forester or forest ranger as an assistant with practical experience, formed a survey team. The combination of theoretical knowledge and practical experience was the ideal condition for good quality work. The good fellowship between the team leader and the assistant in all of the survey teams helped, so that during the three years no accident occurred and the work proceeded practically without any difficulties. Up to 12 survey teams were employed, while the number varied depending on the yearly survey quota and the time of year.

The survey teams were paid by the hour. The hourly wage proved to be a huge advantage, especially in hard to reach regions. The survey teams were largely free, with respect to the organization of their daily assignments. This allowed the team to adjust their time for the day's work to the local conditions. In turn, this maximized the number of sample plots measured every day. The team's expenses for food and accommodations were reimbursed on a per diem basis. Travel expenses were separately reimbursed.

The following was all a part of the survey team's tasks: planning the details of the field survey in the forest districts (daily and weekly programs), contacting to the forest service, measuring all sample plots in the forest district and conducting inquiries, working on public relations in the survey regions, maintaining vehicles and equipment, and writing the work reports.

2.3.2.5 Equipment of the Survey Teams

The WSL provided the survey teams with all of the necessary measuring instruments and working equipment (Figure 3). Important factors for the selection of the measuring instruments were robustness, simplicity, and whenever possible, independence from the use of batteries. During the pilot inventory, for example, an ultrasound distance instrument was tested. It was found that the measuring tape gave better overall results. The survey teams had, apart from the survey equipment, a VW-bus and a mobile phone at their disposal. With this, the teams were self-sufficient and could work independently. The board and forest service could reach the teams easily. The teams could ask for support or help if needed, and could arrange appointments with the forest ranger or the district forest officer. During the pilot inventory and the three years of field survey, the survey equipment proved to be reliable in often very difficult and impassable terrain. Even the relatively clumsy telescopic poles, for the diameter measurement in 7 m height, as well as upper stem calipers, were not too much of an obstacle.

2.3.2.6 Visiting the Sample Plots

Before the survey team could start their work in the survey area, they had to contact the responsible district forest officer and announce their start and the anticipated duration of the work. The district forest officer had already been informed earlier about the NFI field survey and the general schedule.

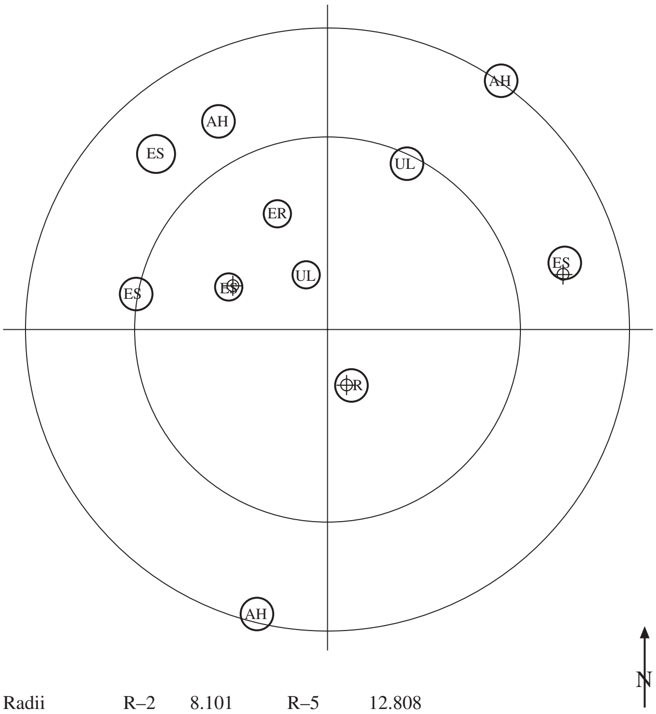
Figure 3. Equipment of an NFI survey team.

Within the survey area it was up to the team to decide in which order they wanted to visit the sample plots. Based on a list which contained all the sample plots, the team was able to compile the weekly and daily work schedule. This list also contained information whether the sample plot was measured in the first NFI or whether it was a new one. Other pertinent information included: the elevation above sea level, the stage of development according to the aerial photography interpretation, whether a forest edge survey was planned, and whether the forest/non-forest decision from the aerial photography interpretation had to be verified.

In order to conduct the sample plot survey, the team drove with the VW-bus close to the sample plot. For this, they used the national map with a scale of 1:25,000. Before the team was allowed to leave the car, they had to choose the sample plot with the handheld computer and record the starting time of the first work phase. If the sample plot had been measured during the first NFI, the team had a copy of the form “sample-plot center and location marking” and “layout sketch” in their records. In addition, a printout for each sample plot was prepared, which showed the position of the sample trees on the sample plot, the sample plot radii, and the permanently marked points (Figure 4). With the help of these records and the map, the teams were able, in most cases, to go directly to the sample plot and identify the blue permanently marked points. For new sample plots, which first had to be located on the ground, the team looked for a suitable reference point (e.g., a prominent point on the ground, which could be identified on the ground and in the aerial photograph or the map without any doubt). The sample plot center was surveyed in from this point.

LFI-1 L+T 1091 6790

2460



Radii R–2 8.101 R–5 12.808

Permanently marked points

	Azi.	Dist.	Descr.
P1.	86	10	ES 38
P2.	329	4.4	ES 33
P3.	182	2.6	Alder 36 at path
P4.	–	–	–

Figure 4. Layout sketch with tree positions of the sample plot with the coordinate x = 679,000 and y = 246,000.

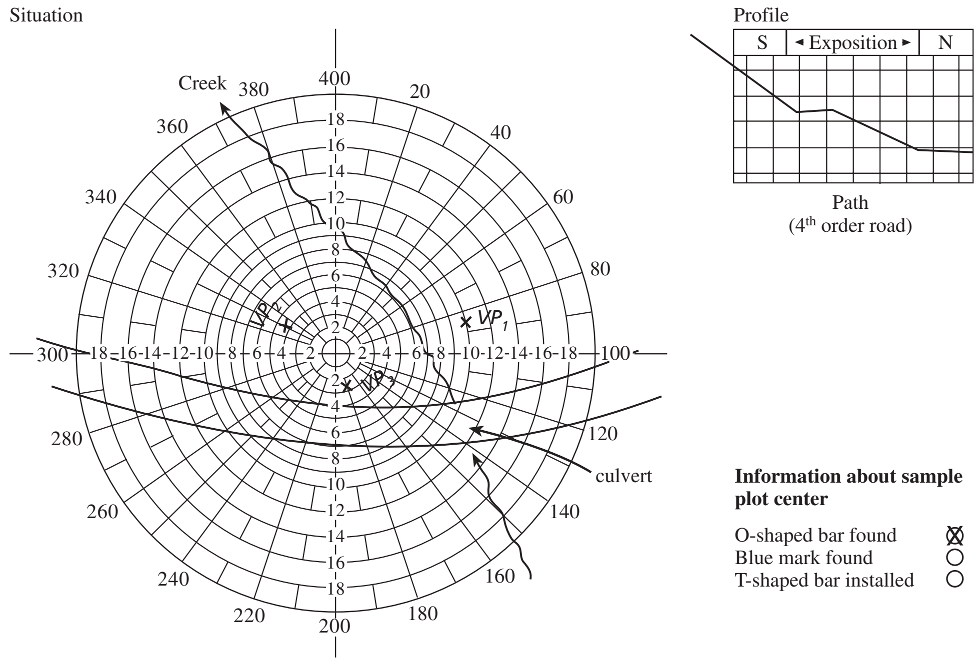
2.3.2.7 Measuring and Permanently Marking the Sample Plot

For measuring the sample plot, a list of reference points was available which contained three reference points from the aerial photography interpretation. From the reference points, and with the help from the handheld computer's survey program, the team was able to measure in the sample plot centers. The sample plot center was marked with an aluminum tee bar. This type of marking was different from the O-shaped bar from the first NFI.

The sample plot center was marked with two or three blue color marks on trees, stones, rocks, etc., and the polar coordinates were measured with respect to the sample plot center (Figure 5). A layout sketch will help in future surveys to find the sample plot centers again. From the first NFI, the permanently marked points on trees lasted longer than colored marks on stones or rocks, which were often grown over by moss or were weathered. Unusable permanently marked points were replaced.

2.3.2.8 Control Survey

Between 1993 and 1995, 6,627 sample plots were measured. Of these, 747 plots (approximately 11%) were measured a second time as a control independently of the first survey (STIERLIN 1996). With the control survey, the quality of work was studied and discrepancies between the first survey and the control survey were determined. The results of the control survey were routinely announced and discussed with the survey teams during the training days (see Chapter 2.8 and 2.9).



Permanently marked points

VP-Nr	Azimut	Oblique Distance	Term	LFI-Nr.
3	1 8 1	2 , 6	Alder DBH 40 (at path)	1
2	3 2 7	4 , 4	Ash DBH 38	1
1	8 4	1 0 , 0	Ash DBH 38	1
		,		
		,		
		,		
		,		
		,		

Figure 5. Example of a layout sketch for the sample plot x = 679,000 and 246,000.

2.3.3 Attribute Catalog

On the one hand, the attribute catalog was determined by the first inventory. On the other hand, the catalog was improved based on the experience made during the analysis of the first NFI and, moreover, complied with the current informational needs. If changes between the first and the second NFI had to be quantified, the definitions for the attributes could not be modified. However, in some cases, changes and refinements were necessary because some attributes of the first NFI were difficult to quantify or to interpret.

About half of the first NFI attributes were used without any changes for the second survey. These are notated in the following catalog with **NFI1=NFI2**. They are not further discussed, since they are explained in detail in the manuals for the first NFI (ZINGG and BACHOFEN 1988) and for the second NFI (STIERLIN *et al.* 1994).

The revised attributes are notated by **NFI1≠NFI2**. The commentary describes the revisions. For some attributes the implications of the revisions are documented.

Some of the attributes were relinquished in the second survey, since they were either not used in the analysis or no change was expected. The relinquished attributes are notated in the catalog mentioned below as “**NFI1**”, and the reasons why they have been given up are explained.

New needs for information required the definition and quantification of approximately 60 new attributes, which are notated with **NFI2**. Most of the attributes are not discussed further as they are defined and described in the manual for the second NFI. For some attributes, which allow statements about the survey methods, comments or results of the NFI2 survey are stated.

The attributes are described in the sequence in which they are found in the “Manual for Field Surveys in the 1993–1995 inventory” (STIERLIN *et al.* 1994). The number behind the title and the attributes (i.e., Chapter 3) refers to the corresponding chapter in the survey manual.

2.3.3.1 Measuring Sample Plots (Chapter 3)

– *Reference points* *(Chapter 3.2)* *NFI1=NFI2*

– *Accessibility* *(Chapter 3.4)* *NFI1≠NFI2*

In the first NFI the reason for the inaccessibility of a sample plot was described with a maximum of a 20 character text. In the second NFI the reason for the inaccessibility of a sample plot was coded with five different code meanings.

– *Sample plot status* *(Chapter 3.5)* *NFI2*

The sample plot status provides information about if and how the sample plot center was found (using a reference point, with or without surveying) (Table 2).

Table 2. Status of the sample plots for the terrestrial sample plots NFI2.

Code	Code meaning	Number of SP	%
1	Found *	4780	85.8
2	Reconstructed	639	11.5
3	Measured / found *	43	0.8
4	Measured / reconstructed	32	0.6
5	Other RP / found *	7	0.1
6	Other RP / reconstructed	16	0.3
7	Not found	52	0.9
	Total NFI 1-SP	5569	100.0
8	First time surveyed	1008	
	Total	6577	

* Aluminum- pipe in the ground found = 4,830 sample plots out of 5,569 NFI1–SP = 86,7% Key: SP = Sample plot, RP = Reference point

For 85.8% of the permanent sample plots from the first NFI, the team located the sample plots without any measurements, and found the pipe in the ground only with the help of the layout sketch from the first NFI. In 11.5% of the cases, the sample plot was found without measurements; however, the sample plot center had to be reconstructed from the existing permanently marked points because the pipe in the ground had disappeared. All reconstructed sample plot centers were marked with an aluminum tee bar. In all only 1.8% of the first NFI sample plots had to be surveyed in again. In 1.4% of the cases, the same reference points were used as in the first NFI. Only about 0.9% of the sample plots of the first NFI could not be found, since they were not correctly located either in the first or the second NFI. For sample plots which were not found, all of the preset values in the handheld computer were deleted, and the sample plot was newly measured just as in a first survey.

– *Difference in measuring the sample plot* *(Chapter 3.6)* *NFI2*

This was not systematically measured and could not be analyzed.

2.3.3.2 Forest/Non-Forest Decision (Chapter 4)

– *Forest/non-forest decision and reason* *(Chapter 4.8)* *NFI1=NFI2*

The decision as to whether a sample plot was within the forest or not was a point decision, which refers only to the sample plot center. In order to detect any changes of the forest area since the first inventory, it was essential that the interpretation be conducted with exactly the same instructions as in the first NFI. The criteria for the forest/non-forest decision were: 1) formulated more precisely; 2) the decision model was made more consistent; 3) the designation of the forest type “brushwood forest” was integrated (STIERLIN *et al.* 1994) (Figure 6).

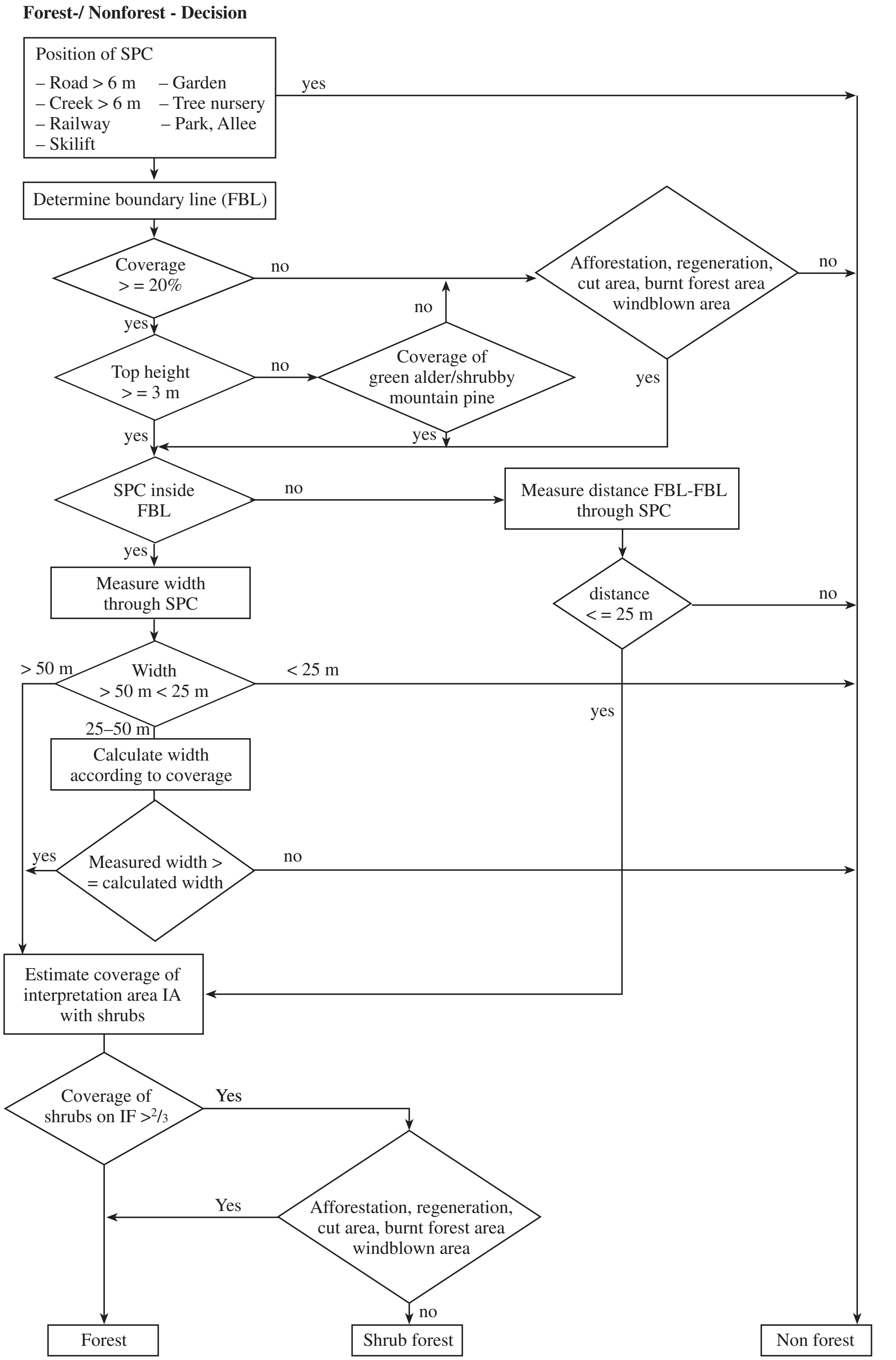


Figure 6. Forest/non-forest decision according to the NFI.

2.3.3.3 Slope and Sample Plot Radii (Chapter 5)

– *Status of the slope values* *(Chapter 5.2)* *NFI2*

For existing sample plots, the slope of the sample plot and the sample plot radii were given. They could not be altered in a subsequent inventory.

– *Slope of the sample plot* *(Chapter 5.3)* *NFI1=NFI2*

For new sample plots, the slope gradient was measured in exactly the same way as in the first NFI (ZINGG and BACHOFEN 1988), and the sample plot radii were calculated with the handheld computer (Figure 7).

– *Sign of the slope* *(Chapter 5.4)* *NFI1=NFI2*

– *Radii of sample plots* *(Chapter 5.5.)* *NFI1=NFI2*

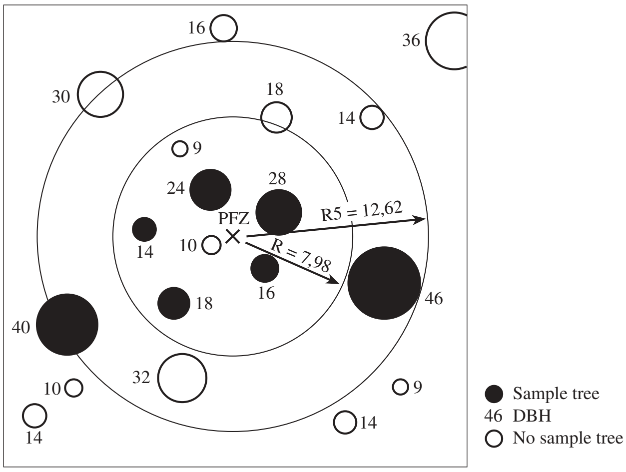


Figure 7. Sample plot radii and sample trees.

2.3.3.4 Permanently Marking of the Sample Plot Center / Situation (Chapter 6)

– *Status of the permanently marked point* *(Chapter 6.2)* *NFI2*

– *Azimuth of the permanently marked point* *(Chapter 6.3)* *NFI1=NFI2*

– *Distance of the permanently marked point* *(Chapter 6.4)* *NFI1=NFI2*

– *Description of the permanently marked point* *(Chapter 6.5)* *NFI1=NFI2*

2.3.3.5 Stocking Boundary, Accessibility Boundary, and Forest Edge Survey (Chapter 7)

The forest edge is an important habitat in the transition zone between forest and the open land. During the second NFI, close attention was paid to the ecological aspect of the forest edge. Several new attributes for describing the forest edge were included in the survey, and the forest edge survey was vastly extended. The survey in the first NFI was limited to the quantification of the boundary line between the stocked part of the sample plot at the forest edge and the unstocked part. Measuring this boundary line helped in projecting the stocking of the entire sample plot. Terms such as forest edge, forest boundary line, stocking boundary, accessibility boundary, assessment line, and boundary line are defined in the Manual for Field Surveys (STIERLIN *et al.* 1994). Compared to the first NFI, the area of quantifying a forest edge was extended. In the first NFI, all forest edge lines were measured, which intersected with the 0.05 hectare sample circle. In the second NFI, all forest edges were measured, which intersected a circle of a 25m radius around the sample plot center.

– *Type of boundary* *(Chapter 7.2)* *NFI2*

– *Forest edge* *(Chapter 7.3)* *NFI1≠NFI2*

The attribute stated whether or not a forest edge was present. This statement was the same in the first, as well as in the second, NFI. However, the definition of the forest edge, that is the stocking boundary, was changed:

– NFI1 forest edge line: Connecting line of all forest edges forming stocking elements with a height of more than 3m.
– NFI2 stocking boundary: Outside tangent (in breast height) on the stems of trees and shrubs with a DBH of 12 cm or more which form the outermost forest edge.

This change was necessary that not two different boundary lines had to be measured: One for the reduction of the sample plot area at the forest edge, and a second one for the forest edge description. If no trees or shrubs with a DBH < 12 cm and over 3m in height were in front of the stocking boundary, the boundary line – according to the NFI1 definition – was the same as in the NFI2 definition. In all the other cases, this resulted in a different boundary line and a different reduction of the sample plot area as in the first NFI. It is advisable for further subsequent inventories to preset the boundary line as the default.

– *Forest edge description* *(Chapter 7.4)* *NFI2*

If the conditions were met, the forest edge description took place along the so-called assessment line. The assessment line is a line of 25m to both sides of the inflexion point (see also “boundary line”) along the forest edge. The forest edge was described along this 50m long line with a total of 11 attributes (Figure 8).

– *Boundary line* *(Chapter 7.5)* *NFI1≠NFI2*

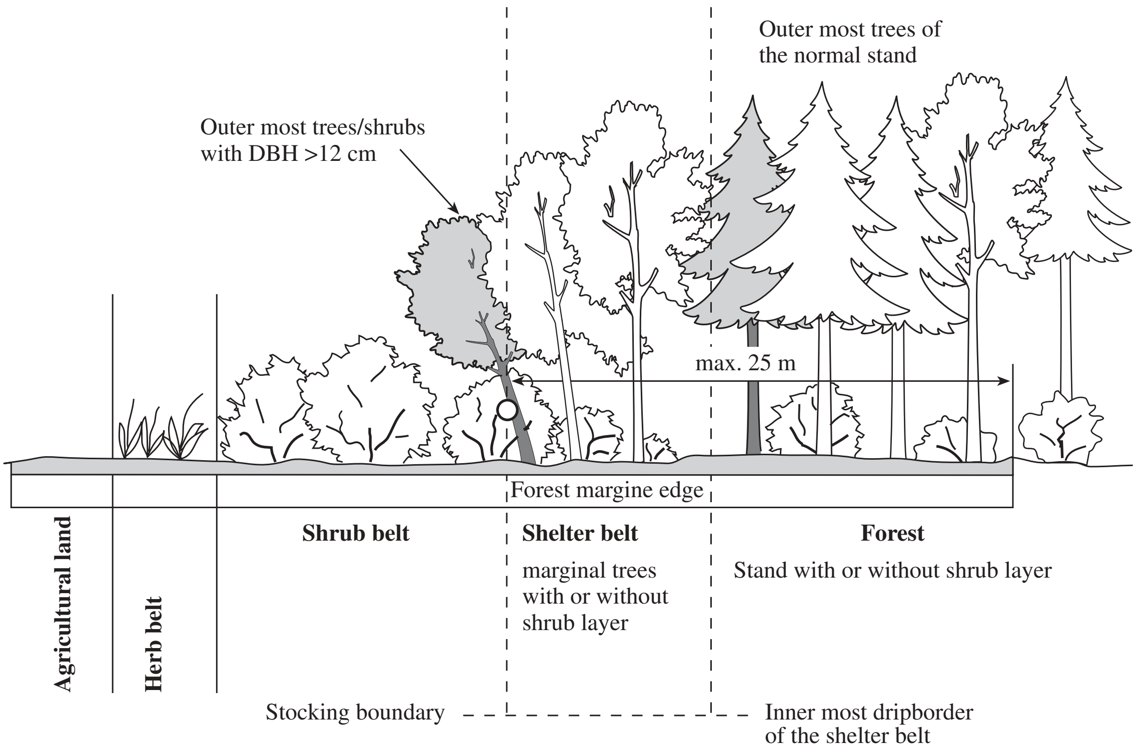


Figure 8. Forest edge in a sectional view.

The boundary line (NFI1: forest edge line; NFI2: stocking boundary) is defined by: 1) an inflection point, which is chosen on the boundary line; 2) by the distance and azimuth from this inflection point to the sample plot center; 3) by both azimuths along the boundary line. The way the boundary line was measured in the second NFI was the same as it was in the first NFI, yet the boundary line is defined differently (see above “forest edge”).

– *Location of the sample plot center* *(Chapter 7.6)* *NFI2*
– *Forest edge aspect* *(Chapter 7.7)* *NFI2*
– *Type of forest edge (vertical)* *(Chapter 7.8)* *NFI2*

- *Width of forest edge* *(Chapter 7.9)* *NFI2*
- *Width of shrub belt* *(Chapter 7.10)* *NFI2*
- *Width of herb belt* *(Chapter 7.11)* *NFI2*
- *Type of forest edge (horizontal)* *(Chapter 7.12)* *NFI2*
- *Forest edge density* *(Chapter 7.13)* *NFI2*
- *Forest edge condition* *(Chapter 7.14)* *NFI2*
- *Border at forest edge* *(Chapter 7.15)* *NFI2*
- *Forest edge surroundings* *(Chapter 7.16)* *NFI2*
- *Species at forest edge* *(Chapter 7.17)* *NFI2*

The survey of trees, shrubs, berry shrubs, and climbing plants helped to determine the botanical diversity and to record important habitats for birds and insects. This could also be used as a basis for the aesthetic evaluation. The survey of the species at the forest edge was conducted from outside of the forest. The area proportion for each of the small wood species was estimated from the forest edge profile (vertical projection).

2.3.3.6 Survey of Individual Trees (Chapter 8)

- *Tree species* *(Chapter 8.5)* *NFI1≠NFI2*

For the comprehensive forest edge survey, it was necessary to extend the list of shrubs which had to be measured. This included berry shrubs, herbaceous plants, and climbing plants. In contrast, willows were no longer differentiated.

- *Distance of tree from plot center* *(Chapter 8.6)* *NFI1=NFI2*
- *Azimuth of tree* *(Chapter 8.7)* *NFI1=NFI2*

Azimuth and distance were used to identify the sample trees of the first NFI. In virtually all of the cases, the sample trees could be identified without any problems. However some difficulties arose, especially for forked stemmed trees. (Should they be considered one tree or two trees?) The decrease in the magnetic declination was another difficulty in identifying the sample trees. Numbering the sample trees with an electronic measurable tree number, for example, should be studied for future inventories.

- *Tree status* *(Chapter 8.8)* *NFI2*
- *Reason for trees present in 1st assessment not found in 2nd assessment* *(Chapter 8.9)* *NFI2*
- *Number of year rings* *(Chapter 8.10)* *NFI2*
- *Remarks on special features of sample tree* *(Chapter 8.11)* *LFI1=LFI2*

The attribute “remarks...” was primarily an auxiliary variable for selecting tariff trees and indicated particular properties of the sample trees (e.g., forked stem, standing dead tree, reserved tree). The comments had to be adjusted to the new survey in the second NFI.

- *Reactions to marking of bark in 1st assessment* *(Chapter 8.12)* *NFI2*

In the first NFI the position at which the DBH was measured was marked with a blazer. The mark was important for subsequent measurements, so that the DBH would be measured at the same stem height. The frequency and the degree of wound reaction to this marking were measured. Table 3 shows that beech is the most sensitive tree species, followed by maple and the other broadleaf trees. In general, it can be concluded that marking the position of the measurement with a blazer does not cause any significant problems (Table 3).

- *Diameter at breast height* *(Chapter 8.13)* *NFI1=NFI2*
- *Circumference* *(Chapter 8.14)* *NFI2*

As a basis for estimating the precise increment, the stem circumference was measured to the nearest centimeter, in addition to measuring the diameter at breast height with a caliper. It is possible that in subsequent inventories, the DBH will not have to be measured any longer using a caliper.

Table 3. Reaction to marking with a blazer on the sample trees of the first NFI.

Main tree species	No reaction		Slight reaction		Considerable reaction		Total	
	Number	%			Number	%	Number	%
Spruce	20,009	94.2	1,094	5.2	133	0.6	21,236	100
Fir	5,623	95.7	233	4.0	16	0.3	5,872	100
Pine	2,081	96.8	66	3.1	2	0.1	2,149	100
Larch	2,356	98.9	27	1.1	0	–	2,383	100
Cembran pine	432	94.1	22	4.8	5	1.1	459	100
Other conifers	158	98.8	2	1.2	0	–	160	100
Total conifers	30,659	95.0	1,444	4.5	156	0.5	32,259	100
Beech	7,654	80.7	1,483	15.7	344	3.6	9,481	100
Maple	1,335	87.7	151	9.9	36	2.4	1,522	100
Ash	1,483	95.7	62	4.0	5	0.3	1,550	100
Oak	1,050	98.2	15	1.4	4	0.4	1,069	100
Chestnut	867	96.6	28	3.1	3	0.3	898	100
Other broadleaf trees	2,535	92.6	174	6.3	30	1.1	2,739	100
Total broadleaf trees	14,924	86.5	1,913	11.1	422	2.4	17,259	100
All tree species	45,583	92.0	3,357	6.8	578	1.2	49,518	100

Key:

Key:	No reaction:	No reaction to the NFI1 blazer mark visible
	Slight reaction:	Small overgrowth or short (up to 20 cm long) Stem parallel cracks in the bark No dead parts of the bark Resin flow
	Considerable reaction:	Large overgrowth (more than 1 cm) Long stem parallel cracks Parts of the bark are dead

– *Crown class* *NFI1*

"Crown class" was an attribute used in the first NFI, which was composed of the crown form, crown length and amount of foliage. In the second NFI the "crown length" and "crown form" attributes were measured separately.

– *Crown length* *(Chapter 8.15)* *NFI2*

– *Shape of tree crown* *(Chapter 8.16)* *NFI2*

Crown form describes the form and the volume of the crown. For this attribute the survey teams were instructed during training sessions, so that only the really outstanding crowns were classified as a class 1 "round," and the crowns that were clearly below average were classified as a class 3 "strongly one-sided." In the second NFI the crowns were assessed with approximately 9% being "round," 75% as "slightly one-sided," and 16% as "strongly one-sided."

– *Layer to which sample tree belongs* *(Chapter 8.17)* *NFI1≠NFI2*

For solitary and reserved trees, an additional code known as "no layer membership" was introduced.

– *Social position* *(Chapter 8.18)* *NFI2*

We quantified the status of a tree within the stand structure in order to describe the sample tree more precisely. The social status is a useful attribute in closed forests. The social status within selection type forests (plenter forests), mountain forests, or in open forest stands could not be assessed; in these cases the attribute did not have any meaning.

– *Tree damages* *(Chapter 8.19)* *NFI1≠NFI2*

For the damage assessment of the individual tree, the attributes "pattern of damage" and "extent of damage" from the first NFI were combined and assessed as one attribute. The "cause of damage" was extended from nine different causes in the first NFI to fifteen different causes in the second NFI. Damages during timber harvest were separated into cutting and skidding damage, as well as other human influences. Crown defoliation of less than 50% was no longer recorded in the second NFI. The timber quality attributes "spiral grain growth" and "deformation" were not considered as damages. The pattern of damage –"bumped tree"– in the first NFI was no longer recorded as damaged, but was recorded as a remark "tilted tree." In the first NFI up to three lines of text could be used for other non-coded damages. The most important damages, such as "dried top" or "missing main branch", were included in the code list of the second NFI. The additional damage description was dropped. These improvements were important to the survey and also had consequences to the damage analysis and the comparability between both inventories.

– *Data status* *(Chapter 8.20)* *NFI2*
– *Tariff sample tree selection* *(Chapter 8.21)* *NFI1≠NFI2*

In the first NFI about 30% of the sample trees, all with an azimuth of less than 150 gon and a DBH of more than 60 cm, were selected as tariff sample trees. During the survey of the second NFI, a random number generator in the handheld computer selected the trees at which the D7 (diameter in 7m height) and the height had to be measured (for approximately 12% of all recorded trees). The selection probability was proportional to the DBH of the sample trees. That is to say, thick trees were selected with a higher probability than small ones (see Chapter 3.2.4).

– *Upper stem diameter in 7m height* *(Chapter 8.22)* *NFI1=NFI2*
  (Figure 9)
– *Tree height* *(Chapter 8.23)* *NFI1=NFI2*
– *Timber quality of the standing tree* *NFI1*

The attribute "timber quality of the standing tree", which was measured in the first NFI, was not measured in the second NFI. Changes were not expected, and a second survey of the quality that had the same evaluation criteria might have shown only changes that did not really exist.

Figure 9. Measuring the diameter in 7 meter height with an upper stem calliper (Finnenkluppe).

2.3.3.7 Young Growth Survey (Chapter 9)

The survey methods for the young growth were fundamentally changed. In the first NFI the young growth data were measured in the center of the sample plot in a circle with a 3m radius (=28 m^2 area). The center of the young growth sample plot was the same as the one for the NFI sample plot. Starting north (0^g) and going clockwise, there were up to 30 young growth plants between 30 and 130 cm in height and between 0 to 4 cm DBH counted and described. For the projection, the azimuth to the last plant was determined next. The trees with a DBH between 4 and 12 cm were measured in the entire young growth circle (ZINGG and BACHOFEN 1988). A second survey in the center of the sample plots would have led to incorrect results, since parts of the sample plot were considerably disturbed during the yearly forest damage inventory and the cantonal inventories.
The young growth was measured in the second NFI on two circular young growth plots ("satellites"), which had an area of 14 m^2 each. One of the circles was moved 10m east, while the other was moved 10 m west from the sample plot center (Figure 10). All young growth plants between 10 and 39 cm in height within the young growth satellites on a circle with a 1m radius were measured as class 1. On the entire area of the concentric circles with a radius 2.12m, all plants higher than 40 cm and up to the tally-threshold of 12 cm DBH (Figure 11) were measured.

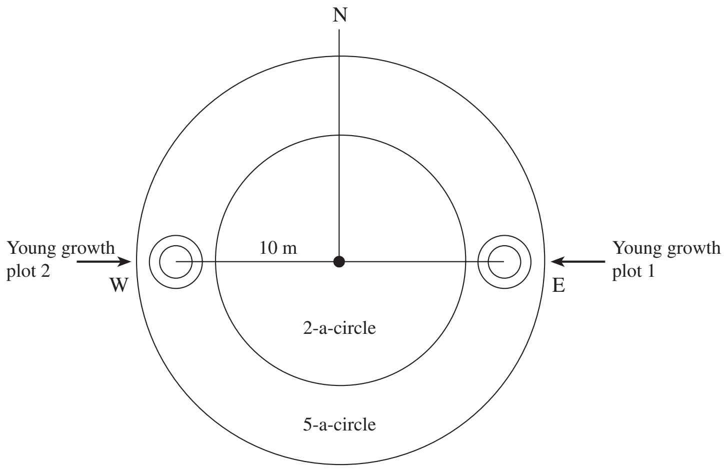


Figure 10. Position of the young growth plots.

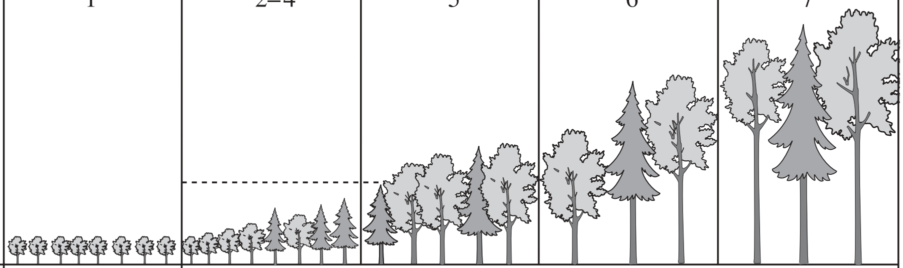
In order to quantify the permissible browsing intensity (EIBERLE 1985) (EIBERLE and NIGG 1983), it was essential to know the yearly browsing caused by hoofed game. Browsing intensity refers to the proportion of terminal shoots browsed per year in percentage to the total number of plants (EIBERLE 1980). In the second NFI young growth plants were registered starting at a height of 10 cm and divided into seven young growth classes. Since the current terminal shoot browsing depended very much on seasonal changes, the browsing event was backdated to the previous year. This was different from the first NFI, which had used current terminal shoots.

- *Radii of young growth satellites* *(Chapter 9.3)* *NFI2*
- *Satellite position* *(Chapter 9.4)* *NFI2*
- *Stage of forest development* *(Chapter 9.5)* *NFI2*
- *Crown closure of regeneration* *(Chapter 9.6)* *NFI2*
- *Type of regeneration* *(Chapter 9.7)* *NFI2*
- *Protective measure* *(Chapter 9.8)* *NFI2*
- *Plant counting* *(Chapter 9.9)* *NFI2*
- *Species* *(Chapter 9.10)* *NFI1≠NFI2*

For the survey of the young growth data shrubs were also newly measured.

- *Young growth size class* *(Chapter 9.11)* *NFI1≠NFI2*

In the second NFI plants with a height of more than 10 cm were recorded, while the first NFI started at a height of 30 cm. Plants up to 130 cm in height were newly divided into four classes (in the first NFI 1 class).



Class	1	2–4	5	6	7
Radius	r small	r large			
Copice shoots	Highest shoot				
Relevant Measure: Height of the terminal bud above the stembase	0,1–0,39 m	> 0,1–1,3 m	>1,3 m	–	–
Relevant Measure: Diameter at the DBH measuring position (DBH)	–	–	below 3,9 cm	4–7,9 cm	8–11,9 cm
Measurement instrument	Young Growth-ranging pole		Young Growth-step caliper		

Stock has to be within the circle (classes 1 and 2–4)

Class 1: 10 cm–39 cm height
Class 2: 40 cm–69 cm height
Class 3: 70 cm–99 cm height
Class 4: 100 cm–129 cm height
Class 5: >130 cm height up to 3.9 cm DBH
Class 6: 4 cm DBH up to 7.9 cm DBH
Class 7: 8 cm DBH up to 11.9 cm DBH

Figure 11. Young Growth Classes.

– *Condition of regeneration* *(Chapter 9.12)* *NFI1≠NFI2*

The condition assessment of the young growth plants in the second NFI were extended by the codes “dry top,” “disease,” “timber harvest,” “damaged,” “lateral shoot browsing,” and “healthy.”

– *Number of plants in class* *(Chapter 9.13)* *NFI1≠NFI2*
– *Closure of regeneration* *(Chapter 9.14)* *NFI2*
– *Closure of regeneration by main species* *(Chapter 9.15)* *NFI2*

2.3.3.8 Area Assessment (Chapter 10)

The area assessment refers to an interpretation area of 50 x 50m. Site factors, traces of landslips, rockfall, fire, grazing, and ecological characteristics were assessed.

– *Status aspect and relief* *(Chapter 10.2)* *NFI2*

For sample plots already existing, the values for aspect and relief were given as default. For new sample plots, both attributes had to be determined.

– *Aspect* *(Chapter 10.3)* *NFI1=NFI2*
– *Relief* *(Chapter 10.4)* *NFI1=NFI2*
– *Traces of landslip* *(Chapter 10.5)* *NFI1≠NFI2*

A distinction was made between landslips due to channel erosion and landslips due to other causes. To be considered as landslip, the extent of its traces had to exceed a minimum threshold.

– *Traces of water erosion* *(Chapter 10.6)* *NFI1≠NFI2*

The assessment of “water erosion” distinguishes between channel erosion, surface erosion, and erosions on slopes. The sum of all partially eroded areas had to be at least 100 m^2 so that the attribute could be recorded at all.

– *Traces of rockfall* *(Chapter 10.7)* *NFI1=NFI2*
– *Traces of snow movement* *(Chapter 10.8)* *NFI1=NFI2*
– *Traces of forest fire* *(Chapter 10.9)* *NFI1=NFI2*
– *Traces of grazing* *(Chapter 10.10)* *NFI1≠NFI2*

The attribute grazing was separately recorded by types of grazing (cows, horses, sheep, etc.) and by intensity (current/not current and intensive/extensive).

– *Obstacles* *(Chapter 10.11)* *NFI1≠NFI2*

The first NFI attribute “limitations for logging” was a combination of obstacles (stumps, stones, etc.) and ground cover. The ground cover was recorded in the second NFI with two attributes: The shrub layer coverage and the berry bush coverage. The obstacles were recorded as a separate attribute. Only obstacles on the interpretation area, which have an influence on the logging, were to be recorded.

– *Limitations for logging* *(Chapter 10.12)* *NFI1=NFI2*

The second National Forest Inventory also recorded additional indicators to evaluate the forest as a biotop and habitat:

– *Special sites and water bodies* *(Chapter 10.13)* *NFI2*
– *Heaps of branches* *(Chapter 10.14)* *NFI2*
– *Stumps* *(Chapter 10.15)* *NFI2*
– *Standing dead tree* *(Chapter 10.16)* *NFI2*
– *Patches without vegetation* *(Chapter 10.17)* *NFI2*
– *Dry stone wall* *(Chapter 10.18)* *NFI2*
– *Geomorphological objects (small relief)* *(Chapter 10.19)* *NFI2*
– *Over-utilization and disturbance* *(Chapter 10.20)* *NFI1≠NFI2*

Within the attribute “over-utilization and disturbance,” seven forms of attributes were distinguished. In the first NFI over-utilization was assessed generally with “existing/not existing”.

– *Recreational facilities* *(Chapter 10.21)* *NFI2*
– *Type of gap* *(Chapter 10.22)* *NFI2*

The attributes “removal” and “utilization,” which were itemized under “area based data”, were recorded in the second NFI during the inquiry at the local forest service (see Chapter 2.3.3.11 “Inquiry at the Local Forest Service”).

2.3.3.9 Stand Evaluation

Only the “relevant stand” is evaluated. This means the stand in which the sample plot center is located.

– *Utilization class* *(Chapter 11.2)* *NFI1≠NFI2*

The segregation of the utilization class was the same as the one for the first NFI, but in the second NFI, for the utilization class A “permanently unstocked forest area,” a stand description for the bordering stand was conducted.

– *Type of forest* *(Chapter 11.3)* *NFI1≠NFI2*

The types of forest distinguished in the first NFI, like brushwood forest, wooded formation, open forest, and normal forest were reduced to “normal forest” and “open forest”. The brushwood forest was integrated into the forest/non-forest decision, and the forest type wooded formation was completely eliminated, since no statements were possible for this attribute.

– *Stand boundary* *(Chapter 11.4)* *NFI1=NFI2*

The stand boundary was measured in the first NFI, and the boundary line was surveyed. In the second NFI the survey of the boundary line was dropped, because this type of information had not been used. It was only assessed with regard to whether a stand boundary intersected with the circular sample plot or not.

– *Origin and management type of forest* *(Chapter 11.5)* *NFI1=NFI2*
– *Stage of forest development* *(Chapter 11.6)* *NFI1=NFI2*
– *Stand age* *(Chapter 11.7)* *NFI1≠NFI2*

The determination of the stand age was conducted as in the first NFI by either counting the annual tree rings on freshly cut stumps, counting branch whorls in young stands, or by estimating the age. In the first NFI the diameter of the counted stumps and the diameter of the heartwood, if present, were recorded. These measurements were dropped in the second NFI.

– *Mixture proportion* *(Chapter 11.8)* *NFI1=NFI2*
– *Closure* *(Chapter 11.9)* *NFI1≠NFI2*

The attributes "normal/loosened," "sparse/open," and "crowded/normal in groups" had been combined in the first NFI. In the second NFI they were reported separately. Instead of five classes, the attribute was divided into eight classes in the second NFI. The consequence of this change was that the canopy cover density from the first NFI could not be compared with the data of the second NFI.

– *Stand structure (vertical layers)* *(Chapter 11.10)* *NFI1=NFI2*
– *Type of next silvicultural operation* *(Chapter 11.11)* *NFI1≠NFI2*

The type of the next silvicultural operation was extended to using the code "mountain forest thinning" and "no silvicultural operation." The code "sanitation felling" was not recorded any further in the second NFI.

– *Urgency of next silvicultural operation* *(Chapter 11.12)* *NFI1≠NFI2*

The urgency of the next silvicultural operation referred to the period in which the next type of silvicultural operation, which was reported under the "next silvicultural operation," had to be completed. The attribute "logging potential" from the first NFI corresponded to the urgency of the next silvicultural operation; whereas, the first NFI only distinguished between "short term" and "long term."

– *Closure of regeneration* *(Chapter 11.13)* *NFI2*

This attribute addressed whether the relevant stand had any regeneration growth and what percentage of the area was covered by the regeneration.

– *Type of regeneration* *(Chapter 11.14)* *NFI1=NFI2*
– *Regeneration protection* *(Chapter 11.15)* *NFI1≠NFI2*
– *Regeneration* *NFI1*

Three attributes were recorded in the first NFI as "regeneration": 1) the type of regeneration; 2) the distribution of the regeneration on the interpretation area; 3) the regeneration protection. The type of regeneration and the regeneration protection were adopted as independent attributes without any changes in the second NFI. The regeneration distribution was substituted by the new attribute degree of regeneration coverage.

– *Reserving of standards and advance planting* *NFI1*

This attribute was assessed in the first NFI as an area attribute, which was dropped in the second NFI. However, the comment "reserved tree" was added for the individual tree survey.

– *Closure of shrub layer* *(Chapter 11.16)* *NFI2*
– *Closure of ground vegetation* *(Chapter 11.17)* *NFI2*
– *Closure of berry bushes* *(Chapter 11.18)* *NFI2*
– *Dominant berry bush species* *(Chapter 11.19)* *NFI2*

2.3.3.10 Stand Stability (Chapter 12)

The stand stability was recorded in the second NFI using the same principles as in the first NFI. On the one hand, all effecting influences at a site (NFI1 = external influences) were evaluated, and from this the "stress profile" was derived. On the other hand, the resistance of the stand (NFI1 = stand) was evaluated at the respective site and recorded in a "resistance profile of the stand." These two profiles gave an overview that was used as the basis for the expert assessment of the overall stand stability. In contrast to the first NFI, the stability definition in the second NFI was explicitly limited to the mechanical stability of the stand against disturbing effects. The questions of ecological stability, as well as long-term stability, were not considered in the second NFI.

– *Stress profile* *(Chapter 12.2)* *NFI1≠NFI2*

The NFI1 offered the opportunity to describe openly two other “external influences.” The most frequently mentioned influences, “game” and “human disturbances,” were included in the stress profile of the NFI2.

– *Resistance profile of the stand* *(Chapter 12.3)* *NFI1≠NFI2*

The assessment criteria “crown length,” “tilted tree,” and “anchorage” were newly included in the resistance profile. The first NFI criteria “suitability for site” and “mixture proportion” was summarized in “tree species.” The attribute “tending status”, assessed in the first NFI, was omitted. The possibility of openly describing the stand characteristics was omitted in the second NFI.

– *Overall assessment of stability* *(Chapter 12.4)* *NFI1≠NFI2*

Stand stability was more precisely defined in the second NFI as “the probability that large damages or a breakdown will occur during the assessment period of an assessed stand.” The values of the assessment scale from 1 to 10 refer to the probability of the occurrence of large damages: codes 1 and 10 correspond to a 90% and 0% probability, respectively.

2.3.3.11 Inquiry at the Local Forest Service (Chapter 13)

The inquiry at the local forest service was revised. Several new attributes were additionally collected. Since 1985, strong technological developments occurred in timber harvesting. Originally developed in Scandinavia, the forwarder and feller-processor have been increasingly used in Switzerland. In steep terrain the mobile cableway has been more frequently employed and in mountainous regions, which are difficult to access, the helicopter has become an important removal tool. These conditions had to be considered for the implementation of the inquiry. Dividing the timber transport into different removal phases (skidding to the next road and transport to the logging depot) made it possible to calculate the logging expenses more precisely.

– *Utilization* *NFI1*

If any stumps were present on the interpretation area they had to be reported. The local forester was questioned about how many years had passed since a prescribed cut, an improvement cut, or an unregulated felling.

– *Type of last utilization* *(Chapter 13.3)* *NFI2*

The local forest service was questioned about the type of silvicultural operation since the last NFI.

– *Number of years since last cut* *(Chapter 13.4)* *NFI1≠NFI2*

If an operation had been performed since the last NFI, the number of years since this operation was asked. If no silvicultural operation had taken place, the NFI data were extrapolated.

For new sample plots, the number of years since the last harvest should have been recorded independently of whether this was done before or after the first NFI. With this information the record would have been complete.

– *Unregulated felling* *(Chapter 13.5)* *NFI2*
– *Person in charge of last harvest* *(Chapter 13.6)* *NFI2*
– *Method of harvest* *(Chapter 13.7)* *NFI2*
– *Pole wood or long wood* *(Chapter 13.8)* *NFI2*

The manner in which the timber was transported from the sample plot center to the sales location was described, so that for each transport tool used, the destination, distance, and the direction of the transport was recorded. A distinction was made between **removing** the timber from within the stand to a truck-accessible forest road and **transporting** the timber on the forest road.

– *Place to which timber is skidded after cut* *(Chapter 13.9)* *NFI2*
– *Logging distance* *(Chapter 13.10)* *NFI2*
– *Timber extraction method* *(Chapter 13.11)* *NFI2*
– *Direction of timber transport* *(Chapter 13.12)* *NFI2*
– *Limitations to extraction method* *(Chapter 13.13)* *NFI1≠NFI2*

The option to record additional limitations in an open text was omitted in the second NFI.

– *Ownership* *(Chapter 13.14)* *NFI1≠NFI2*

For all sample plots recorded in the first NFI, the ownership category was kept the same. For new sample plots the ownership category was assessed during the inquiry, but not for brushwood forest or for inaccessible sample plots. The status of the data was, therefore, not homogeneous.

– *Management plan* *(Chapter 13.15)* *NFI2*

2.3.4 Data Collection

The data for the field survey of the second NFI were directly recorded with a mobile field computer. The American handheld computer PARAVANT (Figure 12), and the tally software that accompanied it, were used (RÖSLER 1994). Recording the data directly affected, fundamentally, the quality improvement of the data gathered in the forest with respects to completeness and plausibility (see also Chapter 2.8). A special plausibility program checked the measurements and the interpretation codes as to whether they were within the permissible range of values, whether certain attribute combinations were permissible and plausible, and whether the data were completely entered. Furthermore, the device was waterproof and shockproof, so that the survey was more independent from bad weather than with the paper forms, which were used in the first NFI. However, the expenditure was very high for programming, preparation of the preset data and copying them onto ramcards, for the data transfer to the survey teams, and for the return of the recorded data. The direct data collection also limited the flexibility of the field survey, since the preloaded default data could not be transferred without difficulties into another machine. The data collection with mobile field computers was surely advantageous to the second inventory, where data from the first inventory were displayed. For a first survey, the advantages and disadvantages of employing a field computer have to be considered carefully. The data flow tested in the pilot inventory ran smoothly during the three years of field surveys (Figure 13). The ramcards that were used for the data transfer proved a success.

Figure 12. Handheld computer PARAVANT RHC 44.

Forest/non-forest decision from the aerial photography interpretation.

Compile list of forest sample plots (including sample plots that have to be verified in the field).

Transfer sample plot default values from the database to the PC.

Copying default values on default-ramcards – including the list with sample plots and reference points.

Sending the default-ramcards to the survey teams.

Transferring the default data to the PARAVANT.

Gathering the data at the sample plots / enquiry at the forest service.

Transferring the complete data set from the PARAVANT to the filing-ramcards.

Sending the filing-ramcards to the WSL.

Copying the data to the PC.

Data transfer from the PC to a temporary database.

Checking the completeness, testing the plausibility of the data, and possibly correcting them.

Copying the final data to the NFI2 database.

Figure 13. Flow of data for the field survey in the second NFI.

2.3.5 Discussion and Conclusions

2.3.5.1 Future Significance of the Field Survey

Field surveys will play a central role in future inventories. They not only provide reliable data about timber production and the production function of the forest, but also for all other forest functions and, especially, for biodiversity. Many attributes in the forest are measurable and can be evaluated. It is essential that it is made clear before the survey; what the recorded attributes are being used for and what kind of results are possible. Field surveys usually need a lot of qualified personnel and thus, accordingly, a large budget. However, if the costs for measuring a single attribute on a terrestrial sample plot are compared with measuring a single attribute using remote sensing methods, the costs are of the same magnitude.

To find permanently marked sample plots in the forest was, in general, not a difficult task. The methods chosen for marking the sample plots on the ground proved a success and simplified the localization of sample plots tremendously. Whether the blue colored marks on trees and stones influenced the forest manager in his silvicultural decisions could not be proven (see Chapter 2.11). For the survey team, the permanently marked points were very important. They shortened the time for finding the sample plot center significantly. In difficult, undeveloped terrain a simple satellite navigation system (GPS) might be an important tool in the future.

2.3.5.2 Pilot Inventory

It is absolutely essential that a pilot inventory also be analyzed! The pilot inventory for the second NFI established important directions for the survey methodology (Chapter 2.8.2.1), but, unfortunately, it was not possible to analyze it any further. Through this kind of analysis, several mistakes with respects to usability and interpretability could have been discovered and avoided in the second NFI. For example:

– Default data for sample trees: Instead of the data for the first NFI, data from the last (SANA-SILVA) survey were given. As a consequence, the reason for missing trees (harvest or natural death) could not be assessed for approximately 1/3 of all trees which did not exist anymore.
– Dead trees: For the first NFI the condition for recording the dead trees was that the timber could still be merchantable. In the second NFI this condition was dropped. The second NFI had more deadwood than the first NFI. An unknown percentage of this increase was due to the change in the attribute definition. The surveys could have been compared if the dead trees had an additional attribute "timber still merchantable: yes/no."
– Stocking boundary: see 2.3.3.5.
– Damage type: see 2.3.3.6.
– Canopy cover: see 2.3.3.9.
– Number of years since last silvicultural operation: see 2.3.3.11.

The changes in the way that attributes were recorded caused many problems to the change analysis. Attribute definitions and assessment instructions should, therefore, be changed carefully, and only if absolutely necessary. For most of the cases it is better to record two attributes: one according to the old definition and another according to the new definition; for example, a forest edge line according to the NFI1 definition, and a stocking boundary for the forest edge description in the NFI2.

In the future, a pilot inventory should be completely tested starting with remote sensing through the analysis. The following must be checked in a main test: different survey methods, the usefulness of attributes, the attribute definitions, work flow, materials, machines and equipment, the data gathering and the data transfer, the plausibility of the data, and of course, the analysis concept and the analysis software.

The following should be included in a publication explaining the project: the methods employed, the sampling concept, the experiences from the pilot inventory with respect to remote sensing, the terrestrial survey, the inquiries, the planning, and date of a future inventory and the results of the entire pilot inventory.

2.3.6 Literature

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2.4 Expenditure of the Terrestrial Inventory

Jürg Zinggeler

The time and financial expenditures of the field work for large-scale inventories are usually not known, or only inadequately known. For the planning and the execution of inventories, the knowledge about the required time for important working stages is indispensable. If these basics are not available, it is difficult to employ personnel and material in a cost efficient way. In the following, the actual expenditures for the terrestrial survey and inquiries are presented in person-hours. The database was based on regular reports (working reports) by the survey team; salary and expense statements; as well as the time that it took to perform the most important working tasks at the sample plots. The time was recorded using a handheld computer. A detailed account of the time and financial expenditures in the second NFI can be found in ZINGGELER and HEROLD (1997).

2.4.1 Time Expenditure

2.4.1.1 Expenditures According to Stages of Work

The stages of work distinguished in the second NFI are presented and described in Table 1. The average time for recording one sample plot for the entire country was 9.0 person-hours (Table 2).

In the Jura and Plateau regions, the time for recording one sample plot was slightly more than 7 person-hours. In the Pre-Alps and Alps, the time increased to little less than nine and ten hours, respectively. With 11.7 person-hours used per sample plot, the Southern Alps had the highest time expenditure.

The time expenditure for the recording of one sample plot in the Southern Alps was about 4.5 hours, or close to 40% higher as compared with the Jura. The walking rates in the Southern Alps were two to three times as long as in other regions because of the poorer forest transportation system, as well as the more difficult topographic conditions. Consequently, the total expenditure increased drastically (Fig. 1).

2.4.1.2 Productive Working Time

The proportion of the productive working time, which equaled the expenditure for the actual data gathered at the sample plot, amounted to a total of 35% of the entire working time (without the time for training and control).

With the help of additional time studies at 62 sample plots, it was possible to break down the productive working time even further (Table 3).

The most time expensive tasks were the measurements and observations of an individual tree, with an average of one person-hour used. For measurements at a tariff sample tree (sample tree for which the tree height and stem diameter at a height of 7 meters were measured), an average of 15 minutes was used. The survey of the young growth took about half a person-hour.

The ground and stand assessment together needed approximately the same working time as the survey of the young growth; whereas, describing the stand stability alone took 12 minutes.

The structure of the attribute group "basic decisions and forest edge" was very heterogeneous and included the forest/non-forest decision; the measurements of the sample plot slope; the survey of the accessibility and stocking boundary; and the forest edge boundary.

Permanently marking the sample plot center took little less than half a person-hour, but was not considered productive working time.

Table 1. Subdivision and definitions of the work phases

Phases of the work	Activity	Remarks
Official Trip	Drive from the place of residency, the WSL, the army car depot, the train station, etc. to the survey area and back.	
Drive and preparation	Changing daily accommodations in the survey area as well as driving from one sample plot to another. Expenditure for the daily work plan (sequence of the sample plots visited, best way to the sample plots), final drawing of the sample plot layout sketches and other final work.	
Walk	All of the times needed to walk from the vehicle to the sample plot and return. The rare case of walking directly from one sample plot the next. In the case of measuring the sample plot, the walk to the reference point.	If no measurements were carried out, this phase also includes the work to permanently mark the sample plot center.
Measuring	Measuring the sample plot center, starting from a reference point, whose coordinates were determined in the aerial photograph.	Starts with reaching or finding the reference point and ends with permanently marking the sample plot. Necessary for the first survey. For subsequent inventories, it is necessary only in certain exceptions.
Inventory	Data gathering on the sample plot.	Starts at the end of permanently marking the sample plot center and ends after the attributes have been all assessed.
Enquiry	Data gathering at the local forest service.	Including making appointments with the forester, driving to and from the forester.
Other work time and inactive time	Preparation to survey the sample plot (week plan and month plan), data transfer, keeping up the material, visiting the district forester, public relations.	"Inactive times" are those times, in which, due to bad weather or technical problems, no sample plots were measured.

Table 2. Time expenditure (without expenditure for the headquarters, without control and training) in person hours per sample plot, divided by work phase and region.

Region	Enquiry	Inventory	Measurement	Walk	Drive and preparation	Official trip	Other and inactive time	Total/ sample plot
Jura	0.5	2.5	0.2	1.1	1.5	0.9	0.5	7.2
Plateau	0.7	2.6	0.3	1.1	1.5	0.7	0.5	7.3
Pre-Alps	0.5	2.7	0.3	1.7	2.1	1.0	0.5	8.9
Alps	0.4	2.7	0.4	2.1	2.1	1.5	0.6	10.0
Southern Alps	0.3	2.4	0.5	3.5	2.3	2.0	0.8	11.7
Switzerland	0.5	2.6	0.4	1.8	1.9	1.2	0.6	9.0

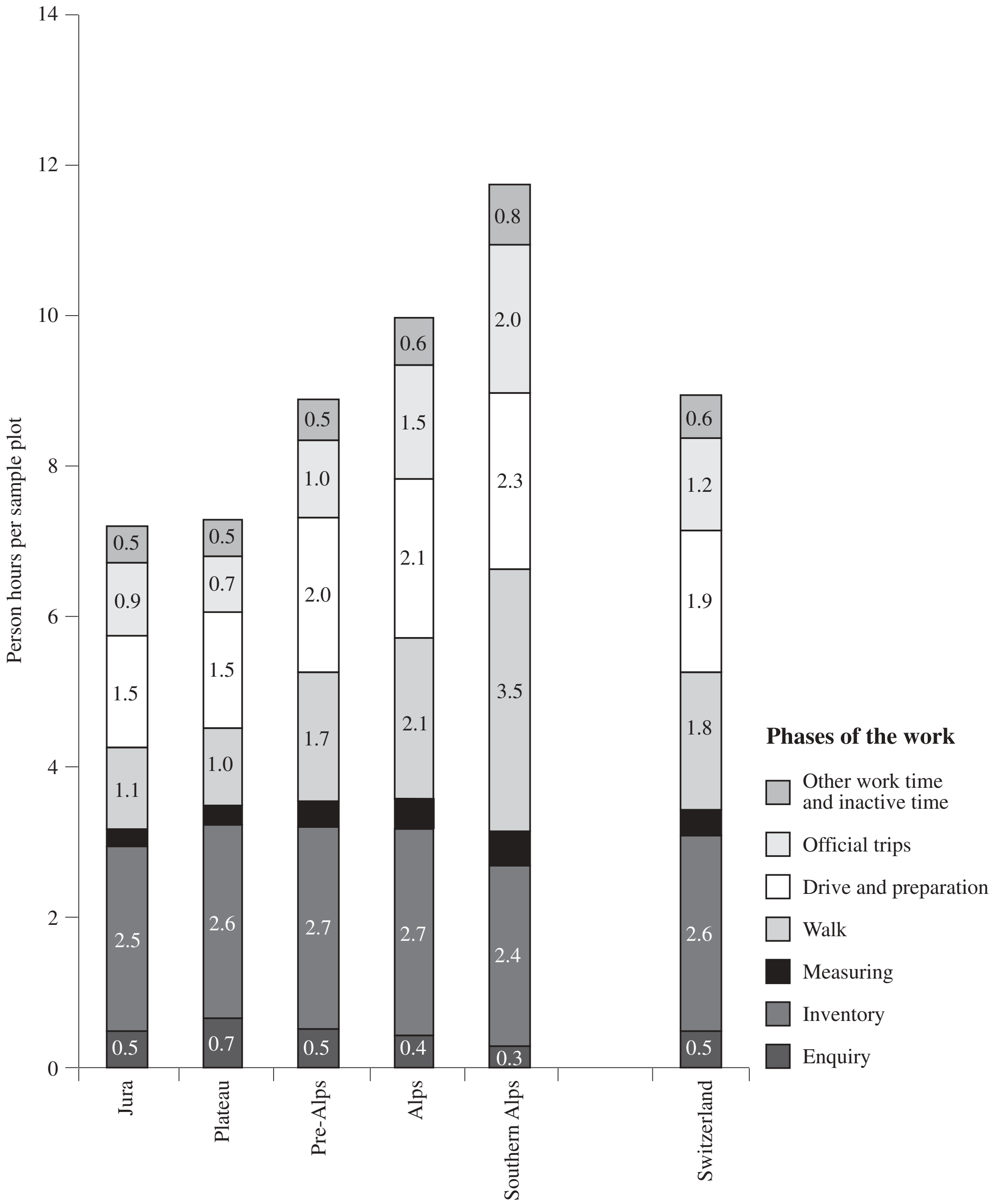

Figure 1. Time expenditure by stages of work in person hours, per sample plot and region (without expenditure for the personal at the headquarters).

Table 3. Time study in respects to the expenditure by attribute group in person work minutes per terrestrial assessed sample plot.

Attribute groups	Person work minutes
Permanent marking of the sample plot	26
Basic decisions and forest edge	14
Individual tree measurements	60
Tariff sample trees	15
Young growth survey	33
Area assessment	10
Stand assessment	9
Stand stability	12

2.4.1.3 Training Expenditure

Training the survey team well forms an important basis for the quality of data for the inventory. At the beginning of the field operation, the staff was intensively trained in a course which lasted several days. These instruction courses were supplemented with four to five training courses per year. During the second NFI approximately 6,780 person-hours, or 9.3% of the entire working time, was spent on this type of training.

2.4.1.4 Control Survey

The control survey was an independent second survey of the sample plot, which was already measured by the regular survey team. With the help of the control survey (Chapter 2.8, 2.9), it was possible to uncover random and systematic differences between the measurements and the descriptions of individual attributes that were taken between the control team and the survey team.

A total of 6,702 person-hours (=9.2% of the entire working time) were required in order to assess the 752 controlled sample plots, which equalled an average of 9.0 hours per sample plot. The expenditures for the control were, therefore, comparable to those of the regular survey.

2.4.2 Ground Survey Expenditures

The expenditures were composed of personnel expenditures (salary and expense reimbursement) of the field staff, their official travels, and the purchase cost of the ground survey equipment that was required.

2.4.2.1 Personnel Expenditures

The terrestrial survey of the 6,615 regular sample plots, as well as the additional 752 control sample plots, cost a total of 3.54 million Swiss Francs in the second NFI (only the expenditure for the survey teams, without the board, and including training). The terrestrial survey of one sample plot, therefore, cost 480 Swiss Francs.

The proportion of the labor costs amounted to 83% of the personnel expenditure, and the expense reimbursements amounted to about 17%. Table 4 shows the details of the terrestrial survey expenditures for one sample plot within each of the different survey regions. The average hourly base cost of 47.75 Swiss Francs corresponded to the average of all hourly wages and expense reimbursements of the field staff between the years 1993 and 1995. The fixed expense reimbursements amounted to approximately 10 Swiss Francs per person-hour.

In all of Switzerland the average sample plot expense (without training) consequently added up to 427 Swiss Francs. Compared to the cost presented above of 480 Swiss Francs per sample plot, the difference amounted to 53 Swiss Francs, which corresponded to the training expenditure of the second NFI.

Table 4. Costs of the terrestrial survey for one sample plot without instruction course, training days, and check assessment by regions. Average hourly wage: sFr. 47.75

	Jura	Plateau	Pre-Alps	Alps	Southern Alps	Switzerland
People hour/sample plot	7.2	7.3	8.9	10.0	11.7	9.0
Cost/sample plot (sFr)	Fr 343	Fr 348	Fr 424	Fr 475	Fr 560	Fr 427

2.4.2.2 Equipment of the Teams and Vehicles

For the survey of the sample plots, extensive survey equipment (STIERLIN et al. 1994) was needed. The field survey team was provided equipment with a total value of 20,000 Swiss Francs per team. For the survey of the 7,367 sample plots (including the control sample plots), a total of 280,000 kilometers were driven. Adding all reported partial expenditures (salaries, expense reimbursement, education, training, equipment, and vehicles), the expense of the survey for one NFI sample plot came to 550 Swiss Francs.

2.4.3 Conclusions

The proportion of the productive working time came to only 35% of the overall total working time in the second NFI. This means that about two thirds of the working time was spent on official travel, walking to and from the sample plot, permanently marking new sample plots, as well as the inquiries. From this it is very clear that giving up measuring particular attributes on the sample plot will reduce the time needed only slightly.

Reduction in the time expenditure can be achieved, especially regarding organizational aspects, by reducing the proportion of official travel through employing local field staff. Furthermore, reducing the extensive training can save a substantial amount of time and expense. However, this would mean a decrease in data quality. Whether or not this is acceptable depends on the goals of the inventory, the desired precision, the total budget, as well as other factors.

2.4.4 Literature

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2.5 Game Browsing Damage Survey

Jürg Zinggeler, Andreas Schwyzer

2.5.1 Introduction

The recording, assessment, and evaluation of young growth that is browsed by ungulates are difficult; nevertheless, it ranks high in today's applied silviculture. The severe strain that is placed onto the forests, as well as onto the cultural landscape through recreational activities, results more and more in driving the deer (*Capreolus capreolus* and *Cervus elaphus*) and chamois (goat antelope native to the mountains of Europe and Asia) out of their traditional habitat. This leads to serious browsing intensities locally, so that natural forest regeneration, to some extent, is only possible under aggravated conditions.

In the first NFI the current browsing of the terminal shoot by ungulates was reported, which means that it was recorded whether the terminal shoot was browsed or not. As the analysis from the first result publication demonstrated, the browsing percentage (e.g., the proportion of browsed plants as compared to the total number of plants) was subject to strong seasonal fluctuations (EAFV 1988). Depending on the time of recording, these fluctuations led to varying results. The results, furthermore, deviated from the annual browsing according to EIBERLE (1980; 1985), which estimated how endangered the regeneration was.

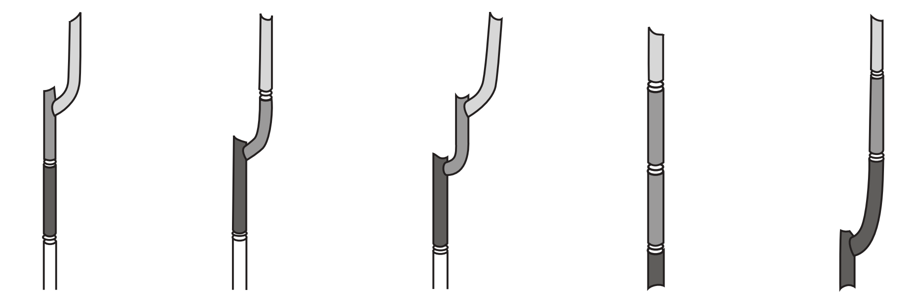
Due to this fact, the methods for evaluating the browsing damage were fundamentally revised (STIERLIN *et al.* 1994). Because of the modified browsing evaluation, the seasonal effects were compensated. However, the data of both inventories were no longer directly comparable.

Based on case studies, both methods of evaluating the browsing damage were compared with each other.

2.5.2 Browsing Evaluation in the NFI1

In the first NFI all tree and shrub species with a height of 30 cm or more were counted as young growth. For the browsing evaluation, a plant was labeled as browsed when the terminal bud of the main shoot was browsed at the time of the recording (ZINGG and BACHOFEN 1988).

The following five browsing patterns (Figure 1) represent the plants, which were assessed as browsed in the first NFI, even though the patterns differ considerably.



Picture 2 Picture 4 Picture 5 Picture 7 Picture 9

Figure 1. Browsed plants according to the NFI1 definition.

In case the terminal shoot was still intact, the first NFI method labeled the plant as not browsed (Figure 2), even if browsing damages that occurred earlier were clearly visible.

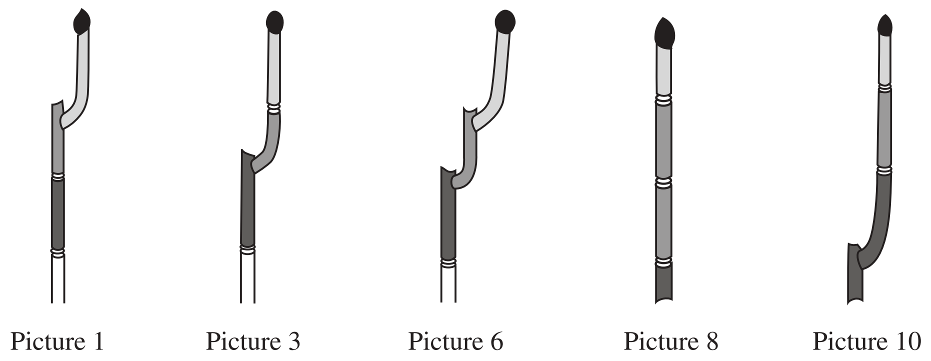


Figure 2. Plants not browsed according to the NFI1 definition.

2.5.3 Browsing Evaluation in the NFI2

In accordance with the study conducted by EIBERLE (1980; 1985), the survey method for assessing the forest regeneration and the browsing rate was adjusted, so that the young growth plants taller than 10 cm were assessed. The plants were divided into four young growth size classes (10–39 cm, 40–69 cm, 70–99 cm, 100–129 cm) and three diameter classes (0–3.9 cm DBH, 4–7.9 cm DBH, 8–11.9 cm DBH) (STIERLIN *et al.* 1994).

The survey method developed for the second NFI attempted to minimize seasonal fluctuations. This was successfully accomplished by backdating the browsing incident, which means that their assessment was conducted over a longer period of time. If below the terminal bud (independent of their conditions) two visible traces of scales were found without any signs of browsing inbetween (where at least the two latest—former terminal buds were not browsed), the plant was considered as not browsed. In all other cases the plant was considered as browsed.

The following browsing patterns (Figure 3) show plants which were considered browsed according to the second NFI method.

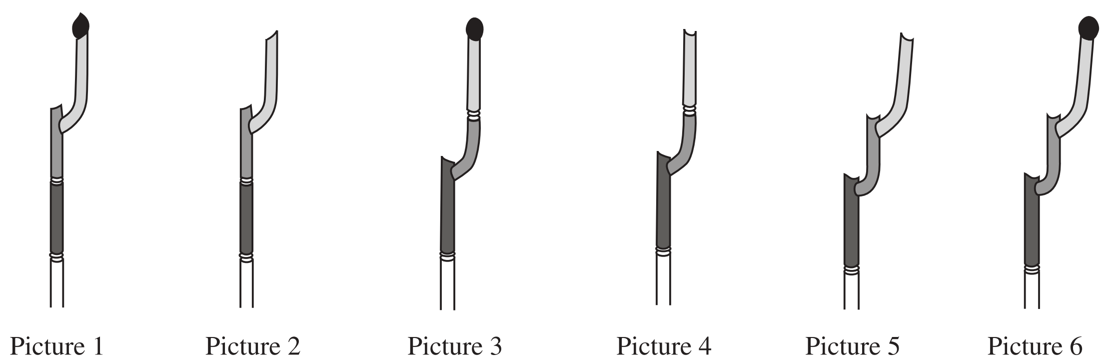
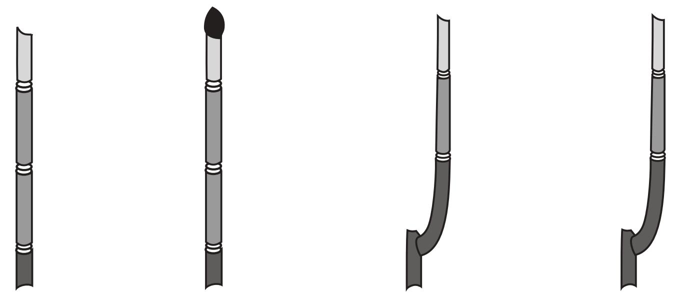


Figure 3. Browsed plants according to the NFI2 definition.

In contrast to the above, the following plants (Figure 4) were not considered browsed, even though they also displayed some signs of browsing.



Picture 7 Picture 8 Picture 9 Picture 10

Figure 4. Plants not browsed according to the NFI2 definition.

2.5.4 Additional Study for "Game Browsing and Plant Reaction"

In order to be able to compare the data of the browsing rate presented in the second NFI with the acceptable browsing rate of individual tree species published in EIBERLE (1985), EIBERLE and ZEHNDER (1985) and EIBERLE and NIGG (1983; 1987), it was imperative to know what the annually-occurring browsing rate of the terminal shoot was from individual plants. For this, the browsing percentage depended on the reaction of the individual plants (St. John's shoots, substitute shoots), as well as on the browsing rate of the ungulates during the course of the year.

The annual browsing damage could not be directly interpreted in a large-scale inventory, because the survey lasted from the spring until late fall. Due to the plants' reaction, it was not possible to clearly allocate the browsing event to a certain year. Additional surveys in the forest, and shoot cutting experiments in the nursery, provided the necessary information to interpret the NFI browsing data.

Experimental Design and Method

Field Trial

The additional surveys in the forest were case studies and were not representative of the entire country of Switzerland. The experimental plots were selected based on preceding data analysis of the first NFI. For this trial, all altitudinal vegetation zones (see Chapter 3.1), as well as the five main tree species: spruce, fir, European beech, ash, and maple were present when possible. In addition to this, a high proportion of plants browsed by deer (*Capreolus capreolus* or *Cervus elaphus*) had to occur on these plots. In each experimental plot, 50 plants were selected and permanently marked.

Between 1996 and 1997, all plots were visited three times a year (before the beginning of the growing season, during the growing season, and after the end of the growing season). The young forest growth was examined with respects to browsing events and growth reaction. In addition, the course of growth of selected plants was documented with sketches. With this information it was possible to report about the periodicity of the browsing rate in the summer and the winter months.

The following variables were measured at the field plot:

- The seasonal trend of the browsing situation
- The proportion of browsing damage patterns according to the NFI2 inventory manual (STIERLIN *et al.* 1994)

– The browsing rate
– The plant reaction typical for the tree species after occurrence of a browsing incident

Nursery Experiment
In contrast to the open field trial, the conditions in the nursery experiment, which was started in the spring of 1996, were relatively homogeneous. All plants were planted in identical substrate and were kept under the same climatic conditions. For this experiment 125 plants for each of the 5 main tree species (spruce, fir, European beech, ash, maple) were used from lowland provenience (Table 1).

As a result of the constant monitoring and care, the plants were not exposed to any excessive stress situations (dryness, too intense solar radiation, etc.). The plants were subjected to one or more winter and summer browsing damages, which were simulated by pruning the shoot. Pruning took place during the end of March/beginning of April and the end of July/beginning of August. The treatment was limited to pruning of the terminal shoot. The side shoots were not pruned.

Table 1. Type of plants in the nursery experiments.

Type		Provenience		Age	Transplanted
	Location	Elevation (meters above sea level)	Exposition	(year)	Yes/No
Spruce	Tägerwilen	520	North	2	No
Fir	Beinwil/Horben	820	North-east	3	Once
Ash	Besenbüren	470	North	1	No
Beech	Hirschthal	600	South-west	1	No
Sycamore maple	Muri/Maiholz	450	East	1	No

The plants were subjected to the following treatment:
1. No treatment
2. One time pruning of the shoot in the spring of 1996
3. One time pruning of the shoot in the summer of 1996
4. Pruning in the spring of 1996 and in the spring of 1997
5. Pruning in the summer of 1996 and in the summer of 1997

The goal of the pruning experiment, in addition to the field experiment, consisted of obtaining a foundation for the interpretation of the browsing evaluation results for the NFI.

The following quantities were observed:
– The time and frequency of substitute shoots after pruning a shoot
– The dependency between plant growth and the treatment
– The frequency of growing St. John's shoots from intact terminal buds

The statistical design of this experiment (SACHS 1992) was a randomized complete block design (RCBD) with five replications.

The measurements in the nursery started before the beginning of the leafing and were usually repeated every three weeks. This ensured that the annual development of the plant growth and the plant reaction after the shoots were pruned could be completely described.

2.5.5 Results

2.5.5.1 The NFI1 Method

Because of its simplicity and low expenditure, the NFI1 method was attractive and should have been preferred; however, it had a significant shortcoming. Using spruce as an example in the pruning experiments (Figure 5) showed that under optimal conditions at the nursery, many of the young trees outgrew the browsing damage very quickly during the growing season. This led to external damage being no longer noticeable (shifting from browsing patterns 2, 4, 7, and 9 to browsing pattern 8). After a browsing event, substitute shoots grew even more quickly from the plants (changing from browsing patterns 2, 4, 7, and 9 to browsing patterns 1, 3, 6, and 10, which were not counted as browsed according to the first NFI method).

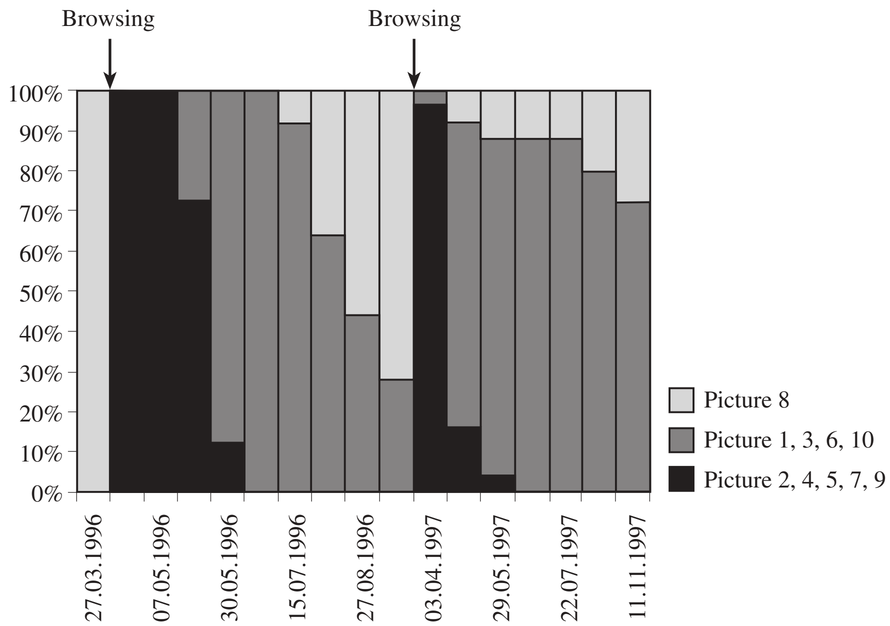


Figure 5. Regeneration of spruce in the nursery after treatment 4 (browsed according to the NFI1: browsing pattern 2, 4, 5, 7, 9).

The change of the browsing pattern, which represented browsed plants according to the first NFI (browsing pattern 2, 4, 5, 7, 9), to ones that did not count as browsed (browsing pattern 1, 3, 6, 8, 10) only happened during the growing season. The survey method in the first NFI found a large number of browsed plants in the spring and a small number in the fall. The results of the browsing survey according to the first NFI methods were, to a large extent, dependent upon the date the survey was taken and was, therefore, applicable for large-scale inventories in a limited capacity.

The same situation was found for the plants that were studied three times a year within the scope of the field experiment (Figure 6). The first NFI method discovered a high proportion of browsed plants in the spring, and only a small portion in the fall. For assessments before the beginning of the growing season, the results of the first NFI method approached the ones of the annual browsing (browsing rate). Nevertheless, the results of the first NFI methods were a bit smaller, since the summer browsing was not considered.

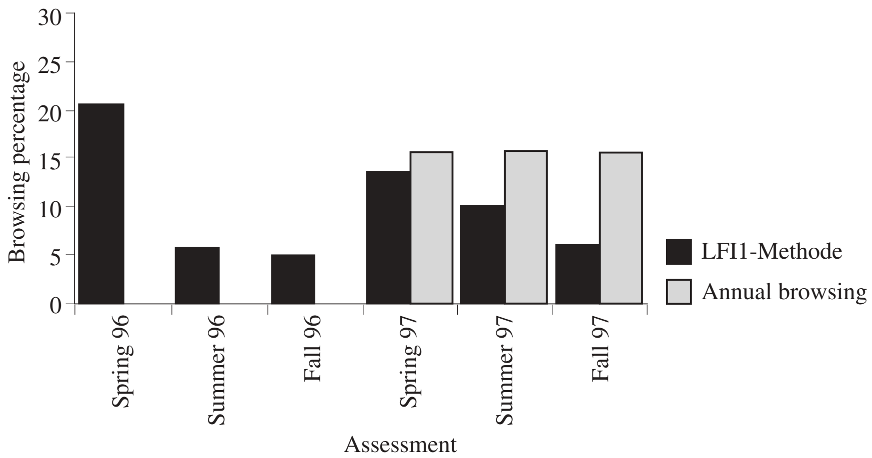


Figure 6. Annual dependency of the browsing percentage assessed with the NFI1 method. Example: Spruce in the field experiment.

2.5.5.2 The NFI2 Method

With the browsing evaluation in the second NFI, it was possible to dampen the effects of the annual browsing percentage fluctuations considerably. The result of a browsing survey with the second NFI method was, therefore, less dependent on the date of the survey than in the first NFI (Figure 7).

The NFI2 method did not allow for more precise information regarding the degree of the annual browsing, since backdating did not refer to a constant number of years. The browsing determined with the second NFI method amounted to approximately twice the annual browsing over all tree species. However, depending on the tree species and site, the results differed from this considerably, as was observed with the example of the spruce.

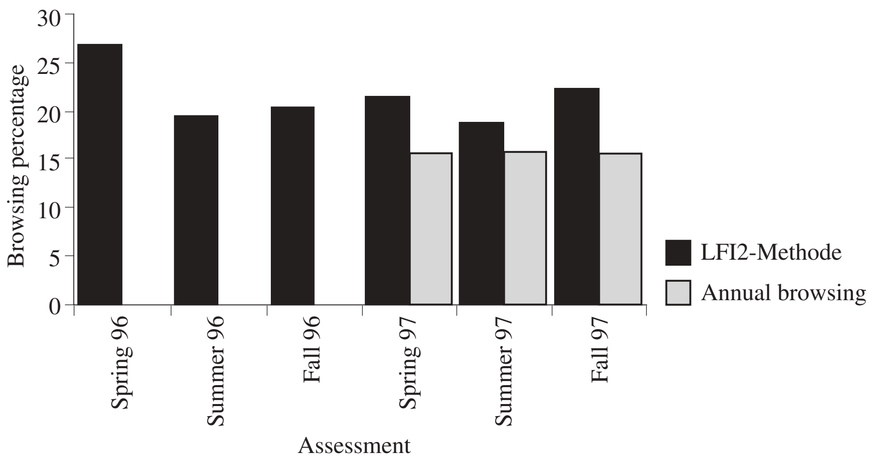


Figure 7. Comparison of the browsing percentages assessed with the NFI2 method with the annual browsing.
Example: Spruce in the field experiment

2.5.6 Conclusions

– The additional analysis confirmed that the methods of evaluating the browsing in the second NFI depended far less on the date of the survey (season). A modification to the second NFI method will be able to not only eliminate the seasonal fluctuations, but to approximate the annual browsing as well.

- Due to its robustness, the method of the browsing evaluation in the second NFI is suited for large-scale monitoring of changes in the browsing rate.
- The browsing that was reported in the second NFI was consistently higher than the annual browsing. For an exact determination of the browsing rate more measurements per year would certainly be needed.
- For the evaluation of the browsing situation, it was not only important to know the browsing incident, but also the reaction potential of the plants. The growth and reaction potential of a plant depended substantially on the plant species as well as the site (climate, altitudinal vegetation zones).

2.5.7 Literature

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2.6 Forest Transportation System Survey

Ingrid Paschedag, Jürg Zinggeler

2.6.1 Introduction

The basic development of a forest with truck accessible roads is an important prerequisite for forest tending and cropping. With knowledge about the course and density of the forest roads, the expenditure for forest tending and cropping can be estimated. Precise knowledge regarding the state of, as well as changes in, the forest road construction is an important planning tool at both the national and regional levels.

2.6.2 Goal

The goal of the survey was to determine the state of the forest roads and changes within the forest roads of Switzerland. The survey was intended to give information about the length, density and distribution of the roads.

2.6.3 Background Information

In the first NFI the forest road survey was similar to the sample survey and the forester inquiry component of the fieldwork (ZINGG and BACHOFEN 1988). Together with the local forest service, the WSL recorded the most important roads for forest accessibility, classified them and drew them onto the national map with a scale of 1:25,000. At that time, these were the most up-to-date maps. The lines of the newly constructed roads and paths, which had not yet been updated, were drawn onto the map by hand using line of sight. This survey took place between the years 1983 to 1985. The length of the network of roads was determined in the first NFI, with the help of the point intersection method (STIERLIN 1979). For this, the number of intersections between the Swiss coordinate grid system and the roads were determined. The length of the roads was estimated based on the number of intersection points. This method was very time consuming and was also prone to errors.

In order to keep the updating expenditures for the second NFI as small as possible, the old maps of the first NFI were updated for the survey. These maps had been in use for the last 15 to 20 years. For a third NFI serious registration and updating problems would arise with these map sheets. These problems will be due to general changes of the road network in the course of three decades; thus a method had to be found to allow updating for future surveys (HÄGELI and ZINGGELER 1996). The decision to digitally record the forest road network was obvious. With the digitization, updating was made more simple and it was possible to analyze the data directly. By recording the road data in vector format it was possible to carry out the analysis, which had not been possible in the first NFI (e.g., the calculation of the oblique distance). Another advantage to the computer assisted analysis of the data was the massive reduction of the analysis time.

2.6.4 Data Collection

Data

The roads were measured on the maps of the first NFI. With this it was also possible to record the state of the roads at the time of the first NFI. Since the roads were also digitized with the same criteria and classification principles as in the first NFI, it was possible to assess the changes.

Only roads that were accessible by truck and located completely or partially in the forest were recorded. Freeways and highways were not included, and class one roads were recorded only if, according to the forest service, they served to access the forest. Since roads that were accessible by tractor and four-wheel drive were only of minor importance for the entire country of Switzerland, they were not updated. As an additional attribute the surface type of the road was recorded. An important difference between the first and second inventory was that, even if truck accessible forest roads were interrupted by bottlenecks that were too narrow to be accessible by truck (e.g., a bridge that will not support heavy vehicles), they were still classified as such. This modification was brought about because the sections of the road behind the bottleneck were truck accessible and, therefore, needed to be classified as access roads. However, as a consequence of this modification, the change to the access roads was slightly overestimated.

The attribute catalog of the road survey in the second NFI encompasses eight categories for the road type and the construction date (NFI1 or NFI2); four categories relating to the position of the roads in respect to the forest; the road class according to the national map; as well as the presence of tunnels (see Table 1 and ZINGGELER 1993).

Table 1. Attribute catalog for the forest road survey.

Attribute	Observation
Road type	Existing road network NFI1 with water bound surface. Existing road network NFI1 with bitumen bound surface. Existing road network NFI1 with hydraulic bound surface. Abandoned/renaturalized roads. Misclassification NFI1. Newly built roads or road improvements with water bound surface. Newly built roads or road improvements bitumen bound surface. Newly built roads or road improvements with hydraulic bound surface.
Location of the road to the forest	In the forest. At the forest edge. In open stands. In the non-forest area.
Road class	Similar to the road classification of the Swiss Federal Office of Topography (BUNDESAMT FÜR LANDESTOPOGRAPHIE 1989).
Tunnel	Tunnel present. Tunnel not present.

Survey Methods

According to a study conducted by HÄGELI and ZINGGELER (1996), the roads should not be directly digitized from the national maps. They concluded that the maps had been affected by map sheet distortion due to their age or wear and tear and, therefore, were no longer sufficiently correctable. The local forest service drew the road data by hand onto the old maps, so that very often the roads did not follow the exact course of the roads on the current maps.

In order to avoid any impact on the analysis as a result of the distortion of the old maps and other inaccuracies, a digitizing table was not used.

The data was entered with the help of a GIS (Arc/Info) system. The digital pixel maps that were without contour lines (see Chapter 2.7 External Data Source) from the Federal Office of Topography were employed and served as the information base for recording the geometric data. They were displayed as background information on the computer screen. The most up-to-date pixel maps were used in each case. An additional information base represented the NFI road maps on which the forest road network was supplemented by the forest service (ZINGGELER 1993). During the time the data was digitized, both sources of information had to be considered. The digital maps delivered the information about the precise position of the individual roads (road positions in the field and road positions with respect to the forest) and their classification. The NFI road maps showed which roads were important for forest access and what type of surface they had. The roads were registered as a continuous line within one attribute combination and between intersections. The attribute data was assigned to the individual roads or line section (e.g., the surface type) after cleaning the polygons, as well as examining the intersection between map sheets

Currently, the Federal Office of Topography is digitizing all maps at a scale of 1:25,000 in vector format. A small portion of their maps were used so that those maps did not have to be digitized (BUNDESAMT FÜR LANDESTOPOGRAPHIE 1996).

2.6.5 Derived Attributes

Since the forest road survey was, in essence a census, a way had to be found that assigned a certain road length to each sample plot without losing the advantages of a census.

In order to accomplish this a grid was placed over the entire data set. The cell size of the grid was a maximum of 25 hectares, which meant that each cell had a side length of 500 m. Cells which were cut off by the national border represented a smaller area. The midpoints of the individual cells corresponded to the respective sample plot center of the NFI grid. By overlaying this grid with the data from the road survey, it was possible to assign to each cell a certain road length (Figure 1).

Total Road Length

The total road length matched the sum of the length of all recorded road segments. Determination of the road length was conducted directly through the GIS. For calculating the total road length, the lengths of all roads running through the forest were added up. These included class 0 (labels which represented new road segments that were not yet recorded by the Federal Office of Topography), as well as classes 3, 4, 5, and 6 (Bundesamt für Landestopographie 1989).

Horizontal Distance Sample Plots – Access Roads

The horizontal distance is the shortest connection between a sample plot point and the closest forest road accessible by truck. Therefore, the distance was calculated without considering the topography.

In the first NFI, the distance from the sample plot to the closest accessible forest road for trucks was measured with a ruler placed directly on the national map. To reconstruct this distance, and in order to determine changes during the last ten years, this distance was also calculated in the second NFI. The determination of the distance was largely simplified due to the employment of GIS.

These calculations were determined with the GIS Arc/Info by ESRI (ESRI 1992). The software had the algorithm ‘near’ implemented, which calculated for each sample plot point the perpendicular line to the access roads. The shortest perpendicular line corresponded to the desired distance. In order to reduce the computing time, the search of the shortest distance was restricted to a radius of 15 km around the sample plot center (Figure 2).

For these calculations a point data file was created, which included the sample plot points of the NFI 500 m grid. A second file contained all digitized roads. The calculated distances were subsequently stored in a database. The calculations were performed twice; once for roads, which already existed in the first NFI (code of the road type: existing roads plus abandoned/ renaturalized roads, Table 1), and a second time for the second NFI (code of the road type: existing road plus newly build roads). For both of these calculations, the misclassifications in the first NFI were ignored. Because of the double calculation, it was possible to determine the change during the last ten years.

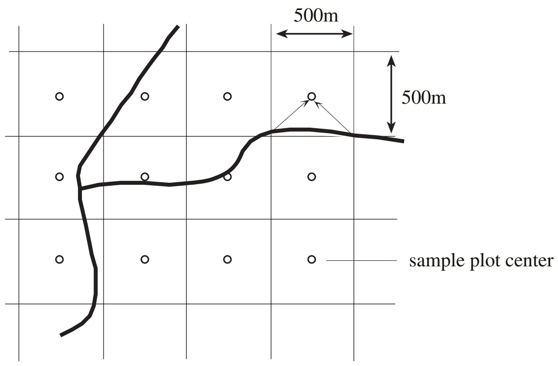

Figure 1. Assigning road sections to the sample plots.

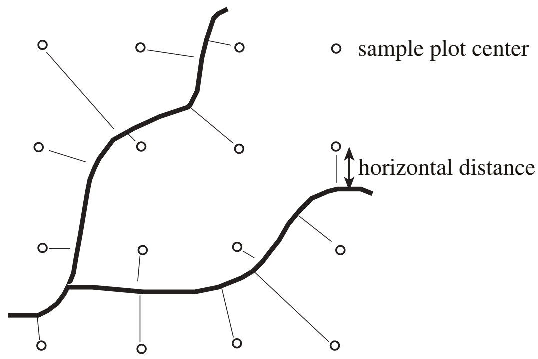

Figure 2. Calculating the horizontal distance from the sample plot center to the next forest road.

Oblique Distance Sample Plots – Access Roads

Horizontal distances provided only insufficient information about how accessible roads really were; however, using oblique distances appeared to approach the true circumstances.

Starting with the horizontal distance (Chapter 2.6.5.2), the oblique distance was calculated by using a digital terrain model (see Chapter 2.7, External Data Source). For this, the coordinates of the point, where the perpendicular line intersected with the access road (see Chapter 2.6.5.2), were overlaid with the digital terrain model to determine the elevation above sea level. Since the elevation of the sample plot center was also known, the oblique distances were calculated very easily with the help of the Pythagorean theorem. Similar to the work of HEINIMANN (1997; HEINIMANN 1986), the oblique distances were divided into the following classes:

- From the road directly within reach of the cable traction (100 m)
- From the road directly within reach of the mobile cable-crane (500 m)
- From the road directly within reach of the conventional cable-crane (1000 m)

Road Density

The road density was characterized by the forest road length in meters per forest hectare.

This attribute was not calculated by using GIS, but with the Statistical Analysis System (SAS). The necessary data for this were calculated in the GIS and inserted into the database. The calculated data were road lengths per grid cell (see Chapter 2.6.5.1), and the forest area was determined using the same method. The forest area had to be taken from the national map, since the NFI could not provide complete coverage. For calculating the forest area per grid cell, the continuous green area which represented the closed forest area, was taken from the pixel map (see Chapter 2.7 External Data Source) and intersected with the grid. A forest area of up to 25 hectares was therefore assigned to one grid cell. The results of both calculations were inserted into the database. In addition, each road length was weighted according to its position in the forest. (That is to say those roads which were on the forest edge were multiplied by a factor of 0.5, while roads in the forest and in open forest stands were fully counted.) Using this formula, it was possible to calculate the forest road length in meters per forest hectare.

2.6.6 Time Expenditure

Depending on the map sheet or the road density, the time expenditure for digitizing varied between 2 hours in the mountain regions and 25 hours in the densely developed Plateau. After the digitization, the attributes were assigned. The entire recording (digitization and attribute assignment) took on average approximately 15 hours per map sheet. Two hundred and forty-nine map sheets cover the entire country. The total expenditure of about 3,735 hours corresponded to 440 working days. In addition, approximately 3 hours per map sheet were spent in order to control the data. Detailed description, with respect to the time expenditure, can be found in HÄGELI and ZINGGELER (1996). In comparison, the expenditure of working time for calculating the derived attributes was relatively small and consisted mainly in writing programs to calculate these attributes.

2.6.7 Outlook

The area of data gathering will be greatly simplified and shortened in future surveys. Only changes will have to be recorded in the survey. Updating the road network on hand is going to be largely simplified and expedited by using the vector data from Federal Office of Topography, since time intensive digitization can be omitted. The classification of roads in the future can be performed directly by the field team who are on the spot with the help from a portable computer which has a GIS installed. With this, the step of drawing the roads on the map can be dropped. This is certainly a factor that can greatly reduce the costs for subsequent surveys.

Another possible use of the data set is the development of a timber transport system. The employed GIS (Arc/Info) offers this option. For this system all road sections will be connected to one network. With this information, it will be possible to calculate the actual distance that has to be covered in order to drive from one point to another. By determining the shortest transportation road it will be feasible, for example, to minimize the transportation time and thus reduce the cost of the transport. By adding other attributes (e.g., how steep the terrain is; and the cost of the timber harvest), the timber harvest planning can be optimized. This system could also be used for planning the employment of the transportation vehicles.

2.6.8 Literature

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2.7 External Data Sources

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2.7.1 Introduction

Starting with the preparation, and leading up to the analysis of the second NFI, several different spatially related pieces of information were used. A large part of the data was already recorded by other institutions, so that they were directly taken over by the NFI. By utilizing these "external" data, a great deal of time and costs were saved in the NFI.

2.7.2 Analog Data

Aerial Photographs

Aerial photographs belong to the most important external data source of the NFI. They were analyzed with analog remote sensing methods. The aerial photographs were produced by the Federal Office of Topography to periodically update the Swiss national maps, and were made available free of charge to the NFI.

The film material used was a panchromatic black-and-white slide film (Agfa Aviphot-Pan and Kodak Panatomic). The aerial photographs from the years 1987 until 1991 were taken with an aerial mapping camera (type Wild RC-10) at a scale of approximately 1:25,000. In 1992 and 1993, the Federal Office of Topography used a high-performance aircraft, which was equipped with an aerial mapping camera (type Leica RC-20). The aerial photographs taken at that time had a scale of approximately 1:30,000 to 1:33,000. All aerial photographs were taken with an endlap of 60% to 70%, so that many interpretation areas were analyzed in several different stereo models (see Chapter 2.2).

The attributes measured in the aerial photographs are described in detail in Chapter 2.2.

National Maps

As in the first NFI, the second NFI was based on the kilometer grid of the Swiss national map (Federal Office of Topography).

For the assignment planning of the field survey teams, the national map with a scale of 1:100,000, as well as the national map with a scale of 1:25,000, were used (Bundesamt für Landestopographie 1987–1992).

The maps with a scale of 1:25,000 additionally served in determining ground control points (see Chapter 2.2) for the orientation of the aerial photographs. They were also used for the inquiries, which the field survey team conducted with the individual district forester. At that time the access roads were delineated on the map by the district forester (Chapter 2.6).

2.7.3 Digital Data Files

Digital Map (Pixel Map)

The Swiss Federal Office of Topography offers digital maps as well as the printed maps (Bundesamt für Landestopographie 1986–1991).

Pixel maps are simple copies of a print in a digital format without establishing any direct reference to the individual map elements. The map information is separated into different color levels and not into thematic groups[1].

The access roads were directly recorded on the computer screen, while the pixel map was displayed in the background (Chapter 2.6).

[1] Source of the statement: *http://www.swisstopo.ch/de/digital/pixel.htm* as of 1997

Since the road survey was a census, all necessary auxiliary data that were used to calculate the derived attributes had to be on hand for the entire area. In order to calculate the road density (Chapter 2.6), the forest area was determined from the continuous green tone of the pixel map that represented the closed forest.

Digital Map (Vector 25)

This data set (Vector 25) is a digital national map with a scale of 1:25,000 (Bundesamt für Landestopographie 1996). In contrast to the pixel maps, digital maps are not separated by different levels of color, but according to thematic groups. The basic element is the individual object (e.g., individual roads), which is stored in vector format. Until the end of 1996, the Federal Office of Topography was able to finish 43 of the 249 map sheets. From these, 18 were used for the survey of the roads. Thanks to these 18 map sheets, the roads in these regions did not have to be digitized, which meant that a considerable amount of time was saved (Chapter 2.6).

Digital Elevation Model

A Digital Elevation Model (DEM) makes it possible to obtain the elevation above sea level for any arbitrary point in Switzerland. The WSL has four different DEM's at its disposal.

Table 1. Digital elevation models available at the WSL.

Name	Grid width	Reference
RIMINI	250 m	(Bundesamt für Landestopographie)
Arealstatistik	100 m	(Bundesamt für Statistik)
Tydac	50 m	Tydac AG
DHM25	25 m	(Bundesamt für Landestopographie)

Bundesamt für Statistik (BFS), 1992: Arealstatistik der Schweiz 1979/85; GEOSTAT, Bern.
Bundesamt für Landestopographie (L+T), 1994: Geländedaten DHM25, Bern.
Bundesamt für Landestopographie (L+T), 1965: Höhenmodell RIMINI, Bern .

The elevation model RIMINI was used in order to find and display the default ground elevation values of the interpretation plot center for the aerial photography interpretation (see Chapter 2.2 Aerial Photograph). On the one hand, the interpretation process was simplified by showing the default value, while on the other hand, it was possible to eliminate sample plots as non-forest sample plots without interpretation equipment, if the altitude of the plot was 2,500 m above sea level. At this elevation it is very unlikely that a plot is forested. Since the aerial photography interpretation took place between the years 1993 and 1995, the DEM25 was not used for all of Switzerland due to the lack of availability. In the course of the analysis of the recorded data, the DEM was used to obtain several different derived attributes. The DEM was used, for example, for the attributes to characterize the site quality (Chapter 3.1), for the road survey (Chapter 2.6), or for modeling the protective function of the forest (Chapter 3.6).

GEOSTAT/Area Statistics

The Swiss Federal Statistical Office determined the land use for all of Switzerland with the help of a hectare grid (BFS 1992a). The land use, which encompasses 69 basic categories, was determined for the total 4.1 million sample points. The land use was determined by a majority decision based on an area with the size of 100 m*100 m for each sample point.
Information about settlement areas was used, for example, to determine the hazard potential for the protective forest model (Chapter 3.6).

In addition, GEOSTAT provided data of the last population census (1970, 1980, and 1990). The data of the population census were primarily used to model the recreational functions (Chapter 3.7). The amount of forest area in Switzerland, given in the area statistic, was used for comparison purposes (STROBEL *et al.* 1999).

Soil Capability Map

The Soil Capability Map (EJPD, Bundesamt für Raumplanung *et al.* 1980) was ordered by the Federal Department of Justice and Police, and the Federal Office for Spatial Planning. The Swiss Federal Statistical Office holds the copyright to this map, which was produced by the Department of Geography at the University of Bern in 1980.

Switzerland was divided into physiographical units based on aerial photographs and topographic and geological maps. For each of these units, soil samples were collected and the associated soil type, along with the soil properties, were determined. The map in the scale of 1:200,000 shows these geomorphological and pedological separated units. These units were evaluated later with respects to their agricultural and forest utilization potential (BFS 1992b).

Characteristics of the Soil Capability Map were used in the derivation of several attributes for the site quality assessment: the total increment, the altitudinal vegetation zones, or the potential natural forest vegetation (see Chapter 3.1).

Simplified Geotechnical Map

The geotechnical map was published by the Federal Office for Water Management (Bundesamt für Wasserwirtschaft 1990). The scale of the map is 1:200,000. The geotechnical map represents rocks primarily in relation to their importance as building ground or building material. The map contains as a secondary attribute the characterization of rocks. For example, with loose rocks, information is disclosed about the grain size or the sorting. The 60 classes of the original map were combined into 30 classes (BFS 1992b). The geotechnical map was utilized in the NFI for calculating the rockfall hazard. This map showed where rockfall could occur and where, due to the prevalent type of rock, rockfall was less likely or impossible. In addition, the acidity of the bedrock was used to assess the site quality (Chapter 3.1).

Forest Statistic

The Swiss Federal Statistical Office, in cooperation with the Swiss Agency for the Environment, Forests, and Landscape publishes a forest statistic every year, which especially focuses on the economical aspects of forestry (BFS 1995).

Among other things, this data set also shows the border of the different forest regions of Switzerland. The production regions, the economic regions, and the forest district were the most important areas for the NFI. In addition to this, measures about the forest area in Switzerland were taken from this statistic and compared with the amount of forest calculated by the NFI (STROBEL *et al.* 1999).

Administration Units

From the Swiss Federal Office of Topography, a national map with a scale of 1:25,000 was used by the Federal Land Surveying Directorate to digitize several administration unit boundaries. They are periodically updated in cooperation with the Swiss Federal Statistical Office.

The national border, as well as the municipal and cantonal borders, belong to the data set that was employed (Vermessungsdirektion *et al.* 1996).

2.7.4 Employed Models

In the following section the external models used in the NFI are briefly introduced. They are described in detail in Chapter 3.1 and 3.6.

Potential Vegetation

With these models it was possible to calculate the plant communities' potential vegetation within Switzerland. The model developed by BRZEZIECKI, KIENAST and WILDI (BRZEZIECKI *et al.* 1993; 1995; KIENAST *et al.* 1994; 1996) requires several parameters to calculate the potential vegetation which include: information about soil property (pH value, soil depth, etc.), annual precipitation, average annual temperature, exposition, and slope.

Protective Functions

The model developed by the land survey company GEO7 was used to assess the protective function that the forests provided (Chapter 2.6). With the help of the GIS (Arc/Info, ESRI 1992), the model calculated the potentially endangered areas where a protective forest could help to reduce the hazard potential (GEO7 1996).

As input parameters, the slope gradient or the type of rock was used.

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2.8 Criteria and Provisions for Quality Assurance

Hans Rudolf Stierlin

Data about the development and state of the Swiss forest were the main products of the National Forest Inventory. It was therefore imperative to care about the quality of data and to spare no effort to collect the best possible data, independent of the type of survey or source. The process of data quality assurance can be roughly divided into three steps: prevention of inaccurate data recording, routine quality control during the data gathering, and data verification before the analysis. All preparation work fell under prevention of inaccurate data recording. For example, the verification and documentation of methods and standards, the planning of the data collection, selection and calibration of working equipment and measuring instruments, evaluation of a suitable computer to collect the data, recruiting of qualified personnel, etc.

During the data collection it was important to ensure that the data were complete, the standards were kept consistent, and that the working equipment and measuring instruments were in good working order. The control surveys, the instruction and training of the survey teams, and periodically visiting the survey teams in the field all helped to meet this goal. Before the data were analyzed they had to be checked to see if they were complete and plausible.

2.8.1 Quality Criteria

What makes out “good data”? The data of the National Forest Inventory should comply with the following quality criteria:
– Precision
– Agreement with the true value
– Completeness
– Comparability
– Plausibility
– Homogeneity
– Representativeness
– Reproducibility

2.8.1.1 Precision

The precision of measurements depends on the measuring instruments and scale as well as on how the measurement is conducted. The field survey of the NFI used relatively simple measuring instruments. Despite this, high precisions were achieved. The precision of the measurements was documented in detail with the control survey (see Chapter 2.9).

The precision of attributes, which are not measured but appraised or estimated, is difficult to characterize. By far, most of the NFI data were categorical variables on a nominal or ordinal scale. The control survey showed the level of agreement and deviation between the first survey and the control survey. These measures characterize the precision of the qualitative data.

2.8.1.2 Agreement with the True Value

The data measured in the NFI need to agree with the true value, whereby the true value for categorical as well as continuous data was always unknown. The analysis of the control survey (see Chapter 2.9) gave details about the agreement between the measurements. The agreement for most of the continuous data between the first survey and the control survey was good. In the NFI great importance was attached to the fact that the assessments of the survey teams corresponded with the standards set in the Manual for Field Surveys (STIERLIN *et al.* 1994).

2.8.1.3 Completeness

The data collected in the forest or from other sources must be complete, because only a complete data set makes a complete analysis possible. For this, the exact definition of the attribute catalog was essential. The attribute catalog had to be kept consistent throughout the entire duration of the survey. Appending additional variables will inevitably lead to an incomplete data set.

2.8.1.4 Comparability

The data from different teams, different seasons, and different regions had to be comparable with each other. The survey attributes had to be defined in such a way that seasonal or geographical differences did not occur. The survey teams had to be trained so that the measurements of different teams were comparable.

2.8.1.5 Plausibility

The data measured in the NFI need to be plausible; that is all measurement values had to be within the defined value range and no inadmissible codes could be used. The attribute combinations had to be meaningful and admissible.

2.8.1.6 Homogeneity

Under homogeneity of the data, the comparability of the first NFI with the second NFI was understood. The data of the second NFI had to be identical to the data from the first survey. Above all, the following three factors were involved:

- The measurements had to be comparable
- The attribute definitions had to agree
- The assessment of qualitative attributes had to be the same as in the first NFI

Caution was therefore advised where new measuring instruments were used (new or more precise measuring instruments do not give better measurements in every case).

The instructions and repeated training of the survey teams played an important role in imparting the standards of the first NFI.

2.8.1.7 Representativeness

The representativeness addresses the degree of concordance between the NFI data and the reality. The systematic sample plot grid of the NFI and the selection procedure of the trees on the sample plots were chosen and verified so that the representativeness of the inventory was guaranteed. Certain sample plots could become “visible” and threaten the representativeness, because the sample plots were visited every year for the last ten years (particularly the sample plots of the national and cantonal forest damage inventory) and because of the points that were permanently marked. The representativeness of the permanent NFI sample plots was verified by measuring additional, new sample plots (see Chapter 2.1 and 2.11).

2.8.1.8 Reproducibility

The measurements or the assessments of qualitative characteristics must be reproducible. This means that different measurements or assessments of the same objects have to produce the same results. Measurements were easy to reproduce, as long as the measurement instructions were observed and the same measuring instruments were being used. The assessment of categorical attributes was more difficult to reproduce and required a high degree of training and control of the survey teams.

2.8.2 Measures to Assure Quality

2.8.2.1 Survey Preparation and Planning

Projects of the magnitude of a National Forest Inventory require careful preparation and planning. A precisely defined method and a clear sampling design were fundamental prerequisites for the success of the National Forest Inventory. With the chosen sample design, the Swiss forest was representatively covered. The methods of the second NFI were tested in 1992 in a pilot inventory in the five regions: Jura, Plateau, Pre-Alps, Alps, and Southern Alps (BRÄNDLI 1992). During that time, the main objective was to check the attribute catalog and to test the inventory manual (STIERLIN *et al.* 1994) with respect to its practicality and consistency. The flow of work and the survey equipment were checked and optimized. The data collection with the field computers, as well as the flow of data between the WSL and the survey teams, had to be newly developed. In the pilot study, the application of the aerial photographs was tested for the forest/non-forest delineation and as an aid to assist the survey teams in locating the sample plots. Since the pilot inventory was not analyzed for the most part due to time constraints, the usefulness of the assessed attributes could unfortunately not be verified.

The planning of the survey was of great importance. The aerial photography interpretation had to be coordinated with the field survey, since the completed aerial photography interpretation was a prerequisite for supplying the survey teams with default values. The field survey was planned in three stages: 1993, 1994, and 1995 (STIERLIN 1993). For each stage the survey teams were assigned different forest districts as survey units. Care was taken that only one team would work in one forest district. The timely order of the field surveys were scheduled in such a way that they started at lower elevations in spring, continued into the mountainous areas in midsummer and returned back to the lower elevation regions during autumn (Chapter 2.3).

The “human” factor played an important role in assuring the data quality. The selection of the team leader (forest engineer) and his assistant (forester or forest warden) was also important to the working climate and to conducting the field surveys without any problems. The survey personnel were selected carefully. The relatively large amount of time spent on recruiting the field personnel was worthwhile. Problems with the personnel were virtually non-existent and the staff members were motivated until the last day of the field survey. The contact between the board at the WSL and the survey teams in the field was an important quality component. The survey teams were able to count on the necessary support of the board at any time.

In the “Manual for Field Surveys of the 1993–1995 Inventory” (STIERLIN *et al.* 1994), the standard methods for the field survey of the second NFI were documented. The definitions and working routines described in it were binding for the survey teams. This set the standard for the terrestrial survey of sample plots and for inquiries at the forest service. For each attribute, a description of the goal and the intended purpose illustrated the significance of its recording. The exact definition of the assessed attributes and the exact measuring instructions or the descriptions of the procedures were important prerequisites for the reproducibility of the measurements and the evaluation.

2.8.2.2 Instruction and Training of the Survey Personnel

At the beginning of the field survey of a particular survey stage, the field teams were introduced to the work and intensively trained. The survey methods and working techniques were taught in the training courses. The survey teams were instructed in the operation of the handheld computer and the measuring instruments. Another important goal of these training courses was the teaching of estimation standards for the qualitative attributes. The board established the assessment standards so that these corresponded with the values of the first NFI. The survey teams had to adopt these standards.

At irregular intervals (at the beginning of the field survey more frequently than at the end of the survey period), so called “training days” were conducted. On each of the training days, a specific topic was taken up and taught. The participation was mandatory for all survey teams. The board selected the training objects and set the standards. The results from the survey teams were compared to these standards with the help of a special analysis program. The board and survey teams discussed afterwards the exercises for each particular object. The evaluation of identical objects under the same conditions and the discussion that followed regarding the standards and discrepancies were of central importance for the homogeneity, the reproducibility, the comparability of data, as well as to ensure that the assessments were in agreement with the "true" value and the standards set.

2.8.2.3 Carrying out the Field Survey

Complete default values are an important prerequisite for a complete survey in subsequent inventories. For example, a sample plot could only be measured if the data for that particular plot were available on the field computer. The application of field computers ensured the completeness of the data collected in the forest and in the inquiry at the local forest service. The field computer checked the data input as to whether all of the relevant survey fields contained a value. If not, an error message was displayed (RÖSLER 1994).

The motivation of the survey team to do a good job was crucial for the data quality. Therefore, it was important to create good working conditions. An appropriate wage and expense reimbursement was as important as good equipment for the teams and support from the board. In the second NFI an hourly wage and per diem base expense was used. Essential components of the team's equipment were a reliable, spacious vehicle; suitably robust equipment which was rugged enough to keep up with the daily work in often very difficult terrain; all of the necessary documents and maps required; and a mobile phone that ensured contact with the survey teams.

The following measurements were taken at the terrestrial sample plot: The diameter at breast height (DBH) and the stem girth were measured precisely to the full centimeter and rounded off to the next centimeter (STIERLIN *et al.* 1994) with a caliper and a tape-measure (with centimeter marks) respectively. The diameter in 7 m heights was measured exactly to the nearest centimeter with the upper stem caliper; 0.5 to 0.9 cm were rounded up and 0.1 to 0.4 were rounded off. The upper stem caliper was so called "self-rounding." The tree height was measured with the "Christen" dendrometer to the nearest meter. The "Christen" dendrometer was self-rounding. Azimuths and slopes were measured to the full gon (0-399) and to the full percentages respectively. In order to warrant exact measurements, the measuring instruments had to be calibrated before they were used. During the field survey the measuring instruments had to be checked periodically and newly calibrated when necessary. For the DBH measurement, the height of 1.3 m above ground and the measurement direction of the caliper were essential for the precision of the measurement. The girth measurement was independent of the measurement direction and more accurate results were achieved if it was used correctly. Difficulties of the girth measurements that were encountered were a sagging measuring tape (especially for very big trees) and reading the wrong meter.

2.8.2.4 Control Survey

About 11% of the sample plots recorded in the second NFI were measured a second time by a control team. The goal of the control survey was the verification of the work quality, guaranteeing the data quality and data consistency, detection of systematic deviations, as well as determining the variation range of the terrestrially measured attributes. The control survey was an independent second survey of a sample plot, which had already been recorded by the regular survey team. For the analysis of the NFI results, the first survey was used in any case. No corrections of the first survey were made on the basis of the control survey. The sample plots that were to be controlled were chosen at random. The tariff sample trees that were chosen by the first survey team were also used and measured again by the control team. The results of the control team (see Chapter 2.9) pointed out difficulties in the assessment of individual attributes. These attributes were then especially emphasized during the "training days".

2.8.2.5 Plausibility Examination of the Raw Data

The possibilities that errors occur in the data are almost unlimited. It was, therefore, absolutely essential that the collected data were checked with respect to their plausibility before they were analyzed. A first and very important plausibility check was already being conducted during the data collection in the forest. The field computer checked the measured value and the codes to ensure that they were within the range of admissible values. In addition, certain attribute combinations were checked to see if they were admissible and plausible.

The plausibility examination in the office was just as important. The analysis of the minimum, maximum, and distribution of the data for each individual attribute pointed to values which were not plausible. For example, the remains of all trees that were recorded in the first NFI had to be checked to reliably know which trees were still living, which were cut, and which ones were new. The plausibility examination of the field computer did not discover all measured values that were not plausible. For instance, recording the wrong meter while measuring the girth, creating typing errors, and entering unreasonable but admissible codes were not discovered. A large portion of these errors were found and eliminated in the office with a plausibility examination. Continuous values, for example, were compared with the data from the first NFI and, thereby, gross errors were discovered. Certainly the expenditures for programming and executing the plausibility checks should not be underestimated.

2.8.3 Literature

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RÖSLER, E., 1994: Evaluation von Hard- und Software für die Datenerfassung im 2. Landesforstinventar der Schweiz. Allg. Forst- Jagdztg. 166, 4: 76–81.

STIERLIN, H. R., 1993: Mit scharfem Blick durch den Wald – Feldaufnahmen für das zweite Landesforstinventar. Wald und Holz 74, 7/93: 18–20.

STIERLIN, H.R.; BRÄNDLI, U.B.; HEROLD, A.; ZINGGELER, J., 1994: Schweizerisches Landesforstinventar: Anleitung für die Feldaufnahmen der Erhebung 1993–1995. Birmensdorf, Eidgenössische Forschungsanstalt WSL.

2.9 Control Survey of the Terrestrial Inventory

Edgar Kaufmann, Andreas Schwyzer

To make mistakes is not desirable. To believe that no mistakes are made is naive. To repress mistakes is not credible. To not know the mistakes takes away the opportunity to improve upon them. To loose track of the mistakes can lead to wrong estimates and conclusions.

The control survey, which was conducted in the framework of the terrestrial survey for the second National Forest Inventory (NFI), served to detect errors and shortcomings as well as to quantify, to evaluate, and if possible, to eliminate them (see Chapter 2.8).

2.9.1 Purpose of the Control Survey

The amount of the deviation (random or systematic) of different assessments on the same objects, which were independently conducted by two survey teams, allowed conclusions to be drawn about the reproducibility of the inventory results. The quality of both assessments was regarded to be equal.

Systematic differences that were brought about by the results from the first and second survey teams indicated differences in the survey procedure or in the survey conditions. Causes of such differences could have been faulty instruments, incorrect handling of instruments, wrong assessments or different survey dates.

The control surveys (or the second surveys) allowed for periodic checks of the measurements and assessments of the survey teams during the field survey and to improve them through training.

The second surveys revealed unclear definitions of the attributes, allowed for an evaluation of the quality for the measured attributes and indicated the potential improvement with respect to future surveys.

This chapter introduces the analysis methods employed and illustrates them with the help of a few examples.

2.9.2 Methods

Out of the 6,400 terrestrial sample plots of the second NFI, approximately 10% were randomly selected for a checkup by a second survey team. The chosen sample plots were not known to the first survey team. Both surveys were conducted independently from each other. The second survey also encompassed the full catalog of the terrestrially measured attributes.

During the field survey, training courses were organized for the field teams in six week intervals. During these courses the results of the comparison between the first and second survey of the previous six week period were presented and discussed together with the survey teams. The main focus of the training days was directed towards the shortcomings, which were discovered by comparing the first and the second surveys.

The analysis methods for the continuous and categorical data were different. The applied statistical methods and evaluation criteria for the data quality based on selected attributes are discussed in the following chapters.

2.9.2.1 Analysis of Continuous Attributes

Measured and counted values from the first and second survey teams were compared graphically with each other. With this, the precision of the survey was visually illustrated, particularly during the training of the survey teams (Chapter 2.8). The displayed graphs were scatter diagrams that showed differences of individual measurements (Fig. 1), bar diagrams, which presented mean deviations and dispersions of deviations (Figure 3), and frequency distributions of deviations between the assessments of the survey and the control teams (Fig. 2).

For the continuous variables, the average difference between the measured values of the first and second survey teams is a measure for systematic differences of the measurements. The standard deviation of the differences (s_d) is a measure for the random measurement error. Assuming that the first and second survey team are measuring with the same random error, $\frac{s_d}{\sqrt{2}}$ is an estimate of the random measurement error.

The hypothesis to distinguish whether or not differences were systematic or random was tested with the help of the t-statistic. Since outliers strongly influence or distort the parametric statistical measure, all analyses were done in two ways: 1) with all of the data included and 2) with only a 99% quantile of the data included (Table 1), i.e. the percentage of data that had the largest deviation between the measurements of the survey team and the ones from the control team was not included in the reduced data set.

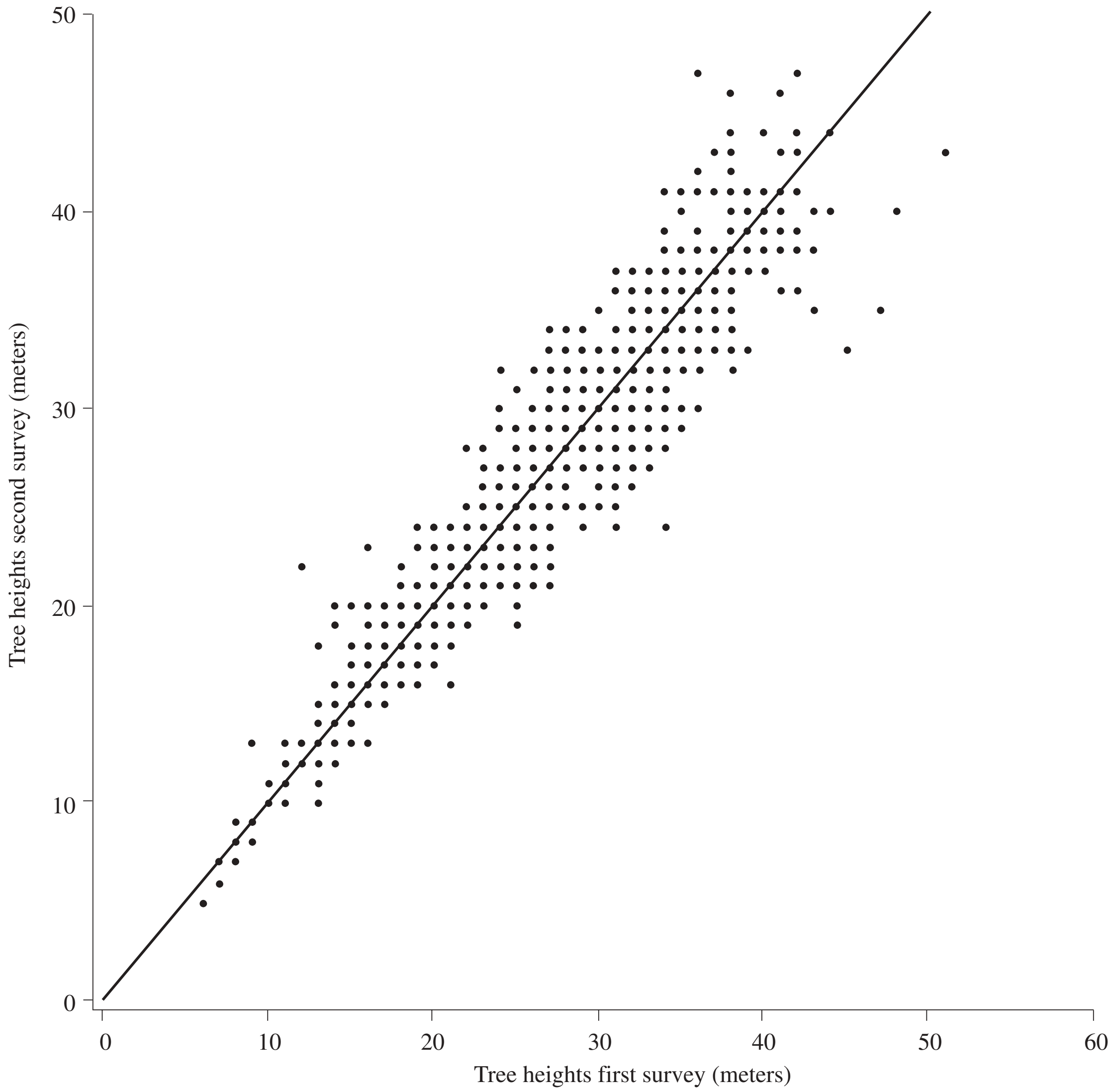

Figure 1. Tree height measurements of the first survey team and the second survey team.

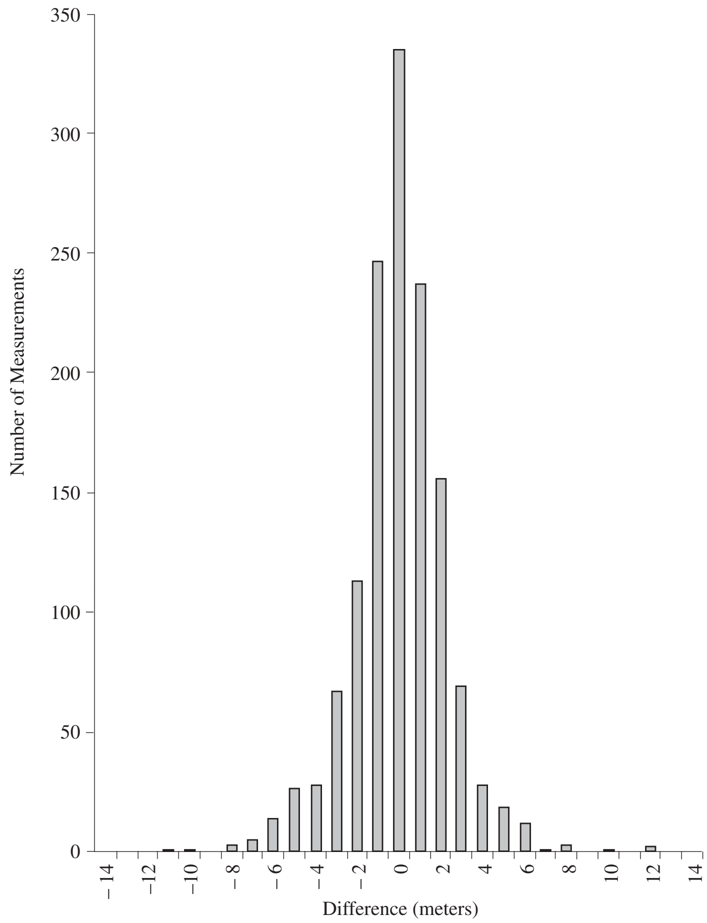

Figure 2. Tree height measurement differences between the first and second survey.

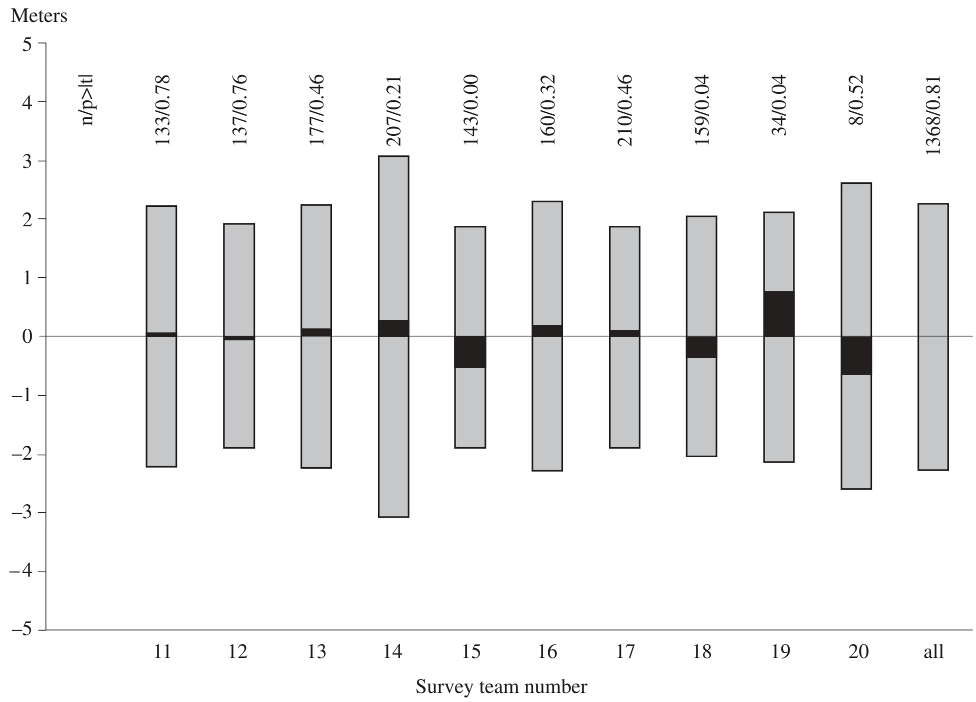

Figure 3. Measurement of tree height: Result of the check assessment in the second NFI by survey teams (group numbers 11–20). Average deviation ($^{1}/n\Sigma(x_i-y_i)$, black) between the measurements of the first survey team (x_i) and those of the second survey team (y_i) at the same tree. Standard deviation of the measurement differences (hatch, difference $D_i= x_i-y_i$), N: Number of measurements, p>|t|: observed level of significance of the t-distribution.

Table 1. Statistical parameters of the **measurement data** in the second NFI, and the difference between first and second survey team.

Attribute	Number	Systematic error	Random error	$P_{(T)}$	Result
All Data					
DBH	8360	–0.8 mm	5.7 mm	0.0001	Significant difference (reason: growth)
D7	1236	–1.8 mm	13.1 mm	0.0007	Significant difference (reason: growth)
Tree height	1368	0.01 m	1.6 m	0.8115	Very good agreement
99%-Percentile					
Attribute	Number	Systematic error	Random error	$P_{(T)}$	Result
DBH	8294	–0.8	3.7 mm	0.0001	Even without outliers significant difference
D7	1224	–2.1 mm	11.5 mm	0.0001	Even without outliers significant difference
Tree height	1357	0.01 m	1.5 m	0.9282	Very good agreement
Only data from the dormant season					
Attribute	Number	Systematic error	Random error	$P_{(T)}$	Result
DBH	1319	–0.2 mm	3.9 mm	0.1189	Very good agreement
D7	225	–0.8 mm	11.3 mm	0.4302	Very good agreement
Tree height	239	0.26 m	1.3 m	0.0389	Moderate agreement

2.9.2.2 Analysis of Categorical Attributes

Most of the attributes assessed in the NFI were categorical. It was not enough to compare the evaluation of the first and second survey teams with each other in contingency tables, and to figure out the proportion of corresponding estimates. The problem is that the fewer classes a categorical attribute has, the larger the proportion of agreeing observations is if they are randomly distributed over all classes. An attribute with two classes is not considered as precise as an attribute with five classes if the proportion of corresponding estimates for both attributes is the same. Thus, suitable test statistics were chosen. These statistics allowed on one hand to compare the assessment qualities of the different attributes with each other. On the other hand, they are robust, i.e. the measures are valid even if numbers of cell frequencies are small and distributions are skewed. These kinds of statistics produce measures of association, i.e. they measure the tightness of the relationship between the assessments of the first and second survey teams. These measures helped to detect whether or not there was any asymmetry around the main diagonal of contingency tables. Also, the marginal distributions of the contingency tables were checked. It was examined if the cell frequencies of an attribute as a result of the assessments of the first and second survey teams were different, with no respect to concordances or discordances at the same objects. The test statistics used for nominal attributes were not the same as those used for ordinal attributes. For the test statistics the notation was as follows:

x: Code for a categorical attribute that was determined by the first survey team
y: Code for a categorical attribute that was determined by the second survey team
l: Index for an observation

i: Row index in a contingency table
j: Column index in a contingency table
k: Number of categories of an attribute

n: Number of observations
n_{ij}: Number of observations in cell i, j

H_0: Null hypotheses: Different assessments by first and second survey teams are random.

H_1: Alternative hypotheses: Assessments by the first and second survey teams are systematically different.

α: Error probability for accepting the alternative hypotheses (accepting the alternative hypotheses for $\alpha<0.05$)

Testing the Assessment of Ordinal Attributes
The **Sign Test** measures the direction of deviations between two assessments in contingency tables (SACHS 1974; SAS 1990a; SIEGEL and CASTELLAN 1988).

Test statistic: S = p – n/2

where p: Number of pairs with $x_l - y_l > 0$
n: Number of pairs with $x_l - y_l \neq 0$

H_1 ($P_S<\alpha$): Discordant assessments are not trend free. That is, a systematic increase of frequencies in certain directions exist.

By calculating ranks, the **Wilcoxon Rank Sum Test** measures, apart from the direction, the amount of the discordance in contingency tables (SACHS 1974; SAS 1990a; SIEGEL and CASTELLAN 1988). Large discordances are weighted higher than smaller ones.

Test statistic: $RS = \sum r_l^+ - \frac{n(n+1)}{4}$
where r_l^+: rank of $|x_l - y_l|$ for $x_l - y_l \neq 0$
H1 ($P_{RS} < \alpha$): Direction and/or amount of discordant assessments are not random.

Gamma is a measure of association, which measures tightness of correlation between two ordinal scaled variables (GOODMAN and KRUSKAL 1979; SAS 1990a; SIEGEL and CASTELLAN 1988). Gamma approaches 0 for independence, 1 for complete dependence and –1 for complete negative dependence. It is possible that the number of concordant observations is small, even though the correlation is high. This is the case when the first survey team chose systematically higher or lower values in all categories than the second survey team. The test statistic is:

$$\text{Gamma} = \frac{(P-Q)}{(P+Q)}$$
where $P = \sum_i \sum_j n_{ij} A_{ij}$ and $Q = \sum_i \sum_j n_{ij} D_{ij}$

$$A_{ij} = \sum_{k>i} \sum_{l>j} n_{kl} + \sum_{k<i} \sum_{l<j} n_{kl}:$$
For each cell the number of observations n_{kl} for which the first and second survey teams either classified higher or lower than the code value of the cell considered.

$$D_{ij} = \sum_{k>i} \sum_{l<j} n_{kl} + \sum_{k<i} \sum_{l>j} n_{kl}:$$
For each cell the number of observations for which the second survey team classified higher and the first survey team classified lower (or vice versa) than the code value of the cell considered.

For ordinal attributes with at least five categories, the marginal distributions were tested with the **Kolmogorov-Smirnov Test** (SAS 1990b). This test is normally used to test continuous distributions. According to (SIEGEL and CASTELLAN 1988), this test can also be used for ordinal data. A significant test statistic means that the frequency distribution of attribute values, as they were measured by the first and second survey teams on one attribute, must be regarded as different. It is possible, therefore, that both marginal distributions do not differ from each other, even for poor agreement of the assessments on the same object.

The test statistic D is the maximum difference between the relative cumulative distributions of the two independent frequency distributions, or the marginal distributions of the contingency tables respectively.

Test statistic: $D = \max\limits_{x=y}\left(\frac{F_1(x)}{n} - \frac{F_2(y)}{n}\right)$

where $F_1(x) = \sum\limits_{i|x_i \le x}^{n} x_i$ and $F_1(y) = \sum\limits_{j|y_j \le y}^{n} y_j$: Cumulative frequencies of the marginal distributions

H_1 ($P_D<\alpha$): The marginal distributions are different. That is, the first and second survey teams determined different frequencies of a certain attribute.

Nominal Attributes
For nominal data there is no rank order between the classes. It is meaningless in which order the categories are listed in a contingency table.

The **McNemar Test** is a special case of the Cochran-Mantel-Haenszel Statistics (AGRESTI 1990; 1990a; SAS 1990b; SIEGEL and CASTELLAN 1988) and a special case of the sign test. The measure indicates whether discordant classifications are randomly distributed within a table, or whether they are more frequent in certain cells. The test for a k x k contingency table developed by BOWKER (1948, cited in LIENERT 1962) is analogous to the McNemar test for a 2x2 Table.

Test statistic: $CMH = \sum\limits_{i>j} \frac{\left(n_{ij} - n_{ji}\right)^2}{\left(n_{ij} + n_{ji}\right)}$ with $\frac{k(k-1)}{2}$ degrees of freedom

H1 ($P_{CMH}< \alpha$): There exists an asymmetry with respect to the main diagonal, i.e. not all frequencies in corresponding cells, which are in a symmetric position to the main diagonal, are the same. This means that the first and second survey teams did not describe the attribute the same way.

The association measure **Kappa** (-1 < = Kappa < =1) measures the tightness of the relationship for nominal data, while considering the expected random agreement (AGRESTI 1996; SIEGEL and CASTELLAN 1988). Especially for very skewed distributions (most of the observations fall into one category), or for attributes with few categories the probability is high that two assessments match at random. Kappa is calculated in the following way:

Test statistic $K = \frac{[P(A) - P(E)]}{[1 - P(E)]}$

where *P(A)*: Proportion of agreeing observations
P(E): Proportion of agreeing observations when no connection exists between two ratings of the same object: $P(\mathrm{E}) = \sum\limits_{\mathrm{i=j=1}}^{\mathrm{k}} \pi_{\mathrm{i+}}\pi_{\mathrm{+j}}$

where $\pi_{\mathrm{i+}} = \frac{n_{i+}}{n}$ and $\pi_{\mathrm{+j}} = \frac{n_{+j}}{n}$ (+: all categories of a row or a column)

2.9.3 Evaluation of the Measurement and Assessment Accuracy

The application of the tests mentioned above are illustrated in the following by means of selected examples.

2.9.3.1 Continuous Data

Continuous data are usually more precisely recorded than categorical data which are based on judgments. In the NFI the following measuring quantities were recorded:
- Diameter at breast height ($d_{1.3}$) on trees with 12 cm <= $d_{1.3}$ < = 60 cm
- Circumference at breast height of trees with $d_{1.3}$ > 60 cm
- Diameter at 7 m height (d_7) of the tariff sample trees
- Tree height (H) of the tariff sample trees
- Number of trees per sample plot having a $d_{1.3}$ >= 12 cm

The overall random measurement error for the $d_{1.3}$ was estimated at 5.7 mm (Table 1). The mean systematic difference between the measurements of the first and the second survey team was 0.8 mm. This small difference was statistically significant at the 95% level (t-test). The systematic difference can be explained for measurements during the growing season by the time gap between the first and the second measurements. Figure 4 shows how the time gap between the two measurements effected the systematic differences of the measurements that were taken during the growing season. The further the two measurements were apart, the larger the average measurement difference was. The cause was attributed to the diameter growth between the measurements. The average difference between the first and second survey was random only if those measurements were compared with each other that were taken after the annual diameter growth was finished (Table 1).

The estimated random measurement error of 13.1 mm for the d_7 was larger than the one for the $d_{1.3}$ (Table 1). Nevertheless, it was small considering the difficulties connected with the measurements. With respect to the significance of the systematic differences, the same was true as for the $d_{1.3}$.

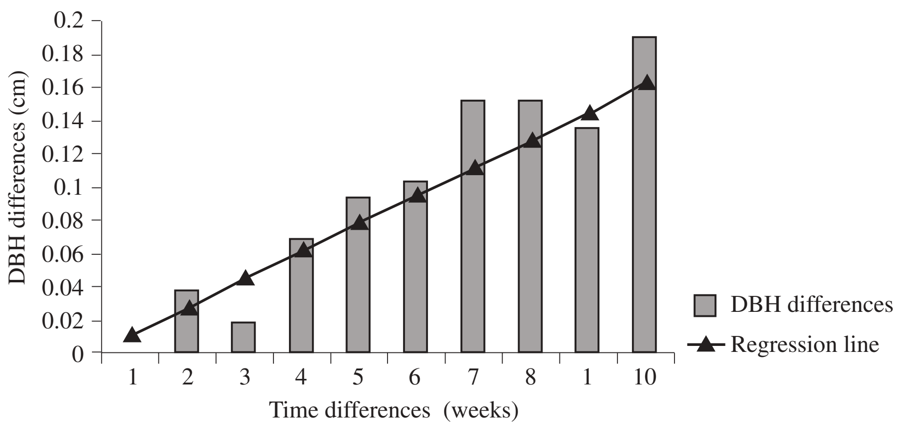

Figure 4. DBH differences between the first and second survey by time differences between the recording dates of first and second survey team during the growing season (April 1 to August 31).

The random measurement error for the tree height amounted to 2.3 m (Table 1). Large differences (>7 m) between two measurements on the same tree were rare (0.8% of all measurements). On average, the tree height measurements of the survey team were not significantly different from the measurements taken by the control team (P_t > 0,05). Training effects were clearly visible (Figure 5), especially for measurements such as the tree height, which required some training. Both the maximum differences and the standard deviation of the differences decreased in the course of one year.

The quality of the individual tree measurements can be described overall as very satisfactory. The good quality of individual tree measuring quantities was fundamental for avoiding systematic biases for individual tree volume and, thus, for growing stock and increment estimates (Chapter 3).

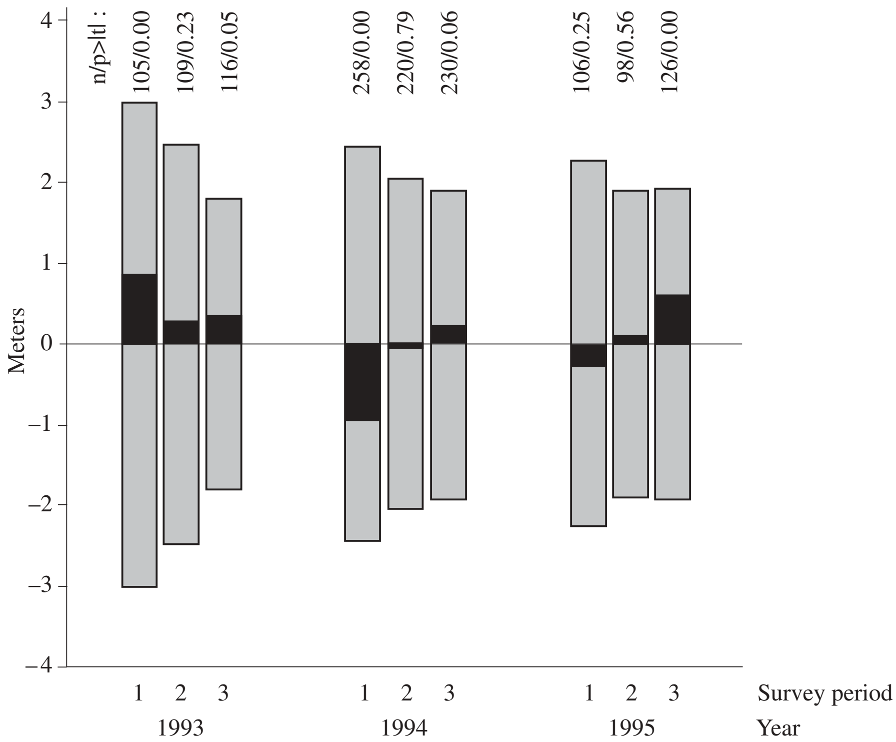

Figure 5. Measurement of tree heights: Results of the check assessment in the second NFI by survey period (1–3) within one year.
Average deviation ($^1/n\Sigma(x_i - y_i)$, black) between the measurements of the first survey team (x_i) and those of the second survey team (y_i) at the same tree.
Standard deviation of the measurement differences (hatch, difference $D_i = x_i - y_i$),
N: Number of measurements, p>|t|: Observed level of significance of the t-distribution

2.9.3.2 Categorical Data

A large number of individual tree, stand, and site attributes in the NFI were assessed ocularly and were not based on measurements. Consistent training of the survey teams, clear assessment criteria that defined classification as precisely as possible, and good knowledge about forests by the survey teams are prerequisites for reliable and reproducible surveys. For the categorical data the following points must be kept in mind:

- Classification instructions are less precise than measurement instructions and always give the survey teams certain interpretation latitude.
- The interpretation latitude can lead to the preference of middle categories for ordinal variables. Good agreement between the ratings by the survey and the control teams can falsely indicate good reproducibility.
- Especially for binary variables (e.g., with the classes “present” and “not present”) with skewed distributions of the attribute (when most of the ratings fall into one class), a large proportion of matching ratings mean little for the rating accuracy. For ratings like this, the McNemar test, for example, is more suitable. This test measures the asymmetry of non-matching ratings independently of the number of matching ones.

Tables 2 and 3 show the number of observations (number of trees or sample plots) for the respective attributes that were rated by the first as well as the second survey teams.

Table 2. Contingency table and statistical parameter for **ordinal** attributes.

Social position (Agreement: 76%, Gamma: 0.94, P_S: 0.00, P_{RS}: 0.00, P_D: 0.01)

		Second survey						
First survey	Code	0	1	2	3	4	5	Total
Missing	0	1271	0	2	19	7	3	1302
Predominant	1	0	33	32	22	4	0	91
Dominant	2	10	45	655	388	7	0	1105
Co-dominant	3	25	18	603	4508	316	0	5470
Subdominant	4	17	1	4	345	1151	52	1570
Suppressed	5	5	0	2	4	223	72	306
Total		1328	97	1298	5286	1708	127	9844

Development stages (Agreement: 64%, Gamma: 0.89, P_S: 0.04 P_{RS}: 0.03, P_D: 0.84)

		Second survey							
First survey	Code	0	1	2	3	4	5	6	Total
Missing	0	9	2	0	0	0	0	0	11
Young growth / thicket	1	2	44	4	1	1	1	3	56
Pole wood	2	1	4	119	10	1	2	11	148
Young timber	3	1	2	22	70	19	2	9	125
Medium timber	4	1	0	1	24	101	24	21	172
Old timber	5	1	5	2	0	28	87	10	133
Mixed	6	1	5	13	10	20	12	59	120
Total		16	62	161	115	170	128	113	765

Mixture proportion (Agreement: 82%, g: 0.94, P_S: 0.80, P_{RS}: 0.74, P_D:1.00)

		Second survey					
First survey	Code	0	1	2	3	4	Total
Missing	0	3	0	1	1	0	5
91–100 % Conifers	1	3	314	19	5	3	344
51–90% Conifers	2	0	31	95	14	2	142
11– 50% Conifers	3	0	5	15	54	22	96
0–10% Conifers	4	0	2	3	12	151	168
Total		6	352	133	86	178	755

Urgency of next operation (Agreement: 36%, Gamma: 0.33, P_S: 0.00, P_{RS}: 0.00, P_D: 0.01)

		Second survey						
First survey	Code	0	1	2	3	4	5	Total
Missing	0	63	6	20	8	16	5	118
Immediately	1	5	26	55	24	14	1	125
In 2 to 5 years	2	4	24	74	60	21	2	185
In 6 to 10 years	3	12	8	44	76	37	3	180
In 11 to 20 years	4	18	5	30	33	34	11	131
In >20 years	5	6	0	2	0	6	2	16
Total		108	69	225	201	128	24	755

Table 3. Contingency table and statistical parameter for **nominal** attributes.

Stand structure	Agreement: 65%, Kappa: 0.39, P_{CMH}: 0.76						
		Second survey					
First survey	Code	0	1	2	3	4	Total
Missing	0	3	2	0	0	0	5
Single layered	1	2	186	85	7	2	282
Multi-layered	2	1	91	278	42	3	415
Structured	3	0	3	12	21	2	38
Cluster structure	4	0	3	6	5	1	15
Total		6	285	381	75	8	755

Stand edge	Agreement: 77%, Kappa: 0.50, P_{CMH}: 0.28				
		Second survey			
First survey	Code	0	1	2	Total
Missing	0	3	0	2	5
Edge exists	1	3	177	74	254
No stand edge	2	0	95	401	496
Total		6	272	477	755

Traces of erosion	Agreement: 87%, Kappa: 0.36, P_{CMH}: 0.00					
		Second survey				
First survey	Code	1	2	3	4	Total
Channel	1	15	3	1	3	22
Surface	2	4	6	1	10	21
Slopes	3	4	2	3	6	15
None	4	29	18	14	636	697
Total		52	29	19	655	755

Geomorphological object		Agreement: 71%, Kappa: 0.57, P_{CMH}: 0.03								
					Second survey					
First survey	Code	1	2	3	4	5	6	7	8	9	Total
None	1	349	11	3	22	14	1	0	8	19	427
Scree	2	4	11	2	0	2	0	0	1	2	22
Loose rock	3	2	3	22	11	3	0	0	1	2	44
Boulder	4	5	0	14	44	13	0	0	1	0	77
Ledge of rock>3m^2	5	8	1	4	10	78	0	0	7	2	110
Karst	6	0	0	1	0	0	1	0	0	0	2
Pit	7	1	0	0	0	0	0	2	0	0	3
Ravine	8	3	0	0	1	3	0	0	9	2	18
Trench over 80 cm	9	15	0	1	4	5	0	0	4	23	52
Total		387	26	47	92	118	2	2	31	50	755

The **social position** was rated differently by the two survey teams, as shown by the statistical measures in Table 2 ($P_S < 0,05$, $P_{RS} < 0,05$, $P_D < 0,05$). The group with the classes "predominant," "dominant," and "co-dominant" could be well separated from the group "subdominant" and "suppressed." This fact was confirmed by the results of a correspondence analysis. Clear assignments within these two groups proved to be very difficult.

The **development stage** was sometimes not clearly determinable, especially when the stand boundary was close to a sample plot center. Despite this, the assessments on individual sample plots conducted by both teams turned out to be not clearly different. The value of the sign test ($P_S = 0,04$) and the rank sum test ($P_{RS} = 0,03$) were right on the borderline. The two marginal distributions were not systematically different from each other ($P_D > 0,05$), meaning that the different stages of development were rated just as frequently by the first survey team as by the second team. The statistical measures here refer to the ordinal part of the table (code 1–5).

The stand **mixture proportions** were well assessed. The correlation between the ratings of the first and second survey teams was very large (Gamma = 0.94). Furthermore, both the related assessments of individual objects, as well as the marginal distributions, were not significantly different from each other ($P_S > 0{,}05$; $P_{RS} > 0{,}05$; $P_D > 0{,}05$).

The **urgency of next silvicultural treatment,** however, could not be objectively assessed. The assessment of this attribute reflected the subjective opinion of the experts as indicated by weak correlations with a gamma = 0.33, systematically different classifications by first and second survey teams ($P_S < 0{,}05$, $P_{RS} < 0{,}05$), and different marginal distributions ($P_D < 0{,}05$).

The measures for the assessment of the **stand structure** and **stand boundary** in Table 3 show a low correlation between the first and second surveys (Kappa = 0.39 and Kappa = 0.5). However, there is no significant asymmetry with respect to the main diagonal ($P_{CMH} > 0{,}05$) in the contingency tables.

The low correlation for the attributes **"traces of erosion"** (Kappa = 0.36) and **"geomorphological objects"** (Kappa = 0.57) and, at the same time, the large proportion of matching observations (87% and 71%) was mainly due to the fact that such traces and objects were not found on most of the sample plots. These attributes were systematically evaluated differently by the first and second survey teams ($P_{CMH} < 0.05$).

If no asymmetry was found in the contingency table, and the marginal distribution of the first survey was not different from that of the second one, it was reasonable to assume that the frequency distribution of an attribute was assessed correctly. Forest areas identified with certain attribute values were in these cases assumed to be reliable, even if the assessments of the individual object had poor agreement.

Systematic error, however, can arise if poorly reproducible attributes are combined with other attributes, either for stratification (e.g. growing stock stratified by stand structure) or for attribute derivations (see Chapter 4.4.). Large random differences between the assessment of an attribute by the first and second survey teams result in ineffective stratification by this attribute. The use of poorly reproducible attributes for the derivation of other attributes is dubious. The plotwise or treewise combination of such an attribute with another attribute is also questionable.

The quality of assessments should not be judged based only on the test statistics, but always in connection with the contingency tables, especially with respect to frequencies of individual attribute values.

2.9.4 Outlook

The methods presented here were used to periodically analyze all variables during the terrestrial survey (KAUFMANN 1995). Additional studies are necessary in order to uncover the cause of misjudgments and to improve the survey quality for future inventories.

2.9.5 Literature

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2.10 Control Survey of the Aerial Photo Interpretation

Ingrid Paschedag, Markus Keller

The goal of this study was to obtain detailed information about the reproducibility of the aerial photo interpretation. The results of this study were used to assess the quality of the interpretation and to improve the aerial photo interpretation of future inventories.

2.10.1 Selection of the Control Samples

After the end of the regular aerial photo interpretation, a second interpretation of a test sample was conducted. This test sample was put together partly from randomly drawn sample plots and from partially random drawn sample plots only. All four interpreters analyzed these test samples. The four interpretations that were conducted for a second time were compared with the first interpretation as well as to each other.

In order to check as many uncertain or contradicting forest/non-forest decisions as possible, a pure random selection of the control sample was not used.

The control sample was compiled considering the following selection criteria:

For the selection of the sample plots, care was taken to ensure that as many suitable areas as possible were in the same stereo model. As a result, frequent change of the aerial photographs in the analytic stereoplotter was avoided (Chapter 2.2.) and the expenditure for the interpretation of the control sample was minimized.

Plots were considered suitable if the terrestrial forest/non-forest decision did not agree with the ones from the aerial photo interpretation. Furthermore, all stereo models (Chapter 2.2) were considered if different forest/non-forest decisions were made in the first NFI for at least three of the aerial photo plots. The test sample was drawn at random from these plots.

About 20 forest and 10 non-forest plots were taken at random from each of the five production regions. With this, the size of the test sample was increased.

Since in this second interpretation “critical” interpretations were examined in particular, the calculated results are only valid for this test sample but not for the entire population. Problems observed in the test sample indicated, nonetheless, possible misinterpretations, especially for difficult interpretations (e.g., for the stage of development).

A possible source of error (position error) for aerial photo interpretation consisted in the orientation of the images (Chapter 2.2). In order to prevent such varying interpretations caused by position error, all interpreters had to use the same stereo model.

2.10.2 Studied Attributes

The attributes studied were divided into three categories: continuous, ordinal, and nominal. A detailed description of the individual attributes can be found in Chapter 2.2 and Chapter 6.

The following attributes were studied:

Forest/non-forest decision	Nominal
Object decision from the grid measurements	Nominal
Relief	Nominal
Stage of development	Ordinal
Canopy cover density	Ordinal
Crown coverage	Continuous
Crown height	Continuous

2.10.3 3 Comparison of the Frequency Distribution between the First Interpretation and the Control Interpretation

The goal of this examination was to test if there were significant differences between the frequency distribution of the first interpretation and the control interpretation. Since the test described in the following compared the expected with the observed frequencies, all examined attributes had to be available as classified data.

To study the frequency distributions the χ^2 test of homogeneity was used (FAHRMEIR *et al.* 1997). For this, all assessed values were compiled in a contingency table (Figure 1).

Interpreter \ Attribute value	1	...	m	
1	h_{11}	...	h_{1m}	n_1
2	h_{21}	...	h_{2m}	n_2
k	h_{kl}	...	h_{km}	n_k
	h_1	...	h_m	

Figure 1. Example of a contingency table.
m: Number of categories for an attribute
k: Number of interpreters
h: Marginal values

The null hypothesis (H0-hypothesis) of this test means that the five determined frequency distributions were equal or similar. Thus, the number of times a certain quantity was detected by each of the interpreters was the same. $\chi 2$ is a measure of deviation between the true frequencies and the expected ones.

$$\chi^2 = \sum_{i=1}^{k} \sum_{j=1}^{m} \frac{\left(h_{ij} - \frac{n_i h_j}{n}\right)^2}{\frac{n_i h_j}{n}} \tag{1}$$

For h_{ij}, h_j, n_i, n, k, and m: see Figure 1.

After calculating χ^2, the proposed null hypothesis was tested. The error probability was calculated for this. The error probability is the probability of being wrong when the null hypothesis is accepted (BORTZ 1993). In the following, 5% was considered the maximum acceptable error probability.

2.10.4 Results

Forest/Non-forest Decision

The forest/non-forest decision was the most important attribute of the aerial photo interpretation. On the one hand, this decision helped with the stratification for the statistical analysis of the NFI; on the other hand, the decision as to which sample plots were measured in the field was made from an aerial photograph. Therefore, it was important that the forest/non-forest decision was highly reproducible.

Table 1: Forest/Non-forest decision. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Forest/Non-forest decision
38	36	34	37	35	Non-forest
72	74	75	73	74	Forest
1	1	1	1	2	Shrub forest
0	0	1	0	0	Not interpretable

As seen in Figure 2, the frequency distributions of the individual interpreter visually differs only slightly. In addition to this, the χ^2 value of 0.957 calculated with (1) indicated that the interpretations were comparable. In the present case, the null hypothesis was accepted.

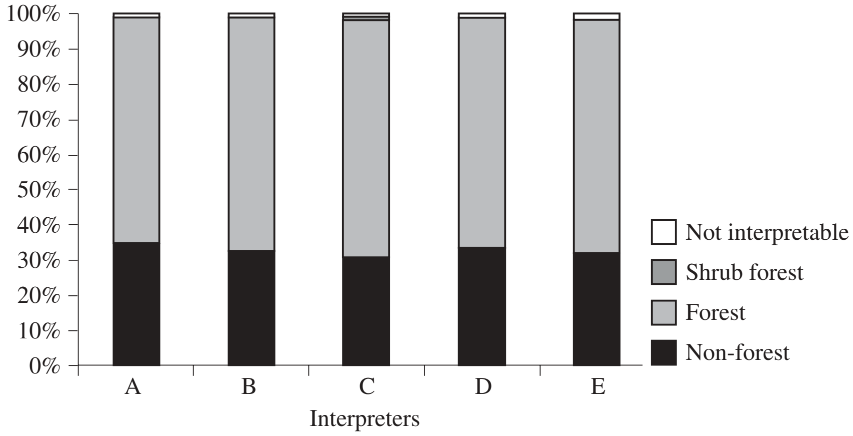

Figure 2. Forest/non-forest decision. Relative frequencies of the attribute values for the five interpreters.

Object Decision from the Grid Measurements

In the first decision, each of the aerial photo plots was classified as forest/brushwood or non-forest. In the next step, the entire interpretation area of 50 m x 50 m was covered by a 25 dot grid and an object decision was made for each of the dots (Chapter 2.2 Aerial Photography). As Table 2 clearly shows, large differences existed between individual objects. The determined frequency distributions suggested that it was not always clear whether or not the floating mark "missed" the tree and, therefore, the forest ground was interpreted. However, it was clear that it could not always be decided with certainty that the interpreted tree was a broadleaf tree or a conifer.

The null hypothesis of the χ^2 test was rejected.

Table 2: Object decision from the grid measurements. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Object decision from the grid measurements
72	70	67	112	49	Non-forest
811	748	709	921	787	Broadleaf
665	616	640	532	602	Conifer
0	4	15	0	7	Larch
145	270	240	142	228	Forest ground stockable
9	8	6	0	2	Forest ground not stockable
19	6	45	18	44	Shrub forest
4	3	3	0	6	Forest road

Crown Coverage

The crown coverage was measured with the help of the dot-grid measurements (Chapter 2.2). The values were determined by the inner nine dots. These nine dots represented approximately the larger circular sample plot of the terrestrial survey (see Chapter 2.3). The reproducibility was also investigated for the crown coverage of the entire interpretation area (25 dots). But since the results showed similar values as the study for the inner nine dots, the following results of one study only are presented.

Even though Figure 3 suggests that the comparability was poor, the calculated value for the χ^2 test was, nevertheless, clearly above the error probability of 5%. Because of this value of 0.74, the null hypothesis could not be rejected.

Since the crown coverage was derived directly from the dot-grid measurements, the question was why the hypothesis should not be rejected, since it was not significantly different than that of the determined crown coverage of the individual interpreter, while the null hypothesis of the object decision for the dot-grid measurements was rejected.

One explanation for this was most likely because the trees were divided into separate classes (broadleaf trees, conifers and larch) for the object decision, while for the calculation of the crown coverage the division did not matter, since the only thing distinguished was “tree” and “forest ground.” The unequal number of interpreted classes for the dot-grid measurements (Table 2) was also traced back to the difficulty of identifying the tree species.

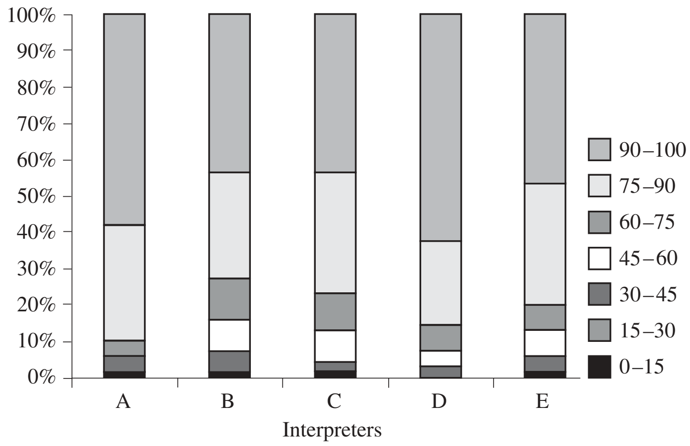

Figure 3. Crown cover. Relative frequencies of the attribute values for the five interpreters.

Table 3: Crown closure. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Crown cover
1	1	1	0	1	0–15
0	0	0	0	0	15–30
0	4	2	2	3	30–45
3	6	6	3	5	45–60
3	8	7	5	5	60–75
22	20	23	16	23	75–90
40	30	30	43	32	90–100

Stage of Development

As Figure 4 shows, the interpretations by the individual interpreters were hardly comparable. Noticeable in particular are the interpreters B and D. For B, a shifting towards a higher stage of development can be seen, while the interpretations of D were limited to two classes.

The value of 0.001 for the χ^2 test suggested rejecting the null hypothesis.

The (aerial photo) development stage was primarily defined by the dominant stand height in the NFI (see Chapter 2.2). As additional help in making the decision, the interpreter looked at other features such as the tree species, the exposition, or the elevation. The interpreter took these features into account and came to the decision about the development stage. Even though these features were taken into account, the decision about the choice of development stage was at the discretion of the interpreter. Because of this, it was difficult to reliably reproduce this decision.

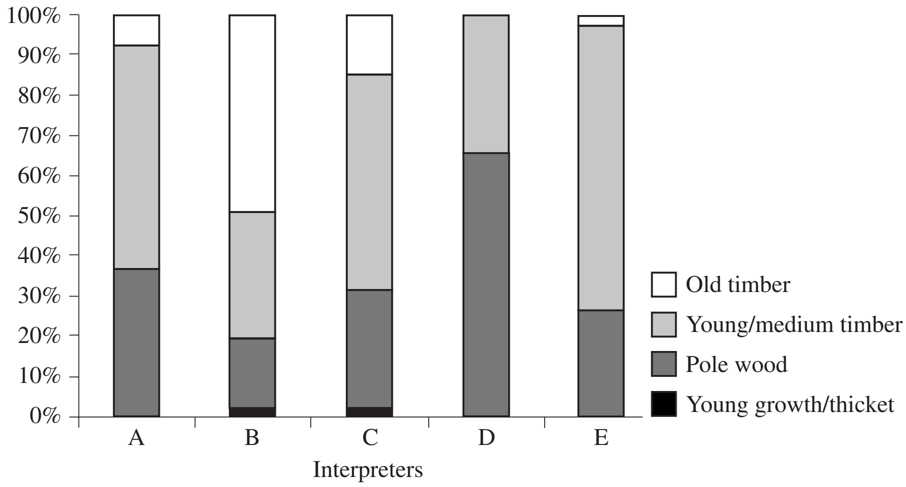

Figure 4. Development stage. Relative frequencies of the attribute values for the five interpreters.

Table 4: Development stage. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Development stage
0	1	1	0	0	Young growth
15	7	12	27	11	Pole wood
23	13	22	14	29	Young/Medium timber
3	20	6	0	1	Old timber

Canopy Cover Density

Based on Figure 5, it can be seen that the distinction between the classes “crowded” and “normal” was particularly difficult. Nonetheless, it must be noted here that for ordinal attributes it was not possible to define an exact dividing line. The value of the χ^2 test was 0.036, so that the null hypothesis was rejected with an error probability of 5%.

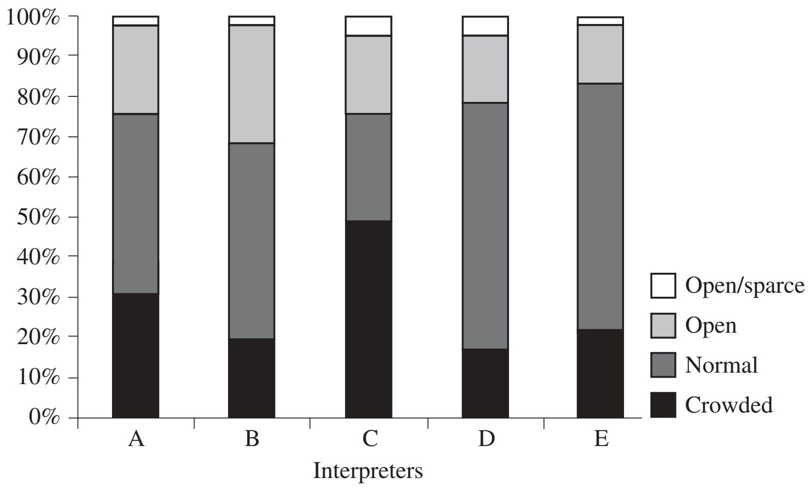

Figure 5. Closure. Relative frequencies of the attribute values for the five interpreters.

Table 5. Closure. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Crown Closure
16	8	20	7	9	Crowded
15	20	11	25	25	Normal
9	12	8	7	6	Open
1	1	2	2	1	Open/sparse

Crown Height

Since crown height is a continuous variable, all values had to be classified in the first place. The class width was 10 m. The class limits corresponded to the classification that was used during the analysis of the NFI for the stratification (Chapter 2.1).

As can be seen in Figure 6, interpreter D measured a smaller tree height more often than the other interpreters did. This was most likely the reason why interpreter D decided upon lower development stages more frequently (Table 4). The value calculated with equation (1) led to the rejection of the null hypothesis.

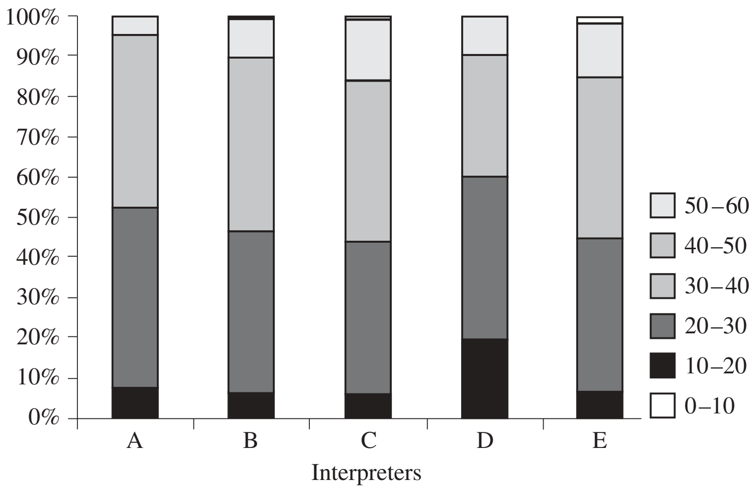

Figure 6. Crown height. Relative frequencies of the attribute values for the five interpreters.

Table 6: Crown height. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Crown height (m)
1	0	0	2	1	0-10
58	53	48	155	53	10–20
358	318	304	324	304	20–30
345	342	319	239	321	30–40
35	83	121	78	107	40–50
1	2	6	0	12	50–60

Relief

The determination of the relief was rendered from the absolute oriented aerial photograph by measuring the four corner points of the interpretation area (Chapter 2.2). Based on these measurements, the interpretation program came up with a suggested value. This suggestion was either accepted or rejected.

Figure 7 shows that the frequency of the categories “plain,” “middle slope,” and “steep slope” was approximately the same for all of the interpreters.

It was also striking that interpreter D used only three classes.
The null hypothesis was also rejected here.

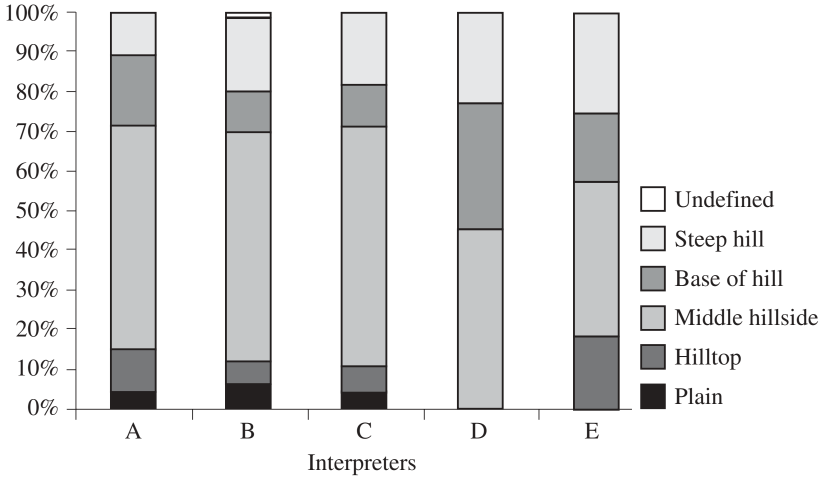

Figure 7. Relief. Relative frequencies of the attribute values for the five interpreters.

Table 7: Relief. Frequencies of the attribute values for the five interpreters.

Interpreter A	Interpreter B	Interpreter C	Interpreter D	Interpreter E	Relief
3	4	3	0	0	Plain
7	4	4	0	12	Hilltop
37	38	40	30	26	Middle hillside
12	7	7	21	11	Base of hill
7	12	12	15	17	Steep hill
0	1	0	0	0	Undefined

2.10.5 Conclusions / Outlook

In this chapter the reproducibility of the results for the aerial photo interpretation was studied, which was based on a selected aerial photo sample. The majority of the control sample plots were aerial photo plots that were difficult to interpret. It was, therefore, not surprising that in many cases the χ^2 test suggested rejecting the null hypothesis.

As expected, attributes that were measured with clear defined measurement instructions were better reproduced than ocular interpretations.

The forest/non-forest decision or the crown coverage was used as an example. Both attributes were, in essence, not interpreted but measured. A pure interpretation was completed for the attribute “development stage.” This example shows clearly that an interpretation, which was only based on describing definitions, was accordingly poorly reproduced.

For future surveys, it is advisable to define attributes, so that they do not have to be based on an expert’s opinion. Furthermore, the control interpretation should be conducted similarly to the terrestrial control (Chapter 2.9) during the survey period.

2.10.6 Literature

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2.11 Representativeness of the Sample Grid

Berthold Traub

2.11.1 Introduction

The Swiss National Forest Inventory established, like most of the European national forest inventories, permanent sample plots, which were repeatedly visited and measured. In contrast to these were temporary sample plots, which were only measured during one particular inventory. In a few of the cases, such as the French Forest Inventory, only temporary sample plots were used. Frequently, permanent as well as temporary samples were used during one inventory.

The terrestrial sample grid of the second Swiss National Forest Inventory was a subsample of the 1 km x 1 km grid (in the following referred to as 1-km-grid) of the first NFI. The samples were systematically located at the diagonal corner points of the first NFI grid, so that the resulting grid had a width of 1.44 km x 1.44 km (in the following referred to as 1.4-km-grid). (See Chapter 2.1.5, Table 4, BRÄNDLI and BRASSEL 1999.) The reduced sample size, and changes from forest to non-forest, created different categories of sample plots in the second NFI which were similar to the "sampling with partial replacement" (KÖHL 1994; WARE and CUNIA 1962).

The grid encompassed sample plots which were measured only in the first NFI because they changed from forest to nonforest (PF-0). Further permanent sample plots exist which were measured in both inventories (PF-A). The commonality between sample plots of types PF-0 and PF-A was that they were permanently marked as NFI sample plots with visible colored marks in order to find the sample in a later inventory. A third category encompassed samples which were newly established and measured only in the second NFI. These were sample plots that changed to forest in the second NFI (PF-B). In addition, new sample plots were also established (PF-C). They were located on a newly established systematic 4 x 4 km grid (in the following referred to as 4-km-grid), which was shifted in an x and y direction by 500 meters. The shift, with respect to the 1.4-km-grid, excluded the possibility of overlapping with the already existing grids.

The samples of the 4-km-grid were the main focus of this study, which dealt with how the visible permanent marks affected the manager's actions of those stands on which the sample plots were located. The marked sample plots could have influenced the forest service or the private forest owner in a certain way. This was ruled out for the new NFI2 sample plots, since it was not possible to predict that the sample plots of the National Forest Inventory would be established. It was conceivable that stands were treated with special care, or that less timber was cut when the stands clearly had "representative" characteristics. KÖHL (1990) draws attention to this problem and cites SCHMID-HAAS (1983). According to SCHMID-HAAS (1983) there is no guarantee that visible sample plots retain their representative characteristics. The objective of this study was to show whether or not certain sample plot or individual tree attributes were different on the marked sample plots in the first NFI versus the newly established ones. Confirming these considerations could have meant that stands with visible sample plots of the National Forest Inventory were managed differently than other stands. Certain results of the National Forest Inventory would have been biased in this case due to permanently marking the sample plots. These considerations were written here in the subjunctive on purpose, since a significant difference between the sample plot collective is not automatically a proof for a causal relationship. It is also possible that one or more covariables existed which partially or mainly influenced these differences. For a general discussion about methods of permanently marking refer to ZÖHRER (1980) and LÖTSCH *et al.* (1973).

2.11.1.1 Goal of the Study

The ultimate goal of this study was to investigate whether or not the visible marking of the permanent sample plots in the NFI influenced the manager significantly, which was manifested in the sample plot and individual tree attributes.
The following hypothesis was tested:

– Null hypothesis, H0: The marking has no effect on the manner in which the forest is managed. The results with respect to the test statistics between the marked and the non-marked sample plots are not significantly different.
– Alternative hypothesis, HA: The differences in the results or the test statistics are so obvious that they cannot be explained by chance alone.

This study here presents a first step in reaching this goal. Apart from the actual analysis of the data, the study evaluated whether the proposed question could be answered with the available data and, if necessary, how the methods could be improved.

2.11.2 Methods

The survey of compared attributes was conducted at different aggregation levels. Attributes which characterized a sample plot, as well as attributes which were assessed on sample plot elements (usually individual trees), had to be differentiated. The sample plot data were either measured or collected directly from the sample plot and its surroundings, or came from the inquiry at the forest service. The sample unit in the NFI was the sample plot. This was the reason that, in order to calculate estimators, the data of the individual elements such as volume and damage of trees, had to be summarized to sample plot figures.

If it was desired to compare the marked sample plots (PF-A) with the non-marked newly established areas (PF-B+C), certain properties of both of the collectives had to be considered. The so-called combined or joint sample plot grid consisted of sample plots, which were considered forest according to the NFI definition at both particular inventories (PF-A). The newly established samples (PF-B+C) were composed of samples especially established for the representative study (PF-C) and new ones that did not fulfill the forest definition criteria in the first NFI (PF-B).

Nothing is known about the history of the plots located on the new 4-km-grid, since in the first NFI no aerial photo interpretation was conducted in this grid. These new sample plots represent, unbiasedly, the state of the second NFI. The corresponding sample quantities had the same expected value as the sample PF-A. The sampling error was higher due to the smaller sample size. However, it was reasonable to assume that the new samples of the 1.4-km-grid (PF-B) had a lower growing stock compared to the sample of the joint grid. Young and open stands were present in this collective with a higher probability than in the joint grid. As a consequence of these considerations, it followed that the three collectives PF-A, PF-B and PF-C should be analyzed separately, and that comparing the tree data was only reasonable between the sample PF-A and PF-C.

In general, it was of interest to examine those attributes, which were assumed to be strongly dependent on the type of management. If the observed attributes were significantly different between the two samples, it could have been attributed to a different type of management, which was motivated by the visible marks of the sample plots. As already mentioned, other influential factors could also have played a role. But since the samples of the collective PF-A and PF-C were distributed systematically over the entire area of Switzerland, both collectives were expected to be influenced by these factors.

If marked sample plots were found in a stand, several different behavior patterns of a manager were conceivable, independent of a certain attribute. In general, a manager's behavior patterns toward a stand could be attributed to indifference. Otherwise intensive and carefully managed stands would be noticeable if the manager wanted to leave a good impression. A low intensive management style was also imaginable in order "not to destroy or disturb any research work". If the behavior was different, it was possible to detect it. And regardless of the direction the manager's behavior took, it could be tested for its significance. It was, therefore, important to find attributes which were influenced by these different behavior patterns.

2.11.2.1 Examined Attributes

(1) Growing stock

a) Comparison of the individual tree volume
b) Growing stock on the sample plot weighted by the tree expansion factor (See also equation 17, Chapter 3.2 and KAUFMANN and BRASSEL 1999)

Data for growing stock and changes in growing stock were of central importance in the NFI. In principle, it could be assumed that these groups of attributes were hardly influenced by the manager. It was nevertheless conceivable that during timber harvest, trees were intentionally left on the sample plots. If the manager would have behaved in this way, the estimated growing stock would probably have been higher from the marked samples than from the new unmarked sample plots. The data for the utilization would have shown the opposite reaction; however, they could not be compared, since the new sample plots did not have any data about the utilization.

(2) Damage

The attribute damage was subdivided into stem damage (exposed wood) and other damage. If there were damages from both groups, a tree counted towards the first group, "damage on the stem". Damages on the stem were mainly caused by harvesting damage or by falling rocks and avalanches. The proportion of the two classes of damage type and the proportion of the two categories of damage cause was investigated. If the markings had any influence, the marked sample plots were expected to have fewer stem and harvesting damages than the unmarked ones, due to increased efforts toward tending. No differences were expected for the damage caused by avalanches. At most, a more intensive wound treatment was conceivable, which allowed the stem damage to heal after many years. The later was, in principle, also possible for harvesting damage.

(3) Number of years after the last operation

This quantity was directly controlled by the manager and was a clear indicator of the influence the sample plot marks had. Two different behavior patterns were possible: (a) The manager thinned more regularly and more often than in other stands in order to create an optimal tending status. (b) The manager rarely intervened in stands that contained a sample plot in order not to disturb the sample plot. This possibility was already considered for the attribute growing stock.

(4) Protective measures against damage caused by game in the stands

Code	Description	Explanation
1	Unprotected	No protective measures against damage caused by game
2	Fenced	The plot center was located in a fenced in young growth stand
3	Individual protection	The young forest plants were individually protected (e.g., the buds were protected with chemical agents or hemp, etc. and individual protection with barbed wire or wire basket, etc.)

These attributes were recorded in the surroundings of the sample plot (interpretation area). For these attributes, similar possibilities applied as they did for the attribute (3) "last utilization". If marks had an influence, the protective measures were expected to be more frequent in the surrounding stands.

(5) Needs of silvicultural treatments in the protection forest NFI2 (See Chapter 3.6)

Code	Description
0–0.17	High need of silvicultural treatment
0.18–0.38	Average need of silvicultural treatment
0.39–0.62	Moderate need of silvicultural treatment
0.63–0.82	Low need of silvicultural treatment
0.83–1.00	Very low/no need of silvicultural treatment

For these variables it could also be assumed that if the sample plot marks influenced the managers, the need of silvicultural treatment was expected to be lower, which would have indicated a more careful management. The urgency of a silvicultural treatment was expected to be inversely proportional to the number of years since the last operation.

(6) Percentage of unregulated felling
This attribute characterized the percentage of resulting unregulated felling in 20% classes of the total fellings, and was assessed from the inquiry at the local forest service. The percentage of unregulated felling could have only been indirectly influenced by the manager, but over a longer period of time would have been an indicator for the care and efficiency of silvicultural treatments.

(7) Standing dead trees

Code	Description	Explanation
1	Present	More than 1 m^3 over 20 cm DBH present on interpretation area
2	Not present	Less than 1 m^3 over 20 cm DBH present on interpretation area

Standing dead trees were registered, provided that their DBH was greater than 20 cm and had more than 1 m^3 growing stock (corresponds to approximately 4 m^3/ha). The volume of standing dead trees was estimated. This attribute also gave some indication about the different treatment of the stands in which the NFI sample plots were established.

The following situation was expected if an influence was suspected:

a) On the marked areas less standing dead trees were expected, since their periodical removal is still regarded as a sign of "clean" forestry. This especially was expected in the private forests, since the behavior of the person responsible there is usually more conservative.
b) More standing dead trees existed because the sample plots were not to be changed or because leaving such trees standing had a positive influence on maintaining the biodiversity. The later situation was more expected in the public forest, where the idea about nature conservation was more likely to have a higher priority than monetary considerations.

There are still wide differences in opinions about how dangerous dry or dead trees are from a phytosanitary perspective, and how this is compensated by the value of natural conservation. In addition to this, the private forest owner weighs the cost of removing the sick or dead trees against the potential danger stemming from them. However, it was expected that the attribute "standing dead tree" – regardless of the possible behavior of individual groups or owner – was a differentiating attribute in general.

(8) Stand stability
The stand stability is the expected persistence of the relevant stand against disturbing influences over a 10-year period (Plateau, Jura, Pre-Alps) or a 20-year period (Alps, Southern Alps). For this, the condition or rather the mechanical stability of the stand was the only deciding factor. The expected development of the stand (e.g., from thicket to pole wood) must not be considered. The ecological stability (species diversity, provenance, closeness to nature, etc.) and long-term stability questions (problems with regeneration, sustainability, consequences of the soil and air pollution, etc.) were not considered either.

2.11.2.2 Stratification

Apart from the attributes introduced above, the collectives were also stratified according to the variables (a) ownership category, (b) mixture proportion and for the comparison of the individual tree volume by (c) main tree species. This procedure ensured that the variables were more homogeneous in the particular strata. This way it was clearer to detect a possible effect of the marks.

Since the actions of the private forest owner were based on attaching different importance to certain goals than the manager of the public forest, the component ownership had to be used for stratification. It can be supposed that the different economical strategies of the two ownership groups affect the attributes investigated here.

The mixture proportion was the estimated basal area proportion of the conifer trees to all trees. This measure serves as an indicator of the silvicultural goal for the surrounding stand and, therefore, is also supposed to influence the examined attributes. Conifer and broadleaf stands are usually managed with different measures according to the different goals.

Code	Description	Explanation
1	Pure conifer	91–100 % conifer*
2	Mixed conifer	51–90 % conifer
3	Mixed broadleaf	11–50 % conifer
4	Pure broadleaf	0–10 % conifer

* (basal area proportion)

For comparisons at the level of the individual tree, the data were not classified according to the mixture proportion, but were differentiated by the main tree species (1 spruce, 2 fir, 3 pine, 4 larch, 5 Swiss pine, 6 other conifers, 7 European beech, 8 maple, 9 ash, 10 oak, 11 chestnut and 12 other broadleaf).

2.11.2.3 Significance Test

After hypotheses were formed, significance tests supported the decision process by accepting or rejecting the proposed hypothesis. It was important for the formulation that the hypotheses were mutually exclusive and that all possible outcomes of the test statistic were covered. The selection of suitable tests took place after formulating the hypotheses and depended upon the scale and the distribution of the investigated variable. It is important to note for the selection of the tests that in each case two variables were compared, which were derived from two independent samples. In general, the effect of the visible marking (independent variable) with respect to the examined attributes (dependent variable) was studied.

Parametric Tests for Continuous Data on a Ratio Scale
For normal distributed continuous data, the t-test is used. For independent samples, the t-test examines whether the averages of both samples are significantly different. In order to check the assumption of normality, the Shapiro-Wilk statistic for small sample sizes ($n<2000$) and the Kolmogorov statistic for larger sample sizes are available in the statistic program SAS. The null hypothesis for both tests is: The underlying population is normally distributed. The alternative hypothesis is: The underlying population is not normally distributed (SAS INSTITUTE 1989).

Non-Parametric Tests for Ordinal Scaled and Not Normally Distributed Data
For the comparison of two independent samples that were on an ordinal scale, the U-statistic of the Mann-Whitney test (MWU test) was calculated (Equation 2). This test was also used if the continuous data were not normally distributed. The MWU test examines whether the rank sums of both samples are significantly different. According to STAHEL (1995), the power of the MWU test is higher than the t-test if the data deviates even slightly from a normal distribution.

Even if the data are assumed to come from a normal distribution it can be advantageous to use a non-parametric test in order to verify the decision to reject the null hypothesis. For large sample sizes (i.e., for $n_1 > 20$ and $n_2 > 40$), the U-statistic is approximately normally distributed. The null hypothesis can then alternatively be tested with the z-statistic. In all of these statistics, n_1 and n_2 denote the sample size for the smaller and larger samples respectively (p. 142, ZAR 1984). The z-statistic can be calculated according to the following formula:

$$z = \frac{|U - \mu_U| - 0.5}{\sigma_U} \quad (1)$$

where $\mu_U = \frac{n_1 n_2}{2}$, $\sigma_U = \sqrt{\frac{n_1 n_2 (N+1)}{12}}$

and $U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R1 \quad (2)$

n_1, n_2: sample size of the smaller/larger sample
N: $n_1 + n_2$
$R1$: rank sum of the smaller sample

Goodness-of-Fit Tests for Nominal Scaled Data

The Pearson-chi-square goodness-of-fit test allows the comparison of the empirical frequencies to the expected frequencies. In the present case, this test was applied to study 2 × r contingency tables (Table 1 and STOKES *et al.* 1997). More specifically, this test was applied to study whether the factor "marking" had significantly influenced the frequencies of the table cells, which is to say the range of classes of the investigated attribute. The null hypothesis of this test was accordingly defined by H0: There is no significant correlation between the treatment and the outcome.

The test statistic Q_P of the Pearson-chi-squared test is calculated according to:

$Q_P = \frac{\sum_i \sum_j (n_{ij} - m_{ij})^2}{m_{ij}}$ where $m_{ij} = E\{n_{ij} | H_0\} = \frac{n_{i+} ; n_{+j}}{n}$, where n_{i+}, n_{+j}, n are the same as in Table 1.

The attributes studied here are usually on an ordinal scale. The exceptions were the frequencies of stem damages and the measures against game damage. To verify the test results, most of the attributes in Table 2 were presented in the ordinal as well as the nominal test category.

Table 1. Illustration of contingency tables.

	Response Variable Categories				
Group	1	2	..	r	Total
1	n_{11}	n_{12}	..	n_{1r}	n_{1+}
2	n_{21}	n_{22}	..	n_{2r}	n_{2+}
:	:	:		:	:
s	n_{s1}	n_{s2}	..	n_{sr}	n_{s+}
Total	n_{+1}	n_{+2}		n_{+r}	n

from (STOKES *et al.* 1997)

Table 2: Examined attributes and used significance test.

Attribute/Test	t-test (continuous)	MWU-test (ordinal)	Chisq test (nominal)
(1) Growing stock	x	x	
(2) Damage			x
(3) Last utilization		x	x
(4) Protection of regeneration against game damage			x
(5) Needs of silvicultural treatments		x	x
(6) Proportion of unregulated fellings		x	x
(7) Dead trees			x
(8) Stand stability		x	x

Multiple Tests

The main focus of the analysis presented here is the comparison between the marked and the unmarked sample plot grid of the National Forest Inventory. The general null hypothesis was always: The marking had no influence on the management of the surrounding stands. Here, the stratification according to ownership categories and mixture proportion made individual comparisons possible within the respective strata. The number of separate comparison *m* was determined by the product of the particular factor levels. For the stratification according to ownership and mixture proportion, *m* equals 8, since the factor ownership had two levels and the factor mixture proportion had four levels. Because of the multiple comparisons, the type-one error rate accumulates (p. 248 BORTZ 1993) and (p. 225 STAHEL 1995). The probability π, that with *m* individual tests the general null hypothesis is rejected falsely for at least one of the tests, is called "experimentwise error". It can be approximated by $\pi(k ? 1) = 1 - (1 - \alpha)^m$, where k= number of tests where H0 is rejected. The general null hypothesis is rejected with an error probability of α if the error probability of the individual test is less than $\alpha' = 1 - (1 - \alpha)^{1/m}$ (testwise error). The error α' can be approximated with the Bonferoni inequality by $\alpha' = \alpha/m$.

For α=0.05, the testwise error rate for the stratification amounted to α' = 0.0064 if both factors were used and to α' = 0.0051 if the category "no response" was also considered. In the case where the stratification was only carried out according to ownership categories, α' equaled 0.025.

Table 3. Number of sample plots and number of trees (growing stock) (Analysis unit: accessible forests without shrub forests).

	Number of sample plots	Number of trees	Collective
New sample plots, new established 4 x 4 km grid	733	8648	PF-C
New sample plots, 1.4 x 1.4 km grid	214	1104	PF-B
Sample plots on joined 1.4 x 1.4 km grid (data basis for change analysis)	5425	62249	PF-A
Total NFI2	6372	72001	PF-A+B+C

2.11.3 Results

A total of 6,372 sample plots were surveyed during the second NFI in accessible forest (without brushwood) (see also BRÄNDLI and BRASSEL 1999). Out of these, 733 sample plots (i.e. 8,648 trees) were in the new 4-km-grid (PF-C) and 214 "grown in" sample plots (1,104 trees) were in the 1.4-km-grid (PF-B). The data of these samples were compared with the already established sample from the 1.4-km-grid (5,425 sample plots, 62,249 trees).

The results of the significance test for the individual tree attributes (individual tree volume, standing volume and damages) were based on the comparison of the collective PF-A and PF-C. For the examination of the attributes sampled from the interpretation area, the collectives PF-A and PF-B+C were compared. Thus, the "grown in" areas were included here.

2.11.3.1 Standing Volume

The volume of the individual trees from both samples (Figure 1) was compared. The results were grouped according to the main tree species as well as according to the ownership category "public" and "private". Since the Shapiro-Wilk test always rejected the null hypothesis (Normal distribution), the usual t-test for independent observations was supplemented by the non-parametric MWU test. Table 4 shows the observed level of significance p>|z| of the z-statistic for the MWU test. Because of the accumulation of the α-error, both measurements were interpreted as significantly different if the p-value was higher than the testwise error rate which corresponded to an experimentwise error rate of 0.05. The correction of the error probability resulted in a testwise error value of α' < 0,00197 (m=2*13[1]=26) for the stratification according to the main tree species and the ownership category. In the case where the data were only stratified according to ownership and not to the main tree species, α' amounts to 0.0253. The results were significantly different for the public forest according to the Bonferoni inequality. The average merchantable timber volume was 1.11 m^3 on the unmarked plots, which was less than the marked plots at 1.17 m^3. Stratification according to the main tree species also resulted in significantly higher values for larch and fir on the marked plots. In the private forest, the trees in the category "other conifers" had a significantly lower average volume for the unmarked plots (nine trees). The 95% confidence interval shown in Figure 2 confirms these differences.

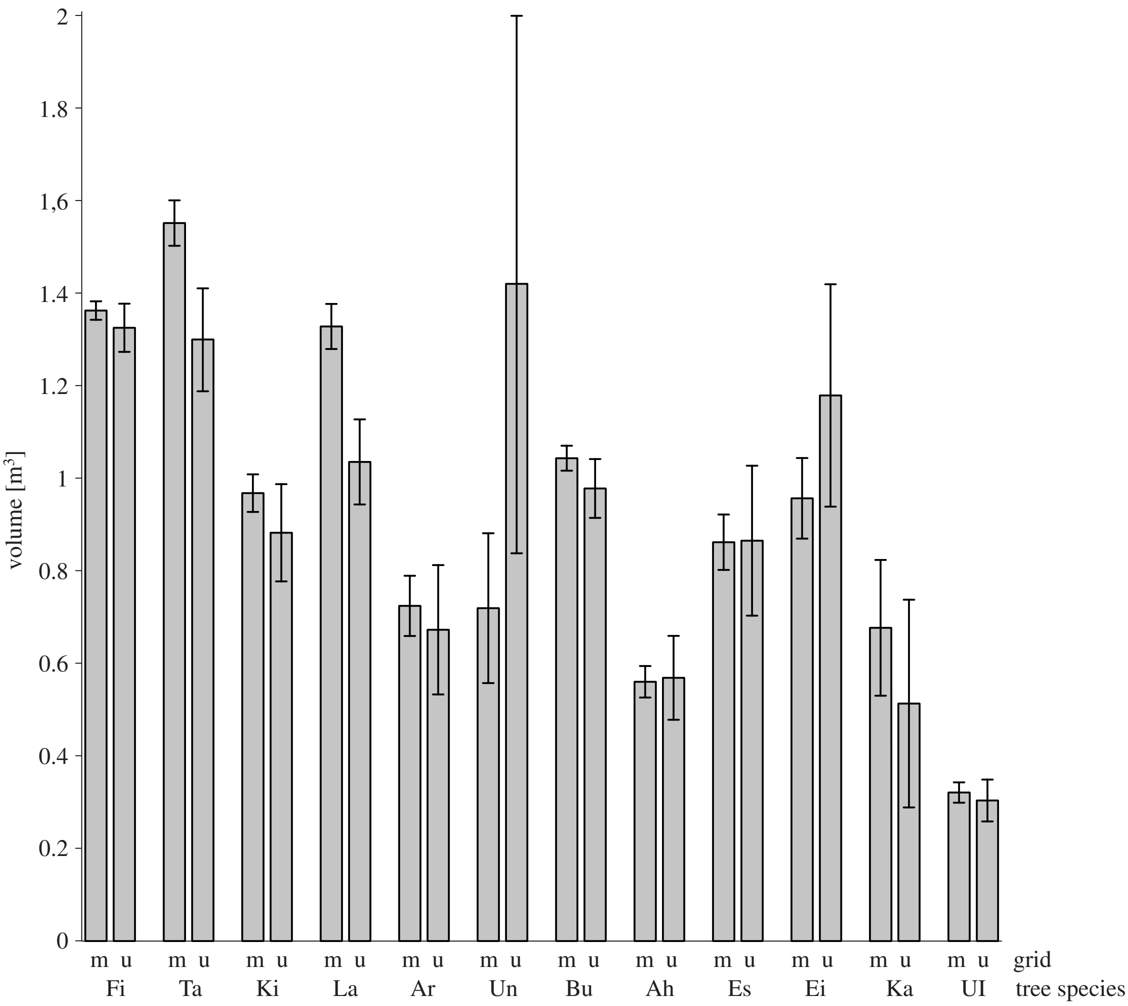


Figure 1a. Public forest: Average volume of individual trees with 95% confidence interval: separately by groups of tree species, and by joined marked 1.4 km grid (PF-A) (m) and newly established sample plots on the unmarked 4 km grid (PF-C) (u).

[1] The attribute "main tree species" was subdivided in 13 groups (inclusive the category "no data")

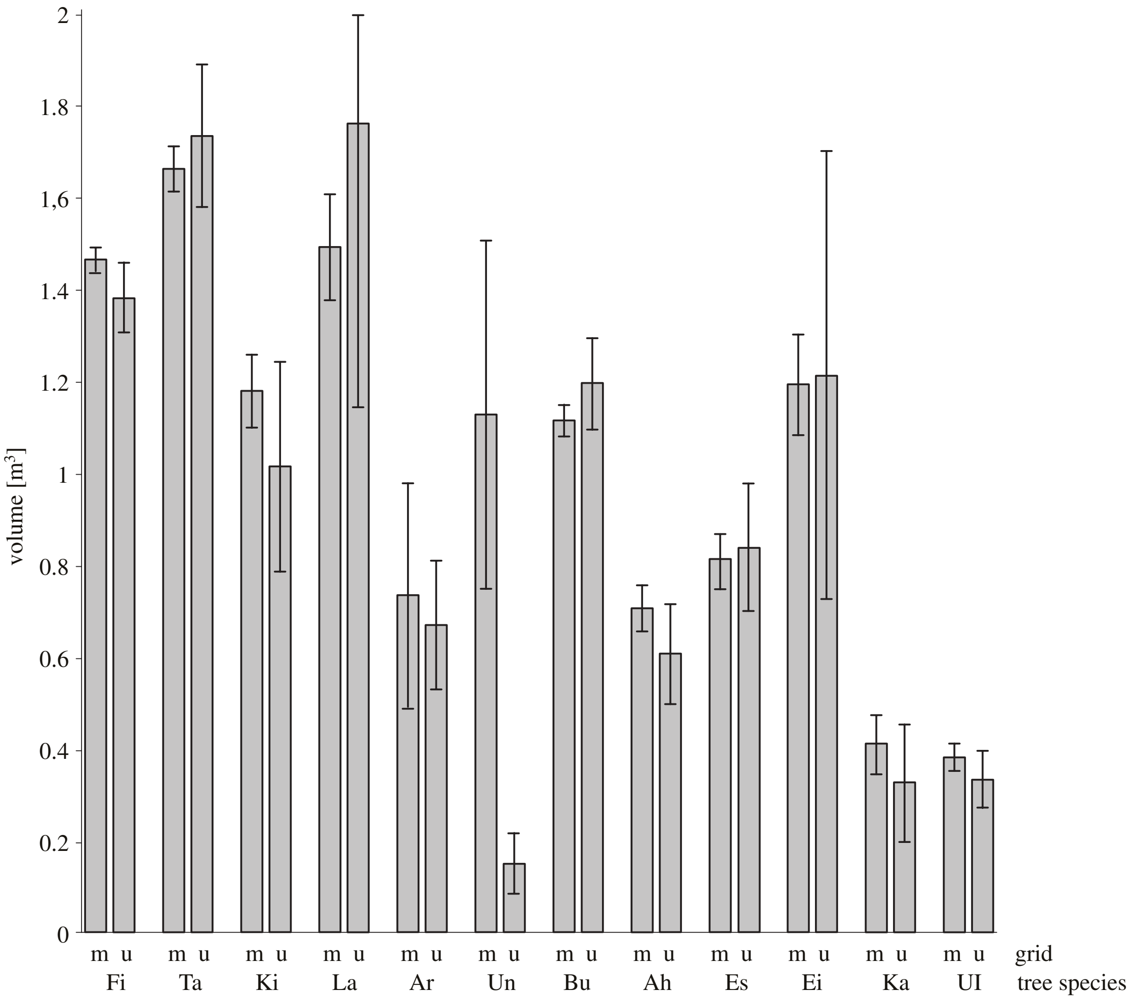


Figure 1b. Private forest: Public forest: Average volume of individual trees with 95% confidence interval: separately by groups of tree species, and by joined marked 1.4 km grid (PF-A) (m) and newly established sample plots on the unmarked 4 km grid (PF-C) (u).

Furthermore, the aggregated standing volume of the sample plots (Figure 2, Table 5) were compared. The attributes “ownership” and “mixture proportion” were the stratifying variables.

For this type of stratification, none of the tests indicated a significant difference for the testwise error value of $\alpha' < 0{,}0051$ ($m=2*5^2=10$). The results are shown in Figure 2 with the corresponding 95% confidence intervals.

[2] The attribute “mixture proportion” was subdivided in five groups (inclusive the category “no data”)

Table 4. Descriptive statistics and test results for the comparison of the attribute volume of single trees, by ownership category and main tree species.

Tree species	Number of stems marked	Number of stems unmarked	Mean value marked	Mean value unmarked	Median marked	Median unmarked	Volume Prob > |Z| (MWU test)	
Public								
Spruce	17312	2638	1.36291	1.32572	1.0275	0.9095		
Oak	849	149	0.95707	1.17944	0.3650	0.3870		
Chestnut	361	78	0.67715	0.51344	0.1850	0.2025		
Other broadleaf	2690	323	0.32115	0.30391	0.1380	0.1340		
Fir	4018	598	1.55205	1.30043	1.1820	0.7860	0.0002	X
Scots pine	1961	279	0.96832	0.88260	0.6810	0.5600		
Larch	2404	416	1.32855	1.03575	1.1065	0.8995	0.0001	X
Cembran pine	521	104	0.72458	0.67294	0.4690	0.3680		
Other conifers	219	43	0.71963	1.42063	0.2010	0.4840	0.006	
Beech	7354	1045	1.04375	0.97837	0.5775	0.6050		
Maple	1247	195	0.56054	0.56907	0.3120	0.3020		
Ash	1039	145	0.86221	0.86548	0.4140	0.3910		
Public	39975	6013	1.16698	1.10692	0.680	0.621		
Total public		45988					0.0012	X
Private								
Spruce	8835	1119	1.46689	1.38431	1.2490	1.0740	0.0255	
Oak	527	37	1.19406	1.21522	0.7800	0.5530		
Chestnut	880	87	0.41055	0.32639	0.1070	0.1280		
Other broadleaf	1524	205	0.38091	0.33350	0.1650	0.1710		
Fir	3227	380	1.66385	1.73676	1.4330	1.4920		
Scots pine	525	53	1.18104	1.01508	1.0720	0.7200		
Larch	425	34	1.49403	1.76650	1.3460	1.4720		
Cembran pine	28	–	0.73425	–	0.4775	–		
Other conifers	67	9	1.12918	0.15111	0.2680	0.1300	0.0001	X
Beech	4151	461	1.11596	1.19788	0.7450	0.9370		
Maple	867	88	0.70615	0.60769	0.4420	0.4330		
Ash	1069	138	0.81512	0.83907	0.4780	0.4145		
Private	22125	2611	1.23695	1.26678	0.811	0.775		
Total private		24736						
Total		70724	1.1919	1.14139	0.729	0.665	0.001	X

X: significant in respects to the critical value of $\alpha = 0.05$. This 'experimentwise error' corresponds with a 'testwise error' of $\alpha' = 0.00197$ including missing observations and $\alpha' = 0.025$ when differentiated solely by ownership

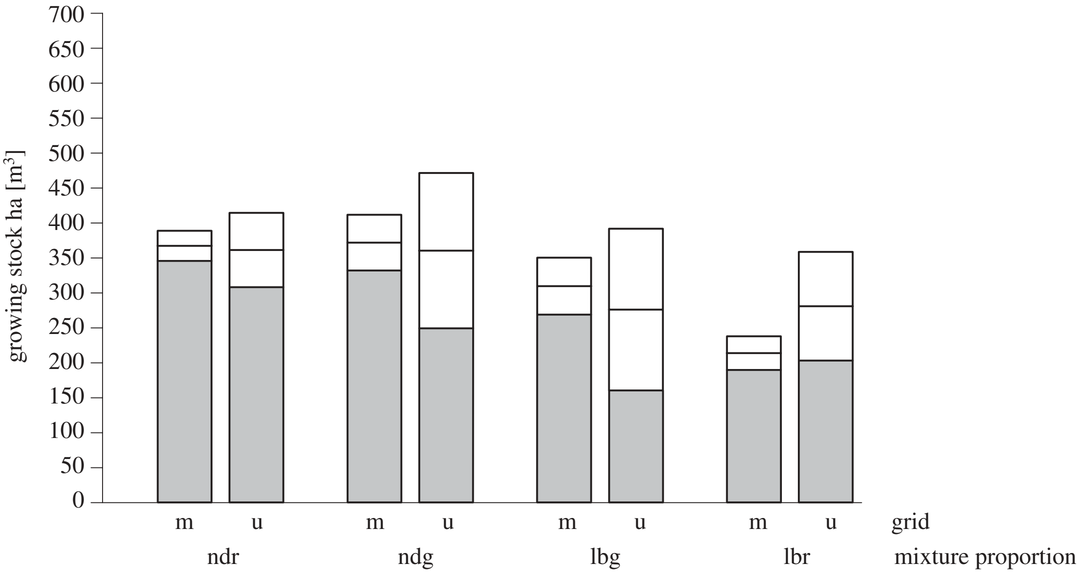


Figure 2a. Public forest: Growing stock per hectare, with 95% confidence interval, separately by ownership category, grid, and mixture proportion (mixture proportion: ndr: pure conifer 91–100% conifer; ndg: mixed conifer 51–90% conifer; lbg: mixed broadleaf 11–50% conifer: lbr: pure broadleaf 0–10% conifer)

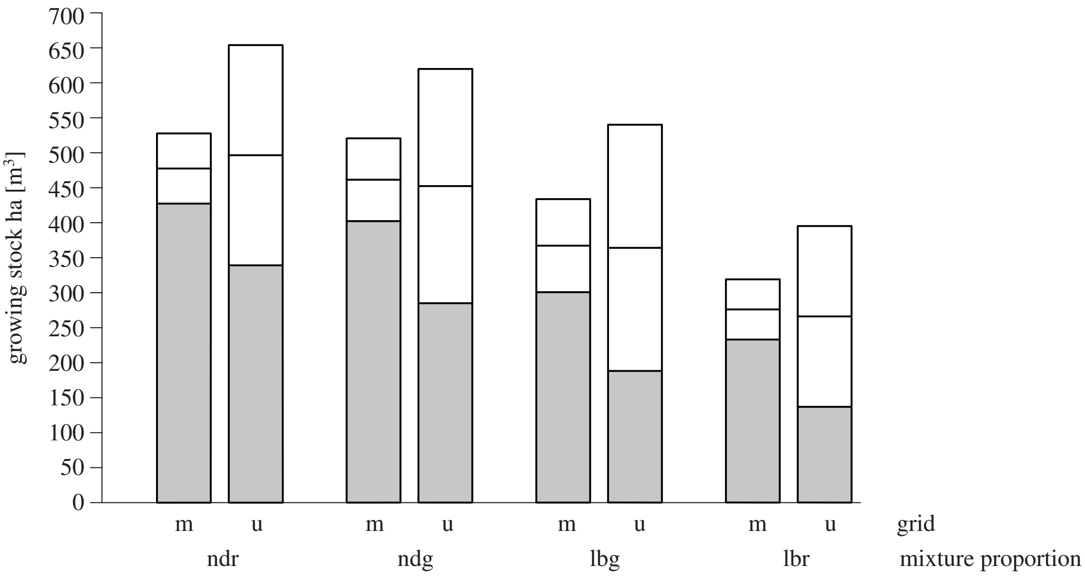


Figure 2b. Private forest: Public forest: Growing stock per hectare, with 95% confidence interval, separately by ownership category, grid, and mixture proportion (mixture proportion: ndr: pure conifer 91–100% conifer; ndg: mixed conifer 51–90% conifer; lbg: mixed broadleaf 11–50% conifer: lbr: pure broadleaf 0–10% conifer)

Table 5. Descriptive statistics for the comparison of growing stock per hectare by ownership category and mixture proportion.

	Sample plot marked	Sample plot *u* unmarked	Number of stems marked	Number of stems *U* unmarked	Growing stock / sample plot marked	Growing stock / sample plot *u* unmarked	Median marked	Median *u* unmarked
Public								
No information	47	9	131	31	174.705	150.164	126.760	84.651
Mixed broadleaf	476	48	5045	442	316.226	286.742	289.900	187.824
Pure broadleaf	683	110	6395	1230	231.505	290.281	199.230	216.469
Mixed conifer	671	88	7596	980	378.390	358.259	356.820	256.409
Pure conifer	1785	268	20912	3347	370.040	367.130	327.970	266.355
Public	3662	523	40079	6030				
Total public		4185		46109				
Private								
No information	16		37		150.986		139.870	
Mixed broadleaf	252	33	2909	377	373.141	362.696	355.425	341.020
Pure broadleaf	360	42	4247	406	294.986	283.829	233.730	197.660
Mixed conifer	451	56	5851	715	462.227	474.313	434.465	429.595
Pure conifer	684	79	9116	1120	480.392	499.227	433.090	484.010
Private	1763	210	22170	2618				
Total private		1973		24788				
Public + private	5425	733	62249	8648				
Total		6158		70897				

2.11.3.2 Damages

The assessment regarding the influence of the marking on stem damage was typically a directional problem, because under the assumption of a significant influence stem damage, in general harvesting damage, were expected to be less frequent (HA). Since such damages were clearly not well regarded, it was obvious that an effect of the marking would result in the manager preventing careless timber removal if such a clearly visible sample plot was located in the stand.

The categories “no damage”, “stem damage”, and “other damage” were formed for the attribute “type of damage” in order to calculate the chi-square test. The corresponding categories for the attribute “cause of damage” were “no damage”, “timber harvest damage”, and “other causes of damage”.

When both of the collectives PF-A and PF-C were compared without stratification, a significant difference between both attributes was determined for the distribution of the three categories ($p > chisq = 0.001$). Contrary to what was expected, the proportions of trees with damage were slightly higher on the marked plots than on the unmarked plots. This was true for “stem damage” as well as for “other damage” (see Figure 4a). The situation was qualitatively identical for the attribute “cause of damage”. After stratification by ownership category and mixture proportion, the difference between the frequency of the three categories was not significant.

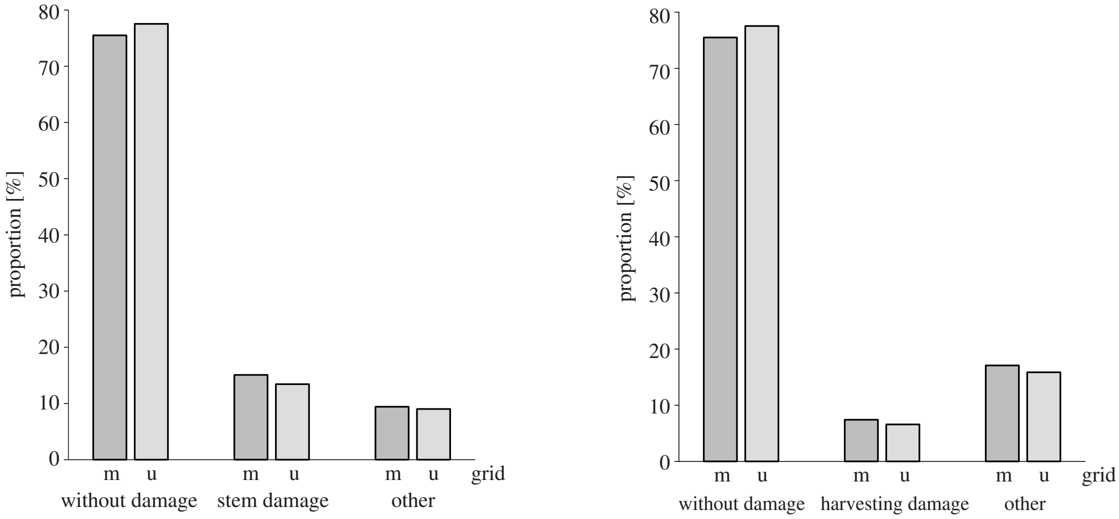


Figure 3. Type of damage
a) Frequency distribution of the attribute "type of damage" (group: all trees).
b) Proportion of stem damage to other damage (group: all trees with damage).

Also, the separate examination of the group of damaged trees showed higher frequencies of "stem" and "harvesting damages" for the marked plots. The differences, however, were only significant (p > chisq = 0,001) in the stratum "public/mixed broadleaf forest" (see Figure 4b, 5b). On the unmarked plots of this layer, 51.7% of the trees (46 out of 89 trees) were damaged during the timber harvest; however, the marked plots had only 35% damaged trees (445 out of 1,273 trees). No significant difference was found between the marked plots and the unmarked plots in any of the other strata.

According to the alternative hypothesis defined in the beginning, in the case of an influence, the proportion of timber harvest damage was expected to be less on the marked sample plots than on the unmarked ones. The overall result without any stratification demonstrated that the influence of this kind did not exist. The stratum "public/mixed broadleaf forest" was the only one with a significant difference between the marked and unmarked sample plot. The significantly higher stem damage proportions on the marked plots were possibly explained by one or more covariate attributes and by the large sample size. Without any further investigations, it is not possible to draw a conclusion about the effects of the marks.

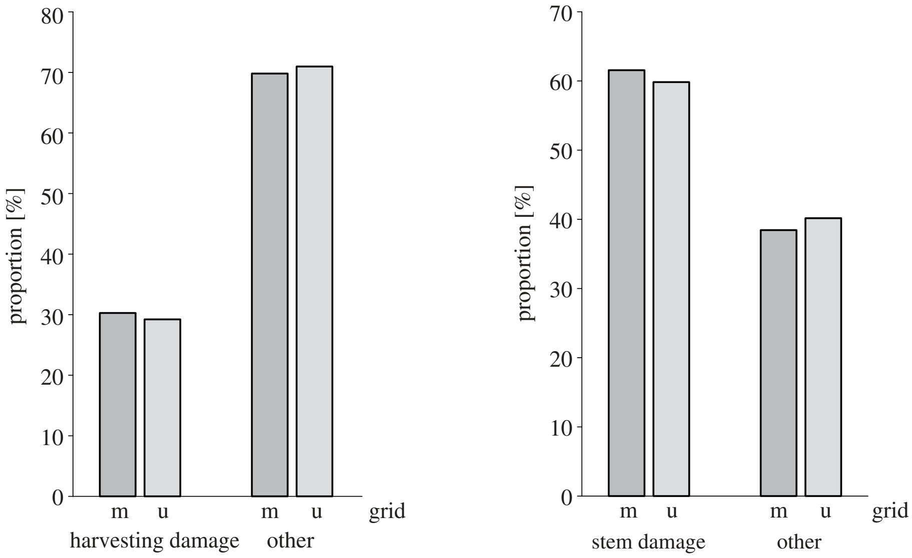


Figure 4. Cause of damage
a) Frequency distribution of the attribute "cause of damage" (group: all trees).
b) Proportion of harvesting damage to other cause of damage (group: all trees with damage).

2.11.3.3 Other Attributes

A significant difference between the marked and unmarked sample plots was only found for the attribute “need of silvicultural treatment in the protective forest” in the stratum “private forest/mixed coniferous forest” ($p > |z| = 0{,}002$ MWU test).

The attributes “standing dead tree”, “stability”, “unregulated felling”, “protective measures”, and “last utilization” did not show in any of the cases a significant difference between the marked and the unmarked sample plots. Figure 5 shows the frequency distribution for the individual classes of the above mentioned attributes. In all of the cases, a weak and non-directed difference between the frequencies of the individual classes were seen.

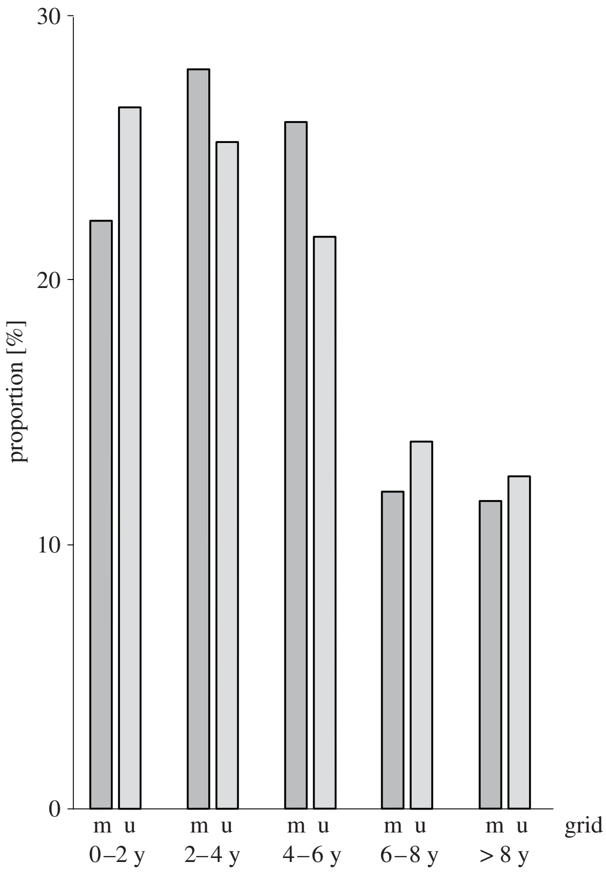
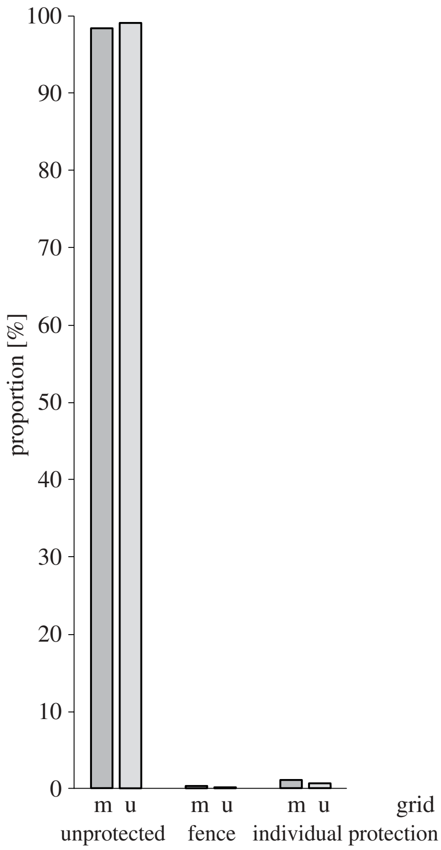
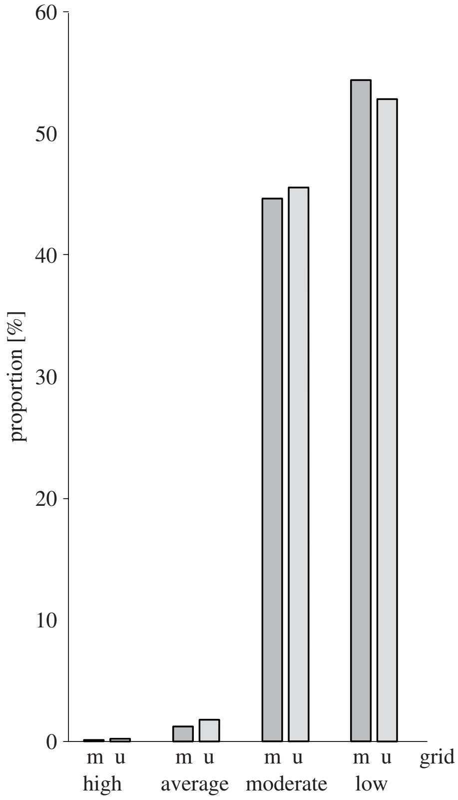


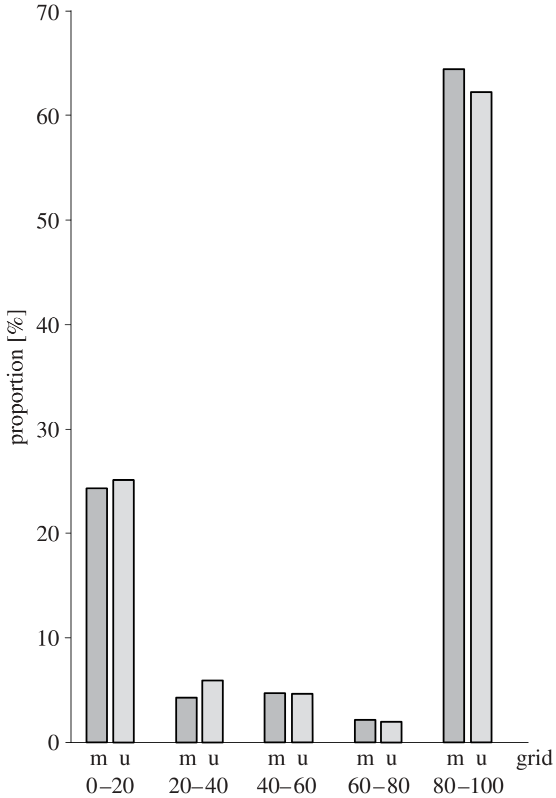
Figure 5. Frequency distribution of the analyzed attributes at an ordinal and nominal scale.
Attribute 3: Last utilization.



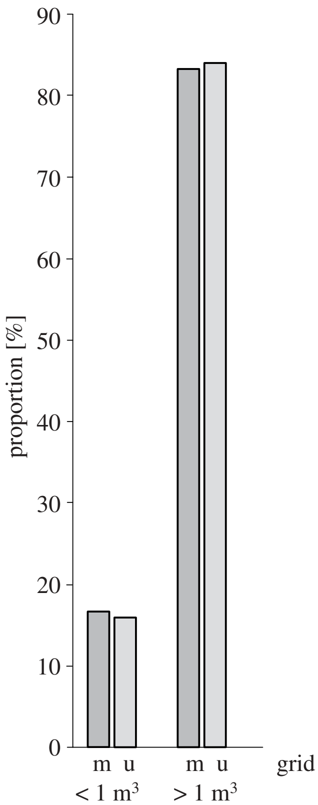
Attribute 4: Protection of regeneration against game damage.



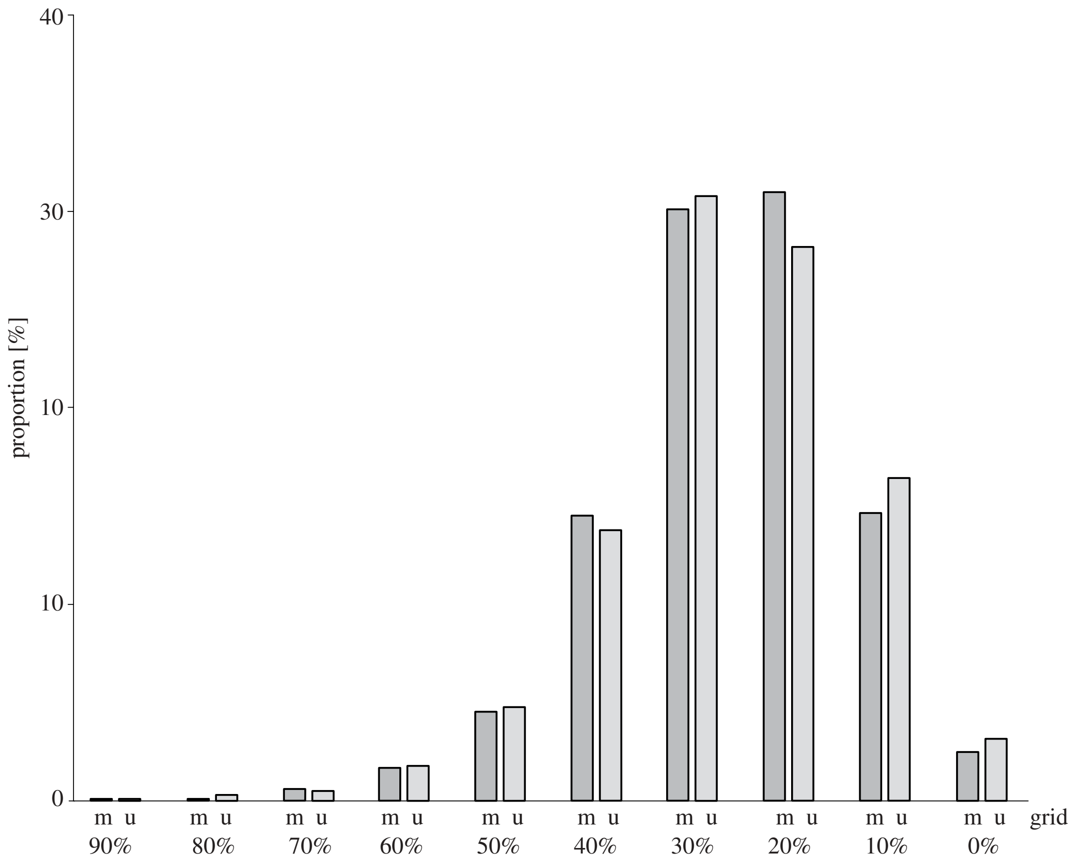
Attribute 5: Needs of silvicultural treatments.



Attribute 6: Proportion of unregulated fellings.



Attribute 7: Dead trees.



Attribute 8: Stand stability.

2.11.4 Discussion

The study about the representativeness of the NFI sample plots was supposed to show whether the managers behaved differently when they knew (based on the markings) that they were in a stand that held an NFI sample plot. The common null hypothesis was: The marks had no influence on the management. The corresponding alternative hypothesis was: The marks had an influence on the management, which was noticeable by significantly different statistical measures or test statistics. In the case where the marking of the sample plot had an influence, several different behaviors were possible. The most likely behavior was certainly that the sample plots and the surrounding stands, whenever possible, were excluded from any kind of forest activity. This meant that a sample plot was viewed as a kind of research facility or experimental area, which was not to be destroyed or influenced. It was also possible that the stands were influenced intentionally in order to present the forest enterprise at its best. The manager removed any signs of an incorrect forest practice (trees with harvest damage, etc.) or protected, particularly, such elements of a stand which increased the species diversity or the structural diversity, since these types of measures are now highly regarded. These two possibilities of contrary behavior presented a problem for the analysis, since they possibly offset each other in the data and, therefore, would not show an effect, even though the manager was influenced.

How can such different behavior be detected? Questioning the people in charge directly was not expected to give an honest answer or, in more statistical terms, to give an unbiased answer. Thus, attributes were studied which reflected the influence of the manager. Whether both populations (sample plot with and without marks) were significantly different was determined by statistical tests. The formulas, which were used to calculate the test statistics, indicated that the sample size played an important role in the calculation. In general, it is true that for a given rejection probability, the sensitivity (power) of the test increases with increasing sample size.

This means that already small differences in the averages, rank sums, or frequencies lead to a significant result. For large sample sizes, the calculation and interpretation of the confidence intervals are helpful, as they are presented here for the comparison of the volumes.

Significant differences were also possible when, apart from the discriminating attribute “marking”, other covariate parameters existed which influenced a certain attribute. By defining a linear model, it would have been possible to assess the effect of individual factors and of such covariates by means of an analysis of variance. But even the most complex model could have only tested those factors which were considered in the model. Thus, there was no guarantee that a certain model could reveal the ultimate cause of the differences.

The performed stratification of the data set in subunits for which the appropriate significance tests were calculated separately was a procedure which also tried to consider several factors (marking, ownership, and mixture proportions). The effect of these input variables could, in principle, be investigated with a three-factorial analysis of variance, which allows for the detection of the main effects of the factors and their interactions. A detailed interpretation of the main effects and of the interactions of the factors is relatively expensive. If a factor or certain interaction has a significant effect, it is further necessary to investigate which level of the factors or combinations caused the significant effect (BORTZ, 1993).

Due to the complexity of the procedure, the separate comparison for each stratum between the marked and the unmarked sample plots was preferred over the analysis of variance. The appropriate correction of the “experimentwise error” by the “testwise error” adjusted the α error accumulation that was caused by the multiple usage of the test.

An influence of the permanent marking of the sample plots was not verified in this study. The differences found here did not allow for the conclusion that the marked sample plots and their surrounding stands were treated significantly different. A bias of the inventory results was not apparent due to permanent and visible markings of the sample plots.

In order to investigate what kind of effect the factor “marking” could have with respects to the manager’s behavior, further studies are needed. These studies should show how strata can be formed with respect to other potential influential factors, so that the strata are as homogeneous as possible.

2.11.5 Literature

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3 Derived Variables and Models

Heike Lischke, Peter Brassel

3.1 Site

Site conditions influence the processes and interactions in the ecosystems, and therewith the state and the changes of the forest. Therefore, the second NFI collected not only data about the forest, but about the site (see Chapter 2.3 and appendix STIERLIN *et al.* 1994) and gathered site information from other sources as well (see Chapter 2.7). These site factors allowed the arrangement of the sample plots into classes with ecologically similar conditions and, thereby, the assessment of other influences within these classes. Furthermore, site factors are the foundation for the study of cause and effect relationships between the environment and the forest.

Depending on the source of the data, the site factors were available for the sample plots of the 0.5 km, 1.0 km, or the 1.4 km grid.

Several different **individual factors** were collected or determined. These were usually secondary factors (DUC and STROBEL 1999) or "proxies", which do not directly affect the trees, but influence the directly acting (primary) factors. In addition, certain **factor combinations** were determined.

3.1.1 Individual Factors

Table 1 gives an overview of the employed individual factors, the grid in which they are available, the sources which they were derived from, and the primary factors which they influence. All factors are assumed to be consistent throughout time.

3.1.1.1 Primary Factors

Rockfall, **snow movement**, **landslides**, **erosion** and **forest fires** (mechanical factors according to WALTER, 1979) were assessed as primary factors. Since these factors could not directly be assessed on the ground and no other data were available with complete coverage, they were assessed based on marks on the trees (e.g., sweep of the bole, tilted tree, damage) as well as on the ground (e.g., stretches without trees, wash outs/undercuts).

3.1.1.2 Secondary Factors

Orographic Factors

Elevation, relief, and **exposition** were measured terrestrially and, if necessary, supplemented by the digital elevation model RIMINI (Chapter 2.7, BFS 1992), which has a 250 m resolution.

The **slope** was interpolated with the help of RIMINI for the entire 500 m grid. Due to the low resolution of RIMINI, the resulting estimate was relatively unrefined. This estimate is sufficient as an approximation for processes acting over larger distances, such as avalanches and water runoff. As an approximation for local factors that are influenced by the slope, the application of interpolated slope is problematic, since it smoothes out the relief. Because of this, the local slope of the sample plot was also measured in the field.

Edaphic Factors

Information about the soil factors: **soil depth, percentage of rocks, soil water capacity, waterlogged soil,** and **nutrient-holding capacity of the soil**, originate from the digitized Soil Capability Map of Switzerland (Chapter 2.7, FREI *et al.* 1980). This map was produced by first dividing Switzerland into "physiographical units" based on aerial photographs, topographical and geological maps. In a second step, soil samples were taken in a subset of these physiographical units and their properties were analyzed. This resulted in an empirical model, which was applied to the entire area. Due to the coarse resolution of the Soil Capability Map, only certain spatially detailed interpretations are possible. Merging the map information with the NFI grid nonetheless compensates possible position errors in simple summarizing analyses, such as determining the forest area with a certain soil property. From the geotechnical map (Chapter 2.7, GEO7 1990), details about the **geology** and the **acidity of the bedrock** were obtained.

The **pH-value of the topsoil**, which is used in the derivation of the potential natural forest vegetation (PNV, see below), was measured in the first NFI.

Climatic Factors

The **average annual temperature** was interpolated using the data from the Swiss Meteorological Institute (SMI), (SMA, 1990, BRZEZIECKI *et al.* 1993). First, the measurements of the SMI stations were adjusted with the help of the empirical temperature-elevation relationship to the elevation independent temperature at sea level. Second, these adjusted values were interpolated onto the 500 m grid. The temperature at the actual elevation was predicted with the help of the digital terrain model RIMINI and the empirical temperature-elevation relationship. The **annual precipitation** was determined from digital precipitation maps.

Table 1. Individual factors and the source these factors originate from, and the priority they are used. RIMINI: digital elevation model (BFS 1992) (Chapter 2.7, External data sources) with a 250 meter resolution. SMA: long-term climatic average values (SMA 1901–1990).

Secondary factors	Grid	Source 1	Source 2	Source 3	Influenced primary factor
Geographic					
Region	0.5 km				Heat, water, nutrients
Orographic					
Elevation	0.5 km	Aerial photograph NFI2	Terrestrial NFI2	RIMINI	Heat, water, light
Relief	1.4 km	Terrestrial NFI2	Terrestrial NFI1	Derived from slope	Light, heat, water
Slope	0.5 km	Terrestrial NFI2	Aerial photograph NFI2	RIMINI	Water, nutrients, light, heat
Exposition	0.5 km	Terrestrial NFI2	RIMINI		Light, heat
Edaphic					
Soil depth	0.5 km	Soil capability map			Nutrients
Percentage of rocks	0.5 km	Soil capability map			Water, nutrients
Soil water capacity	0.5 km	Soil capability map			Water
Water permeability	0.5 km	Soil capability map			Water
Water-logged soil	0.5 km	Soil capability map			Water
Acidity of the bedrock	0.5 km	Geotechnical map			Nutrients
pH-value of the topsoil	1 km	Terrestrial NFI1			Nutrients
Geology	0.5 km	Geotechnical map			Nutrients, water
Climatic					
Average annual temperature	0.5 km	SMI stations	Interpolated using RIMINI		Heat, water, nutrients
Annual precipitation	0.5 km	Rainfall map			Water
Primary factors					
Mechanical factors and fire					
Rockfall	1; 1.4 km	Terrestrial NFI2	Terrestrial NFI1		
Snow movement	1; 1.4 km	Terrestrial NFI2	Terrestrial NFI1		
Landslides	1; 1.4 km	Terrestrial NFI2	Terrestrial NFI1		
Erosion	1; 1.4 km	Terrestrial NFI2	Terrestrial NFI1		Heat, nutrients, water
Fire	1;1.4 km	Terrestrial NFI2	Terrestrial NFI1		Light, nutrients

Region

The data from the second NFI were analyzed according to different regions (Figure 1), which were the results of political, economical (**economic regions, production regions, and protective forest regions**, BRÄNDLI 1999) or ecological criteria (**growth regions** according to KELLER, 1978; 1979, **ecological regions** according to ELLENBERG and KLÖTZLI 1972). All regions are, to a certain degree, also proxies for edaphic factors like acidity, water permeability, and climatic factors, like the north-south temperature gradient and the continental climate in the heart of the Alps (e.g., Wallis).

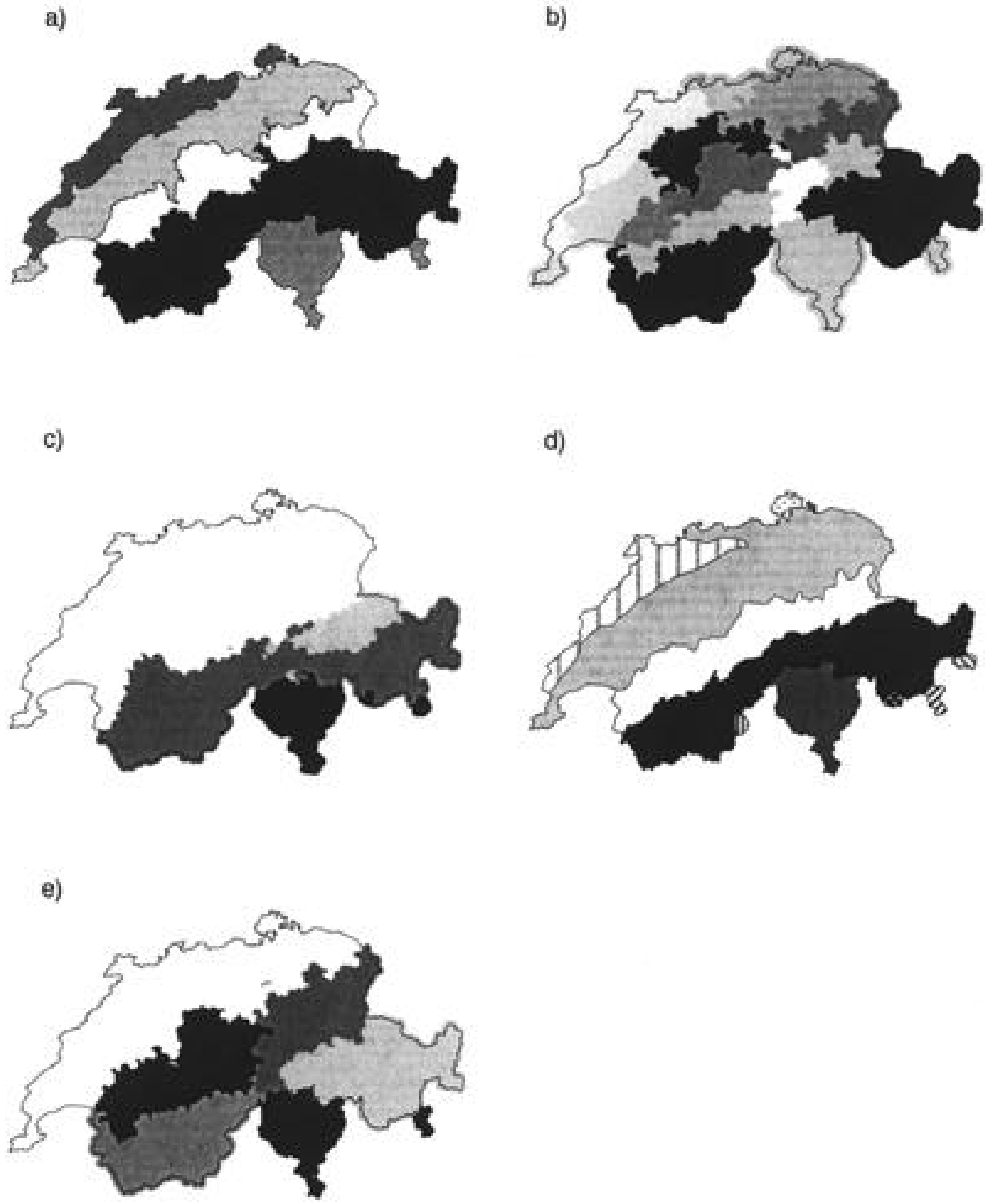

Figure 1. Dividing Switzerland by a) production regions b) economic regions c) growth regions (KELLER 1978; 1979), d) climatic zones (ELLENBERG and KLÖTZLI 1972) and e) protection forest regions.

3.1.2 Factor Combinations

The forest is not only influenced by individual environmental factors, but by several concurrent environmental factors as well. For a simple and ecologically meaningful summary of the sample plots in analyses, several factors were joined to one indicator – the “site property”. Relevant factors were selected and the relationships between them and a quantity describing the forest (e.g., species composition, site index) were derived (e.g., with a statistical procedure) (Figure 2).

Important bases for the derivation of the three indicators used in the second NFI were the phytosociological assessments, which were classified into 71 forest communities according to ELLENBERG and KLÖTZLI (1972). Additional data were taken from forest yield assessments.

The phytosociological assessments comprise, apart from phytosociological information, such secondary site factors as elevation, exposition, or slope. Further factors can be derived, if necessary, by means of interpolation from other sources of data.

These types of data allowed forest communities or site indexes (determined from phytosociological or forest yield data) to be classified into an ecological scheme that was defined by site factors. This scheme is called the ecogram. Since potentially not all relevant site factors were available, the analysis was conducted separately for all of the different regions (see above). This procedure covered other site factors which were not assessed, such as the different continentality of the climate in the North and Central Alps.

The following procedures used in the NFI (Figure 2) differ in the manner in which the forest communities are arranged in the ecological space, and in the indicators that were derived from the forest communities or directly from the site factors.

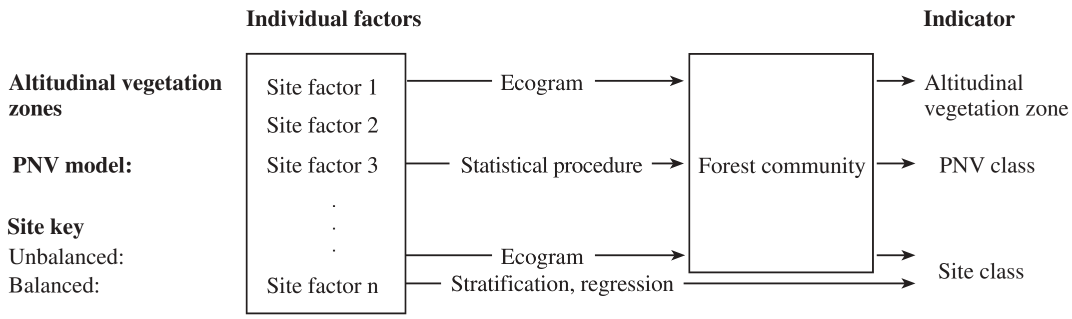

Figure 2. Principle of the indicators used in the NFI for the site properties. The models assign a certain combination of individual factors to one indicator. For the altitudinal vegetation model by BRÄNDLI and KELLER (1985) and for the unbalanced site key by KELLER (1978; 1979) this is carried out by classifying the forest community into an ecogram. This makes it possible for the unbalanced site key to link the site class within the forest communities with the site conditions. The balance site key by KELLER (1978; 1979) estimates indirectly the relationship between the site factors and site class using a height dependent regression with different classes of site factors. The PNV model (BRZEZIECKI *et al.* 1993; KIENAST *et al.* 1994) determines the relationship between the forest community and the site factors by a statistical procedure.

3.1.2.1 Total Increment

The model by KELLER (1978; 1979) in its original form (“unbalanced key”) estimated, with the help of the forest communities, the site quality (site index) from the site factors in Table 2. The site index was either presented as the maximum of the Total Mean Increment (TMI) since establishing the stand – called here “Total Increment” (TI) – or as the mean height of the 100 thickest trees per hectare of a 50 year old stand (productivity index of stand). TI was measured in kilogram dry weight per year and hectare.

Table 2. Secondary site factors in the site class model by Keller (1978; 1979).

Secondary site factor	Class/unit
Region	Jura + Plateau + Pre-Alps, Intermediate Alps, High Alps, Southern Alps
Relief and slope	Syncline, hill, hilltop, steep hill
Aspect	North, South
Acidity of the bedrock	Base-rich, base-deficient, extreme base-deficient
Geology	Lias limestone, Triassic (for the Southern Alps)
Elevation	Meters above sea level

The model used the stand characteristics “stand age”, “stand height”, and the “mean stem diameter” to assess the site index within a forest community. The stand characteristics were partially taken from the phytosociological assessments and partially from the forest yield research plots. Site index and site factors were linked together by the position of the forest community in the ecological scheme.

The forest communities by themselves, and the site index within the forest communities, depend on the elevation h. For this dependency, a model (Equation 1) was developed which took into account that growth is positively influenced by precipitation (which increases with elevation) and temperature (which decreases with elevation).

$$TI = k/(h - c) + m + p \cdot h \tag{1}$$

This model was fitted separately for each factor combination (region, acidity of the bedrock, geology, exposition, and type of relief – Table 3) to the site indexes, which were estimated by using the phytosociological and forest yield assessments. The resulting model, which was used in the second NFI, was a site index key that was adjusted for the elevation, called the “adjusted site index key”. The estimated parameters k, c, m, and p can be found in Table 4. The TI values calculated with Equation 1 are arranged in Table 5 in the site quality classes.

Table 3. Site class dependency on secondary site factors: factor combination according to Keller (1978; 1979). No information, undetermined:

				Factor combination in relief type...				
Region	Acidity	Geology	Expo-sition	Plain	Base of hill	Middle hillside	Steep hill	Hilltop
Jura	Acidic	–	–	7	7	7		8
Plateau			North	7	7	7	7	8
Pre-Alps			South	7	8	8	8	8
	Alkaline	–	–	2	1	2		6
			North	2	1	2	3	6
			South	2	4	5	6	6
Intermediate Alps	Acidic	–	–	9	9	9		
			North	9	9	9	9	10
			South	9	10	10	10	10
High Alps	Acidic	–	–	11	11	11		
			North	11	11	11	11	12
			South	11	12	12	12	12
Southern Alps	Acidic	–	–	13	13	13		14
			North	13	13	13	13	14
			South	13	13	13	13	14
	Alkaline	Lias limestone	–	17		17		
			North	17	15	17	17	
			South	17		17		19
		Triassic	–	18		18		
			North	18		18	18	
			South	18		18	18	

Table 4. Parameter values for the elevation dependency of the total increment (Equation 1). (KELLER 1978; 1979). To each factor combination from Table 3, a combination of parameter values k, c, m, and p belongs.

Factor combination	k	M	p	c	Lower elevation limit (m)	Upper elevation limit (m)	TI maximum (kg/ha year)
1	2.0423E+06	5074.689	1.4886	1873.9	0	1600	4376.94
2	8.1723E+05	6859.791	–1.1286	1761.7	0	1600	6395.90
3	0.0672	6148.48	–3.8008	1600.001	0	1600	6148.48
4	3.9686E+16	2.4050E+10	14590.3106	1650100.1	118	1600	4856.83
5	1.8717E+07	9705.374	3.562	2815.001	0	1600	3402.26
6	7.4488E+14	1.2410E+09	2075.2869	600210.1	610	1600	848.88
7	1.1192E+06	5733.256	–0.3396	2018.5	0	1800	5178.80
8	6.2504E+08	7.3369E+04	6.561	9137.95	0	1800	4968.77
9	1.1581E+07	5341.356	3.6909	2984.6	0	2100	3281.18
10	2.4209E+15	2.2509E+09	2096.7442	1075560	0	2100	2250.99
11	5.0676E+15	3.0666E+09	1857.367	1652500	0	2300	2826.21
12	1.3026E+16	8.2738E+09	5264.7993	1574400.2	561	2300	2530.88
13	8.0530E+05	4830.524	–0.8411	2362.8	0	2100	4489.70
14	8.9986E+05	3291.198	0.1372	2351.4	0	2100	2908.51
15	6.1994E+06	9294.71	–0.1314	2484.4	0	1800	6799.36
16	5.1664E+05	5256.728	–0.0926	1901.5	0	1800	4985.03
17	3.1501E+05	4210.304	–0.4911	1894.7	0	1800	4044.05
18	3.0106E+04	3432.097	–0.4397	1811.4	0	1800	3415.48
19	1.9521E+04	2997.1	–0.6702	1810.9	0	1800	2986.32

Table 5. Classification of the site classes in the NFI.

Site quality	TI (kg/ha year)	Site height at age 50			
		Spruce	Fir	Larch	Beech
Poor	Up to 1500	8		6	8
Medium	1500–3000	15	9	14	13
Good	3000–4500	20	14	21	17
Very good	Over 4500	23	18	26	19

3.1.2.2 Altitudinal Vegetation Zones

This model related the site factors with the altitudinal vegetation zones. The basis of this model (BRÄNDLI and KELLER 1985) was the classification of the forest communities in an ecological scheme of elevation, exposition, acidity of the bedrock, and growth regions (Table 2).

Based on the literature (ELLENBERG and KLÖTZLI 1972; HESS *et al.* 1967; KUOCH 1954; KUOCH and AMIET 1970; LANDOLT 1983), the forest communities were then linked to the altitudinal vegetation zones (Figure 3). The delimitation of the forest area at the timber line was based on the work of BROCKMANN-JEROSCH (1919).

3.1.2.3 Potential Natural Forest Vegetation

The model for the potential natural forest vegetation (PNV) (BRZEZIECKI *et al.* 1993; KIENAST *et al.* 1994) was also based on numerous (7,500) phytosociological assessments that were classified into 71 forest communities according to ELLENBERG and KLÖTZLI (1972). This approach differed from the ones previously discussed. Here, a statistical method was used to determine the probability of the occurrence V_i of each individual plant community i, depending on several abiotic factors $F_1, F_2, .., F_n$ (Table 6).

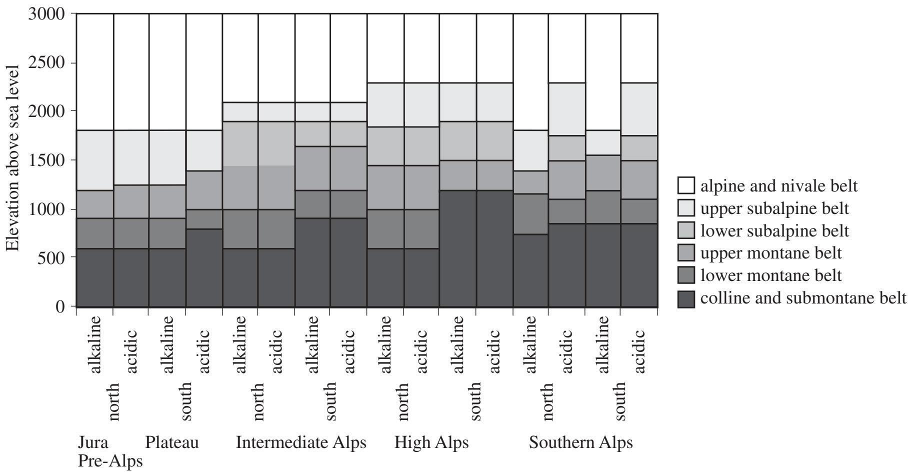

Figure 3. Altitudinal vegetation zones (BRÄNDLI and KELLER 1985).

Procedure: Figure 4 illustrates the procedure with a (non-realistic) example of two forest communities and two continuous factors (average annual temperature and sum of annual precipitation) as well as one discrete site factor (soil depth).

a) Based on the phytosociological data and the factors at the corresponding sites, the frequency of occurrence for each forest community was assessed, depending on the value of the factors.

b) These frequency distributions were fit to a normal distribution. The factors were hereby assumed to be independent. For discrete factors it was only ascertained whether the forest community occurred or not.

c) For the factors, the resulting probability density functions $P(F_1 = f_1, F_2 = f_2, ..., F_n = f_n \mid V_i)$ (for all possible combinations of factors F_k, and each forest community i) make up the PNV model.

d) In order to determine the probability $P(V_i \mid F_1 = f_1, F_1 = f_2, ..., F_n = f_n)$ that forest community i occurred for a given factor combination $F_1=f_1, F_2=f_2, .., F_n=f_n$, the Bayes theorem was used.

$$P(V_i \mid F_1 = f_1, F_1 = f_2, ..., F_n = f_n) = \frac{P(V_i) \cdot P(F_1 = f_1, F_2 = f_2, ..., F_n = f_n \mid V_i)}{\sum_j P(V_j) \cdot P(F_1 = f_1, F_2 = f_2, ..., F_n = f_n \mid V_j)}$$

$$= \frac{P(F_1 = f_1, F_2 = f_2, ..., F_n = f_n \mid V_i)}{\sum_j P(F_1 = f_1, F_2 = f_2, ..., F_n = f_n \mid V_j)}$$

The a-priori probability was assumed to be $P(V_i)=1$. This means that all forest communities occurred when all factors were optimal.

The result was the frequency of occurrence of the forest community i for a certain factor combination. This was relative to the frequency of occurrence of all forest communities for this factor combination.

The model was applied to the 500 m grid of the second NFI. As a result, the model determined the three most probable forest communities as well as their probability of occurrence at each NFI plot, depending on the values of the site factors (Table 6) at the plot. The 71 forest communities were combined into 6 classes for the analysis (Table 7).

From the results of the model, theoretical nominal conditions of the forest composition could be determined, such as the theoretical conifer proportion compared to the assessed conifer proportion, which was used as an indicator for the closeness to nature (Chapter 3.8, Natural Protective Function).

Table 6. Site factors in the PNV model by BRZEZIECKI et al. (1993)

Site factor	Class/unit
Ecological regions according to Ellenberg and Klötzli	Jura with north aspect, Jura with south aspect, Plateau, northern Pre-Alps, western Central Alps, eastern Central Alps, Southern Alps
Slope	°
Aspect	°
Average annual temperature	°C
Annual precipitation	cm
Soil-pH	
Soil depth	
Soil water capacity	
Nutrient-holding capacity of the soil	
Water permeability	
Water-logged soil	
Elevation	Meter above sea level

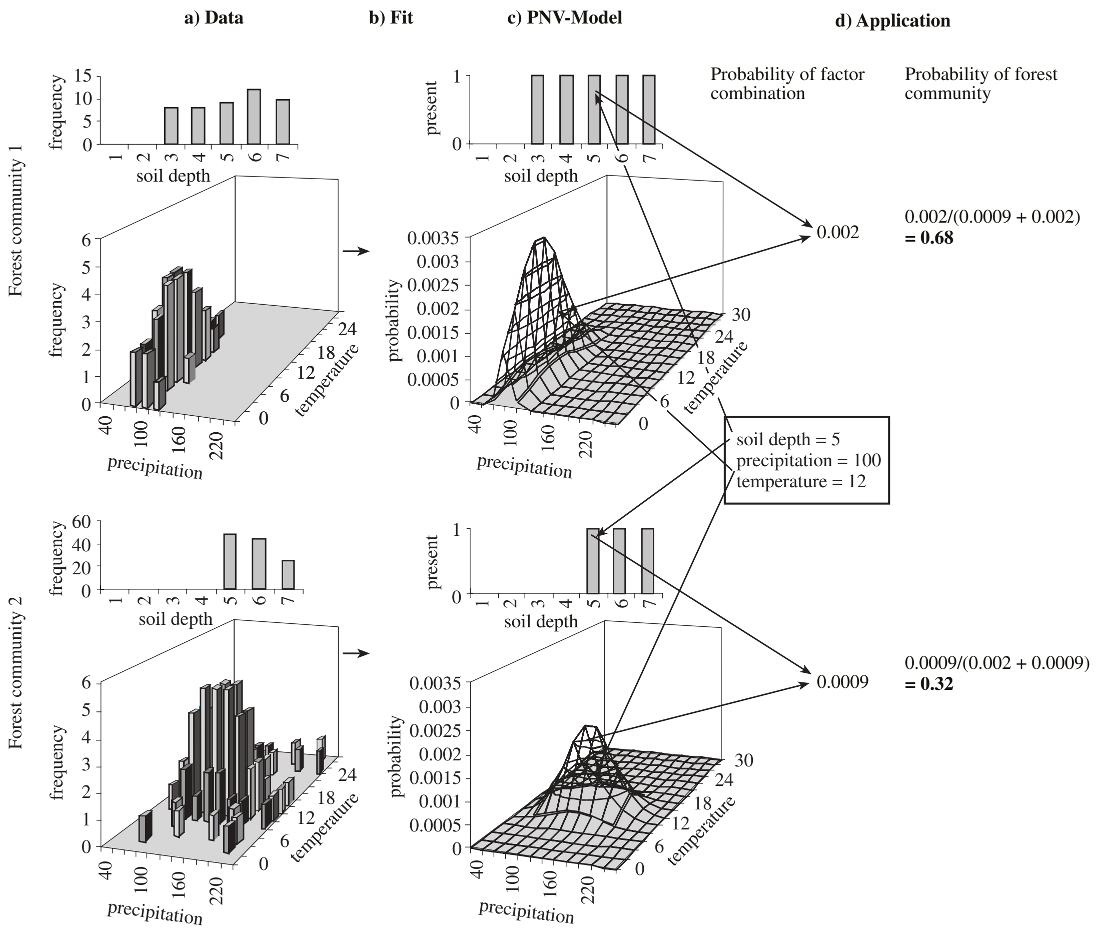

Figure 4. Principle of the PNV model (BRZEZIECKI *et al.* 1993; KIENAST *et al.* 1994). From the occurrence frequency of the forest community for certain factor combinations (a), the probability distributions are estimated (c). By using the Bayes theorem, the probability is determined that this forest community occurs for a certain factor combination (d).

Table 7. Classification of the forest communities according to ELLENBERG and KLÖTZLI (1972) in 6 PNV-classes when the PNV models of BRZEZIECKI et al.(1993) were used in the NFI.

Forest community in the NFI2	Forest community according to Ellenberg and Klötzli
Beech forests	1–17
Beech-fir forests	18–21
Other broadleaf forests	22–45
Spruce-fir forests	46–52
Spruce forest and larch- Cembran pine forest	53–60
Scotch-pine forest	61–71

3.1.3 Discussion, Outlook

Instead of using primary factors that were difficult to assess, easier to assess secondary factors were employed to a large degree. For example, the elevation was used to approximate temperature, which in turn was an indicator for the primary factor ”heat”. Nonetheless, the sole utilization of such secondary factors involves certain problems.

The relationship between the primary and a certain secondary factor is, strictly speaking, only valid for those regions and dates where and when they were assessed. The relationship can not be assumed to be constant in time and space.

It is possible, for example, to use on a certain date and in a certain region, the elevation as an approximation for the temperature. However, the temperature characteristic for a certain elevation increases with decreasing latitude; also, the temperature increases due to other influences such as climate change. It is also possible that the anthropogenic nitrogen input changes the nutrient supply (primary factor). The acidity of the bedrock, which is used as an approximation of the nutrient supply, however, does not change.

It is therefore increasingly desirable to determine primary factors or factors that could be used to calculate primary factors with the help of the laws of physics. An example is the daily sum of heat which can be interpolated using the daily average temperature and the daily temperature amplitude of the closest climate stations and be further modified with the local exposition and slope.

Since forests can react with sensitivity to factors that change over time (e.g., the climate) (BENISTON and INNES 1998; GROTE *et al.* 1998; LASCH *et al.* 1998), information regarding the variability and changes throughout time should be provided.

The Soil Capability Map of Switzerland represents, for the moment, the only information with complete coverage of the soil properties within Switzerland. Small-scale variations of the soil properties are not reflected in the map because of its coarse resolution. In addition, it neglects completely the influence of biological processes, such as the decomposition of organic material in the soil. Supplemented by measurements of numerous soil samples within Switzerland, the map should provide more exact information in the future. Measurements that could also provide information about the small-scale variability would also be desirable.

The approaches that were chosen for the second NFI that determined relevant factor combinations have the advantage that they are: 1) easy to implement, 2) based on extensive data, and 3) do not require any previous knowledge about the processes in the ecosystem.

They are partly based on the concept of forest communities. From the assessed composition of the herbaceous layer, the potential natural vegetation (PNV) was inferred with this model. That is the vegetation that would be present in an equilibrium (climax) without any human influence (since the last ice age) and with constant environmental conditions (e.g., without climate change) (according to TÜXEN 1956). Nevertheless, the herbaceous layer is in a strict sense only a reliable indicator for the tree layer composition in natural forest which is in an equilibrium state (see also WILDI and KRÜSI 1992). The reason for this is because the herbaceous layer composition is influenced, just as the tree layer, by the site conditions, but the tree layer composition also influences the herbaceous layer (p. 139, ELLENBERG 1986). The tree layer composition, however, changes during the succession and because of human interference.

This problem was avoided by using, for the most part, only phytosociological assessments from near-natural, mature forests for the analysis of the site index model, the altitudinal vegetation zone model, and the PNV model.

A new method could consist of using ecosystem process models to select certain forest relevant factor combinations from several individual factors (e.g., temperature and precipitation). Some of these could be, for example, bioclimatic variables, including the drought stress, which can be determined from climate and soil factors with dynamic forest models (BUGMANN 1996; KRÄUCHI and KIENAST 1993; LISCHKE *et al.* 1998) and which influence the growth, mortality, and establishment of trees. With such bioclimatic indicators, it would be possible to stratify the NFI data in an ecologically appropriate way, which would allow the comparison of data with forest development simulations (LISCHKE 1998; LÖFFLER and LISCHKE 2001). Ecosystem process models could also be used to determine, from a multitude of sources, the most important factors by conducting a sensitivity analysis. These approaches could also help to assess how discrete the factor space needs to be.

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3.2 Estimation of Standing Timber, Growth and Cut

Edgar Kaufmann

3.2.1 Introduction

The basis for the standing timber estimation in the NFI are the individual tree volumes, which are estimated with the help of allometric equations. Tree stems are very different in their form. Estimations of the bole volume that are based only on the diameter at breast height $d_{1.3}$ are, therefore, considerably less precise than estimations that are also based on additional measurements of the tree height (H) and on an upper stem diameter. A higher estimation precision requires an augmented expenditure for the measurements.

Whereas the $d_{1.3}$ of all trees was measured in the NFI, an upper diameter (d_7, diameter at 7 meter height) and the tree height were only measured on a subsample, the so-called tariff trees. The volume estimations of the tariff trees that were based on these three measurements ($Y_i = f(d_{1.3},\ d_7,\ H)$) were used to derive tariff functions. The tariff functions estimate individual tree volumes depending only on one measurement variable (the $d_{1.3}$), but additionally on various tree, stand, and site attributes. To take three measurements from all trees for volume estimation is not efficient, since the gain in precision is small compared to the expenditure (KAUFMANN 1993; MANDALLAZ 1995; 1997).

In the first NFI, four trees per sample plot were measured on average (i.e. slightly more than one third of all trees) in a sector of 0 to 150 gon of the plots (ZINGG and BACHOFEN 1988). In the second NFI, on average two trees per plot were randomly chosen as tariff trees in this sector. The selection probability was proportional to $d_{1.3}^2$ (KAUFMANN 1993). For the timber assortment, according to the Swiss timber trade customs (Forstwirtschaftliche Zentralstelle 1976), tree stems are broken down into commercial assortments with the help of taper equations, which continuously describe a stem profile from the ground to the top.

3.2.2 Functions for the Estimation of Individual Tree Volumes

3.2.2.1 Bole Volume Functions

The bole volume functions of the NFI estimate the total overbark bole volume of a tree depending on the $d_{1.3}$, the d_7 and the tree height. Proportions of merchantable assortments are estimated with the help of taper equations (Chapter 3.2.6.1), which describe a stem profile depending on the same three variables. It is, of course, possible to estimate bole volumes with taper equations. Bole volume functions, which estimate the volume depending on the measured variables directly, are by far more simple and usually more precise than taper equations (BIGING 1984; KAUFMANN 1993). As the basis for the estimation of standing volume, growth, and cut both taper equations, as well as bole volume functions, were therefore developed for the NFI.

Measured variables

Since the three-parameter volume functions ($Y_i = f\left(d_{1,3}, upper\ diameter, H\right)$) are by far more precise than two-parameter functions ($Y_i = f(d_{1.3},\ H)$), and since the precision requirement is very high in large-scale inventories in most of the European national inventories, the tree height and an upper diameter of at least some of the trees are measured. Stem forms can be precisely differentiated when a diameter in approximately 30% of the tree height (BRAUN 1969; KUBLIN and SCHARNAGL 1988; POLLANSCHÜTZ 1965) is measured. SCHMID-HAAS and WINZELER (1981) and WINZELER (1986) suggested that a measurement of an upper diameter at a height of 7 m with the use of the Finnish caliper (upper stem caliper), combined with a tree height measurement using the dendrometer “Christen”, are most suitable when the expenditure for the measurements, the expected measurement error and the estimation precision of three-parameter volume functions are all considered.

This measuring method, which was developed in the 1960's for the inventory of Swiss forest enterprises (SCHMID-HAAS *et al.* 1993) was, therefore, adopted for the NFI. Research conducted by WINZELER (1986) as well as the results from the NFI check assessment (Chapter 2.9) confirmed that the three variables can be measured without bias when using the instruments mentioned above.

Overbark bole volume functions

The following functions were derived mainly with the data from approximately 38,000 trees that were measured during the last decades in 2-meter sections in the course of the forest growth and yield studies at the WSL. Since these sample trees did not cover the whole range of stem forms found in the NFI, 500 additional trees (especially species such as spruce, larch, and beech) with extreme form ratios ($d_7/d_{1.3}$ and $H/d_{1.3}$) were measured.

Spruce: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot d_{7i}^3 + b_4 \cdot H_i \quad (1)$$

Fir: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i} + b_3 \cdot d_{1.3i}^2 + b_4 \cdot d_{1.3i}^3 \cdot H_i + b_5 \cdot H_i^4 \quad (2)$$

Pine: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i} + b_3 \cdot d_{1.3i}^2 + b_4 \cdot d_{1.3i}^3 H_i \quad (3)$$

Larch: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot H_i^2 \quad (4)$$

Douglas fir: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot d_{1.3i}^3 + b_4 \cdot d_{1.3i}^2 \cdot H_i^2 \quad (5)$$

Coniferous trees (all species):

$$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot d_{7i}^2 + b_4 \cdot d_{7i}^3 + b_5 \cdot d_{1.3i} H_i^3 \quad (6)$$

Beech: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot d_{7i}^3 + b_4 \cdot d_{1.3i}^3 \cdot H_i \quad (7)$$

Oak: $$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i}^2 + b_3 \cdot d_{1.3i}^3 + b_4 \cdot d_{1.3i}^3 \cdot H_i \quad (8)$$

Deciduous trees (all species):

$$Y_i = b_0 + b_1 \cdot d_{7i}^2 H_i + b_2 \cdot d_{1.3i} + b_3 \cdot d_{1.3i}^2 + b_4 \cdot d_{7i}^2 \quad (9)$$

where:
Y_i: Bole volume including bark in m^3
$d_{1.3}$: Diameter at breast height in meters
d_7: Diameter at 7 meter heights in meters
H: Tree height in meters

The coefficients of the functions are shown in Table 1. The regressor variables of the function for species spruce presented above correspond to a model by WINZELER (1986); those for species fir correspond to a model by HOFFMANN (1984). All regression coefficients of all functions are different from zero at the 95% level (t-statistics). The fewest possible number of regressor variables were included in the functions. All of these improved the model substantially.

Table 1. Coefficients of the bole volume functions.

	b0	b1	b2	b3	b4	b5
Spruce	0.029504	0.46756	2.43885	–5.74664	–0.001826	
Fir	0.039594	0.35832	–0.39142	3.75195	–0.013314	1.62E-07
Scotch Pine	0.055349	0.40341	–0.63535	4.84573	–0.10114	
Larch	–0.0173	0.36366	2.49123	0.000107		
Douglas fir	0.013166	0.35079	2.67531	–2.95083	0.001096	
Conifers	0.008486	0.5436	2.8898	–1.94043	–4.93601	1.33E-05
Beech	0.002542	0.39466	2.56612	–3.67034	0.03567	
Oak	–0.026759	0.31686	5.01484	–7.71408	0.19704	
Broadleaf	–0.021786	0.39992	0.28036	2.30656	–1.20368	

Validation of the Bole Volume Functions

The behavior of the functions, when one measured variable increases and both of the others remain unchanged, can be investigated with the help of partial differentials. The partial derivatives, with respect to $d_{1.3}$, d_7, and H of all of the bole volume functions for all possible $d_{1.3}$-d_7-H combinations in the NFI1 were, apart from a few exceptions ($\partial v/\partial H$ for spruce and fir for trees with $d_7 < 6$ cm), all positive. The volume of a tree almost always increases, therefore, when a predictor variable increases, apart from some rare exceptions.

The functions are very sensitive to changes in the d_7. Measurement errors of the d_7 influence the volume estimation more than the ones of the $d_{1.3}$. It seems reasonable to develop volume functions that are sensitive to those predictor variables which are measured most precisely. But, if in addition to the measurement errors the model precision (i.e. the random error of a volume function) is considered, it is obvious that a d_7 sensitive function estimates a bole volume more precisely than a $d_{1.3}$ sensitive function.

The reason for this is because the d_7 explains more variation than the $d_{1.3}$. This fact is shown in the following by comparing two volume functions for spruce (Functions 1 and 2). Function 1 (the function used in the NFI) is sensitive to changes of the d_7. Function 2 reacts most sensitively to changes in $d_{1.3}$.

Function 1:

$$Y_i = 0.029504 + 0.46756\, d_7^2\, H + 2.43885\, d_{1.3}^2 - 5.74664\, d_7^3 - 0.0018265\, H \qquad (1)$$

Function 2:

$$Y_i = -0.052455 + 0.098718\, d_{1.3}^2\, H - 2.62032\, d_{1.3} + 12.9122\, d_{1.3}\, d_7 + 0.020145\, H \qquad (10)$$

The residual variance components, which are due to the random measurement errors of the input variables, were estimated with a first order Taylor series expansion (KAUFMANN 1999). The random volume estimation error is composed of the measurement errors of the input variables and the model error (variance of the residuals), as it is shown in Figure 1. The variance components stemming from the measurement errors are the averages of 300 replications of stochastic simulations. The measurement errors used in the simulations correspond to those observed in the check assessment of the NFI (Chapter 2.9 WINZELER 1988).

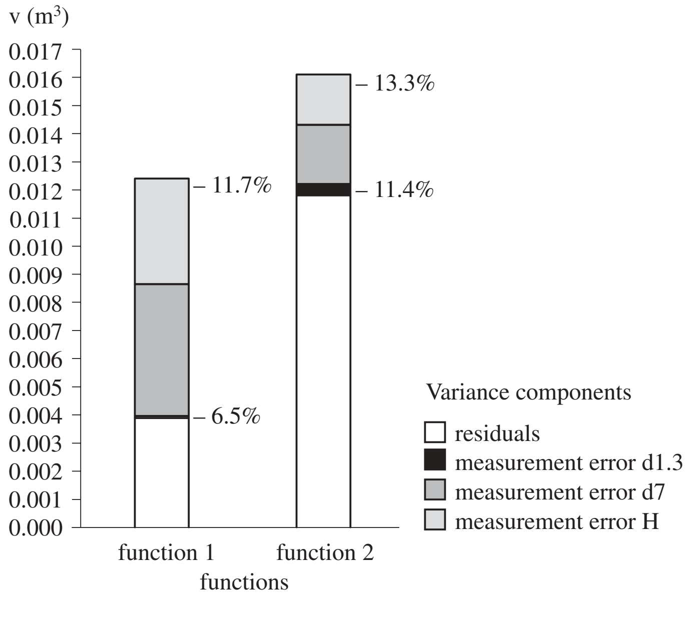

Figure 1. Error components (variances in m^3) of the bole volume functions 1 and 2 for spruce: measurement errors of $d_{1.3}$, d_7 and h as well as model prediction errors.

Due to the higher sensitivity of Function 1 to changes in d_7, the d_7-measurement error has a stronger affect here than in Function 2. The model error (i.e. the standard deviation of the residuals, of 11.4% of the mean volume for Function 2), is higher than the one for Function 1 with 6.5%. This is due to the fact that the $d_{1.3}$, which is not able to explain as much of the variation for the volume estimation as the d_7, has a strong influence in Function 2. The total random error of 13.3% of the mean volume for Function 2 is, despite the smaller influence of the measurement error of the d_7 and the tree height, higher than for Function 1. Therefore, Function 1 gives more precise volume estimates than Function 2, even though the d_7 is measured with a higher random error than the $d_{1.3}$.

For all tree species, the d_7 is able to explain more of the variation for the stem volume than the $d_{1.3}$. Estimations of the standing timber with the d_7 sensitive NFI volume functions presented in chapter 3.2.2.1 are, therefore, more precise than with the $d_{1.3}$ sensitive functions. Using 1,000 trees, an estimation precision of 0.3% (standard error of the mean) was determined empirically (simulation with 50 replications) for the NFI volume functions, when random measurement errors, model errors and excess errors (see below) are taken into account.

How well the bole volume functions fit the sample tree data is presented in Table 2. The average residual (ar) in percentage of the mean volume (average deviation of the estimated volume with the help of a function from the volume calculated based on the diameter measurements in 2 m sections) is displayed in the upper portion of each cell. The standard deviation of the residuals (in percentage of the mean) is given within parentheses. The probability p_t of the t-distribution, that a mean estimated value deviates systematically from the true value, is shown in the middle of each cell. The bole volume functions explain a very large proportion of the individual tree volume variance (all coefficients of determination R^2>98.5%).

Table 2. Goodness-of-fit of the bole volume functions: ar: average residual ($\Sigma(\hat{x}_i - x_i) / n$) and standard deviation of the residuals (rs, in parenthesis) in percentage of the mean. p_t: Probability value of the t-distribution. n: Number of trees. R^2: Coefficient of determination.

		d1.3 (cm)								
		12.–23	24–35	36–47	48–59	60–71	72–83	84–95	96–107	total
Spruce	ar (sr)	0.0 (3.61)	0.0 (3.61)	0.1 (3.95)	–0.2 (4.45)	–0.3 (5.08)	0.9 (3.84)	0.5 (3.55)	0.0 (3.79)	0.0 (6.53)
(R^2: 99.7%)	p_t	0.55	0.75	0.31	0.2	0.38	0.07	----	----	0.88
	n	6622	3521	1780	779	253	60	11	3	13029
Fir	ar (sr)	1.4 (5.00)	0 (4.58)	–0.1 (4.98)	–0.3 (4.90)	0.2 (4.91)	0.1 (5.18)	0.4 (4.46)	0.5 (3.89)	0.0 (7.15)
(R^2: 99.6%)	p_t	0	0.67	0.48	0.12	0.44	0.79	0.47	0.55	0.7
	n	1628	2199	1495	848	423	158	67	19	6848
Scotch pine	ar (sr)	0.7 (4.74)	0.0 (3.92)	–0.4 (5.03)	1.1 (7.86)	-2.5	-1.4			–0.1 (6.16)
(R^2: 99.3%)	p_t	0	0.92	0.13	0.45	----	----			0.73
	n	487	789	334	31	2	1			1644
Larch	ar (sr)	0.8 (4.72)	0.1 (3.87)	–0.2 (4.10)	0.0 (4.57)	0.2 (3.96)	–0.3 (6.47)	0.7 (12.02)	0.9	0.0 (6.15)
(R^2: 99.4%)	p_t	0	0.64	0.28	0.98	0.56	0.8	----	----	0.98
	n	303	454	494	232	102	26	5	1	1617
Dougas Fir	ar (sr)	–0.8 (4.32)	–0.1 (4.21)	0.3 (3.83)	1.1 (3.15)	0.9 (4.11)	-1			–0.1 (4.76)
(R^2: 99.7%)	p_t	0.01	0.69	0.35	0.1	----	----			0.47
	n	169	260	108	23	5	2			567
Conifers	ar (sr)	0.5 (4.40)	–0.3 (4.74)	0.1 (5.14)	0.2 (5.41)	0.3 (5.49)	–0.1 (5.87)	–0.9 (5.25)	–1.0 (4.26)	0.0 (8.17)
(R^2: 99.5%)	p_t	0	0	0.29	0.07	0.2	0.85	0.14	0.27	0.54
	n	9739	7686	4418	1955	794	248	83	23	24957
Beech	ar (sr)	–0.1 (5.06)	–0.1 (5.69)	0.2 (7.43)	0.2 (9.24)	-0.4 (10.61)	–2.7 (9.50)			0.0 (11.29)
(R^2: 98.7%)	p_t	0.19	0.34	0.43	0.68	0.79				0.91
	n	2515	2188	863	244	46	7			5863
Oak	ar (sr)	–0.9 (5.21)	0.5 (4.96)	–0.8 (5.31)	1.0 (7.09)	0.7 (4.92)	–0.1 (3.55)	-1		0.1 (7.80)
(R^2: 99.5%)	p_t	0	0.02	0.02	0.17	0.4				0.71
	n	621	578	254	98	37	9	2		1599
Broadleaf	ar (sr)	0.0 (5.14)	–0.2 (5.70)	0.1 (7.28)	0.9 (8.95)	–0.9 (9.03)	–2.5 (6.82)	–4.6		0.0 (10.88)
(R^2: 98.9%)	p_t	0.96	0.14	0.55	0.37	0.16				0.89
	n	3424	2886	1242	397	89	16	2		8056

All bole volume functions estimate the mean of the sample tree volume unbiased at a 95% level (p_t>0.05). The standard deviation of the residuals ranges from 6.15% (larch) to 11.35% (beech) of the mean. For all 12 cm diameter classes that contain at least 30 sample trees, the maximum systematic deviation from the mean of the sample trees amounted to 1.4%. The average deviations in the range from –0.9 to +1.4%, which in themselves are not very large, are not random (p_t<0.05) for some functions in the lowest or second lowest diameter class. In these classes, the number of trees is very large.

The goodness-of-fit is by itself not a sufficient measure for the qualitative assessment of a function. During the validation, the behavior of the function should also be tested with data that were not used for its derivation. One way to validate is to set aside a portion of the available data for the function verification. For example, if only 50% of the data are used for the function derivation of the tree species spruce, and the function is then tested with the other part of the data, the standard deviation of the residuals increases slightly from 6.53% to 6.58% of the mean.

Another technique is the cross-validation procedure that repeatedly estimates the function parameters. For each simulation run, a group of trees are left out of the analysis and are used for the model validation. Each tree is randomly assigned to a group. With this, each tree is left out exactly once. The number of simulations equals the number of groups. The volume of each sample tree is predicted by a function which was derived without that tree. For the cross-validation of the bole volume functions, 5% of the trees were left out at each simulation run. The increase of the residual variance resulting from this – the so-called excess error – is very small for spruce (0.3%); between 1.8% and 2.2% for fir, pine, larch, and oak, slightly higher for beech (3.5%) and highest for Douglas fir (5.1%). With an excess error of this order, no considerable increase of the model error is expected when the functions are applied to independent data.

Individual tree volumes can be more precisely estimated with three variables, since stem form differences are easily distinguishable with the help of an upper diameter measurement. A study of the function for the tree species spruce, which is very prominent in all production regions and altitudes, showed that by using regional volume functions, the gain in precision was negligible. The **R**oot of the **M**ean **S**quared **E**rror (RMSE, that is the square root of the mean quadratic error) decreased only by about 2%, from 0.0841m^3 to 0.0824 m^3. For the analysis of covariance with classification by region or altitude, the partial F-values for the classification variables (regions) are many times smaller than for the weakest regressor variable. Consequently, regional functions were not derived.

3.2.2.2 Tariff Functions

For most of the NFI sample trees (82% in the second NFI) only the diameter at breast height $d_{1.3}$ was measured. For the estimation of standing timber and increments, so called tariff-functions were derived. These functions estimate the bole volume of a tree with the help of only one measured variable (i.e., the $d_{1.3}$). Similarly, the input variables d_7 and H for the taper equation (Chapter 3.2.6.1) were estimated with tariff functions that had the same form as the ones presented below.

Standard Model

Suitable models for tariff functions are power functions (higher order polynomial models) or exponential functions, such as the ones proposed by HOFFMANN (1982) or PARDÉ and BOUCHON (1988). The following basic form of an exponential model for the bole volume $\hat{Y}_i$ of a single tree was developed by HOFFMANN (1982) for employment in Swiss enterprise inventories:

$$\hat{Y}_i = \exp(b_0 + b_1 * \ln(d_{1.3i}) + b_2 * \ln^4(d_{1.3i})) \qquad (11)$$

The estimation of bole volumes for the entire country with the $d_{1.3}$ as the only explanatory variable in the model is not precise enough. For a function of this type, the standard deviation of the residuals amounts to 37.8% of the mean. It is reduced to 34.0% if a separate function is derived for each main tree species. A further reduction to 31.3% results if production regions are distinguished. This variation finally achieves 26.3% for the tariff functions developed during the NFI. In addition to the $d_{1.3}$, individual tree, stand and site attributes are used as explanatory variables here. The functions are presented in the following.

NFI Tariff Functions

The relevant explanatory variables for bole volume prediction were identified with the help of an analysis of covariance. For this, the tariff functions were linearized using a logarithmic transformation. The analysis of covariance can be regarded as a hybrid between linear regression and analysis of variance. Several different regression surfaces are compared with different intercepts and slopes for each continuous regressor variable (COOK and CAMPBELL 1979). The classifying attributes "tree species", "production region", "storey to which a tree belongs", and "bifurcation of a stem" were found to have a significant influence (F-statistics, $P_F<0.05$). For the continuous variables, significant influence was found for, apart from the $d_{1.3}$, the elevation above sea level, the site quality and the d_{dom} (see equation 12).

The following form of an exponential function, which was used in a similar way by WINZELER (1986) for estimating the standing volume in the first NFI, proved to be suitable.

$$\hat{Y}_{zk} = \exp(b_{0zi} + b_{1zi} \cdot \ln(d_{1.3k}) + b_{2zi} \cdot \ln^4(d_{1.3k}) + \sum_{j=3}^{7} b_{jzi} \cdot B_{jk}) \tag{12}$$

Indices:

z: Type of dependent variable (1..3)

k: Individual tree

i: Tariff number (1..30) (see Table 3)

j: Additional individual tree and sample plot attributes (3..7)

Variables:

$\hat{Y}_{zk}$: Individual tree variable to be predicted:

$\hat{Y}_{1k}$: Tariff volume (stem wood with bark)

$\hat{Y}_{2k}$: d_7

$\hat{Y}_{3k}$: Tree height

b_0-b_7: Model coefficients (Table 4 for bole volume at the time of the first NFI)

B: Additional individual tree and sample plot attributes:

B_{3k}: Site quality (GWL: "**G**esamt**w**uchs**l**eistung"): Total increment in kilogram dry matter per hectare and year (see Chapter 3.1)

B_{4k}: d_{dom}: Average $d_{1.3}$ of the hundred trees having the largest $d_{1.3}$ per hectare in cm

B_{5k}: Bifurcation of a stem (1: yes / 0: no)

B_{6k}: Elevation above sea level (m)

B_{7k}: Storey to which a tree belongs (0: tree belonging to the upper storey/ 1: tree not belonging to the upper storey)

The coefficients b_0–b_7 were estimated using non-linear regression (Gauss-Newton method, SAS 1990) with the help of the tariff tree volumes. These volumes were estimated with the bole volume functions (Equation 1–9). The coefficients of the tariff functions for the time of the first NFI can be found in Table 4. The goodness-of-fit for the tariff functions (average residual ar, p-value of the t-distribution p_t, coefficients of determination R^2, for explanation see Table 2) are presented in Table 5.

Table 3. Tariff numbers in NFI for the bole volume, d_7, H, and increment functions.

Tariff number	Tree species	Production reggion
201	Spruce	Jura
202		Plateau
203		Prealps
204		Alps
205		Southern Alps
206	Fir	Jura
207		Plateau
208		Prealps
209		Alps / Southern Alps
210	Scotch Pine	Jura
211		Plateau
212		Prealps / Alps /Southern Alps
213	Larch	Jura / Plateau / Prealps / Alps
214		Southern Alps
215	Other conifers	
216	Beech	Jura
217		Plateau
218		Prealps
219		Alps
220		Southern Alps
221	Oak (all species)	Plateau
222		Jura/Voralpen/Alpen/Alpen-Südseite
223	Sycamore maple / plane	Jura / Plateau
224		Prealps / Alps /Southern Alps
225	Ash	Plateau
226		Jura / Prealps / Alps /Southern Alps
227	Chestnut	
228	Other boradleaf	Jura/Plateau
229		Prealps / Alps
230		Southern Alps

Tariff curves shift with the increasing development stage of a stand, which means that a tree in a higher stage of development has a larger stem volume than a tree with the same $d_{1.3}$ in a lower development stage (Figure 2). The stage of development is defined by a d_{dom} range (ZINGG and BACHOFEN 1988). The development stage was included in the tariff functions as a continuous variable in the form of the d_{dom}, which was estimated with the help of the trees on a sample plot. Studies of the NFI data set have shown that a d_{dom}, which is estimated with the help of the sample trees, is a suitable measure for the development stage of a stand in which a sample plot is located.

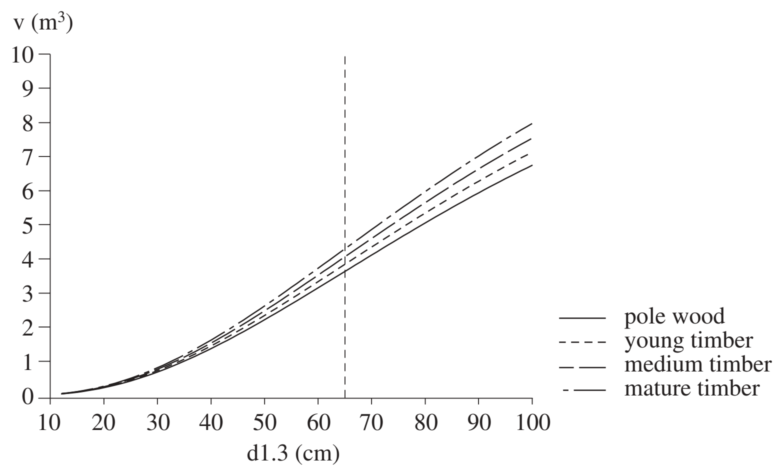

Figure 2. Tariff curves for species spruce in the alpine region for medium site quality in mountainous elevations, by development stage.

Tariff functions with $b_2<0$ (see Table 4) have an inflection point. This point is located at the culmination point of the volume increment. The reason for an inflection point is that the height growth of an individual tree culminates long before the $d_{1.3}$ increment and that trees with very large $d_{1.3}$ have, on average, a smaller form quotient ($d_7/d_{1.3}$) than the other trees. An inflection point prevents volumes of trees with a very large $d_{1.3}$ from being severely overestimated. Figure 3 shows two tariff curves (for spruce, upper storey, Alps, medium site quality, d_{dom}= 55 cm), which were derived with the data set of NFI tariff sample trees. One curve does not include the inflection point (i.e. without the term $\ln^4(d_{1.3})$), and another one includes the inflection point (i.e. with the term $\ln^4(d_{1.3})$ and $b_2<0$). The curve without this term increases very steeply in the upper diameter range, while the curve with an inflection point at 65 cm, flattens out and gives realistic volume estimates for the diameter range up to 200 cm.

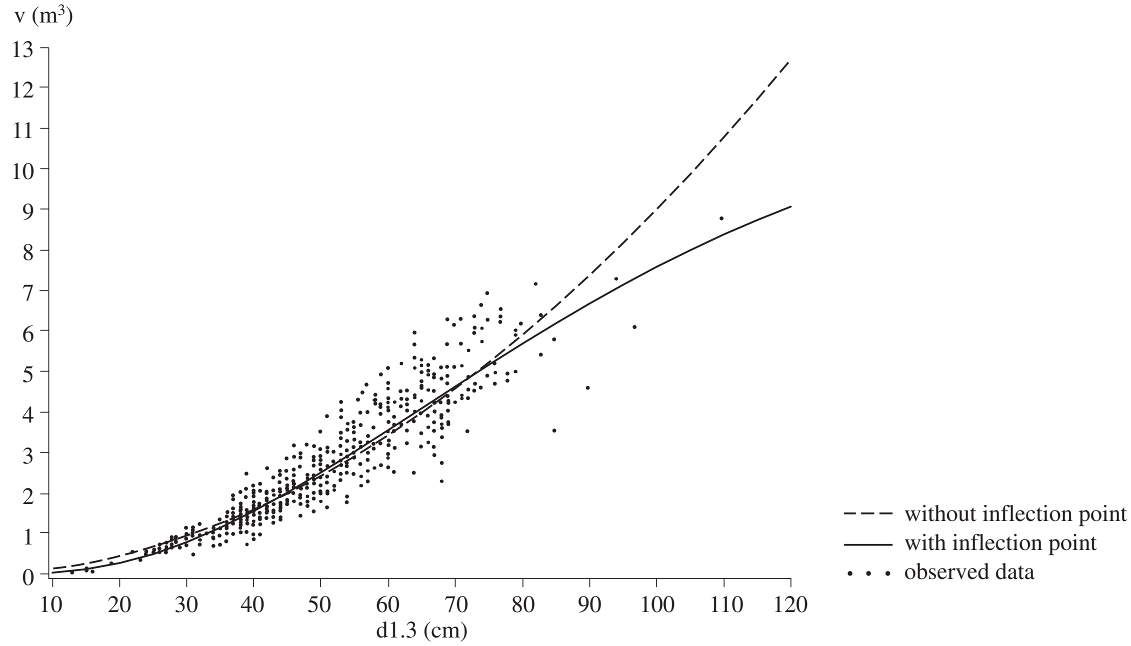

Figure 3. Tariff curves for spruce in the alpine region with and without inflection point.

When deriving the tariff functions, the fact was ignored that the sample trees were not selected completely independent from each other, but in clusters (sample plots). Since trees within one stand usually have similar forms, it is reasonable to assume that on a sample plot the residuals of the tariff functions are correlated with each other. This was indeed the case. Since the sample size in the NFI was large and the cluster sizes were small, the selection in clusters had no influence on the values of the function parameters as it was found in the study. The confidence intervals of the parameters, however, become slightly larger. BRIGGS and CUNIA (1982) came to the same conclusion in their study.

Table 4. Coefficients of the NFI1 tariff functions for the bole volume.

Tariff Number	b0	b1	b2	b3	b4	b5	b6	b7
201	–9.693932	2.875716	–0.003608	2.38E-05	0.006454	–0.354239	–0.000190	–0.293326
202	–10.19071	3.011815	–0.004360	5.66E-05	0.005186	0	–5.09E-05	– 0.124890
203	– 10.40762	3.148954	– 0.004765	3.67E-05	0.005617	– 0.292850	– 0.000207	– 0.345357
204	–11.22559	3.432392	–0.005889	3.39E-05	0.005502	–0.283506	–0.000226	–0.372618
205	–11.02461	3.208716	–0.005054	1.15564E	0.003814	–0.253676	–4.37E-05	–0.368829
206	–11.14165	3.390109	–0.005383	0	0.005589	–0.087306	–0.000157	–0.285632
207	–8.373972	2.428760	–0.002026	3.13E-05	0.005209	0	0	–0.266245
208	–9.127325	2.735734	–0.002371	2.53E-05	0	–0.221676	–5.74E-05	–0.228611
209	–13.29496	4.119043	–0.007279	3.69E-06	0.005529	–0.301906	–0.000352	0
210	–6.819805	1.795885	0.002160	1.97E-05	0.006278	–0.230662	–0.000452	–0.338596
211	–10.72603	3.230300	–0.004654	0	0.002566	0	0	0
212	–10.14396	2.772788	–0.003579	7.62E-05	0.013275	–0.157258	0	–0.309897
213	–10.99258	3.264363	–0.005054	7.14E-05	0.003558	–0.154775	–0.000124	0
214	–10.46496	3.186909	–0.004321	0	0.003074	–0.555413	–0.000304	0
215	–10.14301	3.161973	–0.004693	0	0.004242	–0.137419	–0.000482	–0.388137
216	–9.760576	2.838556	–0.003247	4.15E-05	0.006981	–0.190014	–0.000152	–0.397608
217	–10.86935	3.209637	–0.004539	5.83E-05	0.003261	–0.088868	0	–0.437208
218	–10.59635	3.112840	–0.004627	4.70E-05	0.008531	–0.289871	–0.000150	–0.278017
219	–11.03685	3.277674	–0.005875	3.35E-05	0.014177	–0.125906	–0.000395	–0.517794
220	–8.115184	2.171664	–0.000869	0	0.007345	–0.220946	0	–0.179818
221	–11.03194	3.359299	–0.005177	0	0.002811	0	–0.000202	0
222	–8.957069	2.503072	–0.002034	7.18E-05	0.007726	–0.347306	–0.000375	0
223	–8.015882	2.179587	–9.05E-05	5.85E-05	0.006317	–0.130022	–0.000225	–0.248277
224	–10.67774	3.402548	–0.007804	0	0.005672	–0.113936	–0.000456	–0.148527
225	–11.12480	3.271653	–0.005234	9.41E-05	0.004465	–0.257368	–0.000139	0
226	–8.661268	2.437937	–0.001629	5.90E-05	0.008327	–0.169188	–0.000342	–0.171477
227	–6.269070	1.663056	5.79063E	0	0	0	–0.000380	–0.333926
228	–9.020448	2.555589	–0.002027	4.39E-05	0.002062	–0.239662	0	–0.214907
229	–7.719545	1.867530	0.002000	5.24E-05	0.010988	–0.274791	0	–0.280542
230	–9.757205	3.338594	–0.006130	–0.000264	0	–0.341705	–0.000510	–0.234645

3.2.2.3 Error Propagation of Stem Volume and Tariff Functions

Random and systematic errors of the volume and tariff functions influence the variance and the expected values of inventory results. The extent of these influences was studied with Monte-Carlo simulations. Table 6 presents the results of a simulation study, which investigated the influences of random measurement errors of the input variables $d_{1.3}$, d_7, and H, and of random prediction errors of the bole volume functions on the standard error of the total volume. The volume estimations are based on the approximately 11,000 sample plots of the first NFI. The generated measurement errors corresponded to those observed in the control measurements in the NFI (Chapter 2.9 WINZELER 1988) and the residuals of the bole volume functions to those presented in table 2.

On average, two tariff sample trees per plot were chosen with the selection method used in the second NFI (see Chapter 3.2.4). The volume was predicted once with the tariff volume (Table 6, columns A) and once with the "weighted residual" (WR) technique (Table 6, columns B, description of the expansion technique see Chapter 3.2.3). Furthermore, it was assumed that the residuals of the bole volume functions were independent of each other within one sample plot (Table 6, row 2) and, that these residuals were correlated with each other within one sample plot. That is to say, all generated residuals within one sample plot were positive or negative each time, but overall they did not differ from zero (Table 6, row 3).

Table 5. Goodness-of-fit of the tariff functions: ar: average residual ($\Sigma(\hat{x}_i - x_i) / n$) and standard deviation of the residuals (sr, in parenthesis) in percentage of the mean.
p_t: Probability value of the t-distribution. n: Number of trees. R^2: Coefficient of determination.

		d1.3								
		12.-23	24-35	36-47	48-59	60-71	72-83	84-95	96-107	total
Spruce	ar (sr)	-5.9 (27.7)	-0.7 (22.9)	0.3 (18.7)	-0.1 (18.6)	0.1 (18.9)	-1.1 (19.5)	4.4 (23.9)	-4.4 (24.9)	-0.2 (25.3)
(R^2: 92.5%)	p_t	0	0.08	0.16	0.87	0.76	0.25	0.13	0.39	0.41
	n	4994	3682	6022	2683	1738	431	70	24	19647
Fir	ar (sr)	-1.8 (65.3)	-1.2 (20.3)	0.1 (16.5)	0.1 (16.1)	0.2 (14.1)	-0.3 (13.6)	-0.4 (13.3)	-5.2 (15.8)	-0.1 (21.5)
(R^2: 95.7%)	p_t	0.25	0.05	0.75	0.89	0.75	0.81	0.89	0.46	0.7
	n	1781	1095	1612	648	497	154	28	6	5826
Scotch Pine	ar (sr)	4.2 (25.8)	-0.4 (20.1)	-1.0 (17.3)	1.7 (14.1)	-1.0 (15.9)	-2.7 (9.7)	5.7		0.0 (20.3)
(R^2: 94.8%)	p_t	0	0.76	0.17	0.08	0.61	0.63	--		0.99
	n	448	309	573	202	61	4	1		1598
Larch	ar (sr)	2.6 (36.4)	0.1 (28.1)	0.4 (22.6)	-0.8 (21.5)	-0.2 (20.1)	-0.5 (22.9)	3.3 (16.8)	4.8 (17.9)	0.0 (27.6)
(R^2: 91.3%)	p_t	0.12	0.94	0.63	0.51	0.87	0.83	0.36	0.51	0.99
	n	483	372	608	313	282	84	23	7	2174
Conifers	ar (sr)	-12.5 (37.5)	-12.8 (27.8)	-1.0 (25.1)	-0.5 21.5)	1.4 (17.7)	-1.7 (14.3)	-0.5 (6.6)	-2.4 (17.3)	-1.5 (25.1)
(R^2: 95.7%)	p_t	0	0	0.7	0.89	0.61	0.59	0.89	0.8	0.22
	n	124	81	99	45	39	22	4	4	420
Beech	ar (sr)	-8.5 (27.9)	-0.3 (23.6)	0.4 (19.3)	0.5 (17.5)	-1.2 (18.1)	-0.1 (17.9)	5.2 (19.8)	8.1 (25.2)	-0.6 (27.7)
(R^2: 94.6%)	p_t	0	0.59	0.33	0.5	0.24	0.98	0.43	0.73	0.04
	n	3533	1853	1877	607	295	68	10	2	8245
Oak	ar (sr)	0.8	0.4	-3.1	2.2	1.7	-4.2	0.6	9.2	-0.2 (27.1)
(R^2: 95.5%)	p_t	0.54	0.8	0.03	0.26	0.46	0.16	0.91	0.3	0.79
	n	405	186	183	82	68	29	9	3	965
Ash	ar (sr)	-0.2 (25.0)	-2.3 (19.3)	1.1 (19.3)	-1.0 (17.6)	-1.0 (16.9)	1.5 (23.6)			-0.4 (28.1)
(R^2: 94.7%)	p_t	0.83	0.03	0.38	0.69	0.78	0.9			0.61
	n	741	322	225	55	25	5			1373
Maple	ar (sr)	1.7	-1	-1.1	5.8	-4.6	3.2			-0.1 (31.8)
(R^2: 92.5%)	p_t	0.06	0.34	0.49	0.36	0.4	0.62			0.93
	n	735	328	161	30	13	5			1272
Chestnut	ar (sr)	22.5 (26.4)	-4.7 (26.0)	-12.5 (27.5)	-4.5 (29.2)	-3.4 (32.3)	1.5 (33.2)	2.4 (37.2)	11.3 (35.4)	1.3 (62.1)
(R^2: 88.8%)	p_t	0	0.09	0	0.43	0.61	0.82	0.83	0.34	0.57
	n	459	91	61	28	25	25	12	10	719
Other broadleaf	ar (sr)	1.0 (27.6)	-0.4 (25.2)	0.2 (25.2)	0.4 (22.2)	-3.9 (20.0)	10.4 (17.2)	17.4	-4.5 (9.6)	0.2 (39.4)
(R^2: 94.3%)	p_t	0.14	0.79	0.92	0.91	0.34	0.25	--	--	0.83
	n	1583	352	161	42	25	5	1	2	2171

Table 6 demonstrates that the variance between the sample plots is influenced only slightly by the random error of the bole volume functions. The variance increased by only 2.2% (the standard error of the volume by 1.1% respectively) for the worst variant B and the error assumption 2 in Table 6 as compared to the variance, which was determined without considering random error in single tree volume estimation. Similarly, GERTNER and KÖHL (1992) also found that the random error of the three-parameter volume function only slightly affected the standard error of the standing timber in the NFI.

When the WR technique (Chapter 3.2.3) is used, the standard error component caused by the random errors of the tariff functions is completely included in the sampling error. This is not the case when volume is estimated only with the help of tariff functions. The standard error for the total volume increases by 6.9% compared to the volume estimation only with tariff functions when the WR technique is used and random model errors of the bole volume functions are also considered (Table 7, row 2). The standard error increases by 7.3% when, in addition to the WR-technique, random measurement errors are included (Table 7, row 3). It also finally increases by

7.8% when it is additionally assumed that the residuals of the tariff functions within a plot are highly correlated with each other (Table 7, row 4).

In contrast to the effects of the random error components for the individual tree volume estimation, the effects of the systematic errors do not decrease with increasing sample sizes. WINZELER (1986) attached more importance to the systematic measurement error than to the random ones. GERTNER and KÖHL (1992) determined similarly in their study with the tree species spruce that the NFI method of volume estimation is very sensitive with respect to systematic measurement error.

The resulting biases (in percentage of the total volume) of the simulation study (with 10 replications) described above are presented in Figure 4. A systematic error was added here to the individual tree measurements. A systematic measurement error of +0.5 cm for the $d_{1.3}$ led to a volume overestimation of 1.0%. A measurement error of +0.5 cm for the d_7 led to an overestimation of 2.1%, and a tree height measurement error of +0.5 m resulted in an overestimation of 1.6%. Employing the same systematic measurement error, the upper diameter caused a double bias in comparison to the $d_{1.3}$.

Table 6. Propagation of random errors of the NFI bole volume functions. Variances between sample plots (v) and corresponding standard errors (s), caused by random measurement and model prediction errors. Total volume NFI1, random selection of two tariff trees per plot.
Method A: Expansion only with the tariff volumes. Method B: Expansion with the WR technique.
Errors considered:
1. Sampling error
2. Sampling error, random measurement and model prediction errors.
3. Sampling error, random measurement and model prediction errors assuming a maximal correlation of the residuals of the bole volume function within a plot.

Errors considered	A		B	
	v (%)	s (%)	v (%)	s (%)
1	100.0	100.0	100.0	100.0
2	100.2	100.1	101.0	100.5
3	100.6	100.3	102.2	101.1

Table 7. Propagation of random errors of the NFI tariff functions. Variances between sample plots (v) and corresponding standard error (s), caused by random measurement and model prediction errors. Total volume NFI1, random selection of two tariff trees per plot.
Errors considered:
Sampling error.
1. Sampling error
2. Sampling error, random model prediction errors.
3. Sampling error, random measurement and model prediction errors.
4. Sampling error, random measurement and model prediction errors assuming a maximal correlation of the bole volume function residuals within a plot.

Errors considered	v (%)	s (%)
1	100.0	100.0
2	114.3	106.9
3	116.0	107.3
4	116.1	107.8

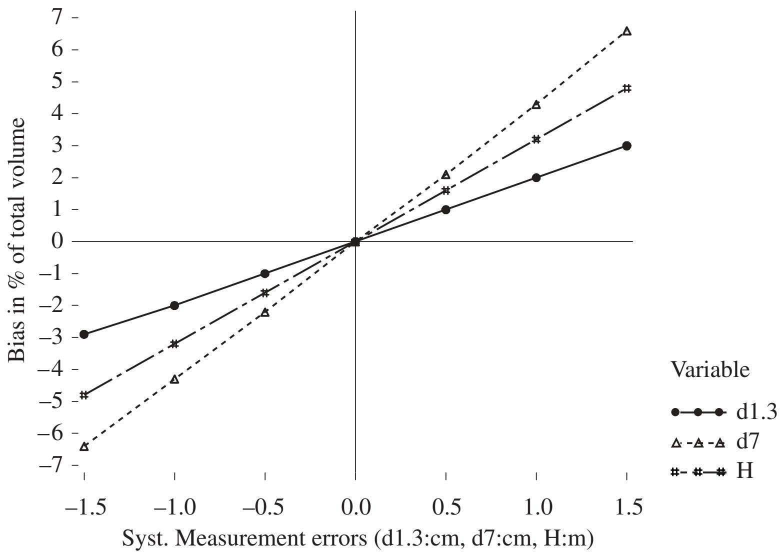

Figure 4. Estimated bias as a result of systematic measurement errors, in percentage of the NFI1 total volume.

3.2.2.4 Functions for Estimating Merchantable Branches and Slash

Merchantable timber includes, apart from the stem, the volume of large branches (with a diameter of at least 7 cm). The proportion (p) of large branch volume (a) to the stem volume over bark (v) is estimated with the help of a logit regression model. The functions were derived with the help of sample tree data from forest yield research plots. The branches of these 12,000 trees were measured.

The ratios $p_i = a_i/v_i$ are estimated using the following logit models:

$$\ln\left(\frac{p_i}{1-p_i}\right) = b_0 + b_1 \cdot d_{1.3i} + b_2 \cdot h1_i + b_3 \cdot h2_i = \text{logit}(p_i) \tag{13}$$

and

$$p_i = \frac{\exp(\text{logit}(p_i))}{1+\exp(\text{logit}(p_i))} \tag{14}$$

where:
b_0–b_3: Regression parameters (Table 8)

$d_{1.3}$: Diameter at breast height in centimeters

h1, h2:	Indicator variable for elevation above sea level
Region Alps:	h1 = 1 for sites between 1000–1500 meters above sea level
Other regions:	h1 = 1 for sites between 600–1250 meters above sea level
Otherwise	h1 = 0
Region Alp:	h2 = 1 for sites above 1500 meters above sea level
Other regions:	h2 = 1 for sites above 1250 meters above sea level
Otherwise	h2 = 0

The proportion of large branches for the species spruce is negligibly small, so the NFI database does not include any large branch volume for spruce. For the remaining conifers and broadleaf species (apart from beech), the large branch proportion is estimated based only on the $d_{1.3}$ (Table 8). For the tree species beech, the regression coefficients additionally differ significantly (likelihood ratio, see below) for the productive regions and for elevation. The significance of parameters was tested with the likelihood ratio test (p. 38, LINDER and BERCHTOLD 1982). The test statistic follows a chi-square distribution. For beech and the other broadleaf species, all parameters are significant ($P\chi^2<0.05$). The effect of the $d_{1.3}$ is not significant for fir ($P\chi^2=0.06$) and clearly not significant ($P\chi^2>>0.05$) for the tree species larch and pine. This means that above a certain diameter, the volume for the large branches increases proportionally with the stem volume.

Table 8. Coefficients of the functions for merchantable branch and slash.

Regions	Species	b0	b1	b2
All regions	Fir	–8.7330758	0.059208154	0
All regions	Larch	–5.8871184	0.010812163	0
All regions	Scotch Pine	–7.7147742	0.072285665	0
Jura	Beech	–4.8322966	0.056314711	0
Plateau	Beech	–5.9903924	0.101889094	0
Prealps, Alps and Southern Alps	Beech	–4.9853383	0.073941728	–0.7056977
All Regions	Other boradleaf	–4.9398872	0.061619224	0

3.2.2.5 Growth Function

Growth functions were needed to estimate the volume of the so called ongrowth trees during the first NFI. Ongrowth trees are the trees that reached the caliper threshold of 35 cm between the two inventories, and were measured only during the second inventory occasion (see Chapter 3.2.5). The cut trees were only recorded during the first inventory occasion; therefore, growth functions were also needed to estimate the increment of the cut trees for the half inventory interval. These functions were an important basis for the scenario models (see Chapter 3.3). A growth function was derived from the inventory data which either predicts a decadal basal area increment of a tree starting from the time of the first inventory occasion, or a corresponding decrement starting from the time of the second inventory occasion (KAUFMANN 1996):

$$\pm \mathrm{BAI} = \mathrm{vz} \cdot \exp[\mathrm{b}_0 + \sum_{j=1}^{6} b_j \cdot B_{ji} + b_7 \cdot (vz+1) \cdot (1-\exp(b_8 \cdot d_{1.3i}) + ..$$

$$.. + b_9 \cdot (vz-1) \cdot (1-\exp(b_{10} \cdot d_{1.3i}))] \qquad (15)$$

$\pm\mathrm{BAI} = \pi/4\ (d_{1.3(2)}^2 - d_{1.3(1)}^2)$: Basal area change in 10 years in m^2

$d_{1.3(2)}$: $d_{1.3}$ at the time of the second inventory occasion
$d_{1.3(1)}$: $d_{1.3}$ at the time of the first inventory occasion
vz: +1 for the prediction of basal area increment in the next 10 years
–1 for the prediction of basal area decrement in the previous 10 years

B_1: BASFPH: Basal area per ha in m^2
B_2: BAL: Basal area of all trees on a sample plot with a larger $d_{1.3}$ than the actually considered tree
BAL is a measure for the competition within a stand
B_3: Site quality (GWL, see Chapter 3.1, 3.2.2.2)
B_4: Elevation above sea level in meters

B_5: Estimated stand age

B_6: Storey membership of a tree (see Chapter 3.2.2.2)

b_0–b_{10}: Model parameters with $0 \le b_8 \le 1$ and $0 \le b_{10} \le 1$ (Table 9)

The form of this growth model is similar to the ones developed by QUICKE et al. (1994) and TECK and HILT (1991). These models also use the competition factor BAL and express the basal area increment as a negative exponential function based on the $d_{1.3}$ ($BAI = b_7 \cdot (1 - \exp(b_8 \cdot d_{1.3}))$). The precision of the growth function for the BAI is low compared to the tariff functions or to the stem volume functions. The R^2 for the tree species spruce, fir, and beech ranges between 40% and 60% for the Plateau, and between 30% and 40% for the Alps. The random measurement error of the $d_{1.3}$, assessment uncertainties of influence factors, and the heterogeneity of stand structures and sites were all too large to explain a diameter change precisely, the more so as a 10 years increment is relatively small. For example, in the Alps the 10 years increment was, on average, 2.8 cm for trees of the upper storey. Nevertheless, the precision of these functions was sufficient for the $d_{1.3}$ extrapolation of cut and ongrowth trees.

For unbiased estimates, bole volume ($v = f(d_{1.3}, d_7, H)$) of ongrowth and cut tariff trees (Chapter 3.2.5) must be extrapolated for the use of the WR technique (Chapter 3.2.3). Because of this, a growth function with the same formulation as the function described above, but with bole volume differences instead of basal area increment as dependent variable, was derived from the surviving tariff trees.

Table 9. Coefficients of the basal area – increment function for the uniform high forest.

Tariff Nr	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
201	-5.972557	0	-0.01411773	1.23803E-04	-0.00014326	0	-0.44190505	1.21888055	-0.04126653	-1.5231641	-0.02379006
202	-5.3576716	-0.00253504	-0.01117313	1.26891E-04	-0.00012378	-0.00809598	0	1.6531399	-0.03091997	-2.1006859	-0.01937307
203	-5.5999909	-0.00430994	-0.0031308	4.65E-05	0	-0.00615716	-0.22077679	2.00165397	-0.02687856	-2.5092794	-0.01758865
204	-5.9825582	-0.00372182	0	3.80E-05	-0.0003579	0	-0.1401818	1.78000818	-0.03350251	-2.1295719	-0.02207817
206	-6.8444118	0	-0.00936935	5.95E-05	-0.00029545	0	0	1.91662896	-0.05240991	-2.2333833	-0.03183865
207	-5.447667	-0.00591097	0	0	2.31573E-04	-0.01053092	0	2.28000974	-0.03124656	-3.0428097	-0.01735486
208	-6.440883	-0.00284107	0	0	0	-0.00606455	0	2.36330484	-0.03903922	-2.830217	-0.02440044
209	-6.5055495	0	0	0	0	-0.01016251	0	2.56963065	-0.03892991	-2.7872422	-0.03099751
210	-5.8575938	0	-0.0121997	0	-0.00098791	0.011110966	0	0.781433661	-0.03031232	-10	-0.00124574
211	-6.9563871	0.007066096	-0.03209735	5.11243E-04	0	0.006015048	0	-0.01971149	-0.09852732	0.086656529	0
212	-6.426157	-0.00741484	0	0	0	0	-0.0001	1.65054997	-0.02778707	-2.2765818	-0.01636538
213	-6.795361	-0.005249	-0.01031298	1.33487E-04	0	0	0	1.67724725	-0.0509718	-1.8539024	-0.035385
215	-6.2673073	0	0	0	0	0	0	1.27544562	-0.06649714	-3.1697299	-0.01099584
216	-6.0035754	-0.01002982	0	5.92E-05	0	-0.00608263	0	1.98923478	-0.03618071	-2.3349154	-0.02527642
217	-7.5435469	0	-0.00548712	1.36378E-04	-0.00032369	0	0	2.17634327	-0.05583974	-2.3437736	-0.03913801
218	-6.9790127	-0.00329626	0	4.21E-05	-0.00050808	0	0	2.20321716	-0.04875115	-2.5636204	-0.03059659
219	-6.5431542	0	-0.01247515	7.35E-05	-0.00070747	0.003120768	-0.54523011	1.55170032	-0.07531738	-1.5899548	-0.05562687
221	-6.9921994	0.008601155	-0.00953882	1.77502E-04	0	0	0	1.37321591	-0.04713288	-1.5589308	-0.03041591
222	-6.1045743	0	0	0	0	0	0	3.60419634	-0.00836617	-7.0902276	-0.00356603
223	-6.5274475	0	-0.01722707	9.07E-05	0	0	0	1.31721666	-0.07515075	-1.4562757	-0.05199407
224	-5.8086525	-0.00885217	0	1.08701E-04	0	0	0	3.10339974	-0.00754785	-10	-0.00208437
225	-5.7187214	0	0	0	0	0	0	1.54015364	-0.03632488	-3.9809956	-0.00779767
226	-6.4276149	0	0	5.21E-05	0	-0.00809001	0	2.2956149	-0.03516852	-2.5650228	-0.02689375
227	-23.117758	0	0	0	0	0	0	9.40725503	-0.17709636	-10	-0.0964788
228	-6.3296482	0	0	0	0	0	0	3.84330169	-0.01163934	-4.6639498	-0.0082585
229	-7.8887806	-0.01893619	0	0	-0.00049786	0	0	2.8269974	-0.06503545	-3.0844061	-0.04931764

3.2.2.6 Stand Age Prediction

The stand age of uniform forests is used as an input variable in the growth functions. Tree ring counts on stumps of freshly cut stems on the sample plots were relevant here (STIERLIN *et al.* 1994). As the stand age could be determined this way only for a portion of the sample plots, a regression function was derived, which allowed predicting the age of a stand in a uniform forest based on explanatory variables that were assessed on all of the sample plots.

$$\text{Age}_i = \exp\left(b_0 + \sum_{j=1}^{3} b_j B_{ji}\right) \tag{16}$$

B_1: d_{dom}/ln(GWL) (definition d_{dom} and GWL see Chapter 3.2.2.2)
B_2: Elevation above sea level in meters
B_3: Z / K
With:
Z: Increment of the survivor trees (pp. 308, HUSCH *et al.* 1972) in m^3/ha
K: Mean basal area diameter (p. 148, PRODAN 1965)

The coefficients b_0–b_3 can be found in Table 10. The coefficient of determination R^2 of this function is 39% for the regions Jura and Pre-Alps, 54% for the Plateau, and 31% for the Alps.

Table 10. Coefficients of the function used to estimate stand age.

Region	b0	b1	b2	b3
Jura	4.054784	0.095935	3.90156E	-0.081179
Plateau	3.440956	0.188870	2.15274E	-0.057807
Prealps	3.945205	0.127037	1.64682E	-0.060118
Alps and Southern Alps	4.293609	0.061116	3.41993E	-0.078227

3.2.3 Expanding Individual Tree Volumes to Sample Plot Values

The $d_{1.3}$ was measured on all trees at both inventory occasions. From these trees a subsample of so-called tariff trees was selected on which, in addition, the d_7 and the tree height were measured. The volumes of these trees were estimated with the bole volume functions (Chapter 3.2.2.1). These volumes were not only used for the derivation of tariff functions (Chapter 3.2.2.2) but for a statistically correct expansion of single tree volumes to sample plot values as well. This was possible because the selection probability of the tariff trees was exactly defined.

In the first NFI a large number of tariff trees were selected. From these data, tariff functions were developed that had a solid foundation and that allowed unbiased volume estimates for large areas. Hence, it would not have been necessary to measure tariff trees in the second inventory. It would have been possible to estimate standing timber, increment, and cut with the help of the tariff functions that have been derived from the first NFI tariff trees. However, if the bole volumes are estimated only with the help of tariff functions, the results on the one hand could be biased for small sampling units; on the other hand, the variance between sample plots could be underestimated due to the smoothing effect of the tariff functions. MANDALLAZ (1991; 1997) and SÄRNDAL (1980; 1989) show that the “weighted residual” technique (WR), an expansion technique that uses the residuals of the tariff functions, results in unbiased estimates of standing volume even for small sampling units, if it can be assumed that the volumes calculated by the bole volume functions are unbiased. In addition, the variance smoothed out by the tariff functions is completely included in the standard error.

The residuals of the tariff functions that were used for the expansion were only known for the subsample of the tariff trees. The expansion to volumes per area unit, they are weighted proportionally to the inverse of the selection probability of the tariff trees (Horvitz-Thompson-estimator, cited in SÄRNDAL 1980). The estimator for the standing volume and the standard error of the WR technique are defined as follows:

Standing volume (per ha) of a sample plot x:

$$\hat{Y}(x) = \sum_{i \varepsilon S1(x)} f_i \cdot \hat{Y}_i + \sum_{i \varepsilon S2(x)} f_i \cdot \frac{\varepsilon_i}{\pi_i} \tag{17}$$

Expected value of the mean standing volume per sample plot:

$$\hat{Y} = \frac{1}{n}\sum_{x=1}^{n}\hat{Y}(x) \tag{18}$$

Standard error of the standing volume:

$$\hat{V}(\hat{Y}) = \frac{1}{n(n-1)}\sum_{x=1}^{n}(\hat{Y}(x) - \hat{Y})^2 \tag{19}$$

where:

$\hat{Y}_i$: Tariff volume of an individual tree i

$\hat{Y}(x)$: Standing volume of a sample plot x

$\hat{Y}$: Expected value (standing volume per hectare) estimated with tariff functions

$\varepsilon_i = Y_i - \hat{Y}_i$: Residual of the tariff function

with Y_i: Individual tree volume estimated with a three-parameter bole volume function $(v = f(d_{1.3}, d_7, H))$

S1(x): All trees on sample plot x
S2(x): Subsample of the tariff sample trees on sample plot x

f_i: Expansion factor to values per hectare (in NFI $f_i = \frac{10000\,m^2}{200\,m^2} = 50$ for trees with $d_{1.3}$<=35 cm, $f_i = \frac{10000\,m^2}{500\,m^2} = 20$ for trees with $d_{1.3}$>35 cm)

π_i: Probability that a tree is selected as a tariff tree and that all three variables ($d_{1.3}$, d_7, H) can be measured

$\pi_i = \pi_{selection} \cdot \pi_{measurable} \cdot \pi_{sector}$

$\pi_{selection}$: Selection probability of a tariff tree (see Chapter 3.2.4, Equation 25)

$\pi_{measurable}$ Probability that $d_{1.3}$, d_7, and H are measurable

$$\pi_{sector} = \begin{cases} \frac{150}{400} & \text{for trees with } d_{13} < 60\text{cm} \\ 1 & \text{for trees with } d_{13} >= 60\text{cm} \end{cases}$$

The expected values for Equation 18 are unbiased if the bole volume functions are unbiased. Equation 19 corresponds to the classical equation for standard error estimation of a one-phase simple random sample. This also means that the equations used for the standard error estimation of the double sampling (KÖHL 1994) are still valid when the WR technique is applied.

The expansion to standing volume per hectare for each sample plot ($\hat{Y}(x)$) is carried out with the Equation (17).

For the total standing volume of the terrestrial sample of the first NFI, the standard error is 0.6864% when the volume is estimated using only the tariff function values. It increases to 0.713% if the WR technique is used, which represents a variance increase between sample plots of 8.7%. The second standard error is larger, since it includes the random error of the tariff functions. Due to the large proportion of tariff trees (34% of all sample trees), the two variances differ only slightly.

Because tariff curves change with increasing stand age (PARDÉ and BOUCHON 1988) or due to silvicultural treatments, they can be biased after a few years, even if they are applied to the same population they were originally derived from. Because of this, separate tariffs were derived for each inventory cycle from the tariff trees measured in each cycle. DUPLAT and PERROTTE (1981) also recommended this procedure. Nevertheless, a small bias of the tariff functions can result in a considerable bias of the increment estimation.

Suppose, for example, that the growth rate amounts to 2% per year (which corresponds approximately to the growth rate in the Alps), and that the increment is estimated with two tariffs. If one of the tariffs underestimates the standing volume by 2% and the other over-estimates it by 2%, then the estimated increment is biased by 20%. Compared to this, the standard error of the increment amounts to 3% in the Alps.

In order to avoid systematic errors, the increment (see Chapter 3.2.5) was estimated with the WR technique in the following way:

$$G_g = V_{sc2} - V_{sc1} = \hat{Y}_2(x) - \hat{Y}_1(x)$$

$$= \left(\sum_{i \in S_1(x)} f_{2i} \hat{Y}_{2i} + \sum_{i \in S_2(x)} f_{2i} \frac{\varepsilon_{2i}}{\pi_{2i}} \right) - \left(\sum_{i \in S_1(x)} f_{2i} \hat{Y}_{1i} + \sum_{i \in S_2(x)} f_{2i} \frac{\varepsilon_{1i}}{\pi_{2i}} \right) \qquad (21)$$

$$= \sum_{i \in S_1(x)} f_i (\hat{Y}_{2i} - \hat{Y}_{1i}) + \sum_{i \in S_2(x)} f_{2i} \frac{(\varepsilon_{2i} - \varepsilon_{1i})}{\pi_{2i}}$$

i: Index for an individual tree
Index value 1 holds for first, value 2 for the second inventory
V_{sc1}, V_{sc2}: see Chapter 3.2.5, Equation 26 $S_1(x)$: all trees on sample plot x
$S_2(x)$: Tariff trees on the sample plots that were assessed in both inventories
f_{2i}: Expansion factor for inventory 2
π_{2i}: Selection probability for a tariff tree at inventory 2
$\varepsilon_{2i}, \varepsilon_{1i}$: Tariff function residuals at inventories 2 and 1 respectively of those tariff trees that were assessed and completely measured at both inventories.

The increment including the ingrowth G_{gi} (see Chapter 3.2.5) contains, in addition to G_g (Equation 21), the ingrowth calculated according to Equation 17.

The above mentioned properties of the WR technique (correction of biased tariff functions, including the random error of the tariff functions in the standard error) are illustrated with the following examples:

The 10 years increment was estimated with a subsample of 6,000 tariff trees that were assessed at both inventories (Table 11). The increment of these tariff trees estimated with the bole volume functions is assumed to be the true increment. For these trees, two different tariff functions were then applied for the two inventories: once the increment was calculated with the NFI tariffs (tariffs from the first NFI) and once with biased Lucerne tariffs (Tariffs II and III, p. 193 PFEIFFER 1993).

The volume increment determined by using the Lucerne tariffs was larger by a factor of 1.7 than the one estimated with the NFI tariffs. From all sample trees, a $d_{1.3}^2$-proportional subsample was randomly selected using a sampling fraction of 18%, 9%, and 4.5%. Only the trees in this subsample were now regarded as tariff trees. The increment was estimated with the WR technique. This was repeated 100 times for each of the sampling fractions of tariff trees. The volume increment calculated using the NFI tariffs as well as the Lucerne tariffs were, on average, the same as those determined with the bole volume functions.

Table 11. Increment estimation using 6000 tariff trees for which in the first and second NFI the d_7 and the tree height were measured. Trees, which were actually treated for the expansion as tariff trees (18% of all trees), were selected proportionally to the $d_{13}{}^2$. The simulation was repeated 100 times.
DV: average volume difference of the 100 simulation runs . The standard deviation of the volume differences are given in parenthesis.

Method of volume estimation	Proportion of tariff trees	Volume (Mio m^3) 1985	Volume (Mio m^3) 1995	DV (Mio m^3) (Mio m^3) 1985–1995
Volume functions	100%	285.3	361.3	76
Tariffs NFI	0%	280.1	354.1	74
Tariffs Lucerne	0%	261.1	386.4	125.3
WR-technique	18%	285.2	361.2	76.0 (1.5)
(volume functions	9%	284.9	361.1	76.2 (2.0)
and tariffs NFI)	4.50%	285.3	361.7	76.3 (3.3)
WR-technique	18%	285.4	361.4	75.9 (2.4)
(volume functions	9%	285.2	361.3	76.1 (3.0)
and tariffs Lucerne)	4.50%	285.8	361.5	75.7 (5.0)

The random errors shown in Table 11 are empirical standard deviations of the increment estimates in 100 simulation runs. They do not contain the sampling error. The deviations between the simulation runs are relatively small compared to the bias of the tariffs.

Table 12 shows the increment estimates of the survivor trees (trees measured at both inventory occasions) of the NFI sample plots located on a 100 km wide strip in the North-South direction throughout all of Switzerland.

Table 12. Increment estimation in a 100 km wide strip in a North-South direction through Switzerland. Using the tariff NFI1, the tariff NFI1 and NFI2, applying the WR technique.
A: Tariff volume differences; B: Increments estimated by using the WR technique.

Region	Number of plots	Number of tariffs used	A Mio m^3	B Mio m^3
Jura	328	1	7.3 (±0.25)	7.7 (±0.30)
		2	8.2 (±0.26)	7.9 (±0.31)
Plateau	539	1	10.5 (±0.28)	10.6 (±0.32)
		2	10.9 (±0.29)	10.7 (±0.34)
Prealps	506	1	9.0 (±0.28)	9.3 (±0.32)
		2	9.8 (±0.29)	9.4 (±0.31)
Alps	505	1	5.4 (±0.24)	5.7 (±0.28)
		2	7.0 (±0.27)	6.0 (±0.30)

The increments in column A are tariff volume differences: once using one tariff for both inventory dates (row 1 — derived from the tariff trees of the first NFI) and once using two different tariffs (row 2 — derived from the tariff sample trees of the first and second NFI respectively).

Column B shows the increments that were estimated using the WR technique. The increments in row 1/column A are systematically different from those in row 2/column B. The increment differences between row 1 and row 2 in column B are random. Furthermore, this table demonstrates, that the sampling error in column B is larger than the one in column A, since in column B the random errors of the tariff functions are included in the sampling error.

3.2.4 Tariff Tree Selection

In order to be able to estimate the standing volume, increment and cut with the WR-technique discussed in Chapter 3.2.4, the tariff trees had to be selected for each inventory period. Measuring the d_7 and H on all trees would have been inefficient, since the gain in precision would have been relatively small compared to the additional arising expenses. It was, therefore, advantageous to select a subset of sample trees that achieved an optimal balance between expenditure and precision. For this optimization, the selection procedure played an important role.

Predicting the Variance between Sample Plots when all Sample Trees are Selected as Tariff Trees

The variance of interest is the one that could have been expected, if in the first NFI the d_7 and the tree height of all trees would have been measured and the standing volume would have been estimated with the bole volume functions. This variance can be estimated with the help of Equation 22 and the effectively assessed subsample of tariff trees (MANDALLAZ 1997):

$$\frac{1}{n}\hat{V}_x Y(x) = \hat{V}(\hat{Y}) - \frac{1}{n}\hat{E}_x V(x) = \hat{V}(\hat{Y}) - \frac{1}{n^2}\sum_{x=1}^{n}\hat{V}(x) \tag{22}$$

where

$\hat{V}_x(Y) = \frac{1}{n}\hat{V}_x Y(x)$ Variance between the sample plots if all trees would be selected as tariff trees. Y(x) is the standing volume on the sample plot x and is calculated with a three parameter volume function ($v = f(d_{1.3}, d_7, H)$).

$\hat{V}(\hat{Y}) = \frac{1}{n(n-1)}\sum_{x=1}^{n}(\hat{Y}(x) - \hat{Y})^2$: Variance between the sample plots if the standing volume is estimated with a subsample of tariff trees (see Equation 19).

$\hat{E}_x V(x) = \frac{1}{n}\sum_{x=1}^{n}\hat{V}(x)$: Component of the variance between sample plots caused by the residuals of the tariff trees that are not assessed. It is estimated with the help of the residuals of the assessed tariff trees.

where $$\hat{V}(x) = \sum_{i \varepsilon S2(x)} \frac{f_i^2 * \varepsilon_i^2 * (1-\pi_i)}{\pi_i^2} \tag{23}$$

The standard error of the standing volume estimated with Equation 22 amounts to 0.710% if the d_7 and H are assumed to be measured on all trees. If the tariff trees are selected according to the first NFI, and if the WR technique is applied, the standard error comes to 0.713%. This means that by measuring the d_7 and H on all trees, the variance cannot be significantly reduced. These results are also true for the individual production regions. These standard errors suggest that the sampling fraction of tariff sample trees can be reduced without a significant loss of precision as well.

Selecting a Subsample of Tariff Trees

With the selection of tariff trees, the relationship between cost (c_t) and the obtained precision of the volume estimation (variance between the sample plots s^2) should be optimized. This is the case when $c_t \times s^2$ is minimized.

The cost (c_t) can be divided into fixed costs (c_0) and variable costs (c_1): $c_t = c_0 + c_1$. The fixed costs do not depend on the number of measured tariff trees. They are assumed to be the expenditure for the assessment of the tree data, the individual tree and stand assessments relevant to the standing volume, and the measurements of the sample plot and of the individual trees (phase III of the terrestrial survey in the first NFI without the expenditure for the d_7 and tree height measurements, see ZINGG and BACHOFEN 1988). In addition, many attributes were assessed in the NFI that are not related to the volume estimation. For that reason not all of the assessment costs were considered for the optimization of the tariff tree selection. The number of trees on which the $d_{1.3}$ was measured remained constant. This is the reason why this expenditure is considered as fixed costs. The variable costs were the result of the number of d_7 and tree height measurements. The expenditures for both of these measurements were determined from time studies on NFI sample plots in different regions of the country, on different stand structures, and in different topographic conditions. It was reasonable to assume overall that it takes five minutes (i.e. 2.5 minutes per person) to measure one tariff tree.

The variance s^2 between sample plots also depends, apart from the number of selected tariff trees, on the selection procedure. Tariff trees can either be selected at random so that each tree has the same probability of being selected, or the selection probability can depend on a measured or estimated tree variable, which is correlated with the target variable, the bole volume.

In the first NFI all trees within the sample plot sector 0–150 gon, as well as all trees with a $d_{1.3} >= 60$ cm, were selected as tariff trees. An NFI sample plot consists of two concentric circles with areas of 200 m^2 and 500 m^2. Within the smaller area only trees with a $d_{1.3} < 36$ cm are considered. These trees have a lower selection probability than trees with a larger $d_{1.3}$. The selection probability changes suddenly with the limiting diameter of 35 cm. This type of selection procedure is called RS (**r**andom **s**election) in the following.

MANDALLAZ (1991; 1995; 1997) has proven theoretically that a procedure which selects trees proportionally to the prediction error of tariff functions is the most efficient. The probability to select a tree as a tariff tree is greater, the higher the estimated difference between the tariff volume and the bole volume is (i.e. the absolute value of the estimated residual $|\hat{\varepsilon}_i|$). For the optimization, the prediction error was estimated with a regression model. This selection procedure is called PPE (**p**robability **p**roportional to **p**rediction **e**rror) in the following.

The $d_{1.3}$ and the basal area $d_{1.3}^2$ are highly correlated with the volume. It is therefore obvious to study the selection proportional to the $d_{1.3}$ (**PPS**, **p**robability **p**roportional to **s**ize) and proportional to $d_{1.3}^2$ (in the following called **PPS2**).

The tariff tree selection is globally optimized when trees are selected independently of their relationship to a certain sample plot. For the study of the tariff tree selection for the RS procedure, the sample plot sector was continuously reduced from the original 150 gon. For the PPS, PPS2 and PPE procedures, the tariff trees were selected as a subsample from the first NFI tariff trees according to the following rules:

$$t_i = \begin{cases} 1 & \text{for } \gamma \cdot f_i \cdot p_i > u(0) \\ 0 & \text{otherwise} \end{cases}, \tag{24}$$

$$\text{with } p_i \propto \begin{cases} |\hat{\varepsilon}_i| & \text{for the PPE} \\ d_{1.3i} & \text{for the PPS procedure} \\ d_{1.3i}^2 & \text{for the PPS2} \end{cases}$$

i: individual tree

t_i: Binary variable, $t_i = 1$ if a tree was selected as a tariff tree, otherwise $t_i = 0$

γ: Scaling constant that determines the slope of the probability line or the number of selected trees respectively

f_i: Expansion factor: f_i=20 for $d_{1.3i}$>35 cm, f_i=50 for $d_{1.3i}$<=35 cm

u(0): Uniformely distributed random number within the interval [0,1]

The PPS, PPS2 and PPE selection procedures are more efficient than the RS procedure, which can be seen in Figure 5. This figure shows how the sampling fraction of tariff trees affects the precision of the volume estimation. The graph shows the standard error of standing volume from the first NFI for all four selection procedures of the tariff trees.

The term $c_t \cdot s^2$ reaches its minimum value for the PPS, PPS2 and PPE procedures at approximately 1 tree per sample plot (8,000–12,000 trees for 11,000 sample plots). The PPS2 and PPE procedures give nearly identical results, because the $|\hat{\varepsilon}_i|$ increase more or less proportionally to the $d_{1.3}^2$. If the fixed costs are cut in half compared to the above described assumptions, the optimum of the PPS2 procedure is at 5,000 to 8,000 trees; if it is doubled, the optimum is at approximately 13,000 trees (1.2 trees per sample plot).

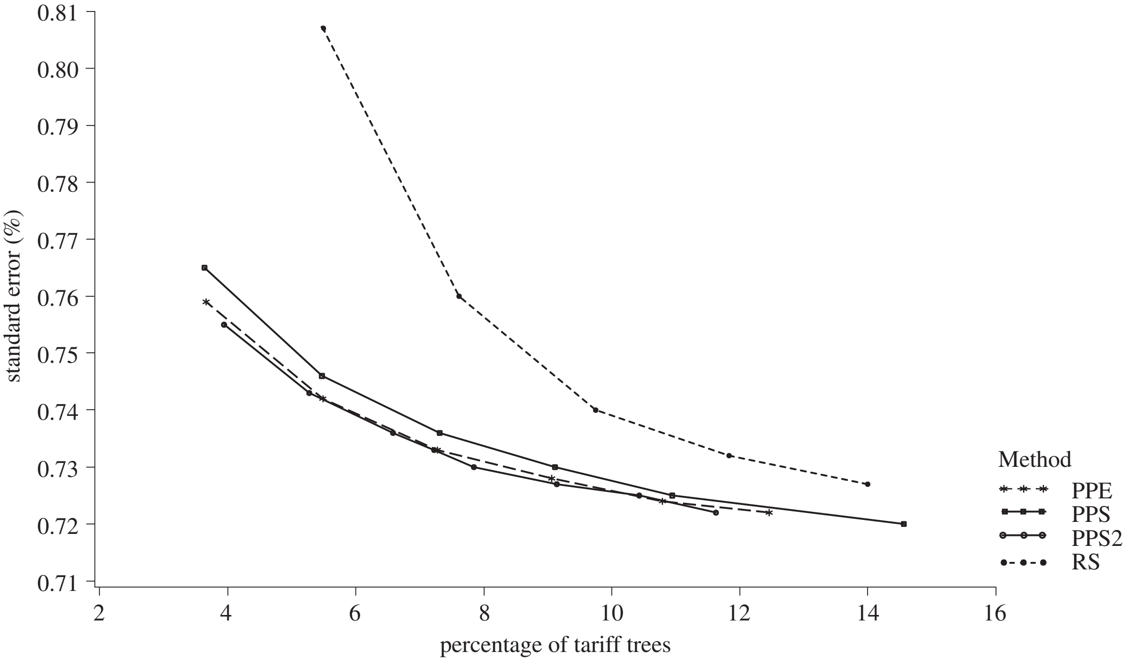

Figure 5. Selection of tariff trees: Standard error of total volume depending on the number of selected tariff trees.
Selection method: PPE: Probability proportional to the prediction error; PPS: Probability proportional to $d_{1.3}$; PPS2: Probability proportional to $d_{1.3}^2$; RS: Selection within a fixed sample plot sector.

Selection of Tariff Trees in the Second NFI

In the second NFI a sufficient number of tariff trees had to be selected for the tariff derivations, taking into account that approximately 2% of the trees are cut every year and that the d_7 or the tree height cannot be measured on approximately 20% of the selected trees. As a consequence, the chosen sampling fraction of two trees was clearly more than the optimum. This was, however, still a reduction by 50% as compared to the first NFI, where on average four tariff trees per sample plot were measured. The selection probability for a sample tree to be selected as a tariff tree is defined as follows:

$$\pi_{Selection} = 0.000015\, d^2_{1.3} f_i\, ,\ for\ \pi_{Selection} >= 1 : \pi_{Selection} = 1 \quad (25)$$

3.2.5 Standing Volume, Growth and Cut

For the estimation of increment and cut it is necessary to know the state of a tree at the first, as well as at the second inventory date. Changes in the state of individual trees could be determined on the plots that have been assessed at both inventory occasions (i.e. the matched plots). Increment and cut refer, therefore, to the matched sample grid. Conversely, standing volume and change of volume can be estimated by using the matched and unmatched plots.

State of Individual Trees

Changes in the state of individual trees were described in the NFI database with the variables "HISTORY" and "IMMERTOT" as follows:

HISTORY:
1 Survivor tree (Tree was recorded at both inventories, see Husch et al., 1972.)
2 Ongrowth tree (Tree grew over the caliper-threshold of 35 cm between the two inventories.)
3 Ingrowth tree (Tree grew over the caliper-threshold of 12 cm between the two inventories.)
4 Cut tree (Tree was removed from the plot between the two inventories. It could be determined that the tree was harvested.)
5 Mortality tree (Tree was removed from the plot between the two inventories. It could be determined that the tree has died between the inventories.)
6 Cut or mortality tree (Tree was removed from the plot between the two inventories. The cause could not be determined.)
8 Tree on a sample plot that was only assessed terrestrially in the first NFI
9 Tree on a sample plot that was only assessed terrestrially in the second NFI

IMMERTOT:
0 Tree was standing and alive in both inventories
1 Tree was already lying or dead in the first inventory
2 Tree was standing and alive in the first inventory but lying or dead in the second inventory
3 Tree was standing and alive in the first inventory. It was no longer present on the plot in the second inventory

The necessary restrictions when selecting individual trees for the estimation of standing volume, growth, cut or mortality are accomplished with the help of the variables HISTORY and IMMERTOT. These restrictions are presented in Table 13.

Table 13. Selection of trees for the estimation of standing volume, increment and cut.
f1, f2: Expansion factors for the first and second NFI respectively; V1: Volume estimated at the time of the first inventory on the sample plot grid NFI1; V2: Volume estimated at the time of the second inventory on the sample plot grid NFI2 or on the matched grid; V1_1: Volume estimated at the time of the first NFI on the matched grid without back dated ongrowth trees using expansion factors f1; V1_2: Volume estimated at the time of the first NFI on the matched sample plot grid with back dated ongrowth trees using expansion factors f2; V_{sc2}: Volume of the surviving and cut trees at the time of the second NFI; I: Ingrowth; Ggi: Gross growth including ingrowth; Gg: Gross growth without ingrowth; Gd: Net change of volume; CM1.5: Cut and mortality at the middle of the inventory interval.

Plot grid	Variable	Calculation	Inventory	HISTORY	Exp. factor	Restriction
NFI1	V1		LFI1	1 4 5 6 8	f1	
NFI2	V2		LFI2	1 2 3 9	f2	
Matched	V1_1	V1_1 = V1_2	LFI1	1 4 5 6	f1	
NFI1/NFI2	V1_2	V1_1 = V1_2	LFI1	1 2 4 5 6	f2	
	Vsc2		LFI2	1 2 4 5 6	f2	IMMERTOT # 1
	Vsc2 + I		LFI2	1 2 3 4 5 6	f2	IMMERTOT # 1
	V2		LFI2	1 2 3	f2	
	Gd	V2-V1_2				
	Gg	Vsc2 - V1_2				
	Ggi	Vsc2 + I - V1_2				
	CM1.5		LFI1.5	1 4 5 6	f2	IMMERTOT> 1

Selection of Trees for the Estimation of Standing Volume, Change in Standing Volume, Growth, and Cut

If the codes of the variables HISTORY and IMMERTOT are set according to Table 13, the following volumes are obtained (according to Husch et al. 1972, $CM_{1.5}$ added):

Standing volume in the first inventory: $V_1 = V_{s1} + CM_1$

Standing volume in the second inventory: $V_2 = V_{s2} + I$

The standing volume estimates are based on individual tree volumes. The expansion to per plot values was accomplished with the WR technique described in Chapter 3.2.3 (Equation 20).

The change in standing volume ($G_d = V_2 - V_1$), refers to the matched sample plot grid.

In the NFI, growth is defined by the following two terms:

G_g: Gross Growth without Ingrowth:

$$G_g = V_{s2} - V_{s1} + CM_{1.5} - CM_1 = V_{sc2} - V_1 \qquad (26)$$

$$\text{where } V_{sc1} = V_{s1} + CM_1, V_{sc2} = V_{s2} + CM_{1.5}$$

G_{gi}: Gross Growth including Ingrowth:

$$G_{gi} = V_{s2} - V_{s1} + CM_{1.5} - CM_1 + I = V_{sc2} - V_{sc1} + I \qquad (27)$$

where:

V_{s2}: Volume of the survivor trees in the second inventory
V_{s1}: Volume of the survivor trees in the first inventory
V_{sc1}: Volume of the survivor and the cut trees in the first inventory
V_{sc2}: Volume of the survivor and the cut trees in the second inventory
CM_1: Volume of the **c**ut and **m**ortality trees in the first inventory
$CM_{1.5}$: Volume of the **c**ut and **m**ortality trees, including their growth up to half of the inventory interval
I: Ingrowth: Volume of the trees ingrown over the caliper threshold of 12 cm

Ongrowth Trees

The trees which were located within the 500 m^2 circle of a plot, but outside of the 200 m^2 circle, and which reached the caliper threshold of 35 cm between the two inventories, were only measured in the second inventory. These trees are called "ongrowth" trees. For the estimation of change in standing volume and increment, the volume of the ongrowth trees at the first occasion is estimated (estimating the $d_{1.3}$ with the help of Equation 15). For both inventories, the expansion factor f_2, which is valid for the second inventory, is used.

The standing timber that is estimated with the expansion factor f_1 (f_1 is valid for the time of the first NFI) at the first NFI without ongrowth trees (V1_1 in Table 13) is the same as the standing volume at the first NFI that is estimated with the ongrowth trees included and with the expansion factor f_2 (V1_2 in Table 13).

Definition of the Cut and the Merchantable Timber Volume

A consistent differentiation between cut and natural mortality was not possible in the NFI. The term "cut" comprises the cut and the mortality volume. The term "merchantable timber" denotes the proportion of the merchantable timber volume that was effectively utilized. In the following it is explained how these volumes were determined.

The term $\mathbf{CM_{1.5}}$, called "cut", encompasses the stem volume over the bark of all trees in the matched sample plot grid which were standing and alive during the first inventory, and which were either lying, dead, or missing in the second inventory (variable IMMERTOT> 1). The "cut" volume includes the growth achieved during one half of the inventory interval. The restriction IMMERTOT>1 includes the portion of the trees with HISTORY=1 that had died off between the two inventories but were still present on the sample plot at the second inventory, as well as the proportion of the trees with HISTORY={4,5,6} that were standing and alive at the first inventory and were missing at the second inventory.

The volume of the merchantable timber comprises the merchantable volume of the trees that have effectively been harvested and utilized between the two inventories.

The merchantable timber volume of a tree consists of the underbark stem and the large branche volume. Stump volume is excluded.

The volume of the merchantable timber was estimated with the help of the proportions presented in Table 14. In table 14, X denotes the merchantable volume of those trees that were standing and alive at the first NFI and that were missing at the second NFI; P(X) is the X- proportion of the total "cut". P(Y|X) denotes the proportion of the X-volume that was effectively utilized. P(Y|X) is estimated from a subsample of two thirds of all X-trees, for which it was clearly possible to differentiate in the field between effective utilization and natural mortality. The proportion of effectively utilized volume of the "cut" is $P(Z) = P(X) \cdot P(Y \mid X)$.

The reduction for the stump and bark volumes was carried out differently in Chapter 6 and Chapter 11 of the result volume. In Chapter 6, the overbark stem volume was reduced by a factor depending on the tree species (25% for larch, 10% for beech, 20% for oak and other broadleaf trees excluding ash and maple, and 15% for all other tree species). In Chapter 11, the merchantable stem wood was made up of assortment volumes. The utilized timber volume of both chapters differ by 0.6%.

Table 14. Proportion of effectively utilized overbark timber volume compared to the total cut and mortality volume.
X:Volume of the trees, that were standing and alive in the first and missing in the second NFI.
P(X): Proportion X of the total cut and mortality volume.
P(Y|X): Proportion Y of X that was effectively utilized.
P(Z): Effectively utilzed overbark timber volume compared to the total cut and mortality volume.

Region	P(X)	P(Y|X)	P(Z) = P(X) * P(Y|X)
Jura	0.93	0.99	0.92
Plateau	0.96	0.98	0.94
Prealps	0.9	0.935	0.84
Alps	0.8	0.91	0.73
Southern Alps	0.66	0.75	0.5
Switzerland	0.9	0.95	**0.86**

3.2.6 Utilizable Timber Volume and Merchantable Assortments

3.2.6.1 Taper Equations

In order to breakdown a bole into merchantable assortments, the stem form must be described with the help of tree variables (in the NFI d_{13}, d_7, and H) that were measured in the field. The reason for this is because a diameter threshold at any position on the stem is relevant for the assortment (FORSTWIRTSCHAFTL. ZENTRALSTELLE 1976).

Prerequisite for Describing Stem Forms

The prerequisite for modeling stem forms is that there must be a relationship between the measured variables or attributes derived from them and the stem diameter at any arbitrary position. Partial linear dependencies as they are presented in KUBLIN (1987) and KUBLIN and SCHARNAGL(1988), were also found in a preliminary study for the development of NFI taper equations. The diameter at a certain position on the stem depends linearly on the $d_{1.3}$ and d_7 for trees with the same form ratio d_7 /$d_{1.3}$ and the same tree height. There also exists a linear relationship between the form ratio and the diameter for a given $d_{1.3}$ and tree height.

Trees having large form ratios $d_l/d_{1.3}$ in the lower shaft area usually have relatively large form ratios $d_u/d_{1.3}$ in the upper shaft area and vice versa. SLOBODA (1985) called these relationships stochastic rank preservation (in German: stochastische Rangerhaltung).

Figure 6 illustrates this fact using an example of the taper curve of section-wise measured spruce trees that have a $d_{1.3}$ of 35 cm, 40 cm, 45 cm, 50 cm, 55 cm, and 60 cm, a tree height of 35 m and a form ratio ($d_7/d_{1.3}$) between 0.7 and 0.8. The property of rank preservation allows diameters to be estimated at any arbitrary position on the stem when the $d_{1.3}$, an upper diameter and the tree height are known. This is confirmed by the remarkably low standard deviation of differences between the measured and the predicted diameters using the NFI taper model for all main tree species (Table 17).

The stem profile of an individual tree cannot, with satisfaction, be described with the help of the $d_{1.3}$ and the tree height. By including an upper diameter, it is possible to predict the diameter at any arbitrary position of the stem with a sufficient precision. The gain in precision that can be obtained by including other form attributes is relatively small compared to the additional expenditures.

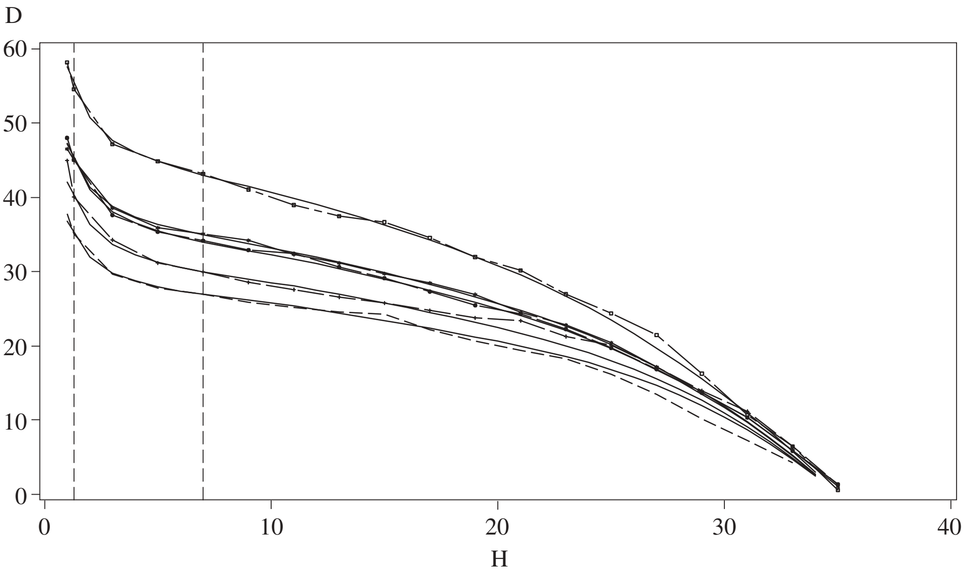

Figure 6. Estimated stem curves (solid lines) and measured diameters, species spruce, 0.7 $\leq d_7/d_{1.3}$ <0.8, tree height 35 meters.

Construction of Taper Equations

Based on the relationship between the measured variables and stem form characteristics known from the literature, and based on the results from a preliminary study, cubic interpolation splines (DE BOOR 1978) were chosen to describe stem profiles in the NFI. A Fortran-77 program developed by ENGELN-MÜLLGES and REUTTER (1986) was used for this task. Some diameters at different heights of the stem, which were estimated with the help of a regression model, were used as knots for these splines.

It has been repeatedly shown (BRUCE and MAX 1990; KLEINN 1989; KUBLIN *et al.* 1984; SABOROWSKI 1982; SABOROWSKI *et al.* 1981; SLOBODA 1985; SMALTSCHINSKI 1984; STERBA 1980) that cubic interpolation splines are very suitable to describe stem profiles. A cubic spline consists of polynomial segments of order three that are twice continuously differentiable. The function values and the first and second derivatives of two adjacent polynomials are the same at the knots (i.e. the intersection points between two polynomials), so that the polynomials that describe one stem profile result in a smooth curve.

The NFI taper equations are constructed as follows:

1. Estimation of upper stem diameters with the help of a regression model
Upper diameters at several locations (i) on the stem are estimated with the help of a regression model. This model was developed with the data stemming from section-wise measured sample trees.The diameters d_{ji} in 1 meter height, at 5%, 10%, 20%, 30%, 50%, 70%, and 80% of the stem length are estimated with the following regression model, depending on the three variables $d_{1.3}$, d_7 and H of the tree i:

$$\hat{d}_{ji}\frac{d_{7i}}{d_{1.3i}} = b_{0j} + b_{1j}\cdot H_i + b_{2j}\cdot d_{7i} + b_{3j}\cdot d_{7i}H_i + b_{4j}\cdot d_{1.3i}H_i \qquad (28)$$

Weight: $w_i = \left(\frac{d_{1.3i}}{d_{7i}}\right)^2$

In order to obtain unbiased estimates of the d_{ji}, the squared errors are weighted with w_i so that:

$$\sum_{i=1}^{n}\left[\left(d_{ji}-\hat{d}_{ji}\right)\cdot\frac{d_{7i}}{d_{1.3i}}\right]^2\cdot W_i \overset{!}{=} \text{minimum}$$

Substituting W_i in this equation

$$\sum_{i=1}^{n}\left[\left(d_{ji}-\hat{d}_{ji}\right)\cdot\frac{d_{7i}}{d_{1.3i}}\right]^2\cdot\left(\frac{d_{1.3i}}{d_{7i}}\right)^2 = \sum_{i=1}^{n}\left[d_{ji}-\hat{d}_{ji}\right]^2 \overset{!}{=} \text{minimum}$$

The coefficients for equation 28 can be found in Table 15.

Especially for broadleaf trees, the diameter at the lower stem areas can be predicted more precisely than for the upper stem areas, since the position of the crown base influences the stem form. For coniferous trees, the coefficient of determination (R^2) amounts to 99.5–99.8% for the $d_{0.3}$, 98.1–99.2% for the $d_{0.5}$ and 90.4–95.5% for the $d_{0.8}$. For beech, the R^2 comes to 99.4% for the $d_{0.3}$, 95.9% for the $d_{0.5}$ and 78.7% for the $d_{0.8}$. The predicted diameters uniformly decrease from the stem base to the top for all trees.

Table 15. Coefficients of the functions that predict upper stem diameters at fixed locations.

Species	Location	b0	b1	b2	b3	b4
Spruce	1m	-0.0322735	0	1.01822722	0	0.00070241
	5%	0.6694153	-0.03912357	1.10731936	0.00183994	-0.00460934
	10%	1.98212707	-0.08931625	1.01658607	0.01297247	-0.01315235
	20%	2.32979631	-0.08534539	0.90240645	0.02113534	-0.01876776
	30%	1.94286823	-0.05605474	0.83535552	0.02046769	-0.01817887
	50%	1.2168963	0.00958755	0.65084147	0.01887258	-0.0163289
	70%	0.1701299	0.11005913	0.37702981	0.01457552	-0.01197956
	80%	-0.35434648	0.14221273	0.23483065	0.01028162	-0.00846602
Fir	1m	-0.61671376	0.01348875	1.05035114	-0.0020169	0.00156697
	5%	0.38173759	-0.01419189	1.08620965	0.00221964	-0.00474542
	10%	2.26735806	-0.07040213	0.95987737	0.0144543	-0.01352572
	20%	2.96815848	-0.09566062	0.87055081	0.02176994	-0.0186884
	30%	2.73444057	-0.08702372	0.81440997	0.02087228	-0.01768526
	50%	1.1004138	0.01780012	0.66899645	0.01685419	-0.01450547
	70%	-1.5623776	0.22157046	0.42897272	0.00991785	-0.00938154
	80%	-2.1747944	0.27151403	0.26857728	0.00707074	-0.00680849
Scotch Pine	1m	0.33030733	0	1.02457213	0.00379692	-0.00300232
	5%	0.63361645	-0.02878408	1.11662853	-0.00140075	-0.00226452
	10%	1.64052474	-0.07434391	1.02397656	0.00732716	-0.00865593
	20%	2.52197576	-0.10863366	0.89019656	0.02174408	-0.01854897
	30%	2.25426126	-0.0958468	0.83243483	0.02315113	-0.01978661
	50%	1.77930748	-0.07293812	0.7132659	0.02046024	-0.01785395
	70%	0.59456933	-0.04502022	0.64238423	0.01239497	-0.01308449
	80%	-0.21832582	0.02805848	0.49054864	0.00834929	-0.01011157
Larch	1m	-0.66468376	0.05510109	1.02942657	-0.00196514	0.00125772
	5%	1.2846204	-0.05446032	1.09672856	0.00096711	-0.00355392
	10%	2.63373613	-0.10524832	0.97468442	0.01231533	-0.01152565
	20%	2.06671786	-0.07194527	0.89571863	0.01959724	-0.01754426
	30%	1.47027445	-0.0459033	0.83956546	0.01894159	-0.01717868
	50%	0.71770215	0.02104711	0.6494292	0.01692222	-0.01490832
	70%	-0.29833773	0.12124127	0.40120178	0.01198215	-0.01057149
	80%	-0.61502206	0.15138558	0.25490171	0.00875077	-0.00784795
Beech	1m	-0.10826337	0	1.03912008	-0.00089265	0.0004035
	5%	0.59974957	-0.01922579	1.04605079	0.00017884	-0.00176683
	10%	1.30630982	-0.03507829	0.98725438	0.00997312	-0.01022303
	20%	1.69247139	-0.05899471	0.9332602	0.01975506	-0.0184943
	30%	1.686064	-0.06477597	0.86990666	0.02075929	-0.01893105
	50%	0.6492604	-0.00148954	0.6994524	0.01686741	-0.01543733
	70%	-1.2748044	0.13125174	0.43584272	0.00958976	-0.00995488
	80%	-0.72813153	0.117301	0.22970511	0.00731678	-0.00673901
Oak	1m	-0.39968038	0	1.08216906	-0.0013725	0
	5%	0.28164521	-0.01204597	1.09435189	-0.00087433	-0.00222605
	10%	1.49493408	-0.05652448	1.0137068	0.01020512	-0.01101364
	20%	1.48586392	-0.06749376	0.98738503	0.0208354	-0.02066637
	30%	1.75309861	-0.07523583	0.89548081	0.02410906	-0.02224103
	50%	0.50951594	-0.00726158	0.74923503	0.01699877	-0.0161029
	70%	-0.80354124	0.11033778	0.48804128	0.01151507	-0.01212845
	80%	-0.62629098	0.11335155	0.29778415	0.00792077	-0.00831111

2. Interpolation between estimated diameters with the help of cubic splines

Between two neighboring estimated diameters, a taper curve is interpolated with a cubic spline. Several spline segments describe a stem profile with a continuous smooth curve. The goodness-of-fit of these splines depends mainly on the number and the location of the knots. The locations according to Hohenadel (d0.1, d0.3, d0.5, d0.7, d0.9 HRADETZKY 1981; KUBLIN and SCHARNAGL 1988; SABOROWSKI 1982) are suitable as knots. Interpolation for polynomial segments with neighboring polynomials is unproblematic, since the first and second derivatives are given at the endpoints. They are defined by the equation system of the continuity conditions (same function values and first and second derivatives of neighboring polynomial segments). Nevertheless, the end segments have to be treated separately. In order to determine the polynomial coefficients, either the first (slope), second (curvature), or the third derivative of the curve must be known in addition to the diameter. If the curvature is 0 at both end points (f"(x)=0), it is called a natural cubic spline (DE BOOR 1978; HRADETZKY 1981). In order to obtain a slightly better fit around the base of the stem, and to reduce the tendency of the spline to underestimate in the upper parts of the stem, the splines are tied in at both of their endpoints (i.e. the curvature is given). SABORWOSKI (1982) had obtained the best fit in the area between 1.3 m and 7 m by setting the starting curvature individually for each tree as well.

For the starting values at the stem base, the shaft curvature is estimated. In order to accomplish this, a polynomial with the form $y = a + b\,x^2 + c\,x^3$ is fitted to the measurement points of the section-wise measured trees at 1.0 m, 1.3 m, and 3.0 m. The curvature, that is the second derivative of this polynomial at 1 m is the target parameter in a regression model which estimates the curvature at 1 meter with the $d_{1.3}$, $d_{1.0}$ and d_7.

$$f''(1.0) = b_0 + b_1 \cdot d_{1.3}^2 + b_2 \cdot d_7^2 + b_3 \cdot \frac{d_{1.3}}{d_{1.0}} + b_4 \cdot d_{1.3} d_{1.0} \tag{29}$$

The coefficients for the curvature model at the stem basis can be found in Table 16. An estimated curvature at the bottom is given for each tree; the curvature at the top is kept constant (–0.001).

Table 16. Coefficients of the function that estimates the curvature at the stem basis.

	b0	b1	b2	b3	b4
Spruce	0.668756	–5.63213E	9.09932E	–0.679303	4.87134E
Fir	0.825355	–4.72139E	6.47683E	–0.836509	4.15204E
Scotch Pine	0.595389	–7.60644E	9.80589E	–0.612327	6.81946E
Larch	0.894741	–4.34839E	6.57241E	–0.920326	3.83439E
Beech	0.643240	–6.54322E	7.60462E	–0.651962	5.87191E
Oak	0.691773	–6.46014E	7.9513E	–0.701271	5.76082E

3. Adjusting the taper curve

A taper curve formed with the estimated diameters do not go exactly through the measured $d_{1.3}$ and d_7. From the statistical point of view this is not necessary as long as the $d_{1.3}$ and d_7 are unbiasedly estimated. If the objective is, however, to compare individual tree volumes estimated with bole volume functions with volumes estimated with taper equations, the individual tree curves have to go through both measurement points. For this purpose the two measurement points, $d_{1.3}$ and d_7, could have been used as additional knots for the spline interpolation. However, using measured and estimated diameters at the same time as knots results very often in curves that do not uniformly decrease or in a strong oscillation of the spline. Only the positions mentioned in the first step are therefore used as knot diameters. With the help of the difference between the measured and the estimated $d_{1.3}$ and d_7, the curve of each tree is shifted so that it intersects with both measured diameters. The adjusting function is linear. The correction factor is proportional to the inverse distance between point h_j on the shaft and the height 1.3 m or 7 m.

$$da(h) = \hat{d}(h) + \frac{(h-a)}{b} \cdot (d_7 - \hat{d}_7) + (1 - \frac{(h-a)}{b}) \cdot (d_{1.3} - \hat{d}_{1.3}) \tag{30}$$

for h <= 7 meters

$$da(h) = \hat{d}(h) + (1 - \frac{h-c}{H-c}) \cdot (d_7 - \hat{d}_7) \tag{31}$$

for h>= 7 meters

$\hat{d}(h)$, $\hat{d}_7, \hat{d}_{1.3}$: Diameter estimated with the help of a spline-Interpolation in centimeters

h:	Arbitrary location on the shaft in meters
$da(h)$:	Adjusted diameter in centimeters
H:	Tree height in meters
a:	1.3 meters
b:	5.7 meters (distance between $d_{1.3}$ and d_7)
c:	7 meters

The 99% percentiles of this adjustment are for section-wise measured spruce at ±0.44 cm for the $d_{1.3}$, at ±1.32 cm for the d_7, and for spruce tariff trees assessed during the first NFI, at ±1.33 cm (for the $d_{1.3}$) and ±3.6 cm (for the d_7). The corresponding 95% percentile of the correction is at 1 mm and 3 mm for the section-wise measured spruce and at 0.6 cm and 2.0 cm for the NFI tariff sample trees. On average, a stem curve of the section-wise measured spruce is adjusted by an absolute value of 1 mm for the $d_{1.3}$ and 3 mm for the d_7. For spruce from the first NFI they were adjusted by 2 mm ($d_{1.3}$) and 6 mm (d_7). These corrections do not create any systematic error, since the average adjustments did not deviate from zero.

Validation of the Taper Equation

Table 17 shows the average deviations ($\bar{x}$) of measured from estimated diameters in the tree height class 30–36 m, as well as the standard deviation of the differences (s_x) along the stem. The standard deviations of the residuals of 1.0–1.5 cm for conifers indicates that the stem profiles can be described very precisely with the chosen method. The standard deviation of the residuals, especially in the upper shaft area, with approximately 2.5 cm for beech and approximately 3.5 cm for oak are higher, since the crown base and the crown volume have a larger influence on the shaft form of broadleaf trees than of coniferous trees. For illustration, Figure 7 shows the estimated stem curve and the variation width of the shaft forms for all section-wise measured firs with a height of 34 m, a d_7 between 44 and 45 cm and a $d_{1.3}$ between 55 and 56 cm.

A stem curve must uniformly decrease from the stem base to the top. This is the case for 98.5% of all calculated stem curves for tariff sample trees in the first NFI. Especially for trees with a very large form ratio ($d_{1.3}/d_7$>0.9), it is possible that a spline slightly increases between two knots. In these cases it is assumed that the corresponding shaft forms are cylindrical in these areas. It is rare (0.5% of all trees) that the splines oscillate so strongly that no stem profile can be calculated.

All calculated stem curves were checked visually on the computer screen for their behavior when the d_7 changed and the $d_{1.3}$ and H stayed the same. These gradual changes are harmonic for all possible $d_{1.3}$-height combinations; that is, stem curves with the same tree height and the same $d_{1.3}$ do not intersect with each other when the d_7 is changed.

The volumes estimated with the taper functions are only slightly less precise (Table 18, standard deviation of the residuals) than those estimated with bole volume functions. The taper functions have a slight tendency to underestimate the volume, which is due to the way the stem curves were predicted in the upper stem areas.

The volumes of the NFI1 tariff sample trees are estimated to be slightly smaller by the taper functions than by the bole volume functions (the difference ranging from 0.2% for spruce up to 1.4% for fir and larch, see Table 19). The average difference between volumes estimated by the bole volume functions and those estimated by the taper functions, as well as the standard deviation of these differences, are very low (KAUFMANN 1993). This demonstrates that the bole volume functions as well as the taper functions are stable.

Table 17. Average deviations ($\bar{x}$) between predicted and measured stem diameters and and standard deviations of the resiuals (s_x) in cm.

Number of trees	Fir 1692		Spruce 2517		Scotch Pine 207		Larch 438		Beech 1179		Oak 72	
Location	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x
1 m	–0.25	1.4	–0.21	1.21	–0.16	0.8	–0.50	1.3	–0.14	0.7	–0.03	0.9
3 m	–0.16	1.1	–0.16	0.92	–0.04	1.1	–0.08	0.9	–0.12	0.8	–0.25	1.0
5 m	0.01	0.7	–0.02	0.60	–0.13	1.3	–0.02	0.7	–0.05	0.7	–0.20	1.3
7 m	0.00		0.00		0.00		0.00		0.00		0.00	
9 m	–0.01	0.8	0.04	0.56	–0.01	1.0	–0.06	0.7	0.03	1.0	–0.17	1.2
11 m	0.00	1.0	0.05	0.69	0.03	1.2	–0.02	0.9	0.08	1.4	0.16	1.3
13 m	–0.01	1.2	0.03	0.83	0.02	1.5	–0.07	1.1	0.13	1.8	–0.39	1.6
15 m	–0.02	1.5	0.02	0.98	–0.10	1.5	–0.11	1.2	0.11	2.0	–0.28	2.5
17 m	–0.05	1.8	0.00	1.16	0.01	1.6	–0.09	1.3	0.12	2.3	0.02	3.4
19 m	–0.11	2.0	–0.01	1.29	0.22	1.7	–0.06	1.5	0.28	2.6	–0.09	3.5
21 m	–0.17	2.3	–0.04	1.41	0.21	1.7	–0.02	1.5	0.29	2.5	–0.27	3.6
23 m	–0.23	2.5	–0.12	1.53	0.18	1.6	–0.04	1.5	0.10	2.4	–0.42	3.5
25 m	–0.24	2.5	–0.16	1.52	0.01	1.6	–0.07	1.5	0.22	2.1	–0.70	3.2
27 m	–0.32	2.3	–0.17	1.42	0.38	1.7	0.01	1.5	0.58	1.6	–0.28	2.8
29 m	–0.44	1.9	–0.20	1.20	0.31	1.4	0.09	1.1	0.70	1.2	0.06	2.6
31 m	–0.48	1.6	–0.19	0.95	0.24	1.1	0.20	0.8	0.69	0.9	0.19	2.0
33 m	–0.49	1.3	–0.22	0.73	0.11	0.9	0.25	0.6	0.55	0.6	0.11	1.5
35 m	–0.44	0.7	–0.21	0.39	0.23	0.4	0.12	0.3	0.29	0.3	0.06	1.0

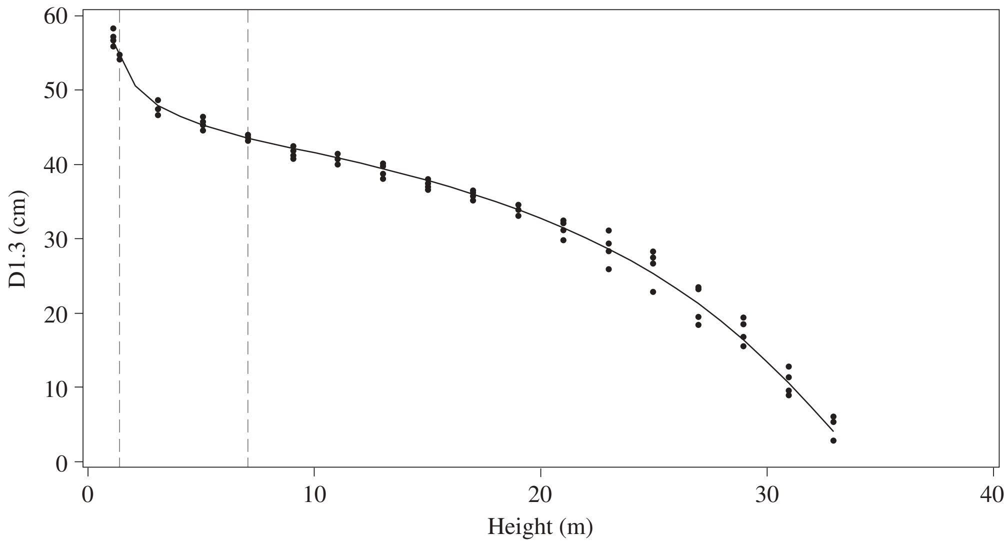

Figure 7. Predicted stem curve (solid line) and measured diameters, species fir, all section-wise measured trees having $d_{1.3}$ = 55–56 cm, d_7 = 44–45 cm, tree height = 34 meters.

Table 18. Goodness-of-fit of the taper equations. ar: average residual ($\Sigma(\hat{x}_i - x_i)/n$) and standard deviation of the residuals (in parenthesis) in percentage of the mean. p_t: Probability of the t-distribution. n: Number of trees. R^2: Coefficient of determination.

		d1.3 (cm)								
		12.-23	24-35	36-47	48-59	60-71	72-83	84-95	96-107	total
Spruce	ar (sr)	-0.4 (3.7)	-0.8 (3.7)	-1.0 (4.0)	-1.1 (4.5)	-0.5 (5.5)	0.8 (5.2)	-0.4 (5.2)	-0.8 (1.7)	-0.8 (7.0)
(R^2: 99.6%)	p_t	0	0	0	0	0.17	0.25	0.8	0.52	0
	n	6617	3521	1780	779	253	60	11	3	13024
Fir	ar (sr)	0.3 (4.6)	-1.0 (4.6)	-1.0 (4.9)	-1.2 (4.9)	-0.7 (4.9)	-0.7 (5.1)	-0.3 (4.4)	-0.8 (4.1)	-0.9 (7.2)
(R^2: 99.6%)	p_t	0.02	0	0	0	0	0.08	0.57	0.42	0
	n	1628	2199	1495	848	423	158	67	19	6848
Scotch Pine	ar (sr)	0.0 (4.7)	-1.1 (3.9)	-1.2 (5.0)	2.0 (8.1)	2.0 (5.7)	4.7			-0.8 (6.4)
(R^2: 99.2%)	p_t	0.86	0	0	0.17	0.7				0
	n	487	789	334	31	2	1			1644
Larch	ar (sr)	-0.4 (3.7)	-1.4 (3.9)	-1.0 (4.2)	-0.7 (4.5)	-1.0 (4.2)	-2.1 (6.3)	-0.9 (12.3)	-2.4	-1.00 (6.3)
(R^2: 99.4%)	p_t	0.06	0	0	0.01	0.02	0.1	0.88		0
	n	303	454	494	232	102	26	5	1	1617
Beech	ar (sr)	-0.4	-0.8	-0.9	-0.9	-2.2	-2.5			-0.9 (11.5)
(R^2: 98.7%)	p_t	0	0	0	0.14	0.17	0.5			0
	n	2515	2188	863	244	46	7			5863
Oak	ar (sr)	0	-0.9	-1.7	0.5	-0.7	-1.9	-3.1		-0.8 (8.3)
(R^2: 99.5%)	p_t	0.98	0	0	0.48	0.48	0.1	0.35		0
	n	621	578	254	98	37	9	2		1599

Table 19. Volumes estimated with taper equations ($\hat{x}_{1i}$) compared with volumes estimated with bole volume functions ($\hat{x}_{2i}$): ar: average difference $\Sigma(\hat{x}_{1i} - \hat{x}_{2i})/n$) and standard deviation of the differences (in parenthesis) in percentage of the mean. n: Number of trees.

		d1.3 (cm)								
		12.-23	24-35	36-47	48-59	60-71	72-83	84-95	96-107	total
Spruce	ar (sr)	-0.7 (2.5)	-1.1 (1.2)	-0.9 (1.0)	-0.3 (1.6)	0.7 (2.4)	1.3 (3.8)	2.5 (6.3)	1.0 (12.2)	-0.2 (4.0)
	n	4993	3680	6020	2682	1738	430	70	24	19640
Fir	ar (sr)	0.1 (8.9)	-1.2 (1.2)	-1.4 (0.8)	-1.4 (1.6)	-1.3 (1.0)	-1.4 (1.1)	-1.4 (1.3)	-2.7 (2.5)	-1.4 (3.3)
	n	1778	1095	1612	647	497	154	28	6	5822
Scotch Pine	ar (sr)	-1.7 (3.5)	-2.5 (1.7)	-1.5 (1.5)	0.0 (1.9)	2.2 (3.7)	5.7 (2.0)	12.4		-0.6 (4.1)
	n	294	279	547	197	59	4	1		1381
Larch	ar (sr)	5.4 (5.8)	-0.1 (2.3)	-1.1 (1.1)	-1.3 (0.8)	-1.8 (1.0)	-2.2 (1.3)	-3.5 (1.8)	4.0 (2.2)	-1.4 (3.0)
	n	482	372	608	312	282	84	23	7	2172
Beech	ar (sr)	-0.1 (2.6)	-1.0 (1.3)	-1.1 (1.3)	-1.2 (2.3)	-1.4 (2.8)	-2.7 (3.7)	-7.9 (4.6)	-12.6	-1.2 (4.5)
	n	3522	1852	1875	607	293	67	10	1	8227
Oak	ar (sr)	-0.7 (5.6)	-2.8 (2.7)	-0.8 (1.8)	0.4 (2.8)	1.0 (3.6)	0.9 (3.1)	1.4 (5.9)	5.5 (5.1)	0.1 (6.0)
	n	402	186	182	82	68	28	9	3	960

3.2.6.2 Assortments

Stem volumes are calculated with the help of rotational integrals, through which the spline function (f(x)), the adjustment function (g(x)) and the bark reduction function (r(x)), ALTHERR *et al.* 1978) are overlaid with each other.

$$V = \pi \sum_{i=1}^{q} \int_{x=h_{i-1}}^{h_i} \left[f(x) + g(x) - r(x)\right]^2 ?dx \qquad (32)$$

where

x: Height on the shaft
q: Number of integration limits
h_i: Integration limits at the following locations:
a) Knots (j) of the splines
b) Intersection point of the of the adjustment functions (7 meters)
c) Limits (k) of the stem sections for the bark reduction models

(0.33 H, 0.66 H; H= tree height)
d) Assortment limits for merchantable assortments

h_0: Basis (x=1 m)
The section from the stem base up to 1 meter in height is assumed to be cylindrical with a diameter of d_{1m}.

Functions:

$$f(x) = b_{0j} + b_{1j} \cdot rx_j + b_{2j} \cdot rx_j^2 + b_{3j} \cdot rx_j^3 \tag{33}$$

j: Knots of the spline function
$rx_j = x_j - x_{j-1}$

$$g(x) = c_1 \cdot x + c_2 \tag{34}$$

c_2: da_i - d_i at the location $h_{i\text{-}1}$

$$c_1 : \begin{cases} \left(\left(d_7 - \hat{d}_7\right) - \left(d_{1.3} - \hat{d}_{1.3}\right)\right) / 5.7 & for\, h_{i-1} \le 7 \\ -\left(d_7 - \hat{d}_7\right) / (H - 7) & for\, h_{i-1} > 7 \end{cases}$$

$$r(x) = b_{0k} + b_{1k} \cdot d_{mk} - b_{2k} \cdot dm_k^2 \tag{35}$$

where $k : \begin{cases} 1 \text{ for } x = 0 \le x = 0.33 \cdot H \\ 2 \text{ for } x = 0.33 \cdot H \le h_{i-1} = 0.66 \cdot H \\ 3 \text{ for } h_{i-1} > x = 0.66 \cdot H \end{cases}$

dm_1: Diameter over bark for x=0.25 H
dm_2: Diameter over bark for x=0.50 H
dm_3: Diameter over bark for x=0.75 H

In the NFI, the input variable d_7 and tree height (H) are only known for the tariff trees. The d_7 and H of the remaining trees are predicted with the NFI tariff functions (see Chapter 3.2.2.2). Table 20 shows assortment proportions of the spruce tariff trees of the first NFI. These proportions are calculated in three different ways (columns A to C). The percentages presented in column A are based on stem profiles that have been calculated with the help of measured d7 and H. Those in column B are based on stem profiles that have been constructed with the help of estimated d7 and H, and those in column C are based on assortment tariffs (see Chapter 3.3.1.4). The differences between the three estimation methods are very small.

Table 20. Estimated proportions of assortments with different methods using the spruce tariff trees of the first NFI (100%: total bole volume under bark).
Estimation methods:
A: Taper equations, d7 and h measured. B: Taper equations, d7 and h estimated. C: Assortment tariff.

Region		Assortment	A (%)	B (%)	C (%)
Jura	Long stemwood	1. Class	17.9 (1.3)	15.7	18.7
		2. Class	23.6 (1.3)	25.4	23.1
		3. Class	26.6 (1.2)	27.9	26.3
		4. Class	12.0 (0.8)	12.7	12.3
		5. Class	9.8 (0.7)	8.1	10.5
		Total	89.8 (0.4)	89.7	90.9
	Short stemwood	middle diam. >= 30 cm	53.9 (1.2)	54.7	52.9
		middle diam. < 30 cm	27.9 (0.8)	27.0	28.5
		Total	81.9 (0.6)	81.6	81.4
Plateau	Long stemwood	1. Class	25.6 (1.2)	25.9	25.3
		2. Class	31.9 (1.0)	32.9	31.3
		3. Class	20.4 (0.9)	19.4	21.3
		4. Class	7.3 (0.5)	6.8	7.6
		5. Class	5.0 (0.4)	4.7	5.5
		Total	90.2 (0.3)	89.7	91.0
	Short stemwood	middle diam. >= 30 cm	51.6 (0.9)	51.4	52.5
		middle diam. < 30 cm	30.8 (0.6)	30.1	28.9
		Total	82.4 (0.5)	81.5	81.4
Prealps	Long stemwood	1. Class	21.3 (1.0)	19.5	20.2
		2. Class	24.5 (0.9)	26.4	26.4
		3. Class	23.3 (0.8)	24.4	20.9
		4. Class	10.7 (0.6)	11.5	12.0
		5. Class	9.1 (0.5)	7.3	9.6
		Total	88.9 (0.3)	89.1	89.1
	Short stemwood	middle diam. >= 30 cm	53.5 (0.8)	53.5	52.8
		middle diam. < 30 cm	28.3 (0.6)	28.0	28.7
		Short stemwood	81.8 (0.4)	81.5	81.5
Alps	Long stemwood	1. Class	16.9 (0.8)	13.4	16.7
		2. Class	18.5 (0.7)	20.0	19.1
		3. Class	23.7 (0.7)	26.7	22.9
		4. Class	15.1 (0.5)	16.3	14.7
		5. Class	12.7 (0.5)	10.9	13.9
		Total	86.9 (0.3)	87.4	87.3
	Short stemwood	middle diam. >= 30 cm	52.4 (0.8)	52.0	52.5
		middle diam. < 30 cm	27.9 (0.5)	27.9	28.4
		Total	80.3 (0.4)	79.9	80.9
Southern Alps	Long stemwood	1. Class	12.6 (2.0)	8.7	14.9
		2. Class	17.7 (1.7)	15.9	16.1
		3. Class	25.8 (1.9)	31.0	24.3
		4. Class	16.1 (1.6)	18.6	16.7
		5. Class	13.7 (1.3)	11.8	13.6
		Total	85.9 (0.9)	86.1	85.6
	Short stemwood	middle diam. >= 30 cm	57.2 (1.8)	56.1	56.5
		middle diam. < 30 cm	24.0 (1.1)	24.4	25.8
		Total	81.2 (0.9)	80.5	82.3

3.2.7 Literature

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3.3 Prognosis and Management Scenarios

Edgar Kaufmann

Changes in standing volume, as well as increment and cut in the Swiss forest during the last 10 years, could be reliably estimated with the help of the two inventories NFI1 and NFI2. Volume and increment depend on the current structure of the forest (age structure, stand density, species composition). These forest structures are, among others, the result of the pursued management strategy. For the next decade, different management strategies will of course be possible. Apart from determining the changes over the last 10 years, it is also of interest to predict possible future developments, depending on different management scenarios. The existing data of the NFI1 and NFI2 are a sound basis for the prediction of medium term developments comprising 20 years.

Developments in the uniform high forest are predicted by a model which works in two decadal steps. The model is based on the data set of the two inventories NFI1 and NFI2, and on mathematical functions that were derived from these data. The increment is estimated on an individual tree basis. Forest structures which are hereby taken into consideration are updated after the first projection decade, and thus influence the growth in the second decade. External influence factors, such as climate, are not included (i.e. they are considered to be constant in this model). Given the probabilities for silvicultural treatments, the standing timber and annual increment for the year 2015, as well as the volume of harvested timber in these 20 years, is predicted.

The extrapolation of the results for the entire Swiss forest is conducted with the help of the prognosis results from the uniform high forest. Relationships between the standing timber from 1995, cut and increment from 1985–1995, as well as the development of increment and cut from 1995 to 2015 in the uniform high forest are applied to the remaining types of forest.

For the first publication of NFI results, four scenarios were calculated. Apart from the medium term potentials of harvest (equilibrium between annual increment and annual cut in 20 years), it was of interest how the standing timber and the increments developed when: 1) the management strategy of the last 10 years will not change in the next 20 years, 2) harvest is minimized and limited to maintain the protective function of the forests, or 3) the timber harvest volume exceeds today's growth substantially.

3.3.1 Models for the Uniform High Forest

In the model, the increment over a 20 years period was predicted on an individual tree basis in two decadal time steps. The extrapolated diameters of the recorded young growth are used to model ingrowth, i.e. trees that grow over the caliper threshold of 12 cm. Trees are harvested or die off with an individual probability. These operations are conducted randomly within given probabilities. The prognosis results are the average values of ten simulation runs. The model starts from the state of the forest in the year 1995 and proceeds in the following way (Figure 1):

I. Extracting Raw Data from the Data Base

The raw data consists of stand, site, and individual tree attributes in the uniform high forest that were recorded on the terrestrial sample plots. The preliminary limitation to the uniform high forest was necessary, since the mechanisms are easier to reproduce for this type of forest and developments can be more easily verified than for other forest types.

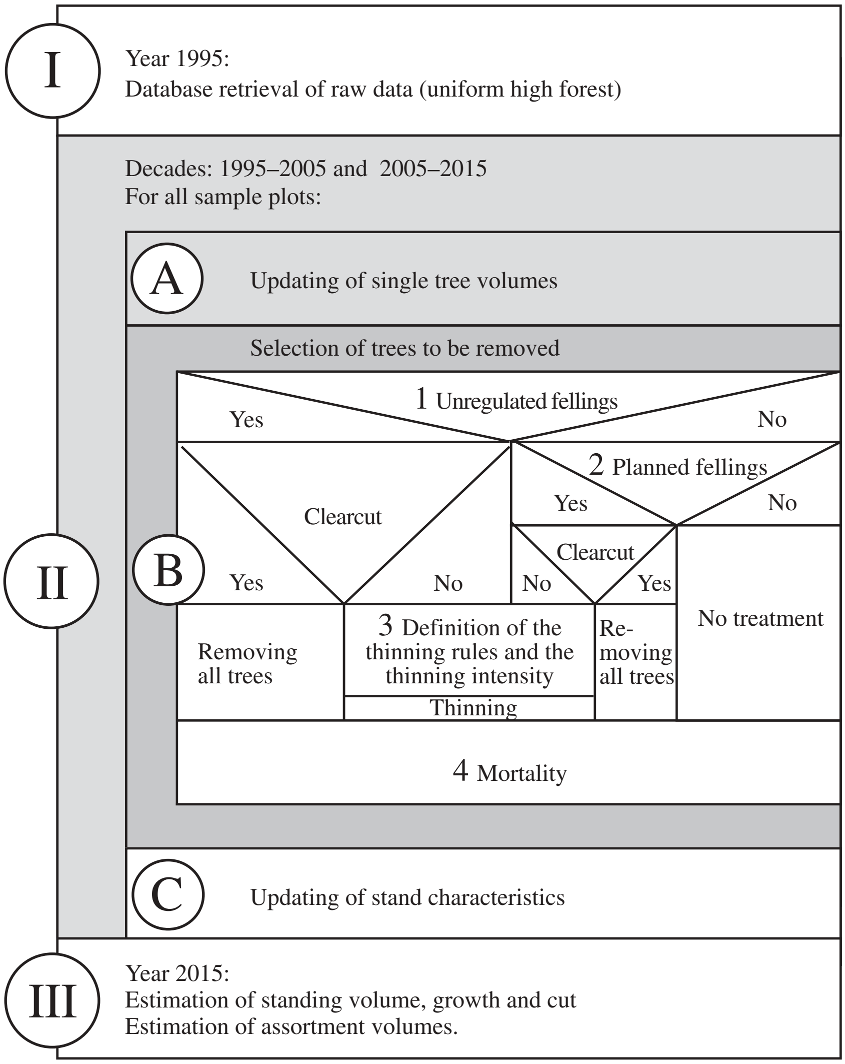

Figure 1. Flow-chart of the prognosis model.

II. Updating Individual Tree Volumes, Selection of Trees to be Removed and Updating the Stand Characteristics

A) Updating Individual Tree Volumes

The diameter growth of all of the surviving trees (Chapter 3.2.5) with a DBH>12 cm (date t_j), and the surviving young growth trees in the young growth class 5–7 were predicted according to equation 1–3 with the increment function for the basal area as described in Chapter 3.2.2.5, Equation 15.

$$\Delta ba_i(t_j) = f(d_{1.3,i}(t_j), BAL, BASFPH, ...,) \quad \text{(See Equation 15, Chapter 3.2.2.5)} \tag{1}$$

$$ba_i(t_{j+1}) = ba_i(t_j) + \Delta ba_i(t_j) \tag{2}$$

$$d_{1.3,i}(t_{j+1}) = \tfrac{2}{\pi}\sqrt{ba_i(t_{j+1})} \tag{3}$$

$$v_i(t_{j+1}) = f(d_{1.3i}, GWL, ...) \quad \text{(See Equation 12, Chapter 3.2.2.2)} \tag{4}$$

where

ba_i: Basal area of an individual tree

v_i: Tariff volume (stem wood over bark) of an individual tree (determined for trees with a $d_{1.3} \geq 12$ cm)

t_j, t_{j+1}: Beginning and end of a 10 year growth period

Each tree dies off with a certain probability either through natural mortality or through utilization. The mortality rate ($mort_{JW}$) for the young growth is predicted by comparing the number of actual ingrowth trees in the second NFI with the trees which were assessed in the first NFI and would, theoretically, have grown in according to equations 1–3. The mortality rate is assumed to be constant. The mortality of the trees with a $d_{1.3}$> 12 cm ($mort(d_{1.3,i})$) is discussed in more detail in part B.

The numbers of trees ($N_{>12}$, $N_{>35}$) are given by the Equations 4 and 6.

$$N_{>12}(t_{j+1}) = \sum_{k|12<d_{1.3,k}(t_{j+1})<35} (1 - mort(d_{1.3,k}(t_j)) + ingrowth(t_{j+1}) \quad (5)$$

$$\text{where } ingrowth(t_{j+1}) = \sum_{k|12-\Delta d_{1.3,k}(t_j)<d_{1.3,k}(t_j)<12} (1 - mort_{JW}) \quad (6)$$

$$N_{>35}(t_{j+1}) = \sum_{k|35<d_{1.3,k}(t_{j+1})} (1 - mort(d_{1.3,k}(t_j)) + ongrowth(t_{j+1}) \quad (7)$$

$$\text{where } ongrowth(t_{j+1}) = \alpha \cdot \sum_{k|35<d_{1.3,k}(t_{j+1})} (1 - mort(d_{1.3,k}(t_{j+1})) \quad (8)$$

Ingrowth: Young growth trees that grew over the threshold of 12 cm within one period
Ongrowth: Trees in the outer sample plot ring that grew over the caliper threshold of 35 cm (see Chapter 3.2.5)
α: Ongrowth rate

Which of the young growth trees can grow over the threshold of 12 cm within 10 years (ingrowth, Equation 6) is determined with the growth equation (Equation 1–3). The young growth plants of the class 5, 6, and 7 of the second NFI survey (STIERLIN *et al.* 1994) are considered as the potential ingrowth up to the year 2015. The plants of the lower classes cannot reach a DBH of 12 cm during the simulation period.

The number of ongrowth trees (ingrowth over the caliper threshold of 35 cm, see Chapter 3.2.5) are calculated as proportions α of all surviving trees with a $d_{1.3}$>35 cm (Equation 8). These rates are determined empirically with the help of the NFI data.

In the growth model, the basal area on a sample plot (BASFPH) and the competiton variable BAL (i.e. sum of the basal area of all trees on a plot that are larger than the subject tree, see Chapter 3.2.2.5) have a derogating effect on the growth: The denser a stand, the higher the competition between the trees, and thus, the smaller the individual tree growth. Conversely, thinning, which reduces the competition pressure, is able to stimulate growth.

B) Selecting Cut and Mortality

1. Probability for Unregulated Fellings

In the first step those sample plots are selected at random, on which some event will cause unregulated fellings within the next 10 years. Within a stratum (A) unregulated fellings (Z) occur with probability $P(Z \mid A)$ (i.e., $P(Z \mid A)$ is the probability that the sample plot belongs to stratum A and that unregulated fellings takes place). These unregulated fellings are either a clearcut on the plot (ra; with a probability of occurrence P_{ra}) or a removal of individual trees (df; with a probability of occurrence P_{df}).

$$P_{Urs}(Z \mid A) = P_{ra,Urs}(Z \mid A) + P_{df,Urs}(Z \mid A)$$

where

Urs: Reason for unregulated fellings (e.g. windfall, insect infestation)

Stratum A defined by: production region, ownership, species composition

2. Probability for planned fellings

A planned silvicultural treatment (N) within a stratum (B) can occur on a sample plot on which no unregulated fellings are conducted. The probability for this is $P(N \mid B \setminus U)$, where U means the sample plots on which unregulated fellings are conducted within a stratum B. A planned felling can either be a clearcut (ra) or a thinning (df).

$$P(N \mid (B \setminus U)) = P_{ra}(N \mid (B \setminus U)) + P_{df}(N \mid (B \setminus U))$$

Stratum B defined by: production region, ownership, d_{dom}, harvesting method, site quality (GWL), expenditure for timber harvest, date of last treatment

3. Performing of thinnings

The thinning intensity (f_s) is defined separately for the trees of the upper layer and the remaining trees in the stratum S, and represents the proportions of trees to be cut. The type of thinning was formulated according to the following rule which was established based on the removals between the first and second NFI: The diameter distribution of the initial stands ($P(A_s,d)$) as well as the removed trees ($P(C_s,d)$) in the strata (S) were described by a Weibull distribution (KAUFMANN 1990). The probability that a tree with a certain diameter *d* from a given initial distribution is removed, is $\frac{P(C_s, d)}{P(A_s, d)}?f_s$ for the strata S, which are defined by:

production region, ownership category, unregulated felling (yes/no), stage of development, the storey that an individual tree belongs to (upper storey, not upper storey).

Figure 2 shows the diameter distribution of the upper storey trees of the initial stand $P(A,d)$, of the removals $P(C,d)$, and the selection probability $\frac{P(C,d)}{P(A,d)}?f$ for development stage "medium timber" in the public forest of the Plateau. This selection probability is the probability that a tree is cut during thinning.

4. Natural Mortality

Natural mortality occurs on sample plots without any treatment within a inventory interval. The probabilities for this are empirical frequencies, which were determined with the help of NFI data set. They are defined by production region, stage of development, and the layer an individual tree belongs to.

The probabilities established in steps 1–4 are used to extrapolate the "business as usual" scenario. For other scenarios, the removals are selected with the same procedure, but with modified selection probabilities (see Chapter 3.3.2).

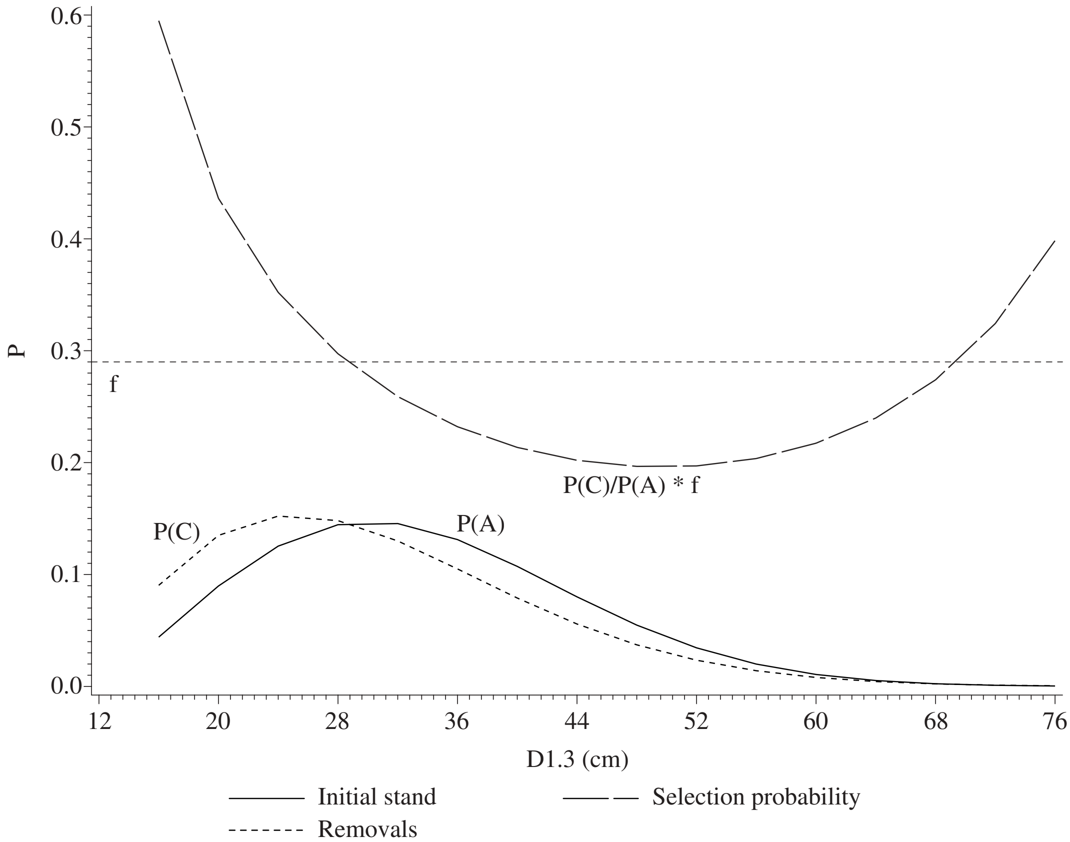

Figure 2. Diameter distribution of the initial stand (P(A)); diameter distribution of the removals (P(C)); thinning intensity (f) and selection probability (P(C)/P(A)) * f) with which trees are selected from the initial stand A in order to obtain distribution C.

C) Updating the Stand Characteristics

Stand characteristics that are used as explanatory variables in the prediction of standing timber and increment (Chapter 3.2.2.2, Equation 12 and Chapter 3.2.2.5, Equation 15, Appendix: variable documentation), or that have an influence on the selection probability of the removals are updated after the first decade, so that the predictions in the second decade refer to changed stand conditions. For example, the d_{dom} updated after the first decade has an influence on the standing timber estimation in the subsequent decade (change of tariff volume). With the help of the d_{dom}, the stage of development, which is used to establish the selection probabilities of the removals, is also updated.

The stage of development is used in the model as a stratifying variable. A correct extrapolation of this variable is therefore necessary. The stage of development in the NFI was assessed with the help of an arbitrary estimated d_{dom} of a stand. In the scenario model, the development stage is established using a d_{dom}, which is calculated with the help of measured tree diameters. There exist random and systematic differences between the development stages that were defined in these two different ways. These differences are reproduced in the model after quantifying the errors with the help of the NFI data sets and the check assessment (see Chapters 2.9 and 4.4).

III. Determining Results

In each of the simulation runs of steps I and II, the standing volume, increment, cut and mortality per production region is estimated. The final results are the average values of 10 simulation runs. Other results as distributions of assortments or age class distributions are obtained from the last simulation run.

For the standing timber and the removals, the distribution of merchantable assortments (see Chapter 3.2.6) is of interest. In the scenario model, only the diameter at breast height is extrapolated. The information necessary to describe the stem form is therefore missing. The volume proportions of assortments are thus predicted with so called assortment tariffs. These tariffs are based on the $d_{1.3}$ and the bole volume of a tree. The NFI assortment tariffs were derived with the help of the first NFI tariff sample trees and a logistic function, as SCHMID-HAAS (1976) had recommended:

$$s_{i+} = \frac{o_{i+}}{1 + (q_i + r_i ?d_{1.3})^{t_i}}$$

where

s_{i+}:	Proportion of the bole volume over bark of the assortment class i and all classes of larger piece dimensions (i.e. with smaller class numbers)
o_{i+}:	Maximal achievable si+
qi, ri, ti:	Parameters estimated with Gauss-Newton method (SAS 1990), (see Table 1)

The assortment volume V_{si} is estimated as the proportion of the stem volume over bark V_{ti} as follows:

$$V_{si} \;=\; V_{ti} \,?(s_{i+} - s_{(i-1)+})$$

Figure 3 shows the assortment proportions as they were determined with the NFI1 tariff sample trees and the corresponding assortment tariff curves for long stemwood of spruce in the Plateau.

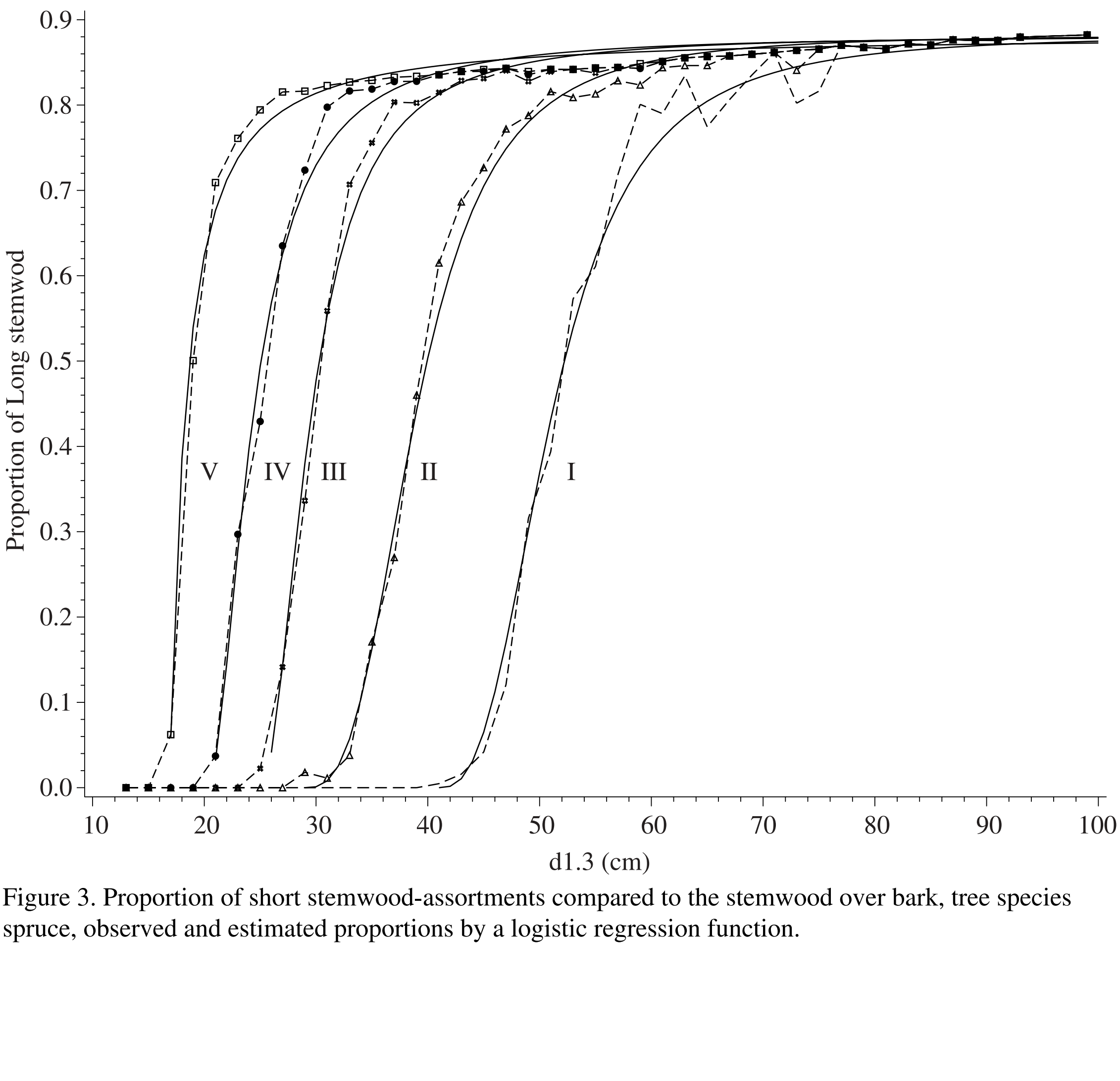

Figure 3. Proportion of short stemwood-assortments compared to the stemwood over bark, tree species spruce, observed and estimated proportions by a logistic regression function.

Table 1. Coefficientsof the conifer assortment tariffs.

	Long stemwood				
	Class	q	r	t	o
Jura under 1000 m	1	–1.1732	0.0402	–4.7146	0.87
	2	–3.067	0.0984	–2.8821	
	3	–5.3472	0.2076	–2.0944	
	4	–1.7943	0.1095	–4.1741	
	5	–5.0227	0.3194	–2.014	
Jura over 1000 m	1	–2.3825	0.0574	–3.6869	0.88
	2	–1.3536	0.0485	–3.9523	
	3	–1.3738	0.0647	–3.3738	
	4	–2.7429	0.1256	–2.2983	
	5	–2.4461	0.1592	–2.6288	
Plateau	1	–4.0292	0.0983	–2.7211	0.88
	2	–2.9016	0.1001	–2.9265	
	3	–5.43	0.2172	–1.9754	
	4	–4.9664	0.2443	–1.8207	
	5	–11.9151	0.7063	–1.1118	
Pre–Alps under 1000 m	1	–2.0369	0.0582	–4.3342	0.88
	2	–2.9706	0.101	–2.7039	
	3	–4.1924	0.1677	–1.8664	
	4	–4.7866	0.2279	–1.8793	
	5	–5.392	0.3229	–1.6034	
Pre-Alps over 1000 m	1	–3.0387	0.0707	–2.3032	0.88
	2	–4.0961	0.117	–1.6941	
	3	–3.5343	0.1309	–2.0485	
	4	–2.8032	0.1335	–2.1566	
	5	–5.392	0.3029	–1.6034	
Alps under 1000 m	1	–1.0346	0.0383	–7.7829	0.88
	2	–0.1469	0.0263	–6.9313	
	3	–2.1585	0.0914	–2.8892	
	4	–3.3876	0.1581	–2.225	
	5	–3.6924	0.2172	–1.8757	
Alps over 1000 m	1	–1.819	0.0463	–3.0043	0.87
	2	–3.398	0.0918	–2.0562	
	3	–2.2444	0.0877	–2.3446	
	4	–2.3665	0.1127	–2.2554	
	5	–2.1861	0.1457	–2.5523	
Southern Alps	1	0.3018	0.01	–10	0.87
	2	–1.8853	0.054	–1.8941	
	3	–2.6219	0.0904	–2.1266	
	4	–2.3996	0.1043	–2.5605	
	5	–2.5677	0.148	–2.3304	

	Shorter stemwood			
Class	q	r	t	o
Upper	–2.8363	0.0979	–2.1098	0.86
Lower	–5.3156	0.2565	–1.2823	0.88

3.3.2 Definitions of the Scenarios for the Result Volume of the Second NFI

For the result volume of the second NFI, the following four basic scenarios were calculated which were supposed to indicate the consequences of different management scenarios. With respect to standing timber, increment, cut, mortality and age class distribution up to the year 2015, the following questions needed to be answered:

- What happens if the forest is managed as in the past ("business as usual", Scenario 1)?
- What happens if forest management is limited to a minimum in the forests which protect a route or settlements below them from avalanches and rockfall (Scenario 2)?
- What is the order of magnitude of the medium term growth potential (Scenario 3)?
- What happens if suddenly the demand for timber increases drastically, and as a consequence more timber is harvested (Scenario 4)?

The probabilities for the removals described above are modified in the four scenarios as follows:

Scenario 1: The probabilities for planned clearcut and thinning as well as for unregulated fellings stay the same for 20 years. The date of the last silvicultural treatment is important. It reduces the probability for thinning in the second decade if there was already a silvicultural treatment in the first decade.

Scenario 2: Planned silvicultural treatments are limited to the protective forests as they are defined in NFI. These forests encompass 8% of the forested area. The probability for windfall in older coniferous spruce stands in the Plateau is increased by 50%; the remaining unregulated fellings occur with unchanged probability. No clearcut is carried out; however, thinning intensities in old stands of protective forests are augmented drastically. When thinning protective forests, up to 60% of the trees are removed in stands that are more than 200 years old and, at most, 15% of the trees are removed in younger stands. None of the other stands were touched. The mortality rate is doubled in stands where no silvicultural treatments are carried out. In this scenario, 85% of all cut trees were unregulated fellings.

Scenario 3: The probabilities for planned fellings are increased so that the current annual increment in the year 2015 equals the average annual cut of the previous 20 years. The increase of harvest was evenly distributed among clearcuts and thinning. The thinning intensity is increased by a maximum of 10% of the number of stems compared to the "business as usual" scenario. The probability for clearcuts is increased for stands older than 120 years than for younger stands. Probabilities for unregulated fellings remain unchanged.

Scenario 4: The probabilities for planned fellings are drastically increased, so that the clearcut areas and the number of the once and of the twice thinned stands increased drastically. During the thinnings, a maximum of 40% of the trees are removed.

3.3.3 Plausibility Study

Whether the model generates plausible results was studied with the help of two kinds of predictions of standing timber and increments over a 20 years period. For Scenario 1 (see Chapter 3.3.2), the standing timber and increment was predicted once starting in 1985, based on data of the first NFI (Table 2 and 3, prediction I) and once starting in 1995, based on data of the second NFI (Table 2 and 3, prediction II). With that, two prognoses for 1995 and 2005 (Table 2 and 3) were available. These results are plausible: The predictions for 1995 and the results of the second NFI, as well as both of the predictions for 2005, are nearly equal. Tables 2 and 3 show average values of ten simulation runs. The results of the simulation runs varied by 0.5–1.5% for the standing timber and the increments, for the cut by 11–18% in the Southern Alps and by 3–7% in the remaining regions.

Table 2. Volumes per hectare for the uniform high forest.
NFI: Estimation for NFI1 (1985) and NFI2 (1995).
Prognosis I: Prognosis for the year 1995 and 2005, starting in 1985 (NFI1).
Prognosis II: Prognosis for the year 2005 and 2015, starting in 1995 (NFI2).

	Jura				Plateau				Pre-Alps				Alps				Southern Alps				Switzerland			
	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015
NFI	342	373			410	434			449	481			317	340			187	220			360	387		
Prognosis I		366	395			426	454			487	518			341	339			215	253			384	406	
Prognosis II			402	435			455	471			512	539			347	352			238	283			407	428

Table 3. Increment and cut in the uniform high forest.
NFI: Estimation for NFI1 (1985) and NFI2 (1995).
Prognosis I: Prognosis for the year 1995 and 2005, starting in 1985 (NFI1).
Prognosis II: Prognosis for the year 2005 and 2015, starting in 1995 (NFI2).

	Jura			Plateau			Pre-Alps			Alps			Southern Alps			Switzerland		
	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15
Increment																		
NFI	9.3			13.9			11.7			7.5			5.1			10.1		
Prognosis I	9.5	9		14.5	14.4		12.2	12.1		8.1	6.5		5.1	5.8		10.5	10	
Prognosis II		8.8	9		14.1	14.2		11.3	11.3		6.6	6.5		4.4	6.3		9.6	9.8
Cut																		
NFI	6.4			11.6			8.4			5.5			2			7.4		
Prognosis I	6.6	5.9		12	12		7.4	8.3		5.1	6.4		2.1	1.7		7.3	7.7	
Prognosis II		5.7	6.1		11.7	12.9		7.7	8.7		5.5	5.7		2.5	1.6		7.3	7.8

3.3.4 Prediction of Standing Timber and Increment for the Entire Forest

The results for the uniform high forest obtained by model predictions were extrapolated for the entire accessible forest. The forest types “uniform high forest,” “non-uniform high forest,” and “coppice forest/coppice with standards” were distinguished.

The average cut volume (including mortality) for the uniform high forest during the period 1995–2015 compared to 1985–1995 decreases to 95% in Scenario 1, to 28% in Scenario 2, and it increases to 172% in Scenario 4. The same changes in terms of percentages were assumed for the remaining forest types. In Scenario 3, the cut for all types of forests were continuously increased until there was a balance between cut and growth in the year 2015.

The relationship between the standing timber in the year 2005 (V_{05}) on one hand and V_{95} (standing timber 1995), $Gg_{85\text{-}95}$ (increment 1985–1995), $CM_{85\text{-}95}$ (cut and mortality 1985–1995), and $CM_{95\text{-}05}$ (cut and mortality 1995–2005) on the other hand are expressed with a regression model. With this model, the V_{05} for the forest type “non-uniform high forest” and “coppice forest/coppice with standards” can be estimated:

$$V_{05} = b_0 + b_1 \cdot V_{95} + b_2 \cdot Gg_{85-95} + b_3 \cdot CM_{85-95} - b_4 \cdot CM_{85-95}$$
$$b_0 : 4.942,\ b_1 : 0.937,\ b_2 : 0.948,\ b_3 : 0.541,\ b_4 : 1.305$$

It is assumed that the development of standing timber over 20 years is linear. This means that for the period 2005 to 2015, the same change is assumed as for the period 1995–2005. The increment for 2005–2015 can be calculated with $Ggi_{05\text{-}15} = V_{15} - V_{05} + CM_{05\text{-}15}$ (see page 309 HUSCH *et al.* 1972).

The extrapolation of the standing timber and increment prediction from the uniform high forest to the entire forest in this manner is preliminary. Non-uniform stands are intended to be included for continued development of the models that are planned. Assuming that the prediction procedures for the uniform high forest lead to correct results, the extrapolations with regards to the entire forest, which were calculated in this simple way, are at least in the correct order of magnitude. An extension of the prediction procedures will, however, give more precise and more reliable results.

In a new version of the model, the treatment probabilities will be determined by logistic models. The parameterization will be, therefore, substantially simplified, and the dependencies between treatment probabilities and explanatory variables will become more transparent. With this, additional scenarios will also be more easily expressed.

The medium term prediction results generated with the model do not only depend on a chosen scenario, but also on whether the growth reaction to the thinning was correctly predicted, and whether the standing timber would be unbiasedly estimated with the NFI volume tariffs in changed forest populations. The increment and tariff functions of the NFI are, strictly speaking, only valid for changes between the two inventories NFI1 and NFI2 and for the state of the forest at both inventories. Whether or not they give the correct results for the prediction period of 20 years cannot be verified with the inventory data. It is therefore planned to study the increment reaction to silvicultural treatments and the shifts in volume tariffs with the help of data from forest yield experiments.

3.3.5 Literature

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3.4 Sustainable Forest Regeneration

Philippe Duc

3.4.1 Introduction and Definition of Terms

The NFI assesses the changes and state of the forest as a basis for monitoring the forest development (BRÄNDLI 1993). A special interest here is given to the sustainability of forest influences with respect to human requirements, in other words, the permanent fulfillment of forest functions. This will only be ensured if the forest constantly regenerates itself enough or if it is regenerated by humans. Sustainable forest regeneration represents, therefore, a key measure in the evaluation of sustainable forest development.

"Sustainability" is a very complex term. Its meaning has changed considerably over time (BERNASCONI 1996; ZÜRCHER 1965). For almost all of the definitions and meanings of sustainability, the main focus is on the sustained use of the essential elements required to sustain life (BÄCHTOLD 1998). GLÜCK (1994) distinguishes between the two definitions commonly used today in forestry: first, sustainability in the sense of a multifunctional forest utilization, and second, the ecological sustainability.

Sustainability in the sense of a multifunctional forest utilization (GLÜCK refers to it as "sustainable multi-purpose forestry") emerged when the concept of sustainable timber production was extended to all forest functions. The goal of sustainable multifunctional forest utilization is to obtain regular yields that are as high as possible from timber sales and from compensations of forestry services, while at the same time fulfilling certain social, legal, operational, or ecological limitations (GLÜCK 1994).

The goal of **ecological sustainability** consists primarily in improving or preserving the ecological stability of forest ecosystems. Sustaining the ecological stability does not, therefore, represent a limitation, but is the actual goal. "Compared with the sustainable multi-purpose forestry, the conservation of the ecological stability turns from being a limitation to being the goal, and the supply of timber and forestry services turns from being the goal to being a limitation (GLÜCK 1994)". The **ecosystem management**, which grew out of this, emphasizes the natural state of ecosystems, especially the biodiversity and the ecological stability. Both should not be diminished under any circumstances, but on the contrary, should be increased whenever possible.

The **evaluation of the sustainability in the National Forest Inventory** was based for the entire forest (BRÄNDLI 1999) as well as for the forest regeneration, on the sustainability in the sense of the multifunctional forest utilization.

3.4.2 Introduction into Calculating Sustainable Forest Regeneration

According to ZÜRCHER (1965), the **examination of the sustainability** is conducted by comparing the present state of the forest with the **normal state** of the forest. The normal state is a desirable state of the forest, which constantly and at all times optimally satisfies all the demands, and which does not contradict the natural law. The **nominal state** of uniform high forests is calculated with an area based normal forest model (see also Chapter 3.4.3); the nominal state of plenterlike forests with an individual tree based plenter forest model (see Chapter 3.4.4). It is important to note that these models are very rough approximations to their complex reality. The normal state of a forest is, above all, a simple model in order to understand and to control the sustainable composition of the forest.

The **normal forest** is a model for a sustainable forest on a homogeneous site and has a constant tree species composition. Furthermore, stands are identical to the yield tables with respect to stand density and stand development, and are balanced in the representation of all age classes. The regeneration area is therefore constant every year. In a fictitious normal forest with an area of 200 hectares and a rotation period of 100 years, each year age class occupies an area of 2 hectares, so that the yearly sustainable regeneration area amounts to 2 hectares per year. Keeping this regeneration area constant ensures a yearly and consistent amount of work for harvesting, young growth tending, and thinning, as well as approximate constant timber yield and revenues.

The **normal forest model** is suitable primarily to evaluate even-aged, clear-cut high forests. The closest type of forest to this model is the uniform high forest as defined by the NFI, which is characterized by a layered structure, and which can be clearly classified as a certain stage of development. In contrast to even-aged high forests that are regenerated by clear-cuts (age-class forest), many uniform high forests in the lower elevations of Switzerland are regenerated under shelterwood, by strips, or in small gaps. In enterprises with regeneration under shelterwood, generations of trees overlap; therefore, the normal forest model is not really applicable (HOLM 1984). In the absence of a model for the shelterwood forest, the sustainable regeneration area is nonetheless calculated with the normal forest model. The use of the normal forest model is based on the following assumptions:

– Uniform high forests are continuously being regenerated in one area and are not converted into plenter high forests.
– The normal forest model provides suitable nominal value for the regeneration, even for forests that are regenerated in smaller areas.

The **plenter forest model** is a model for a selection forest, which is in a structural equilibrium, has a constant number of trees per diameter class, and has sustainable cuttings corresponding to total yield (according to SCHÜTZ 1989). The main idea behind this model is that for each diameter class a certain number of trees can be determined which does not change over time. The reason for this is because only so many stems grow into a certain class as grow into the next higher class or die off naturally during the same period of time (DUC 1991).

The plenter forest model is suitable for the evaluation of stands that have a permanent multi-storied structure and are regenerated in small patches dispersed over the whole stand. This is the case for multi-storied or clustered stands, but not for irregular stands with layered structure. The plenter forest model was, therefore, only used to evaluate plenter forests. The following assumptions were thereby made:

– The plenter forests will not be converted into uniform high forests in the near future.
– The plenter forests are in an approximate structural equilibrium or, even though certain departures exist from the equilibrium, the plenter forest model can still be used.

3.4.3 Sustainable Forest Regeneration of Uniform High Forests

Sustainable Proportion of Young Forest

The sustainable proportion of young forest is that part of the forest area occupied in the normal forest by the development stages “young growth,” “thicket,” and “thin pole wood”. These stages of development should be represented proportionally to the time it takes to grow through a particular stage, as compared to the entire rotation period (ZÜRCHER 1965). This growing time depends on the tree species, site, and length of time the stand was under shelter during the young growth and thicket stage. For this reason LEIBUNDGUT (1981) only indicates approximate values of growing time. The proportion of young forest (according to the NFI’s stages of development – young growth and thicket – with a dominant diameter at breast height that is less than 12 cm) corresponds approximately to the development stages of young growth, thicket, and thin pole wood, according to LEIBUNDGUT (1981). Relating the minimum duration of young forest development given by Leibundgut to the economically optimal rotation periods on good sites in the Swiss Plateau (BACHMANN 1990) results in minimum values for the proportion of sustainable young forest per tree species as shown in Table 1. In lower elevations, the proportion of sustainable young forest amounts to 14% to 28%. This corresponds closely with the sum of the proportions of the development stages for young growth (5% to 10%) and thicket (8% to 12%), which was considered by ZÜRCHER (1965) to be sustainable with respect to the normal forest model (i.e., in the sense of sustainable timber production).

Table 1. Standards for the period of young forest development, the rotation period, and the sustainable proportion of young forest in lower elevations (colline to submontane zone).

Tree species		Period of young forest development	Rotation period	Sustainable proportion of young forest
common	scientific	Years	Years	%
Norway Spruce	Picea abies Karst.	20–30	110–130	18–23
Silver Fir	Abies alba Mill.	30–40	120–140	25–28
Scotch Pine	Pinus silvestris L.	20–30	130–150	15–20
European Larch	Larix decidua Mill.	17–25	120–140	14–18
Common Beech	Fagus silvatica L.	30–40	130–150	23–27
English/Durmast Oak	Quercus robur L. / Quercus petraea	30–40	150–170	19–22
Common Ash	Fraxinus excelsior L.	18–25	80–100	23–25

In the higher elevations the young forest development can take considerably longer. However, since the rotation periods are also substantially longer, the sustainable proportions of young forest are similar to those of lower elevations (Table 2). Depending on the tree species and rotation period, the sustainable proportion of young forest lie approximately between 17% and 30%, which corresponds well to the expectations given by OTT *et al.* (1997). Since the young forest development depends on the site and type of regeneration system, and since the rotation period depends on the goal (especially on the target diameter), the presented values for the sustainable proportion of young forest are not constant, but instead give an approximate dimension. In the NFI a young forest proportion of 10% was considered to be too low; between 10% and 25% as sustainable; and above 25% as too large.

Table 2. Standards for the period of young forest development, the rotation period, and the sustainable proportion of young forest in higher elevations (upper montane and subalpine zone).

Tree species		Period of young forest development	Rotation period	Sustainable proportion of young forest
common	scientific	Years	Years	%
Norway Spruce	Picea abies Karst.	50–75	200–300	25
Silver Fir	Abies alba Mill.	60–90	200–300	30
European Larch	Larix decidua Mill.	40–50	200–300	17–20

Sustainable Regeneration Area

The **sustainable regeneration area** is the forest area that has to be cleared every year in order to ensure a balanced age class distribution in the normal forest enterprise. For a forested area F and a rotation period u, this corresponds to a ratio of F/u. The sustainable regeneration area was calculated in the NFI only for managed forests with regeneration in larger areas. Forest areas with regeneration on an individual tree basis and unmanaged or specifically managed forest areas were not included in the calculation.

The sustainable area of regeneration depends on the chosen or calculated rotation period. In contrast to the normal forest, work is being conducted with actual enterprises and regions with several different tree species, and at sites that have different growth potentials. Since the rotation periods are different on most of the sites for the most common tree species, the sustainable regeneration area cannot be calculated by simply using the assumed mean rotation period u. The rotation periods must be calculated for the present or the future desired proportion of the most important tree species and have to be site specific. The **rotation period** u is the planned, fixed time period between the establishment and the removal of a stand. The period depends mainly on the tree species, site quality, and thinning intensities.

The **optimal (with respect to yield) rotation periods** of a tree species on a certain site is reached when the economic yield curve of the stand reaches the site-specific production capacity during or after its culmination (BACHMANN 1990). The production capacity corresponds to the maximum value of the average economic yield on a site-specific ideal stand. Due to the model calculations carried out by BACHMANN (1990), the optimal rotation periods for the most important tree species on good sites in the Swiss Plateau are known. They are used as a basis for the chosen rotation period in the normal forest model.

As an **indicator of site quality,** Bachmann used the site index (i.e., the height of the dominant trees of a specific tree species at age 50, see Table 3). The better the site index of a tree species, the earlier the tree species reaches its yield-optimal regeneration point. An increase by four productivity classes for spruce results in a reduction of the optimal rotation period by approximately 20 years (BACHMANN 1990). Accordingly, the rotation period on mediocre good sites (site index 22 for spruce) is shorter by 20 years. On medium sites (site index 14 for spruce), the rotation period is longer by 20 years than on mediocre sites (site index 18 for spruce) (Table 4). On poor sites (site index below 14 for spruce), timber production in the lower elevations is usually not very economical. Thus, these site classes were not considered in the model. Because of their similar development and rotation period, the tree species spruce and fir, larch and pine, as well as ash and maple, were combined for the normal forest model.

Table 3a. Site index of the main tree species on similar sites.
Key: E+K: ELLENBERG and KLÖTZLI (1972) (K78): KELLER (1978) (S79): SCHÜTZ (1979) (S93): SCHMIDER (1993).

Site productivity	Forest community according to E+K (1972)	Spruce (K78)	Fir (K78)	Larch (K78)	Pine (K78)	Beech (K78)	(Oak) (S79)	Ash / Maple (S93)
Very good	7, 8, 11, 26, 29	24	20	27	24	20	22	26
Good	6, 9, 12, (18), (20)	22	18	24	22,5	18,5	20	24
Medium–good	1, 10, 13, 17, (19)	20	16	21	21	17	18	22
Medium	2, 14, 15	18	14	18	19	15,5	(14)	(20)
Poor	16, 65	8–12	4–8	6–12	8–12	8–12	6–10	6–12

Table 3b. Site index of the main tree species on similar sites in higher elevations.

Site productivity	Forest community according to E+K (1972)	Spruce (K78)	Fir (K78)	Larch (K78)	Pine (K78)	Beech (K78)
Good	18, 20	22	18	24	22,5	18,5
Medium–good	19	20	16	21	21	17
Medium	21, 49, 51	18	14	18,5	19	15,5
Mediocre–medium	50, 52	16	11	16	17	14
Mediocre	55, 57, 58	14	9	13	15	12,5
Poor	59, 67	6–10	2–6	2–10	6–10	–

The specified rotation periods are based on a mean stand development and medium high thinning. Today, **tending and thinning** the young growth stands early and severely is common practice. For these practices, shorter rotation periods should be expected. This fact was accounted for by using ten year shorter rotation periods for the calculations in one of the three model variants (see also Table 5).

Table 4. Optimally productive rotation period of the most common tree species depending on the site quality (according to BACHMANN 1990).

Site productivity	Spruce	Fir	Larch	Pine	Beech	Oak	Ash/Maple	Other broadleaves
Very good	110	120	120	130	130	150	80	60
Good	120	130	130	140	140	160	90	70
Medium–good	130	140	140	150	150	170	100	80
Medium	140	150	150	160	160	180	110	90
Mediocre–medium	150	160	160	170	170	190	120	100
Mediocre	160	170	170	180	180	200	130	110

Table 5. Variants of normal forest model for the calculation of the sustainable forest regeneration.
Key: TSC: Tree species composition. PNV: Potential natural vegetation.

Model variant	Tree species composition (TSC)	Rotation periods
Current TSC	Current TSC in % of the basal area.	Optimally productive due to the customary thinning concept of the past.
Potential TSC, rich in broadleaf trees	TSC adapted to that site according to PNV, broadleaf rich variant (optimal proportion of broadleaves).	Longer by 20 years as a concession to nature conservation and the long customary regeneration periods taken into account.
Potential TSC, rich in conifers	TSC adapted to that site according to PNV, conifer rich variant (minimal proportion of conifers).	Shorter by 10 years due to current intensive thinning practice.

The **tree species composition today** is the result of site-specific factors, economical considerations, natural disturbances, and historical development. The tree species composition was calculated based on the NFI data. Since mixed stands grow on nearly half of all the assessed forest areas in the lower elevations, the proportion of the individual tree species was not calculated directly from the forest area. It was calculated on what proportion each tree species rep resented out of the entire collection of the trees that were measured. Relevant for the calculation of the proportion is, here, neither the number of stems nor the volume, but rather the basal area. The basal area is approximately proportional to the crown cover area and thus a suitable measure for the area proportion of tree species in mixed stands.

The long term **recommended tree species' composition** depends primarily on site factors and on silvicultural goals. In particular, the ecological stability of the site must be warranted. Detailed information for this is given with explanations for the description of forest communities and the site maps. An example of this is SCHMIDER *et al.* (1993) for the canton Zurich.

The calculation of the **potential tree species composition** TSC was conducted in accordance with those from OBERHOLZER (1993) for the canton Zurich. Based on a complete map of the forest communities Oberholzer calculated the potential natural tree species distribution by first assigning each forest community the proportion of tree species that was naturally expected (e.g., 60% beech for the Pulmonario-Fagetum typicum). In a second step, this was multiplied by the area of the corresponding forest community (canton Zurich: 0.6 x 1,590 ha = 954 ha). Finally, all forest communities were totalled (canton Zurich: 27,300 hectares of beech in a forest area of 49,600 hectares, i.e., 55% proportion of beech in the natural forest).

Oberholzer also conducted similar model calculations for the managed forest. Here, the basis for determining the proportion of tree species was the cantonwide description of forest communities, ecological recommendations with respect to the proportion of broadleaf trees, and economical considerations.

In the NFI the potential tree species composition was calculated in a similar manner. However, a complete map of the forest communities could not be used, since such a map was not available in many cantons of Switzerland. Thus, the distribution of forest communities over the forest area was taken from the model of potential natural vegetation (PNV) developped by BRZEZIECKI *et al.* (1993). On the basis of important site factors, the PNV-model calculates the probability that a certain forest community described by ELLENBERG&KLÖTZLI (1972) occurs at the investigated points (see Chapter 3.1).

In order to show how different tree species' compositions and different rotation periods influence the sustainable regeneration area, two model variants with the potential tree species composition and different rotation periods were calculated (Table 5) apart from the model variant, which was based on the true tree species composition.

The **model variant** with potentially high broadleaf proportion was based on the variant "recommended broadleaf proportion," and the model variant with high coniferous (potential) compositions was based on the variant "minimum broadleaf proportion" according to OBERHOLZER (1993). In contrast to Oberholzer's study, the separation into forest communities or into sub-communities did not make any sense in the NFI, because of the uncertainty of the model calculations. For example, the success rate for the forest communities with the highest probability was only 46% (Breziezcki *et al.*, 1993). The area proportion was, therefore, calculated for each phytosociological unit or subunit. These calculations amounted in the lower elevations of Switzerland to a proportion of 57% for the fastidious beech forest (Eu-Fagion). Since larger differences exist between the different communities of this type, with respect to the natural tree species composition, the most common lowland forest communities (Galio odorati-Fagetum luzuletosum, Galio odorati-Fagetum typicum, Milio-Fagetum and Cardamino-Fagetum typicum) were studied seperately. Only the forest communities Pulmonario-Fagetum typicum, Pulmonario-Fagetum melittetosum and Aro-Fagetum were combined.

Forest communities with moderate to poor yield, on which hardly any timber was used, were not compared with the normal forest model. These forest communities included, for example, mixed oak forests in the northern Alps, all pine forest communities, and rare forest communities (e.g., Salicetum albae or Carici elongatae-Alnetum glutinosae Forests on steep slopes, which for the most part have a protection function, e.g., the Cardamino-Fagetum tilietosum). For this reason, the Taxo-Fagetum were not considered. Other lowland forests today are used either primarily for timber production or timber production is not significantly hindered by other interests (e.g., recreation). The total area of the so-defined production forest is approximately 428,000 hectares (Table 6). This corresponds to a 92% proportion of the uniform high forest or 74% of the accessible forest in the lower elevations.

For these forest areas the sustainable regeneration area was calculated for each of the sites and tree species' groups seperately, with rotation periods that were similar to the optimal rotation periods given in Table 4. The determination of the rotation period for individual tree species on certain sites or for certain forest communities was carried out with the help of the corresponding site class according to KELLER (1978). These are based on the tree height measurements or estimations from phytosociological-productivity studies (e.g., BRAUN-BLANQUET *et al.* 1954; ETTER 1947; ETTER 1949; MOOR 1952; TREPP 1947), or from forest yield experiments plots (KELLER 1978). Missing values in Table 3 were complemented with values from SCHÜTZ (1979), LEIBUNDGUT (1983) and SCHMIDER (1993).

The calculation of the sustainable regeneration area is presented in four tables. In Table 7, the desired proportion of tree species per site unit (forest community or (sub) unit) is listed. Table 8 presents the forest area per tree species (group) for each site unit. They are calculated by multiplying the area per forest community with the corresponding proportion of tree species. Table 9 contains the rotation period per tree species (group) and per site unit. Table 10 shows the calculations for the sustainable regeneration area by dividing the forest area per tree species (group) and site unit from Table 8 by the mean rotation period of the corresponding table cell from Table 9. The exact procedure is illustrated using the example of the model variant 2 with high proportions of broadleaf in the tree species composition in the Jura region. In order to simplify the calculation of the area proportion per tree species, it was assumed that the tree species did not occur individually, but occurred at least mixed in clumps or groups (i.e., they occur on small-scale pure stands).

Table 6. Forest area per vegetation unit. Reference unit: Potentially managed uniform high forest in lower elevations (74.1% of the accessible forest without shrub forest).
Key: E+K: ELLENBERG and KLÖTZLI (1972)

Vegetation unit	E+K No.	Jura 1000 ha	Plateau 1000 ha	Pre-Alps 1000 ha	Alps 1000 ha	Southern Alps 1000 ha	Switzerland 1000 ha
Deer grass-Beech forest	1–4	3.3	33.8	7.9	1.8	8.5	55.3
Woodruff-Beech forest	6	1.7	37.6	1.5	1.1	0	41.9
Woodruff-Beech forest	7	19.9	17.2	1.1	1.4	0	39.6
Millet gras-Beech forest	8	2.7	52.5	12.5	1.4	0	69.1
Lungwort- Beech forest/ Arum-Mixed beech forest	9–11	32.3	24.4	4.3	2.7	0	63.7
Toothwort-Beech forest	12	28.0	8.7	3.8	3.5	0	44.0
Carex-Beech forest	14 / 15	0.4	0.4	0.7	1.5	0	3.0
Fir-Beech forest	18–20	14.3	5.8	20.5	3.6	0	44.2
Lime-Sycamore maple forest	22–25	0.0	0.0	0.4	0.7	0	1.1
Alder-Ash forest	26–32	2.2	9.5	1.7	0.4	0	13.8
Oak-Hornbeam forest	33–36	3.1	3.5	0.0	0.2	7.2	14.0
Spruce-Fir forest	46–52	0.3	0.5	7.7	18.1	8.7	35.3
Bilberry-Spruce forest	54–60	0.0	0.0	0.0	2.0	1.6	3.6
Total		108.1	193.9	62.1	38.3	26.0	428.4
Uniform high forest		116.4	197.2	67.4	58.4	27.5	466.9
Accessible forest without shrub forest		134.8	219.8	81.2	76.6	65.5	577.9

Table 7. Tree species proportion per vegetation unit.
Reference unit: Potentially managed uniform high forests in the lower elevations of the region Jura.
Model variant: Potential tree species composition, broadleaf rich variant with longer rotation periods.

Vegetation unit	E+K No.	Area ha	Tree species in % of the basal area Spruce/Fir	Pine/ Larch	Beech	Ash/ maple	Oak	Other broadleaf
Deer grass-Beech forest	1–4	3316	0	20	40	0	20	20
Woodruff-Beech forest	6	1696	10	15	35	10	20	10
Woodruff-Beech forest	7	19857	20	10	35	15	10	10
Millet grass-Beech forest	8	2700	40	0	35	10	5	10
Lungwort- Beech forest/ Arum-Mixed beech forest	9–11	32304	10	15	35	20	10	10
Toothwort-Beech forest	12	27975	10	15	35	20	0	20
Carex-Beech forest	14 / 15	413	0	20	35	20	15	10
Fir-Beech forest	18–20	14274	60	0	30	5	0	5
Lime-Sycamore maple forest	22–25	0	0	0	0	60	0	40
Alder-Ash forest	26–32	2166	0	0	0	70	10	20
Oak-Hornbeam forest	33–36	3100	0	10	0	10	50	30
Spruce-Fir forest	46–52	333	90	0	5	4	0	1
Bilberry-Spruce forest	54–60	0	98	0	0	1	0	1
Total		108134						

Table 8. Forest area per tree species and per vegetation unit.
Reference unit: Potentially managed uniform high forests in the lower elevations of the region Jura.
Model variant: Potential tree species composition, broadleaf rich variant with longer rotation periods.
Key: TSC = Tree species composition

Vegetation unit	E+K No.	Area ha	Forest area per tree species in hectare Spruce/Fir	Pine/ Larch	Beech	Ash/ maple	Oak	Other broadleaf
Deer grass-Beech forest	1–4	3316	0	663	1326	0	663	663
Woodruff-Beech forest	6	1696	170	254	594	170	339	170
Woodruff-Beech forest	7	19857	3971	1986	6950	2979	1986	1986
Millet grass-Beech forest	8	2700	1080	0	945	270	135	270
Lungwort- Beech forest/ Arum-Mixed beech forest	9–11	32304	3230	4846	11306	6461	3230	3230
Toothwort-Beech forest	12	27975	2798	4196	9791	5595	0	5595
Carex-Beech forest	14 / 15	413	0	83	145	83	62	41
Fir-Beech forest	18–20	14274	8564	0	4282	714	0	714
Lime-Sycamore maple forest	22–25	0	0	0	0	0	0	0
Alder-Ash forest	26–32	2166	0	0	0	1516	217	433
Oak-Hornbeam forest	33–36	3100	0	310	0	310	1550	930
Spruce-Fir forest	46–52	333	300	0	17	13	0	3
Bilberry-Spruce forest	54–60	0	0	0	0	0	0	0
Total		108134	20113	12338	35356	18110	8182,1	14035
Recommended TSC (%)			18.6%	11.4%	32.7%	16.7%	7.6%	13.0%
Current TSC (%)			37.5%	7.0%	36.9%	9.0%	4.8%	4.8%

Table 9. Rotation period per tree species and per vegetation unit.
Reference unit: Potentially managed uniform high forests in the lower elevations of the region Jura.
Model variant: Potential tree species composition, broadleaf rich variant with longer rotation periods.

Vegetation unit	E+K No.	Area ha	Rotation period per tree species in years Spruce/Fir	Pine/ Larch	Beech	Ash/ maple	Oak	Other broadleaf
Deer grass-Beech forest	1–4	3316	140	160	160	100	180	90
Woodruff-Beech forest	6	1696	140	160	160	100	180	90
Woodruff-Beech forest	7	19857	130	150	150	90	170	80
Millet grass-Beech forest	8	2700	130	150	150	90	170	80
Lungwort- Beech forest/ Arum-Mixed beech forest	9–11	32304	130	150	150	90	170	80
Toothwort-Beech forest	12	27975	140	160	160	100	180	90
Carex-Beech forest	14 / 15	413	150	170	170	110	190	100
Fir-Beech forest	18–20	14274	140	160	160	100	180	90
Lime-Sycamore maple forest	22–25	0	150	170	170	110	190	100
Ash-Ash forest	26–32	2166	130	150	150	90	170	80
Oak-Hornbeam forest	33–36	3100	150	170	170	110	190	100
Spruce-Fir forest	46–52	333	160	180	180	130	200	110
Bilberry-Spruce forest	54–60	0	180	200	–	150	–	140

Table 10. Sustainable regeneration area per tree species and per vegetation unit.
Reference unit: Potentially managed uniform high forests in the lower elevations of the region Jura.
Model variant: Potential tree species composition, broadleaf rich variant with longer rotation periods.

Vegetation unit	E+K No.	Area ha	Regeneration area per tree species in hectare Spruce/Fir	Pine/ Larch	Beech	Ash/ maple	Oak	Other broadleaf	Total
Deer grass-Beech forest	1–4	3316	0	4	8	0	4	7	23
Woodruff-Beech forest	6	1696	1	2	4	2	2	2	12
Woodruff-Beech forest	7	19857	31	13	46	33	12	25	160
Millet grass-Beech forest	8	2700	8	0	6	3	1	3	22
Lungwort- Beech forest/ Arum-Mixed beech forest	9–11	32304	25	32	75	72	19	40	264
Toothwort-Beech forest	12	27975	20	26	61	56	0	62	226
Carex-Beech forest	14 / 15	413	0	0	1	1	0	0	3
Fir-Beech forest	18–20	14274	61	0	27	7	0	8	103
Lime-Sycamore maple forest	22–25	0	0	0	0	0	0	0	0
Ash-Ash forest	26–32	2166	0	0	0	17	1	5	24
Oak-Hornbeam forest	33–36	3100	0	2	0	3	8	9	22
Spruce-Fir forest	46–52	333	2	0	0	0	0	0	2
Bilberry-Spruce forest	54–60	0	0	0	0	0	0	0	0
Total		108134	148	80	229	193	47	163	860

3.4.4 Sustainable Forest Regeneration in the Plenter High Forest

Plenter high forests are regenerated on an individual tree basis and not on a large scale in any given area. The control of the forest regeneration can, therefore, not be carried out using the area of regeneration, but must be accomplished by counting the number of new stems and their ingrowth into the lowest DBH class. An assessment of the natural regeneration situation is only possible with concrete ideas about the nominal state. The nominal state corresponds to a permanent structural equilibrium in which the cuttings equal the growth. Such an equilibrium, or corresponding stem number equilibrium, can be calculated with the help of the plenter forest model. The sustainability of forest regeneration is then controlled by comparing a measured and calculated minimal number of young trees of the DBH classes 2, 6, and 10, as well as by comparing effective and calculated minimal ingrowth.

The **fundamental idea** behind the plenter forest model is that for each diameter class a mean number of trees can be calculated which does not change over time. Only so many stems grow into a certain class during a time period as grow out of it, or die off due to cuttings or natural mortality. According to SCHÜTZ (1989), the following **equilibrium conditions** should be considered.

a) Constant number of stems per diameter class
For each diameter class, the ingrowth from the lower classes must compensate the loss through silvicultural operations or natural mortality and the outgrowth into the next higher class.
b) Constant timber volume
Constant number of stems per DBH class also implies a constant total timber volume. The timber volume is only constant when the sum of all the cuttings equals the growth.
c) Constant minimal necessary regeneration
The stand density (e.g., timber volume or basal area) must permit the minimal amount necessary for regeneration or the ingrowth necessary to ensure that the number of stems is kept constant.

As a **basis for the equilibrium calculation,** the proportion p (= passage) of outgrowing stems and the proportion e (=exploitation) of cut or naturally dead stems per DBH class are used.

These proportions can be calculated for certain site units with the help of a long-term time series obtained from the control method (SCHÜTZ 1975) or from yield study sites (SCHÜTZ 1981).

The **equilibrium conditions** can be expressed in an equation as follows:
Constant number of stems in the i^{th} DBH class : ingrowth = outgrowth + mortality/cuttings

$$n_i \cdot p_i = n_{i+1} \cdot p_{i+1} + n_{i+1} \cdot e_{i+1} = n_{i+1} \, (p_{i+1} + e_{i+1}) \tag{1}$$

a) Constant timber volume: total increment = total cuttings
b)

$$\sum_{i=1}^{i\,\max} n_i \cdot p_i \cdot \Delta T_i = \sum_{i=1}^{i\,\max} n_i \cdot e_i \cdot T_i \tag{2}$$

where

n_i = Number of stems in the i^{th} DBH class
p_i = Proportion of stems growing out of the i^{th} DBH class within a certain period of time
e_i = Proportion of cut stems or naturally died off stems in the i^{th} DBH class within a certain period of time
T_i = Tariff values (i.e., timber volume of a tree in the i^{th} DBH class)
ΔT_i =Tariff difference between the DBH class i and $i+ l$

The third equilibrium condition is not as easy to express in a mathematical equation. First, the stand volume should allow a sufficient regeneration; second, the conditions a) and b) must be fulfilled; and third, timber volume and increment must be within a realistic range. For this, SCHÜTZ (1997) used the assumed correlation between the ingrowth and the stand density expressed in the timber volume. Instead of the ingrowth, he used the number of stems from the lowest DBH class (8.0 to 11.9 cm DBH), which is a good indicator for regeneration.

The equilibrium position can be determined approximately with the help of a graph. The position is located at the point of intersection of the trend line of the observed values for the number of stems and timber volume. A second line connects two temporary model states. The intersection point of the two lines corresponds, on the one hand, to a possible realistic state; on the other hand, it corresponds to a possible model state. With the help of the figure, it is also possible to approximate the timber volume equilibrium as well as the number of stems in the lowest measured DBH class (initial stem number), which is necessary to sustain the structure (Figure 1).

Starting with the initial number of stems n_i in the DBH class i, the number of stems n_{i+l} in the next higher DBH class $i + l$ can be calculated by rearranging Equation (1) as follows:

$$n_{i+1} = n_i \cdot \frac{p_i}{(p_{i+1} + e_{i+1})} \tag{3}$$

Using the Equation (2), the resulting stem number curve is checked to see if the results are plausible. If the timber volume does not equal the desired timber volume, or if the calculated model increment or model cuttings results in unrealistically high or low values, the initial stem number of the first DBH class, as a deciding input variable, should be adjusted.

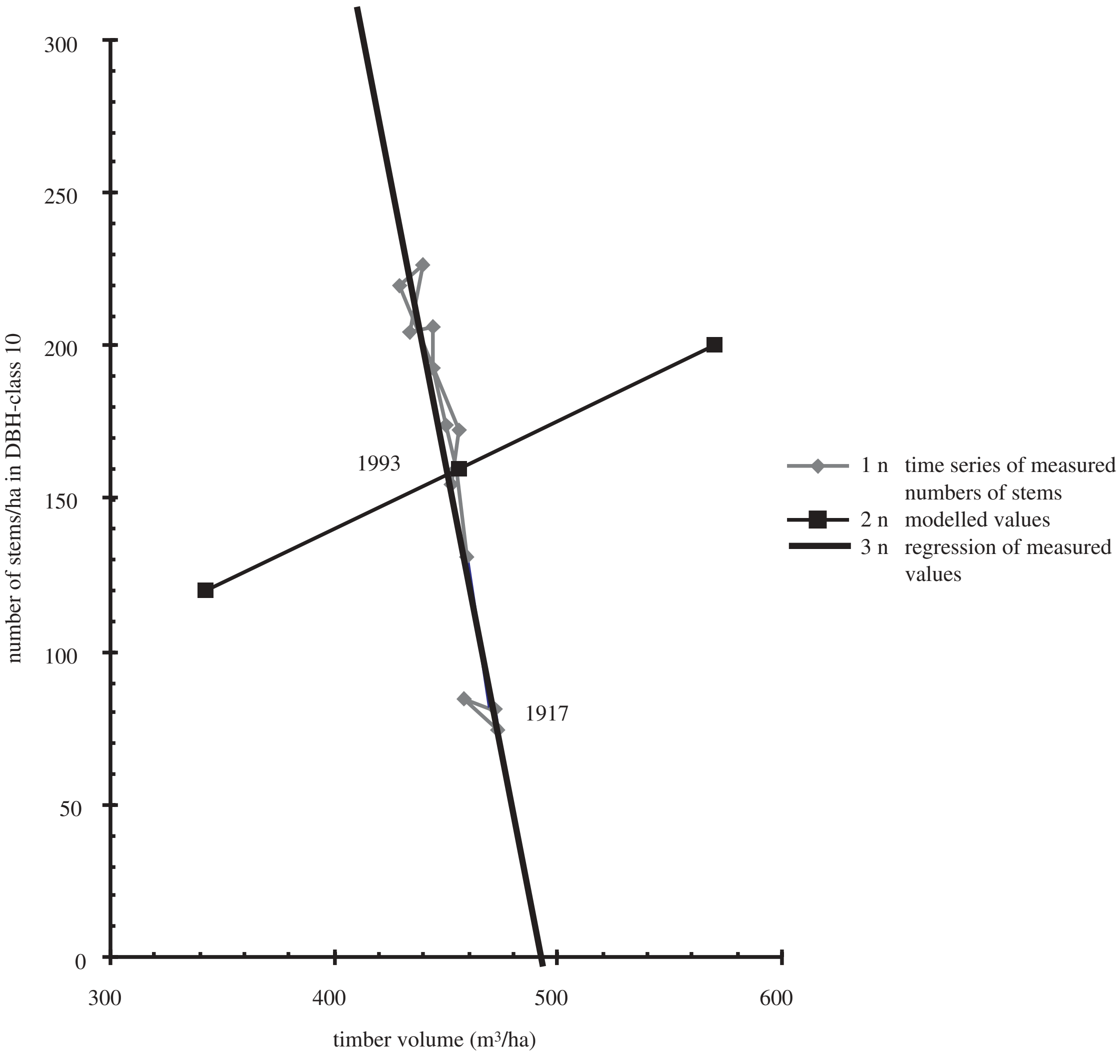

Figure 1. Determining the initial number of stems and the equilibrium timber volume. WSL experimental plot 01–15.1 (Toppwald). The Figure shows the development of the number of stems in the DBH class 10 (8–11 cm DBH) over time from 1917 to 1993 depending on the timber volume of the WSL experimental plot 01–015.1 in the Toppwald (Emmental). The stem number varies depending on the volume in a relatively wide range between approximately 70 and 230 stems per hectare. The two calculated model values that have an initial stem number of 120 and 200 stems per hectare form a line, which intersects the regression line of the observed values for a timber volume of 460 m^3 and has an initial stem number of 160 stems per hectare in the DBH class 10. This value (at the intersection) is taken as the initial number of stems for the calculation of the equilibrium curve of stem number in Table 12.

With the definite chosen initial stem number n_i in the first DBH class (in the NFI 12–15 cm) from the measured stands, the number of regeneration stems (stem number of the DBH classes 2, 6, and 10 cm) necessary to sustain the plenter equilibrium can be calculated by rearranging Equation (1) as follows:

$$n_{i-1} = n_i \cdot \frac{(p_i + e_i)}{p_{i-1}} \tag{4}$$

Stem number-equilibrium curves can be calculated for different sites (SCHÜTZ 1981) and different target diameters (SCHÜTZ 1975). Plenter high forests exist, according to the NFI data, in the montane zone of the regions Jura, Pre-alps, and Alps, as well as in the subalpine zones of the Alpine region. Since the ecological conditions and, consequently, the forest dynamics differ greatly in the two altitudinal zones, the sustainability of the forest regeneration was examined seperately for the montane and subalpine zones.

From the studies conducted by SCHÜTZ (1981), it is known that sites which are situated on limestone in the Jura region and located on molasse in the Pre-alps region remain in a very different equilibrium for the timber volume and stem number curve. Two equilibrium curves were, therefore, calculated as reference values for the plenter forest in the montane zone; specifically one curve for the region of Jura (Couvet) and one curve for the Emmental (Toppwald). For the supalpine zone, nearly all of the required parameters for increment and removal rates were completely known for one single forest in the Alps (Vals). For the purpose of comparison, two additional curves were calculated (one in the Pre-Alps (Sirgriswil), another in the central Alps (Gian d'Alva)), but are not shown.

The model parameters e_i and p_i for the calculation of the equilibrium curve in the Jura region originate from a study in Val-de-Travers (SCHÜTZ 1975). In order to be used for the NFI, the parameters had to be converted from DBH classes that had a width of 5 cm, which was normally used in the canton Neuenburg, to classes with a width of 4 cm. The parameters used for the calculation of the sustainable number of young stems originated from personal studies (DUC 2000) (Table 11).

Table 11. Equilibrium curve of stem number (n) for plenter forests with a north aspect in the Jura region (Val-de-Travers, according to SCHÜTZ 1975).

DBH class	DBH increment in mm per year	Passage p % per year	Exploitation e % per year	Number of stems n /ha	Volume v m^3	Increment i m^3/ha*year	Cuttings c m^3	WSL tariff m^3	DBH class
2	1.80	4.50	3.00	203.7					2
6	2.10	5.25	2.00	126.4					6
10	2.35	5.88	1.50	90.0	2.7	0.42	0.04	0.03	10
14	2.60	6.50	1.25	68.2	7.4	0.58	0.09	0.11	14
18	2.85	7.13	1.20	53.3	12.8	0.61	0.15	0.24	18
22	3.10	7.75	1.15	42.6	17.1	0.73	0.20	0.40	22
26	3.35	8.38	1.20	34.5	21.4	0.72	0.26	0.62	26
30	3.60	9.00	1.30	28.1	24.4	0.73	0.32	0.87	30
34	3.80	9.50	1.40	23.2	26.9	0.73	0.38	1.16	34
38	4.00	10.00	1.50	19.1	28.5	0.73	0.43	1.49	38
42	4.10	10.25	1.60	16.2	30.2	0.66	0.48	1.87	42
46	4.20	10.50	1.70	13.6	30.8	0.66	0.52	2.27	46
50	4.30	10.75	1.90	11.3	30.8	0.59	0.58	2.73	50
54	4.50	11.25	2.10	9.1	29.2	0.54	0.61	3.22	54
58	4.70	11.75	2.40	7.2	27.0	0.48	0.65	3.75	58
62	4.80	12.00	2.70	5.8	24.9	0.44	0.67	4.32	62
66	4.90	12.25	3.10	4.5	22.3	0.36	0.69	4.95	66
70	5.00	12.50	3.70	3.4	19.1	0.29	0.71	5.61	70
74	5.00	12.50	4.60	2.5	15.7	0.23	0.72	6.30	74
78	5.00	12.50	5.50	1.7	12.2	0.17	0.67	7.04	78
82	5.00	12.50	6.50	1.1	8.9	0.11	0.58	7.82	82
86	5.00	12.50	8.00	0.7	6.0	0.07	0.48	8.59	86
90	5.00	12.50	10.00	0.4	3.6	0.05	0.36	9.43	90
			∑>8 cm/ha	436.4	401.9	**9.90**	**9.60**		
Ingrowth:			**∑>16 cm/ha**	**278.2**	**391.8**	8.90	9.46		
DBH > 16.0	4.4 n/ha*J		∑ 16–32 cm	57.0%	19.3%	2.07	0.67		
DBH > 12.0	5.3 n/ha*J		∑ 32–52 cm	25.1%	29.7%	2.71	1.87		
DBH > 0.0	15.3 n/ha*J.		∑ > 52 cm	18.0%	51.0%	4.13	6.93		

The equilibrium curve for the Emmental was calculated with the help of data from productivity study plots in the Toppwald of the WSL (ZINGG and DUC 1998). The sustainable stem number distribution for the regeneration is also the result of a personal study (DUC 1991) (Table 12).

Table 12. Equilibrium curve of stem number for plenter forests in Emmental (Toppwald, according to ZINGG and DUC 1998).

DBH class	DBH increment in mm per year	Passage p % per year	Exploitation e % per year	Number of stems n /ha	Volume v m^3	Increment i m3/ha*Jahr	Cuttings c m^3	WSL tariff m^3	DBH class
2	1.6	4.0	2.0	359.2					2
6	1.9	4.8	1.5	229.9					6
10	2.2	5.4	1.5	160.0	4.5	0.62	0.06	0.03	10
14	2.4	6.0	1.6	113.9	11.4	0.75	0.18	0.10	14
18	2.7	6.6	2.0	79.7	16.7	0.90	0.33	0.21	18
22	2.9	7.3	2.0	57.4	21.8	0.92	0.43	0.38	22
26	3.2	7.9	1.6	44.1	26.5	0.97	0.41	0.60	26
30	3.4	8.5	1.9	33.4	29.4	0.82	0.56	0.88	30
34	3.6	9.0	2.2	25.4	29.7	0.78	0.65	1.17	34
38	3.8	9.5	1.9	20.0	30.2	0.76	0.57	1.51	38
42	4.0	10.0	1.9	16.0	30.5	0.69	0.58	1.91	42
46	4.2	10.5	1.7	13.2	30.8	0.66	0.52	2.34	46
50	4.4	10.9	1.2	11.4	32.1	0.63	0.39	2.82	50
54	4.5	11.3	1.6	9.6	32.1	0.60	0.51	3.33	54
58	4.7	11.6	2.0	8.0	30.9	0.55	0.62	3.88	58
62	4.8	11.9	2.4	6.5	29.0	0.48	0.70	4.47	62
66	4.9	12.1	2.8	5.2	26.2	0.43	0.73	5.09	66
70	5.0	12.4	3.2	4.0	23.2	0.35	0.74	5.77	70
74	5.1	12.6	3.6	3.1	19.8	0.29	0.71	6.47	74
78	5.2	12.9	4.0	2.3	16.5	0.23	0.66	7.22	78
82	5.2	13.0	6.0	1.6	12.4	0.18	0.75	8.00	82
86	5.3	13.1	8.0	1.0	8.5	0.11	0.68	8.89	86
90	5.3	13.2	10.0	0.5	5.3	0.06	0.53	9.75	90
94	5.3	13.3	12.0	0.3	3.0	0.03	0.36	10.63	94
98	5.3	13.3	14.0	0.1	1.6	0.02	0.22	11.54	98

		∑> 8 cm/ha	616.6	472.2	**11.81**	**11.89**
Ingrowth :		**∑>16 cm/ha**	**333.9**	**456.3**	10.44	11.65
DBH > 16.0	6.8 n/ha* J	∑ 16–32 cm	64.3%	20.7%	3.61	1.72
DBH > 12.0	8.6 n/ha* J	∑ 32–52 cm	25.7%	33.6%	3.52	2.72
DBH > 0.0	21.6 n/ha*J	∑ > 52 cm	10.0%	45.7%	3.31	7.21

The parameter for the equilibrium curve in the subalpine zone originates from the work conducted by INDERMÜHLE (1978) and corresponds with his model variant B. Indermühle calculates the equilibrium curve only up to the DBH class 14 (.12–15 cm DBH). Based on the given parameters e_i and p_i, the sustainable number of trees for the DBH classes 10 and 6 were calculated, and for the DBH class 2 they were estimated based on approximate parameter values (Table 13).

Apart from the number of trees, the **ingrowth over the calliper threshold** was also used for controlling the sustainable forest regeneration. Empirical values for the minimal necessary ingrowth were known. For example, SCHAEFFER *et al.* (1930) already points out that the ingrowth over the calliper threshold of 17.5 cm DBH should be between 1.5 and 2.0 Vfm per hectare and per year. However, the empirical values depend on the calliper threshold, the class width, and the site. It is, therefore, much more precise to calculate the sustainable ingrowth from the stem number equilibrium curve. The ingrowth is equivalent to the ingrowth in the lowest calliper DBH class (i.e., in the NFI the outgrowth of plants from the DBH class 10 cm or the ingrowth in the DBH class 14 cm). The sustainable ingrowth EW_1 can be calculated as follows:

$$EW_1 = n_0 \cdot p_0 \tag{5}$$

In the plenter forest of the region Jura, the yearly sustainable ingrowth into DBH class of 14 cm (12–15 cm) amounts to 5.3 trees/ha; in the region of the Emmentale it amounts to 8.6 trees /ha; and in those regions in the subalpine zone it amounts to 3.3 trees/ha. Projected to the mean inventory interval of 10.1 years, this results in a sustainable ingrowth of approximately 50 to 90 stems in the montane zone and approximately 35 stems in the subalpine zone.

Table 13. Equilibrium curve of stem number for plenter forests of the subalpine zone, northern intermediate Alps (according to INDERMÜHLE 1978).

DBH class	DBH increment in mm per year	Passage p % per year	Exploitation e % per year	Number of stems n /ha	Volume v m^3	Increment i m^3/ha*year	Cuttings c m^3	WSL tariff m^3	DBH class
2	0.30	0.8	3.0	1086.8					2
6	0.45	1.1	1.0	383.6					6
10	0.65	1.6	0.5	203.1	6.1	0.26	0.03	0.03	10
14	0.80	2.0	0.5	132.0	14.4	0.24	0.07	0.11	14
18	1.00	2.5	0.5	88.0	17.6	0.31	0.09	0.20	18
22	1.15	2.9	0.5	65.2	22.2	0.30	0.11	0.34	22
26	1.35	3.4	0.5	48.4	24.2	0.31	0.12	0.50	26
30	1.50	3.8	0.6	43.1	29.7	0.37	0.18	0.69	30
34	1.65	4.1	0.6	34.2	31.5	0.39	0.19	0.92	34
38	1.70	4.3	0.7	28.5	34.2	0.41	0.24	1.20	38
42	1.65	4.1	0.8	24.6	37.9	0.44	0.30	1.54	42
46	1.60	4.0	0.9	20.7	40.8	0.37	0.37	1.97	46
50	1.55	3.9	1.1	20.4	49.3	0.36	0.54	2.42	50
54	1.52	3.8	1.3	15.5	44.5	0.28	0.58	2.87	54
58	1.50	3.8	1.5	11.2	37.6	0.21	0.56	3.35	58
62	1.48	3.7	2.5	6.8	26.2	0.13	0.65	3.86	62
66	1.45	3.6	10.0	1.8	8.1	0.04	0.81	4.39	66
70	1.40	3.5	20.0	0.3	1.4	0.01	0.28	4.95	70
			∑>8 cm/ha	743.7	425.5	**4.43**	**5.13**		
Ingrowth			**∑>16 cm/ha**	**408.6**	**405.0**	3.93	5.02		
DBH > 16.0	2.6	n/ha* J	∑ 16–32 cm	59.9%	23.1%	1.29	0.50		
DBH > 12.0	3.3	n/ha* J	∑ 32–52 cm	31.4%	47.8%	1.97	1.64		
DBH >0.0	40.8	n/ha*J	∑ > 52 cm	8.7%	29.1%	0.67	2.89		

3.4.5 Sustainable Forest Regeneration in Other Types of Forests and in the Higher Elevations

The sustainability models described above do not cover the full range of layered high forest types from the lower and higher elevations. In particular, it does not provide information about irregular forests situated in the lower elevations or about the uniform and irregular forests located in the higher elevations. Since the evaluation of the sustainability is conducted for regions or the entire country of Switzerland, the sustainable regeneration area must be calculated for these strata as well.

Because the two models discussed are not well adapted for these possibilities, a highly reduced model approach was chosen in which the rotation period was determined by an expert. It was assumed that irregular high forests in the lower elevations were regenerated over the entire area with a mean rotation period of approximately 120 years. This corresponds to the mean calculated rotation period in the lower elevations of the regions Jura, Swiss Plateau, and Pre-alps. In the uniform and irregular high forest of the higher elevations, a more continuous regeneration of the forest on smaller patches should be aimed for in the future (OTT *et al.* 1997). This should result in a groupwise, layered forest structure of tree clusters, the so-called "Rotten". An actual rotation period cannot, therefore, be determined. Due to the current one-layered structure of many mountain forests, the conversion has to be performed in gaps with minimal dimensions. This provides an opportunity to use an area-based model. As a calculatory rotation period, 200 years was set in accordance with OTT (1973).

3.4.6 Discussion of the Employed Models

Normal Forest Model

The normal forest model is suitable only for the planning and controlling of clear-cut high forests. This is not always the case despite the limitation to the potentially managed, uniform high forests in the lower elevations since, for example, uniform high forests can be converted into multi-layered forests. Employing the normal forest model assumes that the intention of the forest owner, with respect to future forest management, is known. However, this intention was not questioned during the enquiry at the forest service.

The model employed by the NFI differentiates between tree species and site units. It is based for the most part on the assumption that the potential vegetation can correctly be determined using the PNV-model. This model is, however, not very reliable with respect to the forest communities. Furthermore, the scientific research to determine the site class per tree species and forest community (e.g., for the tree species oak and ash/maple), as well as the optimal time of regeneration (e.g., for the tree species pine and maple, and on medium and good sites for spruce, larch, and beech), is missing. Finally, scientific research is also missing that could determine the proportion of minimal and optimal broadleaf species, which is used as a basis for the variant with high broadleaf and high coniferous proportions.

It is therefore clear that the calculation for the sustainable regeneration area, with the help of the normal forest model, is only an approximation. The calculated values of approximately 62,000 ha in 10 years corresponds, at least relatively well, with the 64,000 ha that were calculated 25 years ago by OTT (1973) as the sustainable regeneration area in the clear-cut high forests. However, the analysis shows for the estimated stand age that this area was not close to being achieved in any of the decades. This in turn could mean that not enough forest is regenerated, or perhaps that the model is based on false assumptions or tries to achieve unrealistic goals. A prerequisite for a conclusive evaluation of the sustainable forest regeneration is, therefore, apart from the information about the forest structure today and the created regeneration area, knowledge about the future treatment of the forest. Of these three variables, future treatment is unknown and the forest structure as well as the created regeneration area can only be derived approximately.

– The **determination of the forest (structure) type** depends strongly on whether a stand is classified as a certain stage of development (stage of development young growth/thicket, pole wood, young, medium, or old timber) or not classified as such (stage of development mixed). Even though the inventory manual was not changed between the first and second NFI, the proportion of the plenter high forests was reduced by approximately half. An existing plenter structure could not be lost in such a short period of time, even if all silvicultural operations would have been completely abandoned. Thus, the decline had to be largely the result of how the instructors taught the material in the inventory manual. As a consequence, the inventory manual was applied in the field in a different manner as compared to ten years earlier. The definition of the forest type as a basis for separating regeneration forest areas based on individual trees and area is, therefore, uncertain.

- The **calculation of the regeneration area** that has been newly created in the last ten years represents not only a problem for the NFI, but as a general problem as soon as smaller areas are regenerated or regeneration is conducted under shelter. In such cases it is often not clear whether an area is still in the process of being regenerated (regeneration under shelterwood), or when it can be assumed to be regenerated and can thus be called young growth. The effective regeneration area can be calculated in different ways. None of the possible calculations are precise, but they all have approximately the same results. Nonetheless, a certain amount of uncertainty with respect to the size of the effective regeneration area remains.
- The enquiry at the forest service did not provide any information about the future treatment of the forests. The assumption that today's layered stand will still be treated with clear-cuts in the future is questionable, given the situation of today's forestry practices. Due to economical pressures, forest enterprises are starting to manage their forests according to the plenter principles and slowly convert their forests into plenter high forests. For such enterprises, the success of the regeneration efforts cannot be measured by the cleared areas per period, but on the stem number distribution in the DBH class and on the ingrowth (see Chapter 3.4.4).

For all of these reasons, the normal forest model in the NFI is limited in its reliability, especially in the higher elevations. The model is relatively reliable in the lower elevations of the Jura, Swiss Plateau, and Pre-Alps' regions.

Plenter Forest Model

The plenter forest model according to SCHÜTZ (1975) represents an interesting method by which to calculate the stem number equilibrium curve of plenter forests. For this reason it has already been applied several times in calculating (INDERMÜHLE 1978; SCHÜTZ 1981; DUC 1991;) or in evaluating the equilibrium state of plenter forests (ZINGG and DUC 1998), as well as in evaluating their structure and growth changes (BACHOFEN 1996). However, the model in its current format still has some weaknesses. The following questions in particular must be clarified:

- SCHÜTZ (1975) proves that the stand density, expressed by the cumulative basal area of the thickest trees, has an influence on the diameter increment of the trees in the DBH classes 45 to 70 cm. However, according to BACHOFEN (1996), this relationship does not exist on the long-term WSL study areas in Rougemont (canton Vaud). If such a relationship between stand density and DBH increments exists, it must be considered in the model. The stem number curve in this case can only be calculated by starting with the number of stems in the largest DBH class. This results in some practical problems: If the number of stems in the largest DBH class is set to one, then this usually results in a model timber volume and increment that is too large. For this reason, the stem number in the lowest DBH class was used as a starting point for the calculations of the stem number curve. It is also true that the stem count of lowest class could not be exactly determined, but could be approximated with the values determined up to that point (see Chapter 3.4.1).
- Even if the relationship between timber volume and number of regeneration stems seems plausible, this cannot be used as described to determine the number of stems in the DBH class 10 STZ_{10}. We believe that there exists, in principle, a relationship between timber volume and the number of regeneration stems. Nonetheless, the change in the timber volume has a time-delayed effect on the number of stem STZ_{10}. The analysis of several WSL study sites shows that the relationship between timber volume and STZ_{10} is relatively low (ZINGG and DUC 1998), and that some individual values strongly influence the regression line.
- There exists a linear relationship between the stem number in the DBH class 10 STZ_{10}, which is used as a starting point for the calculation and the equilibrium timber volume. The reason is that for the calculation of the equilibrium curve, the same estimated, constant relative values pi and ei are used. An increased number of stems STZ_{10} results in a correspondingly higher equilibrium timber volume. In reality this should be reversed; however, at

least for homogeneous site conditions, the larger the timber volume, the smaller the number of stems STZ_{10}. Thus, the model misses a negative feedback between the timber volume and the number of regeneration stems.
- The decrease of the stem number in the lowest DBH classes (0.1–3.9 cm DBH) is probably not caused by thinning (DUC 2000), but by natural mortality. There is, however, no information available about the amount of natural mortality in regularly managed forests with layered structures. Therefore, the mortality rate e_i had to be determined ocularly while considering the cutting rate. In the future, more knowledge is necessary about the natural mortality of the regeneration in managed forest.
- The main tree species of plenter forests (fir, spruce, and beech) have different rates per DBH class for the increments and cuttings in the regeneration (DUC 2000) as well as in the measured stands. In addition, the tariff for the tree species is different, which affects the timber calculation of the volume and increments. The model presented here did not take into consideration the different proportions of tree species and their effect on the equilibrium curve.

For all of these reasons, equilibrium curves known today should be seen as being temporary. The goal of the research in this field should be to establish equilibrium models for all important site units.

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3.5 Expenditure for Timber Felling and Extraction

Ulrich Ulmer

3.5.1 Introduction

The expenditure for the Timber Felling and Extraction is a measure of the availability of timber. It is derived (modeled) for the total timber volume in the Swiss forest using a uniform method.

For each of the sample points the objectives were to:
– Determine the timber harvesting method actually being used
– Estimate the corresponding expenditure for the timber felling and extraction
– Convert the calculated work expenditure into Swiss Francs

The input variables for the model result from interviews at the forest service, as well as from the terrain, stand, and tree data in the terrestrial inventory (see Chapter 2.3, Terrestrial Inventory). The model is based as much as possible on work published about expenditure calculation and does not account for regional conditions or the actual timber market situation. The expenditure for the timber harvest was used for timber production considerations, e.g., for the exploitation potential or management scenarios (see Chapter 3.3 Prognosis and Management Scenario).

3.5.2 Methods

The process of the timber harvest is comprised of felling and extraction. During the felling the tree is felled and trimmed (i.e., delimbed and divided into assortments). During the extraction the timber is brought from the felling point to the forest road where it is stored and sold either as a complete tree or in the form of the assortments. For each of the sample points the expenditure for timber felling and extraction is derived from the terrain, stand, and tree data, as well as the information from the timber harvest that was gathered during the interview with the forest service.

The extraction process is divided into separate stages of work (STIERLIN *et al.* 1994). For the individual stages, the corresponding extraction expenditure was calculated (unit: min/m^3) using information about the timber extraction method and logging distance. The total extraction expenditure is the sum of all expenditures of the individual extraction phase. The total timber harvest expenditure is the sum of timber felling and extraction expenditures. In order to compare different procedures the expenditure was converted from minutes into Swiss Francs (unit: Fr./m^3) with the help of system cost rates.

Input variables for the model to determine the timber harvest expenditure are:
– Stand and tree data (e.g., tree species, tree dimensions, timber volume, assortment volume, mean volume per piece)
– Terrain data (e.g., slope)
– Timber harvest data (e.g., type of timber harvest, timber extraction method, logging distance)

Since the assessment of the timber harvest data was not primarily designed for the calculation of the expenditure several limitations apply:
– The survey did not consider the overall timber harvest concepts or methods, but considered instead the individual steps of the process. Since the timber harvest is becoming an increasingly complex system, the expenditure or the cost of the entire timber harvest process is sometimes reflected inaccurately by the sum of the expenditures or the cost of all of the individual process steps.

- For individual timber extraction methods (e.g., helicopter), important factors of influence are unknown. For the expenditure calculation, these unknown factors had to be replaced with assumptions.
- For certain timber extraction methods no valid model was available (e.g., train, boat). Since they only applied to a very small number of cases (approximately 70 out of 9,400 mentioned), an overall rate is used for the expenditure estimation.
- The amount of timber and the assortment distribution resulting from an actual harvest is unknown. The data was, therefore, determined from all trees measured on the sample plot using volume and assortment tariffs.
- When comparing the two inventories NFI1 and NFI2, it must be considered that the retrieval of the extraction data was based on different definitions.

The calculated expenditure of the timber harvest does not reflect the true cost that would incur for the exploitation of a sample plot. Several expenditures such as marking timber, slash removal, or additional expenditures for a thinning are not considered. The expenditures modeled are, therefore, not a basis for a timber harvest calculation.

The interview with the forest service included the last treatment on the sample plot since the first NFI survey (i.e., the last ten years). If no harvest took place, the most probable harvesting method, according to the forest service, was described. The timber harvest processes recorded in this way are not necessarily the most inexpensive ones and should therefore not be considered to be the best possible timber harvesting method for the sample plots. Furthermore, some of the references used as a basis for the calculation are not very recent; because of increases in productivity, this leads to an overestimating of the expenditures.

3.5.3 Employed Sources (Models used)

The timber harvest expenditure is calculated for the timber felling and for its extraction in 99% and 78% of the cases, respectively, with the forest enterprise simulation model FBSM (ERNI and LEMM 1995). The FBSM covers the following cases:
- Timber felling with chain saw
- Hand-skidding
- Extraction with tractor
- Extraction with conventional cable-crane and mobile cable-crane

For the expenditure calculation of the processor, harvester, forwarder, and helicopter, all rates used are all inclusive. They are based on the nomogram design (SCHWEIZER 1996) being transformed into calculation procedures.

(Note: Since at the time of the attribute derivation, the publication by SCHWEIZER (1997) was not yet available, the draft (SCHWEIZER 1996) was used in its place. This draft differs in some points from the final version. In particular, the nomograms being used to determine the necessary time were slightly modified. As a consequence, this resulted in expenditure differences for the processor, harvester, and forwarder in the order of ±10%. For the helicopter, the expenditures were underestimated as compared with the final version by approximately 20%.)

Several different sources are used for the derivation of the expenditure for the remaining harvesting methods.

3.5.4 The Derived Variables for the Individual Working Equipment

Table 1. Timber felling (felling and trimming of the tree).

Working equipment:	**Chain saw** (including axe)	
Input variables:	Mean basal area diameter dg (cm), slope, type of timber (coniferous/broadleaf)	
Derivation of the expenditure:	FBSM (p. 84, ERNI and LEMM 1995) Source: (PFEIFFER 1993)	
Cost rate:	Logger (FW):	40.– Fr./h (WVS 1995a)
	Chain saw (MS):	12.– Fr./h (SCHWEIZER 1997)
	System cost rate:	0.85 Fr./min (1FW+1MS)
Working equipment:	**Processor**	
Input variables:	Mean volume M (Efm)	
Derivation of the expenditure:	Expenditure (min/m^3)=$e^{0.6476-0.6604*\ln(M)}$ Source: (Fig. N, SCHWEIZER 1996)	
Cost rate:	Processor (P):	263.– Fr./h (VSFU 1995)
	Specialist (S):	43.50 Fr./h (WVS 1995a)
	System cost rate:	5.10 Fr./min (1P+1S)
Working equipment:	**Harvester**	
Input variables:	Mean volume M (Efm)	
Derivation of the expenditure:	Expenditure (min/m^3)=$e^{0.9049-0.6653*\ln(M)}$ Source: (Fig. E, SCHWEIZER 1996)	
Cost rate:	Harvester small (VEk):	145.– Fr./h (VSFU 1995)
	Harvester large (VEg):	263.– Fr./h (VSFU 1995)
	Specialist (S):	43.50 Fr./h (WVS 1995a)
	Logger (FW):	40.– Fr./h (WVS 1995a)
	Chain saw (MS):	12.– Fr./h (SCHWEIZER 1997)
	System cost rate:	M≤0.2 m^3 without manual felling: 3.15 Fr./min (1VEk+1S) M>0.2 m^3 with manual felling: 5.95 Fr./min (1VEg+1S+1FW+1MS)

Table 2. Extraction (including preskidding).

Working equipment:	**Hand-skidding**	
Input variables:	Mean basal area diameter dg (cm), distance for timber extraction Dist (m)	
Derivation of the expenditure:	FBSM (p. 85, ERNI and LEMM 1995) Basis: (ABEGG 1980)	
Cost rate:	Logger (FW):	40.– Fr./h (WVS 1995a)
	System cost rate:	0.65 Fr./min (1FW)
Remark:	Normal conditions are assumed.	
Working equipment:	**Horse**	
Input variables:	Volume per piece St (m^3 w.B.), distance for timber extraction Dist (m)	
Derivation of the expenditure:	Expenditure (min/m^3) = 60/(St*(1.24+(1057/(Dist+33.35)))) Source: (KEILEN and DIEHL 1986)	
Cost rate:	Horse (Pf):	20.– Fr./h (SCHMID 1996)
	Horsemen (PfF):	40.– Fr./h (SCHMID 1996)
	System cost rate:	1.00 Fr./min (1Pf+1PfF)
Working equipment:	**Tractor** (including individual cable winch and built-in cable winch) and articulated skidder	
Input variables:	Mean volume per piece Vmit (m^3), distance for timber extraction Dist (m), slope, skidding, assortment	
Derivation of the expenditure:	FBSM (p. 85, ERNI and LEMM 1995) Basis: (ABEGG 1980; 1991)	
Cost rate:	Tractor (T):	65.60 Fr./h (forestry tractor average, 50kW, Double-drum winch (6t), radio equipment)
	Articulated Skidder (KS):	89.40 Fr./h (skidder average, 60kW, double-drum winch (8t), radio equipment)
	Machine operator (M):	41.– Fr./h
	System cost rate:	T: 1.80 Fr./min (1T+1M) KS: 2.15 Fr./min (1KS+1M)
	Source: (WVS 1995b)	
Remark:	Normal conditions are assumed for setting choker and turning.	
Working equipment:	**Forwarder** (including all-terrain crane vehicle, Unimog, and clam skidder)	
Input variables:	Volume per piece St (m^3), distance for timber extraction Dist (m)	
Derivation of the expenditure:	Dist ≤100 m: Expenditure (min/m^3)=$e^{1.3127-0.1328*\ln(St)}$ Dist >100 m: Expenditure (min/m^3)=$e^{1.3127-0.1328*\ln(St)+0.002*Dist}$ Source: (SCHWEIZER 1996) Basis: (LÜTHY 1996a)	
Cost rate:	Forwarder (F):	129.– Fr./h (VSFU 1995)
	Machine operator (M):	41.– Fr./h (WVS 1995b)
	System cost rate:	2.85 Fr./min (1F+1M)
Working equipment:	**Mobile cable-crane** (MSK)	
Input variables:	Mean volume per piece V (m^3), direction of timber transport, total timber volume	
Derivation of the expenditure:	FBSM (p. 87 ERNI and LEMM 1995) Line length L (m) =2*Dist (m) Basis: (FRUTIG and TRÜMPI 1990)	
Cost rate:	Mobile cable-crane Small (MSKk):	64.20 Fr./h (WVS 1995b)
	Mobile cable-crane Medium/large (MSKg):	140.90 Fr./h (WVS 1995b)
	Logger (FW):	40.–Fr./h (WVS 1995a)
	System cost rate:	L≤300 m: 2.60 Fr./min (0.55*MSKk+3*FW) 300<L≤600 m: 3.60 Fr./min (0.55*MSKg+3.5*FW)

Working equipment:	**Conventional cable-crane** (KSK)	
Input variables:	Mean volume per piece V (m^3), mean driving distance Dist (m), total timber volume	
Derivation of the expenditure:	FBSM [S. 87, Erni und Lemm 1995) Basis: (Abegg *et al.* 1986a, 1986b; LEMM 1991)	
Cost rate:	Conventional cable-crane (KSK):	 70.– Fr./h (WVS 1995b)
	Logger (FW):	40.–Fr./h (WVS 1995a)
	System cost rate:	3.30 Fr./min (0.55*KSK+4*FW)
Remark:	The total timber volume is estimated from the line length; the line length is calculated as twice the mean driving distance.	
Working equipment:	**Helicopter**	
Input variables:	Distance for timber extraction Dist (m), tree species (coniferous/broadleaf)	
Derivation of the expenditure:	Broadleaf: Expenditure (min/m^3) = 3.2+0.00055*Dist Conifer: Expenditure (min/m^3) = 0.9*(3.2+0.00055*Dist) Source: (Fig. M, Schweizer 1996)	
Cost rate:	Helicopter small (Heli):	2040.– Fr./h (SCHWEIZER 1997))
	Logger (FW):	40.–Fr./h (WVS 1995a)
	System cost rate:	34.60 Fr./min (1*Heli+4*FW)
Remark:	Height differences are not assessed. Assumptions: ΔH=300 m, newly fallen timber	
Working equipment:	**Truck** (LKW)	
Input variables:	Expenditure (min/m^3) is not determined	
Derivation of the expenditure:	All inclusive rate:	6.00 Fr./m^3 (LÜTHY 1996b)
Cost rate:	Truck transports hardly depend on the distance for the range of distances relevant in the NFI (1–5 km).	
Working equipment:	**Forwarder** (including crane vehicle, Unimog)	
Input variables:	Distance Dist (m)	
Derivation of the expenditure:	Expenditure (min/m^3) = 1.24+0.001*Dist Source: (LÜTHY 1996a)	
Cost rate:	Forwarder (F):	129.– Fr./h (VSFU 1995)
	Machine operator (M):	41.– Fr/h (WVS 1995b)
	System cost rate:	2.85 Fr./min (1F+1M)
Remark:	To this category belongs, especially, transports with the Unimog, crane vehicles, and similar vehicles on truck accessible roads. Assumption: Transport from storage to storage.	
Working equipment:	Other type of timber extraction methods (like rafting/floating, sledge, cable railway, boat, train)	
Input variables:		
Derivation of the expenditure:	Expenditure (min/m^3) is not determined	
Cost rate:	All inclusive rate:	100.– Fr./m^3

3.5.5 Literature

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3.6 Protection against Natural Hazards

Urs-Beat Brändli, Anne Herold

Sustainability and Forest Functions

The goal of the Swiss National Forest Inventory is primarily to monitor the large-scale forest development with respect to the sustainability of the forest (BRÄNDLI 1993). The international consensus regarding the sustainable forest management, together with suitable criteria and indicators, served as a reference for the NFI. "Sustainable management means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" (Resolution H1 of the Ministerial Conference on the Protection of Forests in Europe in Helsinki 1993).

In Article 1, the federal forest law names three groups of forest functions: the protective, the (social) benefit, and the production function. The nature and landscape protective functions are considered as (social) benefits. According to today's understanding, the forest functions are divided into the demands of the society (demand) and the effects of the forest (supply). "Forest functions encompass those tasks that are accomplished by the habitat forest (effects or potential of the forest) and those functions which should be accomplished (demands by human)" (BERNASCONI 1995; BUWAL 1996a). The differences recognized between the demands and the effects require both political and practical action.

Since in the second NFI neither the social demands nor the effects of the forest could be directly assessed, the forest functions were derived later through models. In the present chapter those models regarding the protective functions are discussed. The derived attributes and measures for the production function (timber production) are presented in Chapter 3.2 "Estimation of Standing Timber, Growth and Cut". The models for recreational and nature protective functions are discussed in Chapters 3.7 and 3.8.

Term "Protective Function"

In this chapter, the protective function of the forest always refers to the protection of humans and includes, according to WULLSCHLEGER (1982), the protection against *natural hazards* (rockfall, soil erosion, landslides, scree, torrents, and avalanches) and the protection against *civilization hazards* (noise, exhaust fumes, soot, water pollution, and dust). In a mountainous and densely populated country such as Switzerland, the protection against natural hazards is of the utmost importance, which is why in the second NFI this function was primarily assessed.

According to the current forest law of Switzerland, any forest could theoretically be treated as a protection forest. The term " non-protection forest" no longer exists. Despite this, a forest is usually called a protection forest only if humans or tangible property is protected directly or indirectly against avalanches, rockfall, landslides, erosion, mud flow, or floods. The new forestry law from 1991 coined the term "forest with special protective function" (BSF forest) as an instrument for the incentive policy. BSF forests are forests that protect **humans or substantial tangible properties** against **direct natural hazards**. This interpretation was pertinent to the models in the second NFI.

Models of the Second NFI

The term "protective function" encompasses the social demand for protection (hazard potential, damage potential) and the effects of the forest against natural incidents (protective effect). In general practice and within the NFI specifically, the hazard potentials and the objects at risk are determined first in order to designate protection forests. Wherever these overlap there is potential for damage. The forest stands in the catchment area to such processes are declared protection forests. Whether this type of forest is structured as such that it provides the optimal protection is determined in the NFI later with the help of simple models with nominal values.

In the second NFI, models were used instead of field expertise to designate protection forests to get nationwide comparable results. Models exist for **avalanches** and for **rockfall**. The natural hazards landslide, erosion, mudflow, and floods are not considered here since no suitable models are available yet. The present models for the protection forest against avalanches and rockfall are relatively rough and should be further developed and refined, or be replaced with more suitable models.

The models employed in the second NFI to determine the hazard and damage potentials and the effects of the forest are explained in the following. Apart from the protective effect against rockfall, the models are based on research or on models from other projects. Most of the models were developed in connection with the forest survey program (WEP) 1992–1995 (BLEISTEIN and JOST 1993) within the modules "natural hazards" and "minimum silvicultural operation" for the local assessments in the field. The quality, significance, and applicability of these models for the sampling survey of the NFI were intensely studied between 1996 and 1997, and were discussed with experts. The results of these verifications are stated with explanations for these models.

3.6.1 Protection Demands of the Society

Urs-Beat Brändli

Society must first demand protection forests before they can be designated as such. Protection demands and the term "special protection forests" are defined as functions of the potential natural hazards and the damage potentials:

Protection demands = f(hazard potential, damage potential).

The appropriate mapping of the hazards is part of the cantonal projects, which after the end of the second NFI has been only partially completed. Due to the different cantonal survey methods, they are not suitable as a basis for a nationwide interpretation. This is one reason the second NFI had to work with models. In the NFI it was not necessary to quantify exactly the protection forest area. The so-called NFI2 protection forest is more a tool for the stratification of the total forest for a differentiated qualitative analysis of the state of the forest, and for analyses of the forest effects in space and time. For the characterization of the NFI2 protection forests and forests with special protective functions, see also BRÄNDLI and HEROLD (1999).

3.6.1.1 NFI Model to Determine the Protective Demands

A cost-effective determination of the hazard and damage potentials in the NFI grid and for all of Switzerland had to be based on already existing material. Since several necessary pieces of information were not available on a national level, or with only low resolution, only very rough models and general statements were possible.

The development of the models and the determination of the protective functions was conducted on the basis of existing data, such as the digital elevation model or the so-called pixel maps. Furthermore, a simplified model was assumed for avalanches and rockfall (fall analysis with the generalized gradient method) which was calculated with the geographic information system Arc/Info. The Geo7 Company, located in Bern, Switzerland was entrusted to develop the model (MANI and BALMER 1996). This work was based partially on the findings of the work for the module "supporting measures natural hazards" (BUWAL 1996b). The model's assumptions for the NFI2 protection forests were in accordance with those by BUWAL (1993).

The generalized gradient method (see below) does not allow the evaluation of incidents caused by torrents (floods, erosion, and mudflow). It only encompasses the designation of hazards due to rockfalls, avalanches, and landslides. At the time the second NFI was conducted no practical efficient model existed for the evaluation of incidents caused by torrents. The landslides that were modeled did not agree well with the terrestrial NFI assessment (traces of landslides), so these model results could not be used any further. In addition, too little is known about the ideal forest structure in preventing landslides or erosion (i.e., the requirements for optimal forest effects).

In all of these cases it is not possible with the present knowledge to qualitatively evaluate the protective effects. The protection forests designated in the second NFI were limited, therefore, to those with potential protective effects against avalanches and rockfall.

3.6.1.2 Data Foundation[1]

Elevation Model

The most important basis for the designation of protection forests in the second NFI was the **digital elevation model DHM100** of the Federal Office of Topography (see Chapter 2.7). The model was built with manual map interpretations (RIMINI grid relief) and was interpolated onto a 100 meter grid. The high resolution DHM25 was not yet available for all of Switzerland and had some critical drawbacks for the hazard simulation. Since the spot height of the national map was not used for the interpolation, the ridge height (of mountain ranges) in rocky areas (with contour lines every 100 meters), and consequently the slope, were sometimes significantly underestimated. The additional work necessary would have been too costly to eliminate this. For the DHM100, a few preparatory steps were sufficient, such as the elimination of unrealistic depressions (sink holes) in the DHM.

The representation of the topography in a 100 meter grid led inevitably to a smoothing effect of the relief, which was especially noticeable in the calculation of the slope. A comparison of the DHM100 with the DHM10, which had a 10 meter grid width, in the Mattertal valley (canton Wallis) conducted by the Geo7 Company showed that slopes under 30° were overestimated and slopes over 30° were underestimated. These empirical values were taken into consideration when the thresholds (critical slopes) for the designation of the hazard areas (see below) were determined.

Examples of critical slopes

uncorrected	corrected
11°	18°
22°	25°
28°	28°
34°	30°
50°	37°

The Mattertal, however, was not representative of the topography for all Swiss regions, as was shown by our analyses from the NFI data. By comparing the terrestrial measured slopes of the NFI sample plots (similar to the slopes from the DHM10) with the hectare slopes (identical to the DHM100), strong regional differences can be seen (Figure 1). The regions Alps and Southern Alps had, as expected, the highest similarities with the curve of the Mattertal (only 14 NFI sample plots). Regions with relatively short slopes, frequent inclination changes, and relatively smooth topography were poorly represented by the Mattertal, in particular the Swiss Plateau.

Due to time and cost considerations, optimization specifically for each region could not be conducted. As a consequence, in certain regions the correction function used in the NFI models overestimated the critical slope for the DHM100 and systematically underestimated the potential of rockfall and avalanches. This was especially true in the Jura and the Plateau, where only rockfall occurs, and to a lesser extent in the Pre-Alps and on the north side of the Alps (northern Alps region).

[1] The foundation for the data, the simulated hazard area, and the Arc/Info macros are only available at the WSL for the employment and updating of the damage potentials for the NFI. Other applications have to be arranged with the GEO7 Company, Swiss Federal Statistical Office, and the Federal Office of Topography.

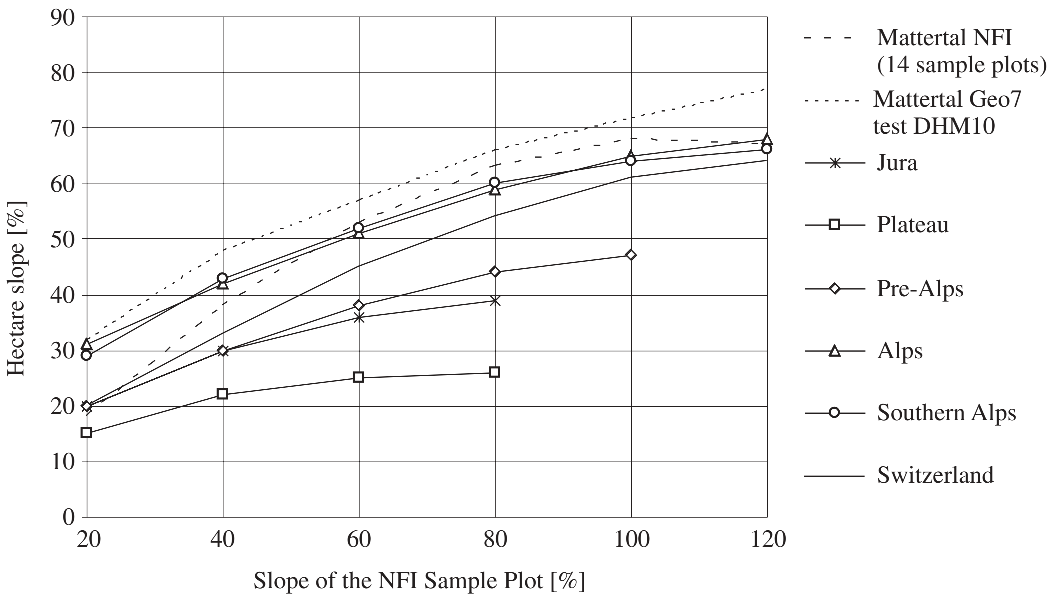


Figure 1. Relationship between hectare slope and sample plot slope.

The slope correction was, in general, relatively imprecise for flat or steep slopes, as for example, the upper limit at which avalanches can emerge (50°). The uncorrected slope of the sample plot from the terrestrial survey was, therefore, used as the breaking criterion for avalanches (see below).

Damage Potential

The threat to human lives and/or substantial tangible property (i.e., roads and **settlement areas)** was assumed to be the damage potential. The latter was taken from the **Area Statistics** 1979/85 (BFS 1992) which, with a grid width of 100 meters, corresponds with the resolution of the DHM100. The damage potential "settlements" in the NFI included industrial and building areas, as well as utility structures and waste facilities (power, waste water, etc.). Whether these buildings were inhabited all year, occasionally, or not at all, could not be detected with the material at hand.

The transportation routes were taken from the **vectorized national map 1:200,000** (Vector 200, as of 1981/85) from the Federal Office of Topography. For the assessment of the damage potential, the vector data set "Roads.dgn" (expressway, main roads) and "Rail.dgn" (railroads) were used and included the station buildings from main, side, and mountain railroads, but did not take into account tunnels, smaller roads, and lanes/footpaths. These vector data were combined with the 100 meter grid. For the final "sampling in the GRID," the edited **NFI sample plot data in the 500 meter grid** (forest/non-forest) was used.

The digitized Swiss road network was not categorized with respect to the damage potential. Thus, only the most important first and second class roads (indicated in red and yellow on the map) could be considered in the highly simplified model. With this model, all transit roads were taken into account; however, some important local access roads in the mountains were not included. The reported damage potential "roads" was, therefore, underestimated in the second NFI.

3.6.1.3 Designation of the Protection Forest

Natural hazards are natural incidents that could endanger human lives and tangible property. The designation of areas affected by such natural incidents was conducted with the help of the generalized gradient method. The slope, flow direction, and flow height was calculated for each pixel cell as well as the generalized gradient for each pixel cell that had damage potential (settlements, important transportation routes) (MANI and BALMER 1996). With these data the starting zones and trajectory areas for rockfall and the starting zone of avalanches can be designated. The ratio of total flow length and flow height equals the generalized gradient (see Figure 2). All damage potentials with a generalized gradient over a certain fixed threshold (see below) are in the range of the respective process. The designation of the NFI2-protection forest is explained in Figure 3, using the NFI2-avalanche protection forest in the Southern Alps as an example.

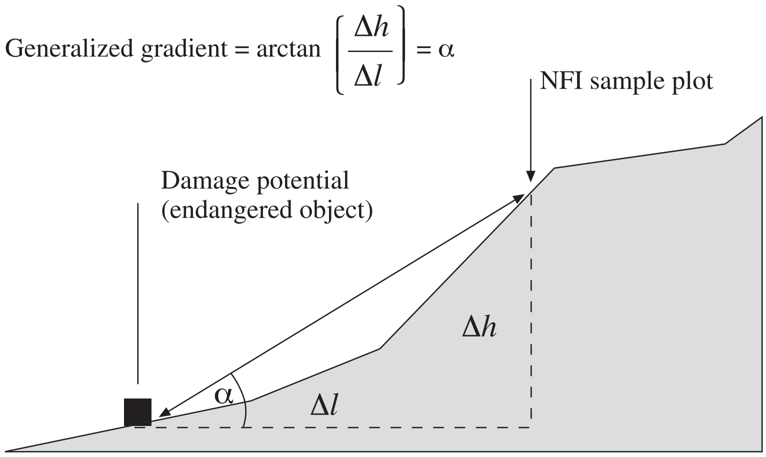
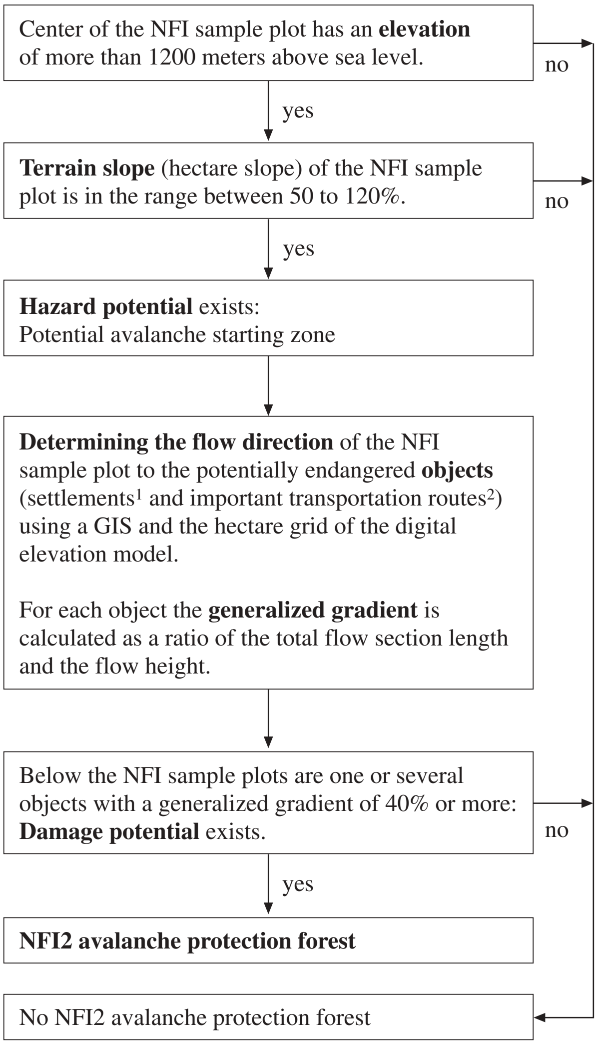


Figure 2. Concept of the generalized gradient method. Δl: Sum of all flow section lengths. Δh: sum of all heights (MANI and BALMER 1996).

Only those hazard areas which were directly related to a damage potential were designated. Settlements and transportation routes were distinguished. Connecting these hazard areas with the forested NFI sample plot points of the 500-meter-grid resulted in the **NFI2-protection forest**.



[1] Settlement areas according to the area statistic 1979/85.

[2] Transportation routes from the data set VEKTOR200 (L+T), as of 1981/85.

Figure 3. Classification schematic for the designation of NFI2 avalanche protection forest using the example of the Southern Alps.

Rockfall

In the rockfall model, all areas with a slope of 34° (65%) or more, and a generalized gradient to the next damage potential of at least 34°, were designated as starting and/or transit areas for the rockfall. Other relevant quantities (tectonic, geology, ledges of rock, etc.) were not considered. The threshold, with respect to the slope and generalized gradient, were taken from the papers of the forestry working group against natural hazards (Rickli *et al.* 1994). These thresholds were more restrictive than those of the Swiss Forest Agency with 27° and 22° respectively (BUWAL 1993) that were also intended for boulders of extreme size that could barely be stopped or slowed down by the forest.

Avalanches

The positive effect of a well-developed avalanche protection forest is founded in the ability to reduce the risk of triggering an avalanche. Avalanche protection forests are, therefore, located in the potential starting zone of avalanches. That is to say, they are located on steep slopes with deep snow. As a consequence, only potential avalanche starting zones with a sample plot slope between 28°–50°, or 50–120%, were identified. Slopes over 50° were considered to be too steep for avalanches, since it is not possible under these conditions for enough snow to accumulate.

Lower elevation limits for avalanches were set at 900 meters above sea level for the Northern Alps, 1100 meters above sea level for the inner Alps, and 1200 meters above sea level for the Southern Alps. The minimum generalized gradient was in accordance to the recommendation in the BUWAL (1993) set to 22° (40%).

Landslides
Areas with a slope (depending on the geological substratum) in range of 16–37° (29–120%) or 23–37° (43–120%) were designated as landslide areas. The Geo7 Company in Bern, Switzerland evaluated the rock classes from the "Simplified Geotechnical Map of Switzerland" (BFS 1995) with respect to their susceptibility against landslide processes. The position accuracy of the digital geotechnical map is, on average, 200 meters. The damage potentials that have a generalized gradient over 11° (20%) and have a distance of less than 500 meters to the area of origin were in the range of the landslide process.

3.6.1.4 Verification and Comparability

The models employed in the second NFI indicated, as a result, that the proportion of avalanche and rockfall protection forests is 9% of the total Swiss forest. This proportion varies between 8% and 20% in the Alps, depending on the regions (BRÄNDLI and HEROLD 1999). The survey teams in the field observed signs of snow movement on 59% of the sample plots in the NFI2-avalanche protection forest. Signs of rockfall were noted on 53% of the plots in the NFI2-rockfall protection forest, and on 19% of the plots in the remaining forests. The modeled potential landslides did not seem to be correlated with the signs of landslides observed in the field. For this reason the model "landslides" was not used further in the second NFI.

Compared to the designation conducted by the cantons, the results from the NFI indicated far less protection forest by canton. The area of the NFI protection forest amounts to 58% to 68% (rockfall) and 25% to 52% (avalanches) of the corresponding BSF forest areas of Grisons and Bern.

One reason for these results is because of the more restrictive NFI model assumptions for the natural hazards, as compared to those models of the canton Grisons, especially with respect to triggering avalanches. Furthermore, the second NFI identified less damage potential, since the methods used only the most important roads of class 1 and 2 (ignoring some of the local access roads in the mountains) and ignored scattered settlements in the Area Statistics. Finally, the cantonal BSF forest designation, with more of an area/spatial character (treatment units), resulted in a larger area than did the sampling inventory that had point decisions. For these reasons, and since landslides, torrents, erosions, and mudflows were ignored, the NFI protection forest proportions of 8% to 20% in Alpine regions are overall much lower than the BSF forest proportions in the mountainous cantons, amounting to approximately 30% to 40%.

Based on the maps with a scale of 1:25,000, 1:50,000, and 1:100,000, a rough, ocular plausibility check of the NFI2-protection forest was conducted in four areas of the cantons Valais, Ticino, Grisons, and Bern. According to these regional assessments, approximately 63% to 72% of all NFI2-protection forests fulfill the conditions of forests with special protective functions. In the canton Grisons 18% of the NFI2-rockfall and 9% of the NFI2-avalanche protection forests are definitely not special protection forests, since the supposed endangered objects are not really located in the hazard areas. This means that in most of these cases the objects were located at the counterslope or the process could not reach the objects because of extreme energy losses due to abrupt changes in slope and/or direction of trajectory. Such cases are not recognized with the generalized gradient method.

Comparisons with mappings of the cantons of Bern[2] and Grisons indicated that on average 56% to 59% of the NFI2-rockfall protection forests and 59% to 78% of the avalanche protection

[2] The mapping in Bern canton is based on a newly developed, refined model of the Geo7 Company, Bern, Switzerland. The employment of this extensive procedure was not possible at a national level during the time of the second NFI.

forests were located within the perimeter of the corresponding "forest with special protective function" (BSF forest) of these cantons (Table 1). Some of the NFI2-protection forests were shrub forests or open stands which were not mapped as forests by the cantons. Most of the differences, however, were based on the inaccuracies in the second NFI models. These differences included the rough terrain model, the inaccuracies with respect to position and relevance of the endangered objects, and most importantly, the shortcomings of the generalized gradient method. Since the latter did not account for the change of the avalanche trajectory, slope of the mountain and counterslopes, some unlikely events were simulated with relative frequency in the side valleys of certain regions – especially in the Leventina area (Ticino).

Despite these shortcomings, this model is, at the moment, the only practical method to select the NFI forest sample plots with protective functions until the extensive surveys of the cantons or other groundwork is available that will cover Switzerland entirely on a national level.

Table 1. Characteristics of the NFI2 protection forest and of the BSF forests.

	Protection Forest according to NFI2 (NFI2 protection forest)	BSF forest according to the forest law (BSF: special protection function)
Goal and context	– Long-term monitoring of state and development for the protection forests at a national level, differentiated by type of natural hazard. – Instrument for science with reproducible results.	– Determining the protection forest area for regional planning and silvicultural measures at the cantonal and local level. – Instrument for the designation of functions. – Incentive policy instrument.
Hazard potential	– Avalanche and rockfall. – Mathematical measure based on an simplified model.	– Avalanche, rockfall, landslide, erosion, torrent, and mud flow. – Mathematical and empirical measures.
Damage potential	– Occupied and unoccupied buildings. – Most important transport systems (railways and roads).	– Permanently occupied settlements. – All important transportation systems and feeder roads for permanently occupied buildings.
State of the survey	– Complete for Switzerland. – Temporary solution.	– Was not finished in 1996 for all cantons.
Procedure	– Point decision for the NFI sample plots.	– Area decision for larger forest parcels (planning unit, perimeter)
Comparability	– Can be compared at a national level. – Separate evaluation of avalanche and rockfall protection forest possible. – From the NFI protection forest 56-59% (rockfall) and 59-78% (avalanche) are also BSF forest in the canton BE and GR.	– Difficult to compare at a national level. – Differentiation of the BSF area by the individual natural hazards is not planned or carried out in every canton. – The comparability of the methods and the plausibility of the results was not systematically studied at a national level.

3.6.2 Current Protective Effect of the Forest

Anne Herold, Urs-Beat Brändli

The protective effects correspond to the current capability or suitability of the stand to prevent certain hazardous natural incidents before they occur, or in order to dampen their effects. The actual protection, that is whether or not natural incidents actually reach an object, is always the result of the interaction between site factors, stand properties, and incident properties. Nonetheless, the protective effects of the **forest stand** are analyzed in the second NFI independently of the other protective effect factors. This approach is very reasonable, since in the second NFI no detailed information exists about the site conditions along the path the incidents fell or about the incident properties (mass, energy, etc.). Thus, in the second NFI only the quality of the protection achieved from the stands was investigated, and not whether the endangered objects were protected in the end.

In the models of second NFI for the current protection effects of the forests against avalanches and rockfall, the site-specific potentials were not accounted for. For example, it was not considered (in the models) that portions of a rocky area could not be fully forested, or that certain sites are only appropriate for larch trees which are leafless in the winter and thus are hardly suitable as protection against avalanches. The models show only how well the current stocking protects. In contrast, the analysis of the structural sustainability in the protection forest (Chapter 3.6.3) includes the site properties through the model of the potential natural forest community (PNV) (BRZEZIECKI *et al.* 1995).

3.6.2.1 Current Protective Effects against Avalanches

Anne Herold

Background

Forest stands may rarely or not at all slow down avalanches if their fracture lines are above the stands. It is, however, possible that the forest can reduce the risk of triggering **forest avalanches** by intercepting snow in the tree crowns thus interrupting the evenness of the snow cover as well as minimizing snow accumulation due to the wind. This is why the break off of forest avalanches indicate weakened or absent protective effects of the stocking. The evaluation of the protection forest against avalanches is, therefore, based in the second NFI on the research of forest avalanches conducted by MEYER-GRASS and SCHNEEBELI (1992).

This research investigated how the type of stands, the site and the type of snow conditions in the Swiss Alps affect the start of forest avalanches. The goal was to determine which attributes and quantities had the highest influence on forest avalanche events. Table 2 (taken from MEYER-GRASS and SCHNEEBELI 1992) presents a synthesis of the relevant parameters that trigger forest avalanches along with their critical values (thresholds). These thresholds depend on five types of forest stands which are presented.

Table 2. Parameters and thresholds important for the start of forest avalanches according to Meyer-Grass and Schneebli.

	Forest type				
Parameter	Broadleaf	Broadleaf /conifer	Conifer evergreen	Conifer evergreen/ not evergreen	Conifer not evergreen
Crown coverage (%)	<80%	<70%	<35%	<30%	<35%
Width of gaps (m)	>5 m	>5 m	>10 m	>10 m	>10 m
Coverage of ground vegetation (%)	>50%	>50%			
Slope (°)	>38°	>42°	>38°	>35°	>32°
Number Stem/ha (DBH>16cm) depending on the slope:					
30°	50		50	200	300
35°	250		150	300	300
40°	600		250	400	300
45°	850		350	550	300
50°	1100		450		300

Plausibility in the field

MEYER-GRASS and SCHNEEBELI (1992) specify the number of stems per hectare trees with a DBH above 16 cm (No./ha >16) as the relevant stand density. Not considered here is the fact that with increasing diameter the tree crown gets wider and can therefore achieve the same snow interception effects with fewer number of stems. In addition, initial model calculations using NFI data suggested that this measure of stand density is not optimal for older stands (with larger diameters and fewer numbers of stems).

Using the sum of all diameters at breast height per hectare ($\sum$DBH) as a measure of density includes the stages of development. In the summer of 1996 both stand density measures were for this reason studied with respect to the plausibility by comparing the nominal and the actual value (threshold/stand value) of selected stands in Domleschg (GR) between 1100 and 1700 meters above sea level. For this comparison, stands for all three needle winter forest types (evergreen, leafless in the winter, and mixed) were selected.

Before the data were gathered each stand was first ocularly assessed as to whether the snow interception from the current crown closure was sufficient, not sufficient, or was unclear to prevent the start of avalanches. The goal was merely to test the plausibility of the results for both density measures in obvious situations thus avoiding fundamental misinterpretations. In addition, the crown closure was estimated. It was noted whether a gap of more than 10 meters in diameter between the stand border existed. Subsequently, the diameter of trees on "fictitious" NFI sample plots were measured and both density measures were calculated. The results of both nominal/actual value comparisons were then compared with the ocular evaluation. This study was also conducted in the surrounding stands on some "real" NFI sample plots.

The results confirmed the assumptions that for old timber, the DBH sum is the more suitable density measure. In stands with somewhat smaller diameters (young and medium timber), both density measures are either equally good or the DBH sum is more plausible than the number of stems (No./ha >16). As an example of these interpretations, a stand with older timber (d_{dom} ≥60 cm), 100% spruce and 90% crown closure without gaps can be used. It is obvious that such a dense stand can prevent, even in steep terrain, the start of an avalanche. The DBH sum (165 m/ha) exceeds the threshold even for the steepest slopes, while the number of stems (320 No./ha) does not reach the threshold for a terrain slope that is over 90%.

Derivation of the Avalanche Protective Effect in the Second NFI

For each sample plot point, the threshold of the appropriate forest type (nominal) is compared with the observed or measured value of the sample plot (actual). The more thresholds that are being reached, the higher the probability is for good protective effects. The NFI attributes used for the nominal/actual value comparison were:

- **Winter forest type**: Broadleaf forest, broadleaf/coniferous forest, evergreen coniferous forest, mixed, evergreen/leafless in the winter coniferous forest, winter leafless coniferous forest. Calculated with the help of the mixture proportion and the basal area proportion of larch.
- **Slope**: Slope of the interpretation area. Calculated using the elevation measurements of the grid points in the aerial photograph.
- **DBH sum** (∑BHD): Sum of the tree diameters at breast height. Calculated with the help of terrestrial assessed trees on the sample plots and extrapolated to a hectare.

As discussed above, the ocular plausibility in the field indicates that the results of the nominal/actual comparison of the DBH sums in the medium and old timber are more plausible than those from the stem number method. The crown closure determined from aerial photographs is also slightly higher correlated with the DBH sum than with the number of stems of those trees with a DBH above 16 cm. The values of the DBH sum, which correspond to the nominal number of trees by Meyer-Grass and Schneebeli, were determined from the NFI data with a binomial regression, where the stem number of trees over 16 cm DBH is the independent variable and the DBH sum is the dependent variable. Table 3 shows, as an example, a high thinned spruce stand on a medium site (site class 16) when during the stand development, the values for the stand density parameter (as determined from the yield table, EAFV 1968) reach the thresholds. If the nominal values for the evergreen forest and 90% slope are substituted into the model, this optimally stocked "yield table stand" (even-aged, single-species stand, high thinned, and even crown closure) would reach the stem number between the age of 50 and 110 years; whereas the stand surpasses the threshold of the DBH sum starting at an age of 40 years during the full time of development. The latter result appears to be more plausible, especially for older, fully stocked yield table stands, since the snow interception is also sufficient in older stands when they are fully stocked.

- **Gap**: Presence of stand gaps on the interpretation area. Gaps with a dimension of at least 10 meters from stand border to stand border were recorded, as long as they were at least partially in the interpretation area.
- **Coverage**: Crown coverage. Calculated from the interpretation of 25 grid dots in the aerial photograph.

The derivation of the protective effects with the help of these five parameters is illustrated in Figure 4. Thresholds are shown in Table 4.

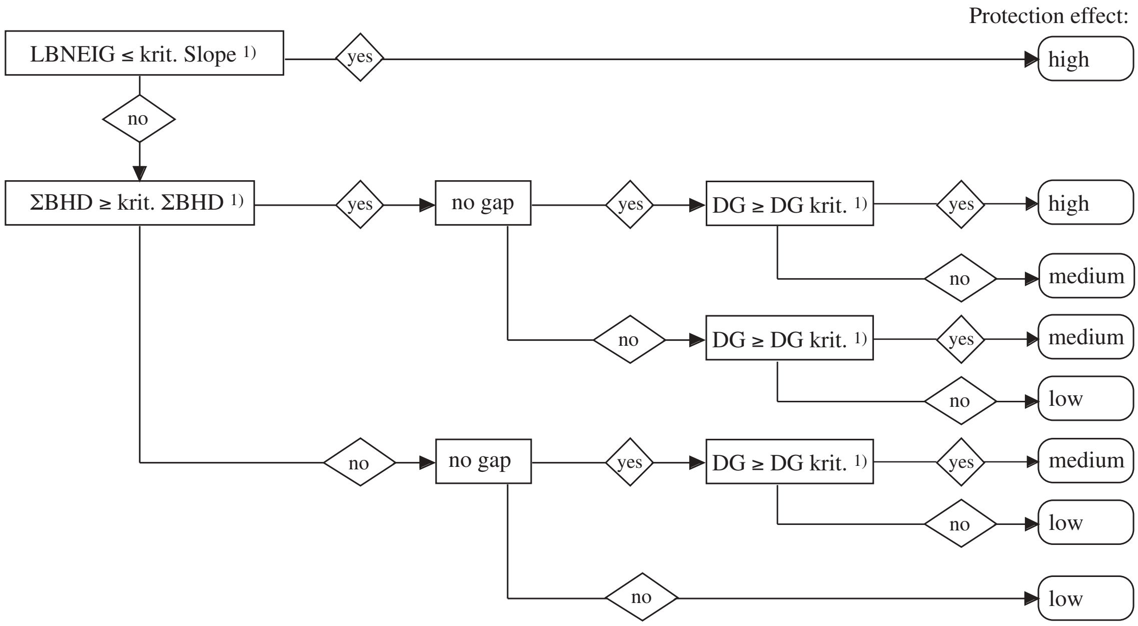


Figure 4. Derivation of the protective effect against avalanches.
∑DBH/ha: Sum of all diameters at breast height per hectare.
krit.: Critical value (threshold) according to Meyer-Grass and Schneebeli.
LBNEIG: Slope of the interpretation area, which is determined from aerial photographs.
DG: Crown coverage of the stand.
[1] from Table 4.

Table 3. Comparing the stand density parameter DBH sum (∑DBH/ha) and number of stems (number stems >16/ha).

Stand age (year)	Stem number >16/ha (DBH >16cm)	∑DBH/ha (DBH >12cm)		
20			Example:	
30	**0**	**24.8**	Nominal values	
40	**237**	121.2	for evergreen forest and	
50	510	156.7	90% slope:	
60	596	167.2	Stem number>16/ha (DBH >16):	300
70	594	164.0	∑DBH/ha (DBH >12):	97
80	525	149.1		
90	451	135.6		
100	394	125.7	Threshold fulfilled	
110	340	116.5	**Threshold not fulfilled**	
120	**290**	106.6		

Values determined from the yield table “spruce, site class 16” for the “remaining stands”.

Table 4. Critical slope and crown coverage by winter forest type.

Slope and crown coverage in %	Winter forest type				
	Broadleaf	Broadleaf /conifer	evergreen	evergreen/ not evergreen	Not evergreen
Slope	70	70	70	64	58
Crown coverage	80	70	50	50	50

Critical stand density by slope and winter forest type in ∑DBH/ha

Slope of terrain (%)	Winter forest type: Broadleaf	Broadleaf /conifer	evergreen	evergreen/ not evergreen	Not evergreen
59–64					100
65–70				98	100
71–77	129	91	65	114	100
78–84	182	91	81	130	100
85–92	219	91	97	153	100
93–100	254	91	112	176	100
101–109	288	91	128	176	100
110–145	321	91	144	176	100

The stocking density is not relevant in the marked area.

Discussion

The main drawback of the research on which the model is based (Meyer-Grass and Schneebeli 1992) is the short observation period of only five winters, of which none were typical avalanche winters. The variability of the snow and weather conditions is more accurately recorded the longer the observation period is. The avalanche frequency and the extent of avalanches depends directly on these conditions.

Forests with lower densities and lower crown closures can still protect against avalanches occurring in normal annual snow and weather conditions. However, higher thresholds, which means denser forests, are needed if the forests are intended to offer protection from rare, heavy, or even extreme conditions. That is why the standards with respect to the forests (meaning the thresholds at which the start of avalanches are prevented), should always be determined by considering the heaviest snow and weather conditions under which the forests are still expected to offer protection. These “relevant snow and weather conditions” are best characterized by the return period[3]. Over longer observation periods, the threshold values could be established differently for conditions that occur annually (normal), every 20 to 50 years (rare), and possibly every 100 years (extreme).

Meyer-Grass and Schneebeli (1992) wrote in relationship to this the following observation: “... in the observed area and during the observed years, no winter with high avalanche intensities occurred. The number of stems per hectare represent, therefore, rather lower threshold values; avalanche fracture lines could probably also occur in denser stands or stands with slopes that are not as steep.” In other words: The selected model leads to conclusions that are only valid for “normal” snow and weather conditions with shorter return periods. As a next step it should be attempted to determine the number of years for these return periods. Meyer-Grass and Schneebeli (1992) regarded an extrapolation of the threshold values to longer return periods as theoretically possible if a series of observations of avalanche frequency and intensity exists which is undisturbed by factors unrelated to weather.

[3] Also called recurrence interval or recurrence period. The long-term average interval of the time expressed in number of years within which an event will be equaled or exceeded.

3.6.2.2 Current Protective Effects against Rockfall

Urs-Beat Brändli

The effects of forests against rockfall are highest in the starting zone and runout zone. Most of the protection forests are located, however, in the transitional zone (track) where, according to BUWAL (1993), their effectiveness is very limited. If a falling (rockfall) process is already in progress, forests can rarely bring it to a complete stop. Forests provide, however, a very significant contribution by reducing the energy which lessens the bouncing of tumbling rocks and blocks. For the evaluation of forest effects, all NFI2-rockfall protection forests are considered transitional zones, due to the small number of sample plots as well as missing detailed research about forest effects in different zones.

Background

Effect Factors of the Forests against Rockfall

Today, the knowledge about how forests protect against rockfall is still not adequate and by far less extensively understood than for forest effects against avalanches. Qualitative relationships between influential factors are described, but knowledge regarding the effectiveness of a forest is missing (i.e., the maximum possible effects a forest can have with an optimal structure). Forests have a certain effect against rockfall as JAHN (1989) showed in an experiment. A site specific, absolute evaluation of the effects of a forest is, however, not possible on this basis.

If aspects such as terrain slope, terrain roughness, ground cover, or subsoil are not considered and only stocking is studied, the following effect factors are examples that can be found in literature.

Positive Effects	**Negative Effects**
Starting zone	
– Closed forest	– Gaps
Transitional (track), and runout zone	
– Closed forest	– Gaps
– Dense stocking	– Lamellar structure (forest aisle, free of trees in falling direction)
– Wide forests	
– Large “effective DBH” (SUDA 1989) (comparable with Σ DBH in NFI)	– Tree distance in falling direction >30 m (GSTEIGER 1989)
– Trees with a DBH larger than 10 cm (SUDA 1989)	
– Large number of trees/hectare	
– Large DBH: high energy absorption	

Sustainable Effects (aspects of the stability standards)

- Stands with permanent regeneration and high DBH dispersion (plenter forest)
- Less sensitive tree species:
  - Larch is more resistant than spruce/fir
  - Sycamore maple and basswood are more resistant than beech

Extent of the Rockfall Phenomenon in the Forest

According to the second NFI (BRASSEL and SCHWYZER 1999), approximately 16% of the NFI sample plots showed signs of rockfall; in the region of the Alps, this amounted to 27%. In all of Switzerland approximately 3%, and in the Alps 6%, of the NFI sample trees had damages that could clearly be linked to rockfall (HEROLD and STIERLIN 1999). In a typical protection forest, such as the “Bannwald” of Altdorf, the proportion of damaged trees amounted to 36% (JAHN 1989). This phenomenon includes not only rockfall, but also rockslides with larger boulders, which could only be slowed down by the forest. For the study, with respect to forest effects, GERBER (1994) defines the rocks and boulders by their diameter:

Rocks		ø <0,5 meter
Small boulders	0,5 meter ≤	ø <1,0 meter
Boulders	1,0 meter ≤	ø <1,5 meters
Large boulders	1,5 meters ≤	ø <2,0 meters
Giant boulders		ø ≥2,0 meters

Forest Effects and Optimal Structure

The fundamental question now is, which rocks and boulders can still be slowed down by a forest with what type of structure? Near the town of Balzers, JAHN (1989) conducted in a pole wood suitable experiments with “relatively small rocks” that had a mass between 3 and 125 kg. At a high specific weight of 2.7 kg/dm^3, this corresponds to a regular rock cube with a side length between 10 and 36 cm. In this experiment the deposit rate of the rocks in the forest was, depending on the density of the pole wood, about two to ten times larger than on the bare control plot with the same average slope (71%).

Based on his empirical studies of rockfall events, GERBER (1994) showed that pole wood is more effective against rocks than older timber. Conversely, for small to medium size boulders, older timber is more effective than pole wood. For boulders with a diameter of more than 1.5 meters, older timber has only a small effect. Forests by themselves cannot protect against these kinds of events, no matter how they are structured.

Using a simulation model ZINGGELER (1989) studied, how a large “rock” with a dimension of 0.5 m x 0.4 m x 0.3 m and 40° slope could be slowed down by a forest. The greatest acceleration of a rock is in the first 30 meters. Consequently, the **m**ean **t**reeless **s**ection (MTS) (i.e., the distance between two tree contacts), should be less than 30 meters whenever possible. In the simulation model, especially the younger timber (mean DBH 16 cm overall respectively mean DBH 20–35 cm in the main stand) and montane plenter forests (mean DBH 20 cm, multistorey, and more than two stages of development) were able to dampen the impact velocity and rebound height. Furthermore, due to the higher mean diameter, the montane plenter forests furthermore, cause a more lateral deflection, which results in an even higher energy reduction. Montane plenter forests can also be regenerated in smaller patches (single tree selection) in a sustainable manner. Because of this, the risk of unstocked forests and critical stages of development can be avoided. Rocks in pole wood (relative thin stems, mean DBH 13 cm, mean DBH 35–50 cm in the main stand) can, however, achieve relatively high impact velocities and rebound height. The same is true for older timber (mean DBH 29 cm, mean DBH in the main stand >50 cm) because of the relative long **m**ean **t**reeless **s**ection (MTS).

Overall, the stand density, the distribution of the stocking (as short of a treeless section as possible), and the absence of gaps must be considered as the most important factors in the evaluation of the protective effects against rockfall. Depending on the diameter of the rock, the mean diameter and the diameter dispersion of the stand carry a different weight.

NFI2 Model for Forest Effects against Rockfall

The optimal stage of development with respect to forest effects depends on the rock or boulder diameter; however, the NFI did not have any information about the local rockfall incidents (diameter, frequency). Because of this, the stage of development regarding the upper stem diameter d_{dom} was not taken into account in the NFI model. Under these conditions, the “stand density index” (SDI) is the most suitable measure for protective effects in the second NFI. This is true since the SDI, in contrast to other stand density measures (No.>12 cm/ha; No.>16 cm/ha; basal area/ha; DBH sum), is mostly independent of site class, stand age, and tree species mixture (Table 5). The SDI is calculated with the help of the number of stems per hectare from those trees with a DBH larger than 12 cm and the mean diameter of the stand.

According to REINEKE (1933): $SDI = 10^{(\log N + 1{,}605 \log dg - 1{,}605)}$

or rearranged according to DANIEL and STERBA (1980): $SDI = N^*(25/dg)^{-1{,}6})$

N: Number of stems per hectare, dg: Mean diameter (diameter of mean basal area tree)

Table 5. Variation of the SDI, calculated for the example spruce, based on yield tables, site classes 8 to 30.

Spruce	site class																		
	8			**16**							**20**			**24**			**30**		
stand age	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0	∑DBH	G	N_{12}	N_{16}	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0
20														3800	8.2	639	2700	11.0	726
30				3789	7.7	576	25	17,7	177	0	2708	10.3	655	2130	12.9	739	1511	16.8	800
40				2376	11.1	648	121	23,0	796	237	1725	14.4	714	1339	17.7	771	966	22.6	822
50	4337	6.5	503	1591	14.5	666	157	26,2	902	510	1167	18.5	721	908	22.5	767	664	28.5	819
60	2928	8.5	521	1135	17.9	665	167	28,5	860	596	839	22.5	709	656	27.2	751	480	34.3	796
70	2102	10.5	525	846	21.3	655	164	30,0	764	594	630	26.6	696	495	32.0	735	365	40.1	777
80	1565	12.5	516	650	24.6	633	149	31,0	608	525	486	30.7	675	384	36.8	713	284	45.9	751
90	1211	14.5	507	515	28.0	617	136	31,8	492	451	388	34.8	659	307	41.5	691	228	51.7	729
100	963	16.5	495	419	31.4	603	126	32,5	409	394	318	38.9	645	251	46.3	673	187	57.5	709
110	788	18.5	487	346	34.8	587	117	32,9	346	340	263	42.9	624	208	51.1	653	156	63.3	690
120	655	20.5	477	290	38.2	571	107	33,2	290	290	221	47.0	607	175	55.9	634	131	69.2	668

N_0: Number of stems/ha (DBH >0 cm).
Dg_0: Mean diameter (DBH >0 cm) [cm].
SDI_0 Stand density index.
N_{12}: Stem number /ha ((DBH ≥12 cm).
N_{16}: Stem number /ha ((DBH ≥16 cm).
∑DBH: Sum of the diameters for all trees greater or equal 12 cm DBH per hectare [m/ha].
G: Basal area (sum of the cross sectional area at 1.3 meter height for all trees with a DBH over 0 cm, per hectare) [m^2/ha].

Based on the considerations and relationships discussed above as well as due to the inventory catalog of the second NFI, the NFI2 effect model for rockfall was limited to the following factors:

– **Stand density index** (at an 5 ar area)
– **Gaps in the stand** (equivalent to a MTS >20 meters)
– **Coverage of tree crowns less than 60%** (on a 50 x 50 meter area)

The stand density is regarded as an indicator of the palisade effects against rockfall. Stand gaps and/or low crown coverage are indicators for critical, treeless sections. Similar to the evaluation of forest effects against avalanches with the DBH sum (∑DBH), the SDI is combined with the input variable gap and crown coverage. In case of gaps and/or crown coverages of less than 60%, the effects in the NFI2 model was reduced for each by one class. Since the parameters "gap" and "crown coverage" are only available in the second NFI, conclusions about changes of the protective effects or comparisons with the first NFI must be limited to the stand density (SDI).

The interpretation or evaluation of the stand density (SDI) as a measure for the relative protective effects against rockfall was carried out in four classes with equally large ranges in values (Table 6). The classification was based on the EAFV yield tables, in particular those for spruce (BADOUX 1983). Depending on the site class and stand age, newly thinned, normally dense to loose spruce yield table stands (remaining stands) had SDI values between 477 and 822 (Table 5).

Table 6. Relative protective effect against rockfall based on the stand density (SDI).

Protective effect[1]	Stand density SDI	Comparable basal area (m^2/ha)	Control stands[2]
Low	Up to 400	Up to 18	Sparse and open stands
Medium	401–800	19–41	Normal and loose stands, thinned stands
Good	801–1200	42–65	Dense stands
Very good	Over 1200	Over 65	Very dense stands

[1] Ocular, relative assessment in the field.
[2] Based on field assessment, NFI data, yield tables, and literature, e.g. LEIBUNDGUT (1982), p. 41–43:
Peručica PF5: 65 m^2 basal area or SDI 971 (equilibrium phase, plenter phase).
Peručica PF1: 67 m^2 basal area or SDI 796 (all phases).
Peručica PF2: 74 m^2 basal area or SDI 921 (early optimal phase).
Peručica PF4: 80 m^2 basal area or SDI 1130 (late optimal phase).

The minimum and maximum values for remaining stands of the four yield tables spruce, fir, larch, and beech were between 453 (120 year old beech stand, site class 26) and 961 (40 year old fir stand, site class 26). Fully stocked, newly thinned stands, therefore, never have an SDI value of less than 400, and only on the best sites (rarely protection forests) are values sometimes over 800. The median SDI value of all NFI sample plots was 600. Based on these relationships, one class was defined with SDI values between 400–800, while the remaining classes were defined at intervals of 400.

Assuming that only forests that are denser than newly thinned stands can have a good current effect, the threshold for “good” was defined by a value of 800. Stands with an SDI under 400 are not fully stocked (i.e., the crown closure is sparse or open) and provide only relatively low protection. Only 5.6% of all NFI sample plots achieved an SDI of more than 1200. These could be stands that provided, at the moment, optimal and very good protection, but due to the high stand density, their stability is seriously threatened.

Absolute judgements with respect to the protective effects are not possible with the SDI. However, assuming that protection forests require enough light for a sufficient regeneration, the optimal sustainable density could at most be in the range of montane virgin forests during the equilibrium phase (plenter phase). For some of the virgin forests described by LEIBUNDGUT (1982), the stem number distributions in diameter classes are also published. Depending on the development stage, we have calculated SDI values between 800 and 1100 for the virgin forests of Peručica. For example, the SDI value of a virgin forest in the equilibrium phase comes to 970.

The yield-study plenter plots of the WSL have long-term mean SDI values of 595 (Jura), 613 (Alps), and 651 (Emmental). The two control plots “Dürsrüti” have long-term mean values of 744 and 826 with maximum values between 900 and 1000 (ZINGG, oral communication). It still needs to be resolved whether SDI values in the range between 600–1000, according to different site quality, are the sustainable optimum with respect to protection against rockfall in the (montane) plenter forest.

Discussion and open questions

During the preparation for the second NFI, no detailed information or facts were available about how the forest and terrain affects the rockfall. Consequently, it was not possible to assess the necessary specific data.

Today, at the end of the 1990’s, several different process models for the rockfall are being used in practical operations in order to map hazardous areas (computer simulations for an arbitrary number of defined rocks/boulders). Apart from the terrain topography, these models also account for the type of rock, soil (e.g., roughness, elasticity), and forest (DBH, No./ha). However, with respect to the effect of forests, the models are still relatively rough. Input variables are considered the number of stems per hectare and size class. With these data the mean treeless section is also calculated. Forest aisles, gaps in the stands, and especially the true distribution and clustering of trees in a stand are still not considered.

The **SDI** as a measure for the stand density, in the case of unknown relevant rock diameters, are presently, after applying it to the second NFI, also being studied in applied forestry as a relative measure for forest effects and as an absolute measure for sustainable forest structures. Additional studies need to show to what extent this measure is suitable (depending on the rockfall phenomenon) for absolute assessments with respect to actual forest effects. In this connection, other quantities (No. >16, ∑DBH, etc.) should be validated as well.

It is still an open ended question as to which diameter of the rocks/boulders what "**stand diameter**" is optimal, and which are, in each case, the suitable effect indicators (measuring quantity). At the moment it is the general consensus that the ideal rockfall protection forest should be closed and dense, but should not contain wide trees with large crowns that need a lot of room. The hypothesis is currently discussed that the ideal "stand diameter" should amount to approximately 1/3 to 1/2 of the relevant rock diameter, depending on the accepted risk and the geology. Nonetheless, the method to determine the "stand diameter" with respect to the calculations is not defined.

New insight regarding the effects of different **tree distributions** could, in principle, be gained from the following four procedures:

– Observing "silent witnesses" in rockfall forests with high rockfall intensities
– Falling boulder experiment in test areas with forest or "artificial forest" (poles)
– Falling boulder experiment with an "artificial forest" in a model of approximately 1:20 in a large laboratory
– Falling boulder simulation in a computer model (effects of different tree distribution)

In view of the **third NFI** it is important to support and assist the research in these areas. Through engaging contact between basic research and applied forestry, it is possible that the attribute catalog in the next NFI survey will contain all necessary information. It is important to record **forest structures** more differentiated and more representative of the stand as well as the stand mosaic (i.e., with the help of aerial photographs of the entire interpretation area or larger areas). Furthermore, additional information about **other parameters** from existing rockfall process models (geology, surface roughness, subsoil, rockfall material) should be assessed through observations in the field, analysis of aerial photographs, or enquiry at the forest service if these do not already exist.

3.6.3 Stability Standards in the Protection forest

Anne Herold

Apart from the current protective effects of the forest, the sustainability of the forest structure is also an important topic. The goal was to estimate whether a forest would still fulfill its function after 20 to 50 years.

This medium-term stability of forest structures is measured on five qualitative attributes of the stand constitution: the *stand structure* (horizontal and vertical), *diameter dispersion*, *crown length*, *slenderness*, and *regeneration*. These test criteria are compared on each of the sample plots to the nominal value, known as the so-called stability standards. Since the standards depend on the site, the nominal values are defined differently for each forest community.

3.6.3.1 Background

WASSER and FREHNER (1996) developed the stability standards for the most frequently occurring site types from the sub-montane up to the upper sub-alpine zone. Along the lines of this research, which is referred to in the following as "the guiding method," stability standards are used to determine a silvicultural minimum goal, which corresponds to "the minimal state of the forest that is still able to reduce the hazard in a sustainable way". The stability standards were defined by montane silvicultural experts according to the concept of how the natural forest should be structured. This approach was chosen under the assumption that in natural forests "the risk for large-scale damages is small and the conditions for natural regeneration are good." In this sense, minimum stability standards were defined for the following properties of the stand and differentiated according to site type:

– Mixture of tree species
– Vertical stand structure
– Diameter dispersion
– Horizontal stand structure
– Crown length or crown form of the stability support[1]
– Slenderness of the stability support[4]
– Stand (vertical or lop-sided) and anchoring of the stability support[4]
– Regeneration: germination bed, natural seeding, plants growing up

For example, the minimal stability standards are defined as follows for the "Reed grass-fir-spruce forest" (according to ELLENBERG and KLÖTZLI, 1972, forest community number 47: Calamagrostio villosae-Abietetum), which is a relatively common NFI protection forest:

– Mixture of tree species:	Fir: 30%–90% Spruce 0%–60% Larch 0%–60% Service berry: seed trees[2]
– Vertical stand structure:	Two-layer
– Diameter dispersion:	Sufficient viable trees in two different stages of development
– Horizontal stand structure:	Small cluster (spruce) and individual trees (fir)
– Crown length of the stability support:	Length at least half of the tree length
– Slenderness of the stability support:	Less than 0.8
– Stand and anchoring of the stability support:	good[3]
– Regeneration: germination bed:	Half of the area without strong vegetation competition
natural seeding:	Fir on 1/5 of the area
plants growing up:	on 1/10 of the area

Today, forest communities have been recorded in the field for only a small portion of the NFI sample plot grid. Thus, this information was calculated with a model. For each sample point, the potential natural vegetation according to BRZEZIECKI *et al.* (1993) was derived (see Chapter 3.1). This model gives, for each point of the sample plot grid, several possible forest communities with their corresponding probability of occurrence. The most probable forest community was regarded as the "valid" one and was used as the input variable for the stability standard determination. Since the probabilities of occurrences were between 12% and 100% (with a median of 55%), this input variable includes a considerable uncertainty.

[1] Stability supports are either the strongest individual trees in the upper layer (structure trees); trees that stand close to each other and that depend on each other, and whose crown length is up to three-quarters of the tree length (small cluster); or trees that stand close to each other and have a common crown surface and whose crown length totals three-quarters or more of the tree length.
[2] At least as many service berry trees that are needed to perpetuate the species.
[3] All trees are vertical and have strong, deep roots; the soil is appropriate for the present species so that the roots can easily penetrate the soil.

3.6.3.2 Study Regarding the Fulfillment of the Stability Standards

The stability standards according to WASSER and FREHNER (1996) were compared with forest structures found on each of the sample points. The more the attributes of the forest structure (i.e., test criteria) fulfilled these standards, the higher the rating was for the medium-term stability of the forest structures.

Several different problems arose during this application. The NFI attributes "stand structure" and their outcomes were rarely defined as stability standards in the guiding method and were, therefore, rarely directly applicable. In order to come as close as possible to the definition of the guiding method, several different attributes had to be combined differently for each attribute outcome (see also Table 7 or 9).

The NFI does not have any information about the anchoring of the stability support, germination bed, and natural seeding. The tree species mixture and the stability support were not assessed at the stand level, but originated from the 200 m^2 and 500 m^2 sample plots. This fact, and the uncertainty of the modeled natural potential vegetation, required some modifications and simplifications in the model for the stability standards.

Table 7. Minimum stability standards with respect to the vertical (structure) and horizontal (crown closure) stand structure. Required variable combinations by forest community.

Forest community (EK No.)		Minimum stability standards in respect to: STRUCTURE		CROWN CLOSURE
1–17 OR 21–32 OR 38–41 OR 43–45		>0	AND	>1 AND ≠ 6
18–20		2	AND	>2
	OR	>2	AND	>1
46–47		>1 AND <4	AND	>1
	OR	4	AND	>0
48–53 OR 56–60		2	AND	>2
	OR	3	AND	>1
	OR	4	AND	>0
54 OR 55		<3	AND	>2
	OR	3	AND	>1
	OR	4	AND	>0
33–37 OR 42	OR	>4	AND	<4 AND >7
>60	OR	>0	AND	>0

Meaning of code STRUCTURE:
1 = One layer
2 = Multi-layer regular
3 = Stratified
4 = Cluster structure

Meaning of code CROWN CLOSURE:
1 = Crowded
2 = Normal
3 = Open
4 = Open/sparse
5 = Sparse
6 = Grouped/crowded
7 = Grouped/normal
8 = Complete

As the most important modification, the test criterion "tree species mixture" had to be relinquished. The reasons for this are first, the mixture proportion depends very much on the site. Information about the forest community, which describes the site has to be very precise, so that the mixture proportion can be compared with appropriate standards. However, this was not the case as it was previously discussed. Second, the mixture must be derived from the tree data in the sample plots, since it is not known in the NFI at the stand level. The size of the sample plot (200 m^2 and 500 m^2), however, is not large enough to reliably estimate the proportion of different tree species. This is not the case for the slenderness or the diameter dispersion, which are calculated as the mean (or maximum-minimum difference) of continuous quantities (DBH, tree height) for all trees on the sample plot.

In the above mentioned example, the standard with respect to mixture is "at least 30% fir, maximal 60% spruce and maximal 60% larch." Even in a stand where such mixture exists, it is not guaranteed that it is present on the 500 m^2 sample plot, since the trees are not evenly distributed and this area is too small.

Detailed information about the NFI definition of the minimal stability standards for the five test criteria are presented in Tables 7 to 11. The interpretation of this is discussed in the following with the help of the above mentioned example of the "Reed grass-fir-spruce forest" (according to ELLENBERG and KLÖTZLI (1972) forest community number 47: "wood reed-fir-spruce forest").

In this example, the stand should not be single-layered with respect to vertical and horizontal **stand structures**. If the stand is multi-layered, the canopy cover density should be anything but crowded, and if the stand has a cluster structure, the canopy cover density is not relevant (Table 7).

Since the **diameter dispersion** is estimated on the sample plot (500 m^2), standards are only meaningful for coniferous forest communities of the upper montane, oreal, and subalpine zones, as long as the stand is either one or multi-layered (WASSER 1997, oral communication). Over a larger area, layered stands have a sufficient diameter dispersion and clusters are stable even without a diameter dispersion. In our example, the difference between the largest and the smallest DBH should at least total 15 cm if the stand is single-layered. The difference is unimportant if the stand is layered or clustered (Table 8).

Table 8. Minimum stability standards with respect to the diameter dispersion. Required diameter difference by forest communities.

Forest community (EK No.)	Minimum stability standards: $DBH_{max} - DBH_{min}$ [1)]
1–45	≥0 cm
46–60 AND (stratified OR cluster structure)	≥0 cm
(46–52 OR 54–58 OR 60) AND layered structure	≥15 cm
(53 OR 59) AND layered structure	≥25 cm
>60	≥0 cm

[1)] Because this should be the diameter dispersion of the "viable trees," sample trees that are slightly one-sided or have short crowns (<1/4 of the tree length); those that are strong one-sided and have short crowns; and those that are strong one-sided and have medium crowns (<1/2 of the tree length) are not considered.

The mean **slenderness** of trees in the upper layer must be less than 0.8 (Table 9). In the subalpine zone, the **crown length** is usually required to be at least 2/3 of the tree length. In the NFI this information is unknown. The classification of the crown length goes down only to half of the tree length, which is not a sufficient limit for subalpine forest communities. This problem can be circumvented by requiring a higher standard with respect to the slenderness of the stability supporting trees in these forest communities (apart in the clustered stands), since crown length and slenderness are highly correlated. In our example, at least half of the upper layer trees must have long crowns (crown length amounts to at least half of the tree length) (Table 10).

In our example, the **regeneration** had to cover at least 10% of the interpretation area (2500 m^2) (Table 11).

Table 9. Minimum stability standards with respect to slenderness. Required maximum mean slenderness of the stability support[1] by forest communities.

Forest community (EK No.)	Minimum stability standards: Avg(BHOHD/DBH)
1–47 OR 49–52 OR 54–56	<0.8
(48 OR 53 OR 57–60) AND cluster structure	≥0
(48 OR 53 OR 57–60) AND (layered OR stratified structure)	<0.7
>60	≥0

BHOHD: Estimated tree height [meters].

BHD: Diameter at breast height [cm].

[1)] Stability support: Only trees of the **upper layer** are included.

Table 10. Minimum stability standards with respect to the crown. Required crown form or length of the stability support[1] by forest communities.

Forest community	Minimum stability standards:	
(EK No.)	CROWN LENGTH	CROWN FORM
1–17 OR 21–32 OR 38–41 OR 43–45	–	3 for ≤50% of all trees
18–20	1 for ≥50% of all trees	–
46–60	1 for ≥50% of all trees Bäume	–
33–37 OR 42 OR >60	–	–

Meaning of code CROWN LENGTH: 1 = Crown length >1/2 of the tree length.
2 = Crown length 1/2–1/4 of the tree length.
3 = Crown length <1/4 der of the tree length.

Meaning of code CROWN FORM: 1 = Round
2 = Slightly one-sided, average
3 = Strong one-sided

[1)] Stability support: Only trees of the **upper layer** are included.

Table 11. Minimum stability standards with respect to the regeneration. Required regeneration coverage by forest communities.

Forest community (EK No.)	Minimum stability standards: REGENERATION COVERAGE:
1–32 OR 35–41 OR 43–45	≥1%
46–58 OR 60	≥10%
59	≥1%
33–34 OR 42	1%–75%
>60	≥0%

Result of the Stability Standards

With the help of the proportion of fulfilled and unfulfilled stability standards, a simple measure for the structural sustainability was generated for each of the samples. The more standards that were fulfilled, the better the medium-term stability of the forest structures was rated. BRÄNDLI and HEROLD (1999) classified the proportion of fulfilled stability standards in three parts: “less than a third,” “between one and two-thirds,” or “more than two-thirds.”

3.6.3.3 Discussion

1. The stability standards of the guiding method are based, even today, on expert opinion. The actual median-/long-term structural development of the stands assessed and treated with this method is (still) not completely verified.
2. The assessed attributes with respect to the stand structure in the first and second NFI were not defined for this purpose, and the suitability was very limited as well (see also the discussed problem of the crown length). In particular, more refined assessments of the regeneration situation (in the montane forest) and the tree species composition in the stands were missing in the second NFI.
3. It is not sufficiently accurate to deduce the stand structure from the tree data of the 500 m^2 sample plot, since this area is too small to assess correctly certain structural attributes in certain forest communities.
4. The model for the evaluation of the stability standards would be more meaningful if information about the site type (forest community) would be assessed in the field.

3.6.4 Literature

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3.7 Recreational Function

Urs-Beat Brändli, Ulrich Ulmer

3.7.1 Introduction

The significance of the forest as recreational area has increased constantly over the last few decades. According to estimates by Jacsman, approximately 220,000–250,000 people visit the Swiss forest at the same time during a nice Sunday afternoon (JACSMAN 1991). Even the Swiss montane population rates the importance of the recreational function of the forest as high as the protection function (ZIMMERMANN *et al.* 1996). Consequently, the forest is, according to the Federal Law of Forests, supposed to fulfill in a sustainable manner, apart from the production and protection function, non-profit functions, such as recreation (Chapter 3.6). The most intense discussions during the process of the cantonal forestry legislation very often touch upon the question of recreational use. In summation, it can be said that recreation in the forest is very important in Switzerland.

Similar to the forest function definition in Chapter 3.6, which has become more accepted as of late (BUWAL, Bundesamt für Umwelt Wald und Landschaft 1996), it is possible for recreational functions in the forest to distinguish between the recreational demands which society places on the forest (demand) and the recreational effects of the forest (supply/opportunity).

Models of the second NFI

The current knowledge, with respect to recreation in the forest, comes mostly from case studies that cannot be applied to all of Switzerland without problems. The focus of these studies "recreation in the forest" are mainly directed towards the recreation in areas of urban agglomeration, recreational demand, visitor frequencies, recreational land-use pressure, external yield, etc. (for example see JACSMAN 1998; NIELSEN 1992; SCHELBERT *et al.* 1988). Therefore, it was not possible to go back to already existing models in order to come up with information about recreation in forests on a national level.

Even though in the second NFI a survey of forest functions could not be realized due to methodological and financial reasons, some new data with respect to the recreational use of the forest was gathered. In addition, some simple models for recreational demands and forest effects were developed. Due to this, information for the entire country of Switzerland is available for forest policy discussions and decisions on a national level. The models presented here have, however, **pilot character**. For example, the model of recreational demands is limited to **short-term (local) recreation** (Chapter 3.7.2). All models shall be extended and refined during future NFI surveys. This is, however, only possible when more fundamental knowledge about the multiple effect factors and mechanisms of recreation in the forest is available.

3.7.2 Recreational Demand of the Society

Recreation in the forest is, in essence, part of the landscape and outdoor recreation (JACSMAN 1990). Often they cannot be discussed separately. The forest is especially important for sports and recreation in densely populated areas and tourist regions. In urban agglomerations, with the absence of alternatives, outdoor recreation is often entirely concentrated in the forest. The numerically most important group seeking recreation in the forest consists of hikers and walkers (BURKHALTER and SCHADER 1994; JACSMAN 1990).

The analyses of the second NFI are directed entirely toward **local recreation** for many reasons: First, the largest demand for recreation consists in daily recreation and, therefore, most likely conflicts with the interest of other forest functions, such as nature protection and timber production. Second, data and models to quantify other forms of recreation, such as excursion recreation did not exist in the second NFI. Local recreation in this context is defined as outdoor recreation in local areas (JACSMAN 1994). For this reason, residential towns as well as tourist towns that have a considerable number of guest rooms, are taken into account.

3.7.2.1 NFI2 Models for Recreational Demand

Theoretical Approach

Several different approaches and methods exist in order to quantify the demand of forest recreation. According to JACSMAN (1994), land-use planners define the term *recreational demand* as the number of humans that are/would like to be involved in outdoor recreation. Frequently, the current "number of visitors" is used that is established by large-scale field surveys. Such observations are conclusive indicators for recreational demand only in accessible forests. Other methods must be used to answer the question whether forests in regions with high demands also have a well developed road system and are therefore accessible. Jacsman, for example, estimated with the help of models the regional mean use intensity of forest recreation in Switzerland (JACSMAN 1990). The true recreational demands at the national level are, however, not known. As mentioned above, the necessary requirements were missing in the second NFI in order to further develop and employ the complex models of JACSMAN (1994) for sample surveys. Thus, the demand for local recreation was estimated in the second NFI with new, but simple models.

The demand for local recreation in the forest depends on several factors (JACSMAN 1994): For one, it depends on the number of inhabitants, weekenders, vacationers, and the individual type of recreation or recreational activity (hiking, sports) performed. It also depends on the size of the town, distance to the town, forest density, and distribution of the forest. The landscape-oriented recreation in urban areas and near villages (local recreation) is regarded as a year-round phenomenon and is mostly independent of the season. The number of motorized vehicles per capita, the climate, and weather are less important factors for local recreation than for other forms of outdoor recreation. But on a larger scale, no facts are available about the types of recreation. Thus, and since it is not known how the size and distribution of forests and settlements within Switzerland influence the recreational demand, the NFI2 models derive the recreational demand simply by using the number of inhabitants and long-term visitors.

How can local recreation be defined with respect to settlement proximity? According to JACSMAN (1990), the average annual duration of one stay in the outdoors was 45–75 minutes for local inhabitants; 70–110 minutes for long-term visitors (tourists); and 100–140 minutes for short-term day visitors (trippers).

The NFI model describing this recreational demand is based on the assumption that one walk, including return, does not normally exceed two hours (Jacsman, oral communication). Depending on the pace, this results in an estimated maximum distance of approximately two times 3–5 km (which equals 6–10 km in total). Depending on the route configuration (route curvature) and slope of the terrain, the actual covered horizontal distance can be significantly shorter.

Based on studies conducted in the test region of Zurich and Davos, it is reasonable to assume a horizontal activity radius of 2–3 km. Sometimes a chain of mountains limit, in reality, recreational use and thereby reduce the activity radius. Due to this, the lower limit of the relevant activity radius (i.e., 2 km) was used in the model. Based on these considerations, the recreational demand is defined as follows:

The recreational demand on the NFI sample plot is proportional to the population and tourism density within the proximity of 2.0 km.

The population density (E2) and household densities (W2, Wt2, Wd2) (see below) that were used for the derivation of the recreational demand were calculated at the WSL with the help of a geographic information system (ARC/INFO). The quantities correspond to the sum of all hectare values of the information grids GEOSTAT (BFS 1994b) within the proximity of two kilometers of each NFI sample plot (i.e., an area of 12.6 km^2).

Model Development

A measure for the population and tourism density is the number of inhabitants and visitors per hectare. The number of inhabitants was available from the 1990 population census in a hectare grid of the Swiss Federal Statistical Office (BFS). The number of visitors could theoretically be derived from the number of occupied beds according to the tourist industry (hotels, bed and breakfast places, holiday homes, youth hostels, campsites). As a simplification, only the number of available beds in hotels was used as an indicator, unless there were no other data obtainable. These data for hotel and health resort enterprises were, for 1995, only available for each municipality in printed form (BFS 1994a) and were, therefore, only used for the model development in the test regions of Davos and Zurich. In both of these regions the probable recreation demand was oculary estimated on a total of 51 NFI sample plots in the field. Apart from the actual local recreation, "traces" of recreational activities were included as well. It is important to note that especially in Davos these traces are partially the result of excursion tourism.

Categories of recreational demands (ocular estimation):
1 None
2 Probably low
3 Average
(walkers or traces showing walkers/hikers used an area: rubbish, beaten path, campfire)
4 Considerable
5 Very high

It is a fair assumption that inhabitants and (long-term) visitors are different with respect to their demand for local recreation in the forest. But how do visitors or their indicators, such as the "number of beds", need to be weighted? The demand model EN1 gives equal weight to the number of inhabitants (E2) and to the standardized number of beds (B). This resulted in a similar coefficient of determination (R^2) of 0.57 and 0.51 for both test regions. However, in respect to the ocular estimation, the model EN1 did not result in supraregional comparable values (Figure 1). Thus, several models with different weights were tested. The function EN showed the best comparability of the regional model values and had correspondingly the highest correlation between the ocular assessment and the mixed model (total) for both regions combined (Figure 2):

$$B = BG/EG*E2$$
$$EN1 = BG/EG*E2 + E2$$
$$EN = 10*BG/EG*E2 + E2 \qquad (1)$$

EN: Recreational demand
BG: Total number of available beds in hotels in the corresponding municipalities (1995)
EG: Total number of inhabitants in the corresponding municipalities (1990)
E2: Total number of inhabitants in a radius of 2 km (1990)

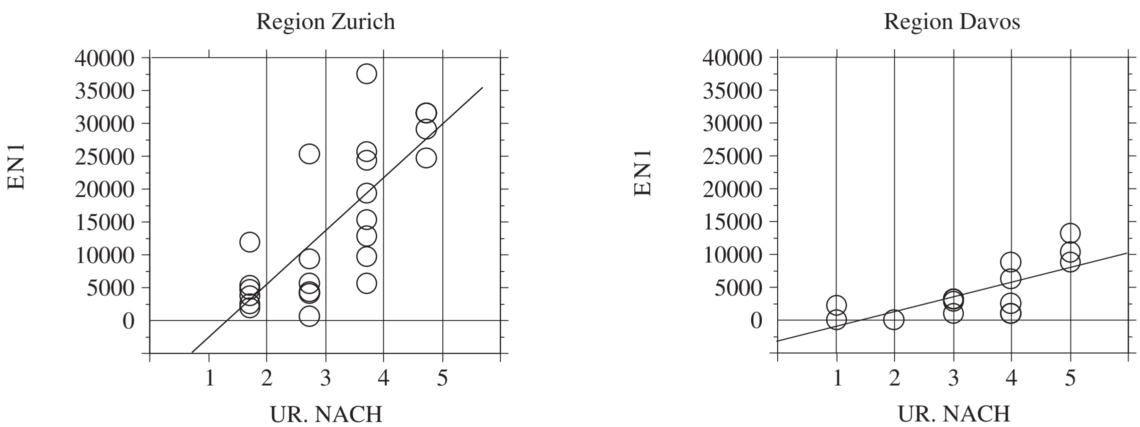

Figure 1. Comparing the model values (EN1) with the expert's assessment (UR.NACH) for the recreational demand of accessible forests in the test regions of Zurich and Davos. EN1 = BG/EG*E2 + E2 BG: Total number of available hotel beds in the municipality. EG: Number of inhabitants in the municipality (1990). E2: Number of inhabitants within a radius of 2 km (1990).

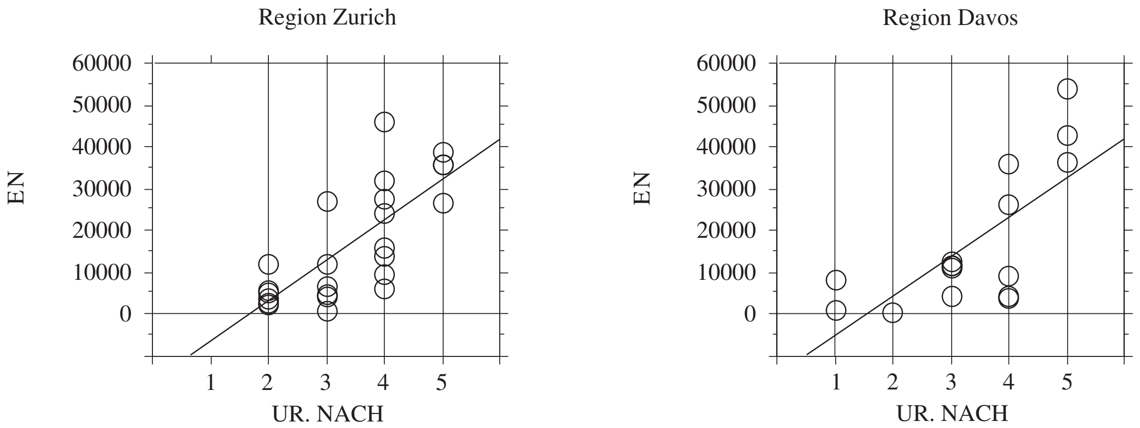

Figure 2. Comparing the model values (EN) with the expert's assessment (UR.NACH) for the recreational demand of accessible forests in the test regions of Zurich and Davos. EN = 10*BG/EG*E2 + E2 BG: Total number of available hotel beds in the municipality. EG: Number of inhabitants in the municipality (1990). E2: Number of inhabitants within a radius of 2 km (1990).

Model ERHOLNA

Since the number of hotel beds was only available for each municipality and not in digital form, the tourism density on the national level had to be estimated in the second NFI with the help of an auxiliary variable. The "number of temporarily occupied or unoccupied households per hectare", calculated on the basis of the population census 1990 (BFS 1994b), was determined in the NFI to be a suitable indicator for the beds in hotels. The true number of available beds per municipality (BG) was well reflected by the following model MBG (R^2=0.88) in the test area:

MBG = (1,33 * WG * Wt2) / W2

MBG: Number of available beds in hotels in the municipalities according to the model
WG: Total number of households in the corresponding municipalities (1990)
Wt2: Number of temporarily occupied or unoccupied households within a radius of 2 km (1990)
W2: Total number of households within a radius of 2 km (1990)

The appropriate indicator for inhabitants is the "number of permanently occupied households per hectare" according to the 1990 population census. The linear regression between the household density and the population density had a very high coefficient of determination (R^2) of 0.99. This shows that there is a close relationship between inhabitants and permanently occupied households, or between the number of beds in hotels and the temporarily occupied households (see above). Therefore, as an alternative to the model EN (1), a simple model based solely on the number of households, was developed for potential recreational demand. In the first approach, two types of households (Wd2, Wt2) were added up with equal weight. Compared with the ocular assessment of recreational demands, it was obvious that for the same ocular values the number of households was three times lower in the tourist region of Davos than in the highly populated region of Zurich. As a consequence, several models were tested, which gave a higher weight to the temporarily occupied and unoccupied households (indicator for vacation homes). The highest coefficient of determination and a good interregional agreement between the ocular assessed recreation demands and the number of households was achieved with a model that attached a five-times higher weight to the temporarily occupied and unoccupied households than to the occupied households (Figure 3):

ERHOLNA = Wd2 + 5*Wt2 (2)

ERHOLNA: Recreational demands according to the model NFI2
Wd2: Number of permanently occupied households within a radius of 2 km (1990)
Wt2: Number of temporarily occupied or unoccupied households within a radius of 2 km (1990)

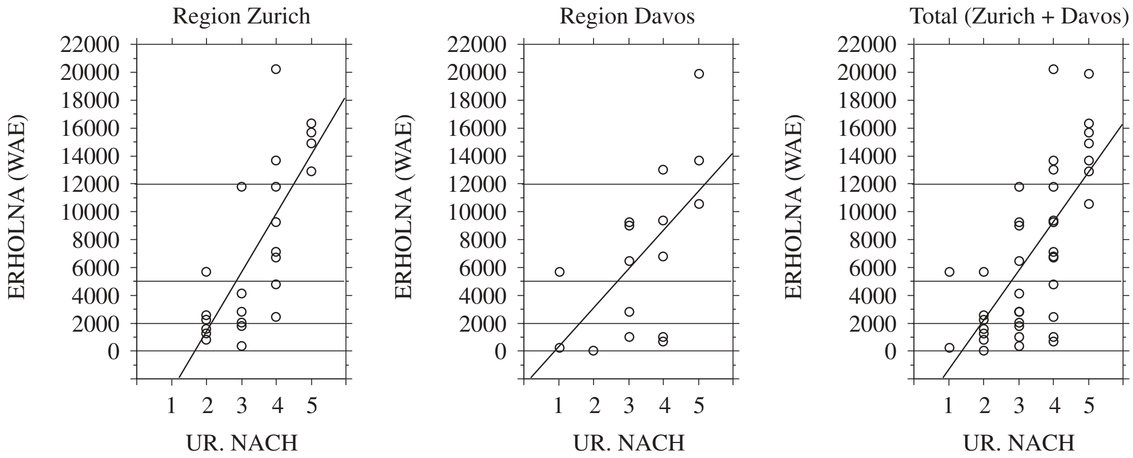

Figure 3. Recreational demand: Comparing the model values (ERHOLNA) with the expert's assessment (UR.NACH) for the recreational demand of accessible forests in the test regions of Zurich (R^2=0.56), Davos (R^2=0.37), and total (R^2=0.47). WAE: Household equivalents.

Validation and Interpretation

The calculated quantities of the potential demand for recreation are expressed in household equivalents (WAE). The values range in the NFI2-grid between 0 and 42,521 WAE. Based on the ocular assessments from the test regions in 1995, and with additional ocular assessments in the year 1996, the model quantities can be interpreted as follows (see also Figure 3):

Up to 4 WAE:	=	No recreational demand
5 to 1999 WAE:	=	Low recreational demand
2000 to 4999 WAE:	=	Moderate recreational demand
5000 to 11999 WAE:	=	High recreational demand
Over 12000 WAE:	=	Very high recreational demand

The scale is not valid everywhere, especially since regional differences in the behavior of the local population (city/country) and the visitors (summer/winter tourism) were not considered. The main intent was not only to quantify forests in areas which have high or very high actual recreational demand, but to quantify those forests in areas that have low or no recreational demand as well.

The recreational demand model was verified in regions with very high and very low values for recreational demand (region Montana-Sierre-Val d'Anniviers (VS), region Nyon-Marchairux-Vallée de Joux-Grand Risoux (VD) and region Zurich-Mutschellen (ZH/AG). It could be seen that no/low and high/very high recreational demands were well assessed. In forests near agglomeration areas, where the model indicated "moderate" recreational demand, traces with significant recreational demands were found. As a consequence, this class could be interpreted as "considerable recreational demand" in the Jura, Plateau, and Pre-alps where recreational demand is mainly the result of the local inhabitants. The "moderate recreational demand" outcome for the Alps resulted mainly from using the model for tourism density.

3.7.3 Recreational Effects of the Forest

In the context of outdoor recreation, JACSMAN (1994) refers to the term "recreation opportunities" and makes a distinction between the quantitative opportunities (area, capacity) and the qualitative opportunities (recreational suitability). The recreational suitability is comprised of five components: environmental qualities (natural hazards, emissions), event potentials (beauty, naturalness, diversity, uniqueness), suitability for activities (type and intensity of possible recreational use), equipment (facilities), and accessibility (distance or travel time). In the NFI, similar to the terminology of other forest functions, the term *recreation effect* is used in place of *recreational suitability* or *recreational opportunities*.

To what extent a forest stand is really suitable for recreational use is thus determined by a multitude of criteria. After looking through the German-speaking literature, with respect to the term *recreational suitability* (Arbeitsgruppe Landespflege 1982; BENTS 1974; GUNDERMANN 1972; KIEMSTEDT 1972; RUPPERT 1971; SCAMONI and HOFMANN 1969; WULLSCHLEGER 1982), several effect factors can be named. Based on the weighting and mention by the individual authors, the effect factors can be grouped according to their importance as follows:

Very important:	Conifer proportion (mixture proportion), ligneous species diversity, stand structure (layering), stages of development (age classes), outer forest edge, inner forest edge, acoustical disturbances, smoke and dust emission, large bodies of water and shore
Important:	Variety of forms (shaft, crown, standing dead trees), naturalness of the stocking, tending status and type of utilization, accessibility of the stand, road density, distance to the next road, position of the forest area, optical disturbances
Less important	Crown closure, composition of the ground vegetation, visual range in the forest, overview of the landscape, regional forest proportion, local climate, form of the surface (slope, relief), recreational facilities, places of interest, visitor density (population pressure), color diversity (shaft, crown, ground vegetation, i.e., herbaceous layer)

The actual evaluation of the recreational opportunity requires weighting and the combination of effect factors in a model. From the above mentioned literature several approaches to evaluate the forest effects are known. The validity of most of these models is limited to certain areas. Furthermore, the models are partially contradictory and cannot be applied to all of Switzerland.

The sample survey of the second NFI provides information about the forest stands. That is, it provides information for a relatively small, homogeneous reference area. An appropriate method to evaluate the recreational suitability of forest stands was developed by SCAMONI and HOFMANN (1969). The employment of these models in the second NFI was not possible for two reasons: A large part of the required criteria, such as public transportation, parking space, zoological gardens, restaurants, air-hygiene, and nuisance factors could not be assessed in the second NFI. Moreover, even today in Switzerland current studies are missing about the relevancy of criteria, such as tree species diversity, conifer proportions, stand structures, sites (aspect, slope, relief, climate), acoustical and optical disturbances as well as others.

The recreational effect of the forest was in the second NFI evaluated therefore based on the parameters "**accessibility**", "**infrastructure of recreational use**", and "**natural characteristics**" of the forest stands. These are aspects that can be directly influenced by a forest manager and forest owner. Thus, they are of central importance as indicators for sustainable forest management.

3.7.3.1 Accessibility and Infrastructure

A basic requirement for recreational use, especially for local recreation, is **road accessibility**. During the second NFI, this accessibility was evaluated, based on the horizontal distance of the sample plot center to the next truck-accessible forest road (transportation distance), as well as on the length of the forest roads per hectare forest (density of the forest roads). The forest road network, which was relevant for the timber transport, was updated and digitized in the second NFI. As defined on a 1:25,000 national map, these are usually second to fourth class roads that have a minimum width of 2.5 meters and allow vehicles that have a load carrying capacity of 10 tons axle load. The calculations of the transportation distance were conducted with the GIS ARC/INFO (HÄGELI and ZINGGELER 1996). The transportation distance did not contain any information about roads and paths of the class 5 and 6 (tractor roads, skid trails, paths, hiking trails, and bikeways). For this reason, the occurrence of such roads (yes/no) were also assessed in the field on the 50 meters x 50 meters interpretation area (STIERLIN *et al.* 1994).

The term **infrastructure** refers here to facilities for local recreational use: benches, rubbish bins, permanent campfire areas, playgrounds, campsites, ski and chair lifts, ski slopes and cross country trails, fitness trails, and others. Such facilities are indicators of a deliberate improvement in recreational opportunities by the forest owner, manager, or other institutions. If neither roads and trails, nor recreational facilities existed on the NFI interpretation area, the area was searched for the occurrence of other **traces** of recreational use: rubbish, wood carvings, trails that were not planned (human, horse), campfires, etc.

During the interpretation, NFI sample plots were considered directly accessible if they included special recreational facilities or trails, and/or if they were within 30 meters of a forest road. Forests were considered “not developed” if the transportation distance was over 200 meters, which corresponds with a mean road distance of more than 400 meters.

Categories for accessibility/infrastructure:

Good:	Distance to the next forest road ≤30 meters and/or recreational facility existing
Moderate:	Distance to the next forest road 31–100 meters
Poor:	Distance to the next forest road 101–200 meters
Non-existent:	Distance to the next forest road >200 meters

Based on the attribute accessibility/infrastructure, as well as the model for recreational demand (ERHOLNA, Equation 2), the current importance of the forest with regard to local recreation is determined according to Table 1.

Table 1. Model for the current importance of the forest to the local recreation, that is based on recreational demand (ERHOLNA in household equivalents (WAE)) and accessibility/infrastructure.

		Accessibility/infrastructure			
Recreational demand		Good	Moderate	Poor	Non-existent
	ERHOLNA				
None	0–4				
Low	5–1999				
Medium	2000–4999				
High	5000–11999				
Very high	over 12000				

Current importance to the local recreation

	High (typical local recreation forest)
	Medium
	Low/none

3.7.3.2 Natural Characteristics

The suitability of a forest for the purpose of recreation depends, among other things, on its composition and structure, the so-called natural characteristics. The natural characteristics are determined by site conditions and by anthropogenic influences, especially forest management. Nature lovers and forest walkers very often have high demands in regard to the aesthetics and diversity of the forest appearance. The evaluation of the forest appearance is, however, always subjective. Depending on the season, region, and the individual preference, the demands are so diverse that in the literature, and based on personal experience in the forest, only a relatively small consensus could be determined for the natural characteristics.

Despite this realization and despite lack of funds, an attempt was made to develop an initial model for the natural characteristics with **pilot characteristics**, similar to the model used for the protection forest (Chapter 3.6) and nature protection (Chapter 3.8). The current level of knowledge and the derivations of the models do not allow for an absolute judgement or for a representative population judgement. However, certain relative statements about regional differences and temporal developments are possible.

For the development of the NFI models for the natural characteristics, the relevant NFI parameters were initially evaluated in 1995, and the attributes were subjectively weighted by an intern based on the literature (Table 2). Subsequently, tree, stand, and area attributes were assessed and a subjective overall assessment of the natural characteristics was conducted on 51 NFI sample plots in the test regions of Zurich and Davos.

Table 2. Parameter and weights of the attributes in the NFI model for natural characteristics.

Parameter	Abbreviated name	Attribute	Weight
Stage of development	EST	Young growth / thicket	1
		Pole wood	2
		Young timber	2.5
		Medium timber	3
		Old timber	4
		Mixed	5
Stand structure	STRUK	One-layered	1
		Multi-layered	2
		Multistorey	3
		Cluster structure	2
Coverage of ground vegetation	BODVEGDG	Snow cover	1
		Less than 1%	1
		1–9%	1
		10–25%	3
		26–50%	4
		51–75%	3
		76–100%	2
Coverage of shrub layer	STRADG	Less than 1%	1
		1–9%	1
		10–25%	3
		26–50%	4
		51–75%	3
		76–100%	1
Surrounding of forest edge	WRUMG	Settlement and transportation routes	0
		Arable land, artificial meadow, vines	1
		Fertile meadow	2
		Fertile meadow with trees/shrubs	3
		Pasture	1.5
		Grazing woodland, stocked pasture	3
		Tall forbs	1
		Dry meadow	3.5
		Wetland	2
		Bodies of water: lake, river	5
		Rock, scree, wasteland	1.5
Type of gap	LUECKEN	No larger gaps in the stand	0
		Cutover or windfall areas	1
		Forest meadow without woody plants	4
		Forest meadow with woody plants	3
		Blocks, scree area	2
		Erosion and landslide areas	0
		Rock areas	3
		Avalanche rides, forest aisle	2
Basal area proportion of the recreation species (birch, sessile and common oak, Scotch pine, mountain pine, Swiss stone pine, larch, and cherry tree)	ERHARTEN	0%	0
		1–10%	2
		11–50%	4
		51–100%	5

A detailed analysis (stepwise regression) of these field data indicated that the subjective overall assessments by the intern is mainly explained by the parameters “stage of development”, “crown closure of the ground vegetation (herbaceous layer)”, and “stand structure”. The remaining parameters were not significantly correlated with the subjective assessment, which was partially due to their rare occurrence and the relatively small data set.

The parameter “coniferous proportion”, as well as the “ligneous species diversity”, proved to be not suitable for a model that was supposed to be valid in lower as well as in higher elevations. Instead, the occurrence of individual tree species that have particular aesthetic appeal, such as birch, sessile and common oak, sweet cherry, Scotch pine (*Pinus sylvestris*), mountain pine (*Pinus mugo*), Swiss stone pine (*Pinus cembra*), and larch were introduced afterwards into the model as a new criterion “recreational species”.

The weights of the seven parameters in the overall model “natural characteristics” (ERHNATU3) were determined based on the correlation with the subjective assessment. Most of the parameters for the natural characteristics were first introduced in the second NFI (STIERLIN *et al.* 1994). For the comparison with the first NFI, a strongly reduced model (ERHNATU1) with the two most relevant parameters “stages of development” and “stand structure” was derived:

ERHNATU1 = EST + STRUK
ERHNATU3 = 4*EST + 2*STRUK + BODVEGDG + STRADG + WRUMG + LUECKEN + ERHARTEN
(For variables see Table 2)

The values for natural characteristics can range for the models ERHNATU1 and ERHNATU3 between 2 and 7, as well as 8 and 42, respectively. The following thresholds were determined for the interpretation of the model values based on field verifications:

Natural characteristics	ERHNATU1	ERHNATU3
Low	up to 2.5	up to 12
Tends to be low	2.6–4.0	13–20
Tends to be high	4.1–5.5	21–28
High	above 5.5	above 28

The result volume publication of the second NFI used the following classification:

Natural characteristics	ERHNATU1	ERHNATU3
Low	up to 3.0	up to 15
Medium	3.1–5.0	16–25
High	above 5.0	above 25

The model ERHNATU3 was standardized and verified in the regions of Davos and Zurich. In addition, plausibility tests were conducted in the same areas as for the demand model. These tests indicated that the natural characteristics which were determined in the NFI-area, with a maximum dimension of 50 x 50 meters, were plausible for large, homogeneous stands. For small stands and especially for a mosaic of stands, the overall aspects of natural characteristics are often not adequately reflected.

3.7.4 Discussion and Outlook

One of the tasks of the NFI is the comprehensive control of sustainability at the national level. Suitable indicators for the recreational functions are for the most part still missing today. An important goal for the future is to develop these indicators, and also discover ones for excursion recreation, which was not studied here.

Appropriate survey methods must be developed and their applicability to sample inventories should be tested. The models presented here are only the first step. A new efficient method to assess additional factors, such as the number of visitors, the type of recreation, the infrastructure (parking space, gastronomic facilities, places of interest, marked hiking trails) or nuisance factors (noise, etc.) could be to conduct enquiries at the local forest service. The extended employment of the GIS for the analysis of the information grid and digital maps also should be checked.

Natural Characteristics
The importance and significance of the natural characteristics of a stand for recreation in the forest is not clarified. The fundamental questions, whether and how the forest visitor perceives (at all) the natural characteristics of a forest stand, and whether these characteristics are important and influence their selection in using a certain area of the forest remain unanswered.

It is possible that other criteria, such as accessibility, trail and road systems, sports trails, peacefulness, cafes/restaurants along hiking trails, and missing recreational opportunity alternatives are much more important and that the natural characteristics of a stand plays a minor role.

Open questions that are interesting in this context are:
– Which factors influence a forest visitor?
– Are the natural characteristics of a stand relevant for/during a forest visit?
– Which visitor groups notice the natural characteristics of the stand?
– Which aspects of the natural characteristics are preferred and which are avoided (indicators)?

The NFI inventory design was optimized in respect to the state and changes of timber volume and forest area. The data assessment was conducted from an aerial photograph or on the ground in the sample plots with the maximum dimension of 50x 50 meters. This leads to certain **methodological problems** for the assessment of the recreational effects of the forest.
– For the recreation in the forest, individual stands with their natural characteristics are not so important. It is often the stand mosaic, that is to say, the contrast and diversity (e.g., light/dark, small/large, broadleaf/coniferous forest, dense/loose), as well as the sequence of individual stands, that makes a forest with its natural characteristics attractive for a forest visitor.
– Contrary to the target parameter, timber volume and forest area that can be objectively measured and interpreted (continuous quantities), the evaluation of the natural characteristics of the stands are always subjective and depend on regional preferences of the forest visitors.

Based on the current open questions as to the significance of the natural characteristics and the above mentioned methodological problems, two directions can be followed with future NFI surveys in order to better quantify recreational effects:
1. Characterization of the ideal recreation forest can be better understood by questioning the population (systematic sample or regional case studies) with respect to key criteria, effect factors, and indicators, as well as their relevant evaluation area.
2. Development of suitable survey methods, especially for the assessment of the important stand mosaic and spatial sequence, as well as development of new models for natural characteristics and for recreational value overall. Standardizing and verifying the models using uninfluenced lay people.

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3.7.5 Literature

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3.8 Nature Protection Function

Urs-Beat Brändli

The preservation of the biological diversity (biodiversity) is, since the world conference in Rio de Janeiro in 1992, recognized to be one of the most important issues of our time. In this context forests are of great importance. With their large area, longevity, and structural diversity, Swiss forests comprise approximately 20,000 animal species and 500 vascular species' habitats (LANDOLT 1991; MEYER and DEBROT 1989). In addition to this are uncounted fungus, algae, bacteria, lichens, and moss species.

Since January 1, 1993 the new Federal Law on Forests has been in effect throughout Switzerland. The purpose of the new law is, among other things, "to protect the forest as an ecosystem near to nature". The term "ecosystem near to nature" is not further defined by the legislature. However, the meaning of "protect", for the purpose of nature protection, is indicated within several law articles pertaining to prohibition of deforestation; possibilities to limit accessibility to people and even limit large events in the forest; possibilities to designate forest reserves in order to preserve the species diversity of fauna and flora; protection against environmentally dangerous substances; regulation of the wildlife population; financial aid for expensive silvicultural operations conducted to protect nature; contributions to measures which protect and support forest reserves.

Conservation in Switzerland is at present primarily directed towards the preservation of endangered species and habitats (species and biotope protection). Most of the studies and inventories (forest conservation inventories) deal with a selection of "high quality" sites. Today, open forests that have low timber volume and some mature timber, forests that have not been managed for a while, forests rich in oak, and larger forests that are not accessible and are barely disturbed are accepted as "forest forms that deserve to be protected and supported" (BUWAL 1996). Here, two criteria are very important: threatened and rarity. The control of full reserves and partial reserves in order to protect valuable and endangered objects are the subject of special national inventories (e.g., flood plain forests, sphagnum bogs); however, extensive ecological evaluations over larger forested areas are missing for the most part.

An integrated conservation cannot be limited to threatened species and species-rich patches that are left over. The large-scale biodiversity of a region is mainly determined by the area used for agriculture and forestry, and for settlements. The area proportion used in the canton of Aargau amounts to 98% (WEBER *et al.* 1993). Therefore, at the national level the NFI is used, apart from other tasks, to recognize problems as well as to control the results of measures beneficial to forest conservation outside of the biotope protection in a stricter sense. The biotop protection "in a stricter sense" refers to the protection of special sites and special forests by designating parks or nature reserves and certain silvicultural operations. In addition to this, "regular" areas are managed to balance ecological impacts. The tools to balance ecological impacts for managed forests include for example: using natural regeneration and tree species adapted to the site; increasing older timber (longer rotation period) and dead timber; protecting and cultivating certain tree species; avoiding monoculture; and improving stand structure. The NFI is the national control instrument for such general nature protection measures and indicators.

For a comprehensive monitoring program that controls biological diversity, and for its development, the NFI would have to be expanded further. But even with its design today, it is an important instrument for the **long-term monitoring of the ecological sustainability in the utilized forest**, especially in the managed forest. For this, all forest stands have to be studied, even the ones with low ecological values, since due to natural development or specific tending operations they could turn into higher valued biotopes over time (VOLK and HAAS 1990).

Since the diversity of animals and plants (biodiversity) is, even today, neither exactly defined nor measurable, the so-called "indicators", "key criteria", or "measures" are used to evaluate forest stands. For the most part these are important habitat parameters for certain animal groups, such as birds, insects, or small mammals. DUELLI (1995) writes: “The efforts to reduce the whole complexity of biodiversity to single indicators is an unsolvable task: One tries to measure diversity with one single value. However, as soon as we want to preserve and support biodiversity according to the [Earth Summit] convention in Rio de Janeiro for reasons of state, it is necessary to measure and evaluate”.

Indicators and biotope value models can thus never provide an integral answer about the state of nature. The evaluation of species diversity is inevitably always oriented on the limited knowledge and value concept of humans. We speak consequently of nature protection function: A part of society that makes demands on the forest, and in return the forest ideally provides the appropriate effects. The indicators that the NFI selected are therefore oriented as much as possible toward the current expectations of nature conservancy organizations. The association of the indicators with biotope values and ecotone value models is an attempt to combine the individual aspects into one single “measurable quantity”. The goal here is primarily to provide overall information about the spatial distribution and temporal development of the potential forest effects as a habitat for fauna and flora. The ecological value analysis in the forest and on the edge of the forest is one method used to evaluate the success of the forest management that is relevant to nature.

3.8.1 Methods for the Ecological Evaluation of Forest Stands and Forest Edges in the NFI

At the present time there exists neither for lowland forests nor for forests in mountainous regions, procedures for the ecological value analysis that are feasible, universally valid, and verifiable, and which can also be applied to NFI conditions without any additional development. Hence, during the field survey of the second NFI, initial versions of such procedures were developed that were intended to provide the background and experience for the application of future inventories. They were also to allow for an initial assessment of the actual ecological value of stands and forest edges.

3.8.1.1 Background

The evaluation of the state and the development of the forest, with respect to the biodiversity, took place in the second NFI and was primarily based on individual indicators (see also Table 1).

Table 1. Ecological attributes in the second NFI and their significance as an indicator.

NFI2 attribute	Type of data	Indicator for or valuable for:	Type of indicator
Coordinates x,y,z	Area data	Region and elevation: supply of solar radiation, climate, altitudinal vegetation zones; important for all species	Biotope (site)
Aspect, relief, landslides, erosion	Area data	Supply of solar radiation, nutrient supply, changes of site, open area, important for all species	Biotope (site)
Special sites and water bodies	Area data	Dry and wetlands; habitat for specialist, rare plants and animals, amphibians	Biotope (site)
Geomorphologic objects, small relief	Area data	Special sites for plants; habitat particularly for reptiles or amphibian (e.g., salamanders, toads)	Biotope (site)
Dry stone walls and heaps of stones	Area data	Habitat for animals like reptiles (lizards, snakes)	Biotope (site)
Sunny patches without vegetation	Area data	Habitat for insects (e.g., *Bombus terrestris*)	Biotope (site)
Heaps of branches and wood	Area data	Habitat for small mammals, birds, insects, reptiles	Biotope (stand)
Stumps and dead timber on the ground	Area data	Habitat for insects (larvae), fungi, moss, lichens	Biotope (stand)
Type of gaps	Area data	Forest site with higher supply of solar radiation; habitat for special plants, insects, game	Biotope (stand)
Standing dead timber	Area data	Habitat for insects, fungi	Biotope (stand)
Disturbances	Area data	Dumping ground, old/new forest drainage, buildings in the forest	Influence

NFI2 attribute	Type of data	Indicator for or valuable for:	Type of indicator
Heavy utilization	Area data	Extensive anthropogenic damages of the forest vegetation and/or trees	Influence
Type and intensity of grazing	Area data	Influencing the ground flora	Influence
Number of years since last treatment	Timber harvest	Influenced by the timber harvest	Influence
Amount of timber yield	Timber harvest	Influence through timber harvest; supply of solar radiation	Influence
Tools for timber harvest	Timber harvest	Influence through timber harvest (horse, cable crane, heavy machines)	Influence
Forest transportation system	Accessibility	Disturbance through road construction and road usage	Influence
Age of stand	Stand data	Old timber stands: valuable as habitat for insects and birds	Biotope (stand)
Stand edge, forest edge	Stand data	Transitional biotope: habitat for insects (caterpillar), birds, shade-intolerant plants, game, reptiles	Biotope (stand)
Closure of ground vegetation	Stand data	Browsing supply for game, indicator for supply of light; habitat for insects (e.g., wild bees)	Biotope (stand)
Stage of forest development (DBH_{dom})	Stand data	Young growth, old timber, etc.: habitat for game, insects, birds (e.g., hole nester), small mammals	Biotope (stand)
Crown closure of the stand	Stand data	Supply of solar radiation, coverage: flora, insects, birds, game	Biotope (stand)
Closure of shrub layer	Stand data	Vertical structure (birds) and cover (game)	Biotope (stand)
Stand structure (vertical layers)	Stand data	Vertical structure: birds, small mammals	Biotope (stand)
Forest type	Stand data	Coppice with standards, coppice forest, chestnut plantations (Selve) , selection-type forests, etc.: valuable habitat for insects, birds	Biotope (stand)
Number of ligneous species	Stand data	Wide species conservation	Species
Type and closure of berries	Stand data	Habitat and food for small mammals, birds (e.g., wood grouse), insects, game	Biotope, species
Tree and shrub species	Tree data	Ligneous species diversity, ligneous species ecological valuable for insects, birds, small mammals (oaks, soft wood, etc.)	Biotope, species
Proportion of dead branches >20%	Tree data	Habitat for insects	Biotope (stand)
Tree damages	Tree data	Habitat for fungi, insects, birds, small mammals	Biotope (stand)
Trees with cavity	Tree data	Habitat for birds, small mammals and bats	Biotope (stand)
Stem diameter	Tree data	Old timber: important, for example, as tree cavity for black woodpecker (small mammals, bats, hole nester), insects	Biotope (stand)
Type of regeneration	Young growth	Closeness to nature for the forest regeneration	Influence
Protection of regeneration	Young growth	Obstacle for game, species perpetuation (e.g., silver fir, yew, etc.)	Influence
Aspect of the forest edge	Forest edge	Supply of solar radiation	Biotope (site)
Proportion of the individual ligneous species	Forest edge	Species diversity for tree and shrub species	Biotope, species
Structure of forest edge	Forest edge	Depth and incline of the transitional biotope	Biotope (stand)
Width of shelter belt	Forest edge	Width of the border biotope, light entry	Biotope (stand)
Width of shrub belt at forest edge	Forest edge	Width of the border biotope, habitat for birds, insects, small mammals, reptiles, game	Biotope (stand)
Width of herb border at forest edge	Forest edge	Width of the undisturbed herbal vegetation; flora, insects	Biotope (stand)
Density of forest edge	Forest edge	Supply of solar radiation, cover for game	Biotope (stand)
Shape of forest edge	Forest edge	Interlink and surface of forest/field; habitat diversity	Biotope (stand)
Limits of forest edge	Forest edge	Disturbance of the biotope forest edge	Influence
Surroundings of forest edge	Forest edge	Network of biotopes, disturbance of the border biotope	Influence
Condition of forest edge	Forest edge	Influence on the ecolocical quality and development of the forest edge	Influence

The assessment of species diversity indicators was, due to the costs, very limited: Ligneous species on the terrestrial grid in the second NFI (6412 sample plots) as well as a detailed survey of the entire vegetation on the 4.0 x 4.0 km grid (approximately 730 sample plots). The main focus was in the second NFI on the so-called habitat and influence indicator (BRÄNDLI and ULMER 1999), especially on those for which concrete ideas about the nominal condition with respect to conservation existed (Schweizerischer Bund für Naturschutz (SBN) 1989; Schweizerischer Bund für Naturschutz (SBN) 1992; VON BÜREN *et al.* 1995).

The goal of several research projects in the 1980's was to describe biodiversity in forests with standardized methods and a minimum of cost. Especially in the Federal Republic of Germany, different forest biotope evaluation methods were developed (AMMER and UTSCHIK 1982; AMMER and UTSCHIK 1983; AMMER and UTSCHIK 1986; AMMER and UTSCHIK 1988; BECHET 1976; DIETERLE 1988; GÖHRINGER 1988; HAAS 1989; KAULE 1991; SCHIRMER 1991; VOLK 1993; VOLK and HAAS 1990). Similar approaches in Switzerland can be found by GUNTERN (1988) and STOFFEL (1992). All evaluation methods have the following ideas in common: Assessment of qualitative indicator attributes (closeness to nature, diversity, rarity, threatened, abundance), evaluation or weighting, transformation, aggregation, quantification, and presentation as a total value, which was often considered as the biotope value/rating.

3.8.1.2 Procedures

For the development of the models in the NFI, the literature in Switzerland and the surrounding countries was examined for applicable evaluation models for forest stands and forest edges. The main focus here was the search for criteria (e.g., closeness to nature), the weights of the parameters with respect to each other, and the classification recommendations for the model values. The different approaches were studied in respect to the parts they have in common. Based on this, the parameters were selected from the existing data catalog of the second NFI. Parameters were only evaluated if their ecological value for certain animal groups (birds, insects, and small mammals) was qualitatively or quantitatively known and if they had already been used in models described in literature. Of special importance were the habitat requirements of two indicator species: black woodpecker and wood grouse. The forest, as a habitat for plants, was only indirectly considered by using indicators for light and temperature. The models presented here in the NFI should not obscure the fact that currently only few verified, universally valid and feasible indicators for the ecological value analysis are available for mountain forests as well as for forests in lowlands.

Based on literature, three partial models for the criteria "closeness to nature", "species diversity,' and "structural diversity" were designed. Subsequently, an NFI survey team that was experienced in ecological matters ocularly rated these criteria on their stands and forest edges on a discrete scale during the usual data survey of the second NFI. They supplemented their survey with a final overall assessment of the biotope and ecotone value (field opinion). In the eastern and southern areas of Switzerland, a total of 351 forest stands, 79 having a forest edge, were ecologically assessed. After gathering the data, the models for the criteria and the overall assessment were optimized in the sense that they correlated, as best as possible, with the ocular ratings (BRÄNDLI *et al.* 1996). The weight for the attributes and the individual indicators was the subject of the model optimization in particular.

In the following, the models were also tested on NFI sample plots in the cantons of Aargau, Zurich, Vaud, Valais, and Grisons (field tests). The second NFI had neither sufficient funds nor time to validate the models with respect to the actual observed species diversity of the avifauna for example. If possible, these types of additional studies and model optimizations should be conducted while preparing a third NFI.

3.8.1.3 Application

The NFI models are directed to the **ecological dynamical aspects of the managed forest**; those attributes that (possibly) are substantially influenced by the type of forest management. Site parameters (elevation, aspect, area distribution, special sites, plant communities, etc.), which can either barely or not at all be influenced by the manager over a short period of time, were not intentionally used for the ecological evaluation models of the forest stands and forest edges. But the NFI site parameters were used as indicators for the ecological potential of the corresponding site. This strict separation of site potential and the real ecological diversity of the stands is the prerequisite to derive the improvement potential for stands (required action) and to control the success of the measures (VON BÜREN *et al.* 1995). Apart from an "optimal model" for the biotope value that includes all relevant parameters of the second NFI, a "minimum model" was developed as well, so that comparisons with the first NFI were possible even though it contained considerably less ecological data.

3.8.2 Biotope Value of the Forest Stand

The biotope value is derived based on the three criteria "closeness to nature", "ligneous species diversity", and "structural diversity". Criteria such as "rarity" and "threatened" could not be integrated, since the second NFI was not optimized with respect to the appropriate parameters. Each one of the three criteria that were used is a variable composed of several parameters (attributes) whose outcomes could take on different values. The criteria themselves receive different weights in the final model:
biotope value = a*(closeness to nature) + b*(ligneous species diversity) + c*(structural diversity)
a,b,c: constants

3.8.2.1 Closeness to Nature of the Forest Stocking

Spruce plantations in areas of broadleaf mixed forests are not adapted to the site. Such forests are regarded as going against nature (unnatural) and ecologically of inferior quality. In the Plateau, the species spectrum is one-third lower in mostly pure spruce stands than the species spectrum in oak forests at the same elevation level (MÜLLER 1991). The replacement of the broadleaf forest by coniferous forests in general, results additionally in a steep decline of species and a strong decrease of the population density of soil organism (HEYDEMANN 1982).

Furthermore, broadleaf forests in lowlands allow, at least at the beginning of the vegetation period, more light and warmth to enter the stand and to reach the forest ground than coniferous forests. As a consequence, the living conditions and the turnover in the soil and in the lower vegetation layer are improved – an important prerequisite for many herbaceous plants and grasses. Spruce monocultures in broadleaf forest areas create long-term problems for the soil and the soil organism (Schweizerischer Bund für Naturschutz (SBN) 1989). Large proportions of conifers or spruce in a broadleaf forest area are thus regarded as indicators for a reduced diversity of fauna and flora.

The evaluation of the "closeness to nature" for the coniferous proportion is based on the model data for the potential natural vegetation (PNV, see Chapter 3.1) according to BRZEZIECKI *et al.* (1993) and on the current stocking as defined by the NFI (trees over 12 cm DBH). The relevant quantities for the evaluation of the current mixture of tree species in the natural area of the broadleaf forest are the current basal area proportion of conifers overall as well as the basal area proportion of spruce and fir (Table 2), similar to KIENAST *et al.* (1994) and differentiated by forest communities. The communities 1 to 46, according to ELLENBERG and KLÖTZLI (1972), are classified as broadleaf areas. Exotic species such as northern red oak are rare in Switzerland and were not considered in the model.

In broadleaf forest areas, stands that contain less than 10% or 25% conifers are considered "close to nature". The natural proportion of silver fir in individual broadleaf communities is taken into account here. “Moderately far from the natural state” are broadleaf forests with a coniferous proportion of up to 75 %; “far from the natural state” are those with a coniferous proportion of above 75%. If the proportion of spruce trees alone is above 75%, the stand is considered in the NFI to be “very far from the natural state”.

Since the model for the PNV does not account for some specific edaphic site factors, such as karren fields, some local misclassifications are possible. This is especially true for higher elevations in the western parts of the Jura (region around the Col du Marchairuz), where the prevalent forests are not mixed broadleaf forest as in the model, but are very often mixed fir forests (Dryopterido-Abietetum). Consequently, the proportions of mixed broadleaf forests “very far from the natural state” are overestimated in these regions.

The small size of the NFI sample plots makes conclusive interpretations impossible, such as whether a stand possesses all of the important natural tree species like silver fir or mountain ash (*Sorbus aucuparia* L.) in mountain forests. Stockings in areas of coniferous forests (i.e., on NFI sample plots with the modeled communities 47 to 71 according to ELLENBERG and KLÖTZLI, 1972) cannot be evaluated as a result and are rated in the biotope value model with respect to the closeness to nature (BWNATURN) by the same value 4 as natural mixed broadleaf forests. In contrast to that, mixed broadleaf forests that are “very far from the natural state” receive the minimal value of 1 (Table 2).

Table 2. NFI model for the closeness to nature of the forest stocking (BWNATURN): Code, definition of code, derivation based on the thresholds for the proportion of conifers and spruce as well as rating of the attribute.

Code	Definition of the code (class)	Derivation based on the thresholds for the conifer and spruce proportion	Rating (weight)
1	Mixed broadleaf forest that is very far from the natural state	>75% spruce [1)]	1
2	Mixed broadleaf forest that is far from the natural state	>75% conifer [2)], <75% spruce	2
3	Mixed broadleaf forest that is moderately far from the natural state	10%/25%–75% conifer [3)]	3
4	Mixed broadleaf forest that is close to nature	<10%/25% conifer [4)]	4
5	Conifer forest community	E+K No. 47–71	4

E+K No.: Number of the forest community according to ELLENBERG and KLÖTZLI (1972)
1) E+K No. 1–46
2) E+K No. 1–46, excluding fir for E+K No. 20 and 46
3) 10–75% conifer for E+K No. 1–7; 9–11; 13–17; 21–44
25–75% conifer for E+K No. 8, 12, 18, 19
25–75% conifer (excluding fir) for E+K No. 20, 46
4) <10% conifer for E+K No. 1–7; 9–11; 13–17; 21–44
<25% conifer for E+K No. 8, 12, 18, 19
<25% conifer (excluding fir) for E+K No. 20, 46

3.8.2.2 Diversity of Ligneous Species in the Upper Layer

Mixed stands with a large number of ligneous species usually contain more animal and plant species, as well as having a larger overall number of individuals than single-species stands, as has been shown for birds. A diverse avifauna, in turn, can be an indicator for rich species diversity of a biotope. This is true since birds live off other animals and plants and are thus relatively high in the food pyramid.

In particular for the species protection of fauna, the occurrence of pioneers or softwoods such as willow, birch, alder, native poplar, Scotch pine, or the occurrence of special tree species such as oak, chestnut, sweet cherry, wild fruits, and sorbus species are important as habitats and food sources (see also for example VON BÜREN *et al.* 1995). For example, of all native ligneous species, oak has the largest species spectrum of lignicolous beetles (BROGGI and WILLI 1993).

The diversity of ligneous species is based in the NFI on the dominant individuals that shape the biotope; that is trees which belong to the upper stand layer and have a DBH of at least 12 cm. The diversity among ligneous species (BWARTEN) is calculated as a function of the number of tree species per sample plot (500 m^2) and the occurrence of special species (minimum of one individual in the upper layer). The values for ligneous species diversity can range between 1 and 7 (Table 3). In the result volume publication for the second NFI, ligneous species diversity is interpreted as follows: 1–2 = “low”, 3–4 = “medium”, 5–7 = “high”. (BRÄNDLI and ULMER 1999).

Table 3. Derivation and weights for the ligneous species diversity in the NFI model (BWARTEN).

Number of tree species	Weight
0 or 1 species	1
2 species	2
3 species	3
4 species	4
5 and more species	5
Occurrence of special species [1)]	**Weight**
No	0
Yes	2

[1)] Birch, willow, alder, native poplar, native oak, sorbus species, wild cherry, wild apple and pear trees, Scotch pine, sweet chestnut

3.8.2.3 Structural Diversity of the Stand

In forests with a good vertical and horizontal structure, the supply of heat, light, or water is considerably higher than in poorly structured ones. These factors influence the density and diversity of the (herbaceous) vegetation, which is an important source of food for herbivores and, therefore, indirectly for carnivores. According to USHER and ERZ (1994), it is at least partially possible to use the considerably more simple assessment of structural attributes instead of the number of animal species that are directly counted. Diverse structured forests increase the chance of a better habitat and site network for individual animal and plant species. Highly structured forests also offer more protection, cover, and/or overview (eyrie trees).

The diversity of the avifauna is regarded as being a good indicator of the general ecological diversity, since birds, depending on the species, feed on plants (fruits, seeds) and/or animals (insects, soil organisms). The special habitat requirements of breeding birds that live in the forest (MÜLLER 1991), especially the mountain cock and the black woodpecker (RIECKEN 1992), was given the highest priority in the selection of the NFI structural parameter. In addition, certain habitat requirements of other species such as insects, small mammals, wildlife, amphibian, and reptiles were taken into account (see Table 1). The weight of these attributes (see Table 4) was based on expert opinion and on the literature.

During the field validation (see procedures), the parameters (attributes, variables) and their categories (classes) were checked with respect to their plausibility and some of the weights were slightly changed (EST, STRUK, BHDGT50). In particular, the parameters “crown closure” (R^2=0.23), “stages of development” (R^2=0.12), and “stand structure” (R^2=0.09) had a significant statistical relationship with the ocular assessment of the structural diversity. These three “key parameters” were already assessed in the first NFI and formed the minimum model (BWSTRU1M) for the analyses of the development. BWSTRU1 is a more comprehensive comparison model and BWSTRUKT is the optimal model for the second NFI. Even though BWSTRUKT is much more detailed, the coefficient of multiple determination R^2 with 0.44 is hardly larger than for the model BWSTRU1M (R^2=0,36). The parameters for the three structural models are explained in Table 4.

Table 4. Parameter and weight of the attributes used in the NFI model for the structural diversity of stands.

Parameter (attribute)	Abbreviated name	Categories (classes)	Weight
Crown closure	SCHLUSSG	Crowded	1
		Normal	3
		Loose	3
		Open	6
		Sparse	6
		Grouped/crowded	5
		Grouped/normal	5
		Complete	4
Stages of development	EST	Young growth and thicket	2
		Pole wood	1
		Young timber	2
		Medium timber	3
		Old timber	6
		Mixed	4
Stand structure	STRUK	One-layered	1
		Multi-layered	3
		Multistorey	5
		Cluster structure	5
Basal area proportion of trees with a DBH >50 cm	BHDGT50	0%	0
		1–24%	2
		25–49%	3
		50–100%	5
Damage proportion of the stand (excluding needle/leaf loss of unknown cause)	BSTSGRAD	No damage detected	0
		Slight damage	1
		Moderate damage	2
		Heavy damage	3
		Very heavy damage, dead	4
Forest edge	WARA	Not existing	0
		Existing	5
Stand edge	BESTGREN	Not existing	0
		Existing	2
Type of gap	LUECKEN	No larger gaps in the stand	0
		Cutover or windfall areas	3
		Forest meadow without ligneous species	5
		Forest meadow with ligneous species	4
		Blocks, scree area	2
		Erosion and landslide areas	2
		Rock areas	2
		Avalanche ride, forest aisle	2
Coverage of shrub layer	STRADG	Less than 1%	0
		1–9%	1
		10–25%	2
		26–50%	3
		51–75%	4
		76–100%	5
Coverage of berry bushes	BEERDG	Less than 1%	0
		1–9%	1
		10–25%	3
		26–50%	5
		51–75%	3
		76–100%	2
Stumps, lying dead timber	STOECKE	Not existing	0
		Existing	2
Standing dead trees	DUERRSTA	Not existing	0
		Existing	3
Heaps of branches	AHAUFEN	Not existing	0
		Existing	2

BWSTRUKT =	EST + SCHLUSSG + STRUK + BHDGT50 + BSTSGRAD + WARA + BESTGREN + LUECKEN + STRADG + BEERDG + STOECKE + DUERRSTA + AHAUFEN
BWSTRU1 =	EST + SCHLUSSG + STRUK + BHDGT50 + BSTSGRAD
BWSTRU1M =	EST + SCHLUSSG + STRUK
EST:	Stage of development
SCHLUSSG:	Crown closure
STRUK:	Stand structure
BHDGT50:	Basal area proportion of tree with a DBH >50 cm
BSTSGRAD:	Damage proportion of the stand
WARA:	Forest edge
BESTGREN:	Stand edge
LUECKEN	Type of gap
STRADG:	Coverage of shrub layer
BEERDG:	Coverage of berry bushes
STOECKE:	Stumps, lying dead trees
DUERRSTA:	Standing dead trees
AHAUFEN:	Heaps of branches

Based on the comparison to the field assessments, which take into account the nature conservation demands, the structural diversity of the stand BWSTRUKT can be interpreted as follows:

Up to 14	Very homogeneous
15–20	Homogeneous
21–25	Heterogeneous
Over 26	Very heterogeneous

The theoretical values for BWSTRUKT range from 3 to 56. The values actually determined in the second NFI range between 4 and 41 (mean 20), where 41 corresponds to a very high structural diversity. In the result volume publication of the second NFI, the following classes were formed:

Up to 15 Low   16 to 24 Medium   Over 24 High

3.8.2.4 Biotope value of the Stand

The biotope value of the stand is based in the NFI on the criteria “closeness to nature”, “ligneous species diversity”, and “structural diversity”. These three criteria were *standardized* during the derivation of the biotope value by dividing their observed values by the maximum achievable values. By comparing several different empirical “biotope value models” with the subjective general assessment from the field tests, those models where the *structural diversity was weighted twice* obtained the highest correlation.

The model BIOLFI2 is optimized for the extensive attribute catalog of the second NFI and considers most of the relevant structural attributes known from the literature. It is particularly suited to recognize regions with high structural diversity. The model BIOLFI1 and BIOLFI1M include only attributes that were already assessed in the first NFI. These models were used to illustrate the change between 1983/85 and 1993/95. The correlations of all three models to the field assessments are all the same. The choice of model for the analysis depends ultimately on which attributes are relevant for the comparison to other studies. If there are no preferences in this respect, the simplest model should be chosen that is easiest for others to comprehend. In the result volume publication of the second NFI, the simplest model BIOLFI1M was used for comparison with the first NFI (BRÄNDLI and ULMER 1999).

BIOLFI2 = BWNATURN/4 + BWARTEN/7 + 2*BWSTRUKT/56
BIOLFI1 = BWNATURN/4 + BWARTEN/7 + 2*BWSTRU1/27
BIOLFI1M = BWNATURN/4 + BWARTEN/7 + 2*BWSTRU1M/18

For the interpretation of the model values, the following thresholds were determined based on the ocular field validations, which took into account the conservation demands:

Biotope value	BIOLFI2	BIOLFI1	BIOLFI1M
Low	Up to 1,30	Up to 1,40	Up to 1,40
Tends to be low	1,31–1,85	1,41–1,85	1,41–2,00
Tends to be high	1,86–2,40	1,86–2,35	2,01–2,60
High	2,41–4,00	2,36–4,00	2,61–4,00

The values that were observed for BIOLFI2 in the second NFI range between 0,54 and 3,21 for a total of 6,330 stands (mean 1,91). In the result volume publication the following classes were formed:

Up to 1,60	= Low
1,61–2,00	= Medium
Over 2,0	= High

It is important to note that the transition from "low" to "high" is not distinct (Figure 1). The data from the field assessment in 1995 indicate that the dividing value is between 1.75 and 2.0 at approximately 1.85. In the second NFI the biotope values for 60% of all the stands exceeded this threshold.

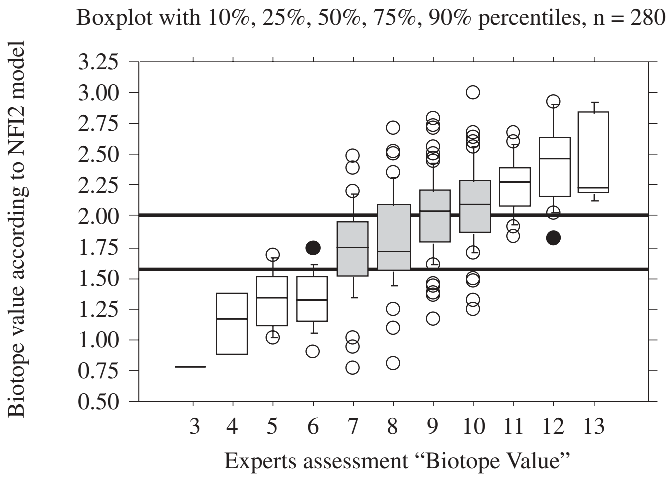

Figure 1. Relationship between the calculated model values and the ocular assessments for the "biotope value." The ocular assessment corresponds to the total of the three partial assessments "closeness to nature," "species diversity," and "structural diversity" with possible values ranging between 3 and 15.

3.8.3 Econtone Value of the Forest Edge

Forest edges are boundary or edge biotopes and are referred to as ecotones. This means that they are transitional zones between different biotopes. The forest edges offer habitat for plants and animals that live within open fields and the forest and, in addition, for organisms that are specialized in living in transitional habitats. For some species that have been displaced from intensively used cultural landscapes and are therefore endangered, it is possible that the ecologically valuable forest edges present a last refuge and chance of survival (VON BÜREN *et al.* 1995).

Intact forest edges play an important role in the network of habitats. This was the reason that in the second NFI all forest edges which were in the proximity to the sample plots were recorded for the first time. These 1,048 forest edges were assessed in detail along a 50 meter assessment line. The goal was to representatively record the diversity of the forest edges in Switzerland (BRÄNDLI *et al.* 1995). The NFI methods for the forest edge survey were developed by the author and are described in the manual for field survey (STIERLIN *et al.* 1994). The NFI procedure was developed to analyze the forest edges qualitatively and to detect changes. The length of the forest edge cannot be determined with this method.

The actual ecotone value refers at the forest edge cross section (Figure 2) to the zone elements “herb border”, “shrub belt”, and “shelter belt”, as well as to the “structure” in general, and refers along the forest edge (Figure 3) to the element “shape”, “density”, and “ligneous species”. The surroundings (open land), as well as the forest stands bordering to the inside, are not forest edge elements in the narrower sense.

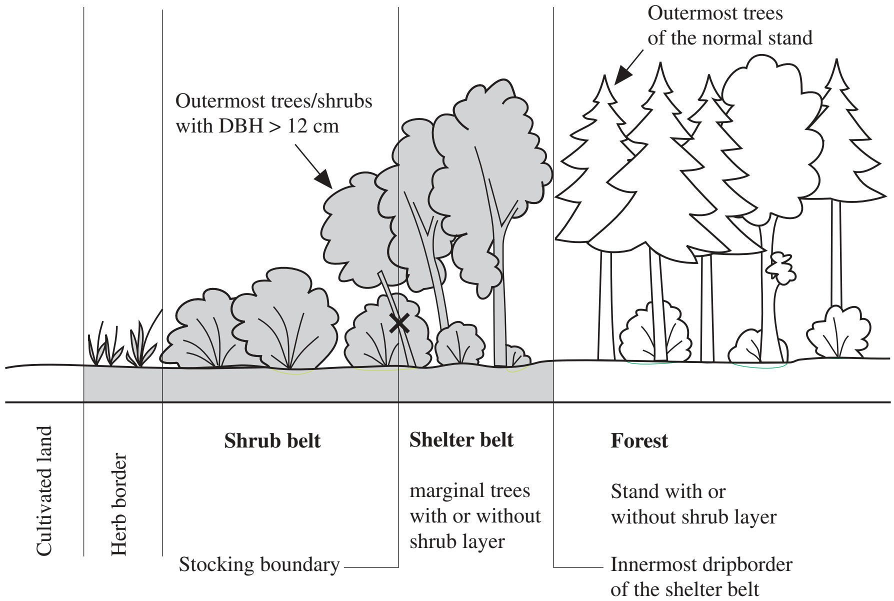

Figure 2. Forest edge in a cross-sectional view.

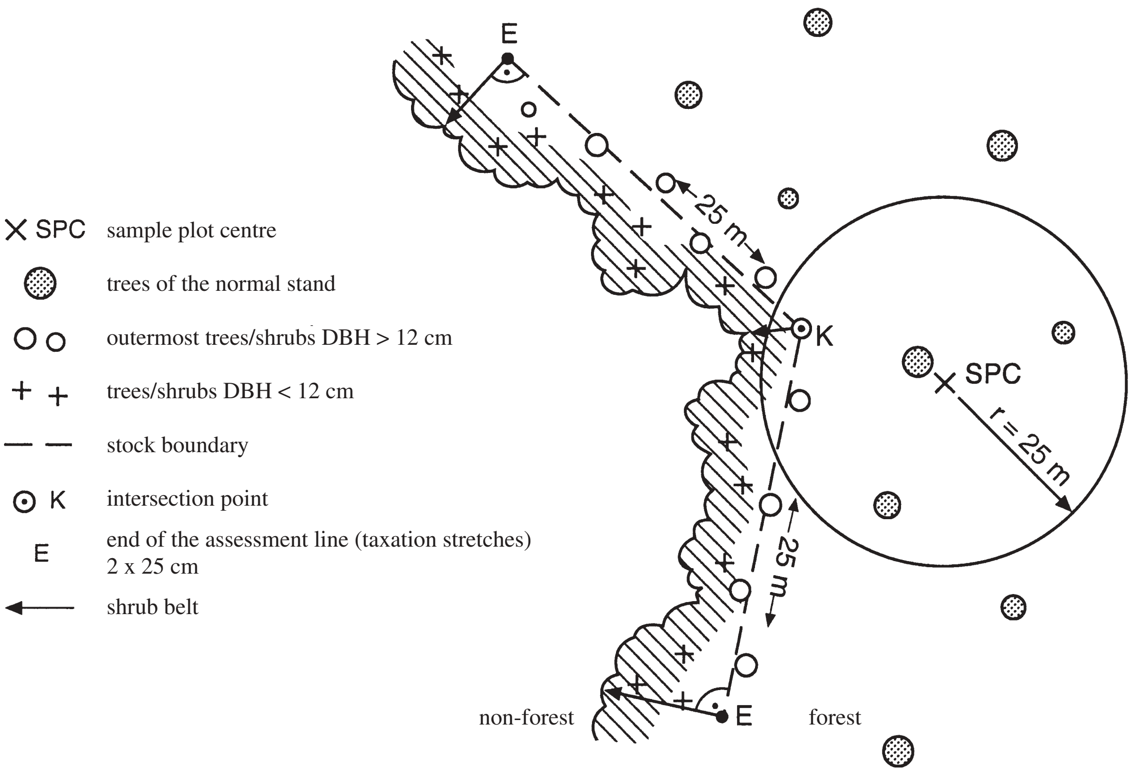

Figure 3. Situation with a forest edge – assessment line and sample plot.

Similar to the biotope value of the stand, the ecotone value was developed based on examples from literature (see for example, HONDONG *et al.* 1993; KRUG 1992; KRÜSI and SCHÜTZ 1994; VON BÜREN *et al.* 1995) as an integral model quantity for the ecological values of the edge biotope. Furthermore, the ecotone value was checked by experts in the field with respect to its plausibility and was developed further when necessary. The model is based solely on indicators that are related directly to the forest edge, influenced by forest and agricultural operations, and able to reveal ecologically relevant developments. The important ecological forest edge aspects that include "site" (aspect, elevation, soil, etc.), "surrounding", and "biotope value of the stand" are not integrated. They are seperately discussed and are particularly important for the derivation of the potential improvement of forest edges that have low ecotone values.

The ecotone value model is based on two criteria: "ligneous species diversity" and "structural diversity". The criterion "closeness to nature" was not introduced or studied, since the necessary background about the forest edge communities was not available, and because most of the forest edges in the middle of Europe have been created by humans and are thus only "semi-natural" biotopes. Furthermore, the evaluation of the criterion "closeness to nature" in the cultural landscape is not considered very meaningful according to COCH and HONDONG (1995). Parameters such as dead trees, heaps of branches, or older timber along the forest edge were not specifically assessed. They were part of the biotope values in the bordering stand, which included the forest edge as well.

The assignment of model values for ligneous species diversity, structural diversity, and ecotone values to the relative classes "low", "medium", and "high" was oriented with the notion of conservation and was based on expert opinions in field tests in several regions of Switzerland (see Chapter 3.8.2.1). The NFI indicator model for the forest edge evaluations is suitable for spatial and temporal comparisons, but does not allow an absolute judgement with respect to the ecological value of individual forest edges.

3.8.3.1 Ligneous Species Diversity along the Forest Edge

The ligneous species diversity (WRARTEN) encompasses the three aspects "number of ligneous species" (WRANZART), "proportion of briers" (WRDORN), and "proportion of softwood and special species" (WRWEICH). The "number of ligneous species" takes the preservation of species into account here.

During the assessment of the ligneous species at the forest edges, approximately 100 different native and non-native species were differentiated (see page 71, STIERLIN *et al.* 1994). Of the 1,048 assessment lines that were 50 meters in length, between 1 and 28 different ligneous species were observed. Even though the statements, with respect to the ecological importance of individual ligneous species, are in part contradictory in the literature, it was attempted to take into account the occurrence of valuable species (WRDORN, WRWEICH) as well. "Briers", for example, are regarded as potential breeding biotopes for birds and are used by numerous insects as a food source. The "softwood and special species" are primarily valuable food sources for insects, birds, and small mammals. Commonly used, but undifferentiated, general attributes like "coniferous proportion" were not taken into the model; instead, the coniferous proportion was taken into account separately by tree species and by site of the bordering stand for the derivation of the criterion "closeness to nature" in the model "biotope value" (see 3.8.2.2).

WRARTEN =	WRANZART + WRDORN + WRWEICH
WRANZART:	Number of tree and shrub species according to the species survey at the forest edge
WRDORN:	Total proportion of briers: $\sum(A_i)$
WRWEICH:	Total of the softwood/special species proportion: $\sum(A_k)$
A_i:	Coded proportion A of the ligneous species i_n; n=1–7
A_k:	Coded proportion A of the ligneous species k_m; n=1–27

A:	Coded proportion of a forest edge area occupied by a ligneous species: 0 = Missing 1 = Very rare or all individuals smaller than 1.3 meters 2 = Sparse, less than 1% of the forest edge area 3 = 1–5% of the forest edge area 4 = 6–25% of the forest edge area 5 = 26–50% of the forest edge area 6 = 51–75% of the forest edge area 7 = 76–100% of the forest edge area
i:	The 7 ligneous species: *Berberis vulgaris, Crataegus* sp., *Hippophaë rhamnoides, Prunus mahaleb, Prunus spinosa, Rhamnus cathartica, Rosa canina*
k:	The 27 ligneous species (groups): *Alnus glutinosa, A. incana, Betula pendula, B. pubescens, Castanea sativa, Corylus avellana, Hedera helix, Malus silvestris, Pinus sylvestris, Populus alba, P. canescens, P. nigra, P. tremula, Prunus avium, P. padus, Pyrus communis, Quercus cerris, Q. petraea, Q. pubescens, Q. robur, Rubus fruticosus, R. idaeus, Salix* sp.*, Sorbus aria, S. aucuparia, S. domestica, S. torminalis*

The mean value for all 1,048 NFI sample plots with a forest edge indicated that the criterion ligneous species diversity (WRARTEN) was almost equally determined by the number of species (WRANZART) and the occurrence of special species (WRDORN, WRREICH):

	Mean	Maximum
WRARTEN	22.1	57
WRANZART	11.5	28
WRDORN	3.1	11
WRWEICH	9.4	28

Based on the validation of the model values by experts in the field, the values for WRARTEN, which are relative to the conservation requirements, can be interpreted as follows:

Ligneous species diversity	
Up to 11	Low
12–20	Tends to be low
21–29	Medium
30–38	Tends to be high
Over 38	High

The values determined for the ligneous species diversity in the second NFI range between 1 and 57. On the same basis as above, three classes were derived for the result volume publication of the second NFI:

Up to 15	Low
16–25	Average
Over 25	High

3.8.3.2 Structural Diversity at the Forest Edge

The parameter selection and weighting for the model "structural diversity" is based on the data catalog from the second NFI, the field tests in 1995, and accounts given in the literature of their ecological relevance. Site parameters (e.g., aspect) and site-specific attributes (proportion of broadleaf) were not considered in the structure model. Other attributes of the second NFI (thick or dead trees, heaps of branches, heaps of rocks, etc.) were assessed on the sample plot and cannot be directly related to the forest edge area. They were used for the biotope value of the stand. Zoological attributes such as anthills, droppings, etc. were not assessed in the second NFI.

Table 5. Parameter and weight of the attributes used in the NFI model for the structural diversity at the forest edge.

Parameter (attribute)	Abbreviated name	Categories (classes)	Weight
Structure of forest edge	AUFBAU	Without shelterbelt, without shrub belt	1
		Without shelterbelt, with shrub belt	2
		Steep shelterbelt, without shrub belt	2
		Wide shelterbelt, without shrub belt	2
		Shrub belt unter the shelterbelt	3
		Shrub belt in front of the shelterbelt	4
		Multistoried shelterbelt with shrub belt	5
Width of shelterbelt	MANTELBR	0-2 meters	1
		3-4 meters	2
		5-6 meters	3
		7-8 meters	4
		over 8 meters	5
Width of shrub belt	STRABR	0-1 meters	1
		2 meters	2
		3 meters	3
		4-5 meters	4
		over 5 meters	5
Width of herb border	KRAUTBR	Less than 0,5 meter (not existing)	1
		0,5-1,0 meter	2
		1,1-2,0 meters	3
		2,1-5,0 meters	5
		over 5,0 meters	7
Shape of forest edge	VERLAUF	Straight	1
		Undulating	2
		Indented	3
		Deeply indented	4
		Patchy	5
Density of forest edge	DICHTE	open; 0-24% closed	1
		sparse (or with gaps); 26-50% closed	2
		loose; 51-75% closed	3
		dense; 76-100% closed	3

The structure diversity (WRSTRUKT) at the forest edge was calculated from six forest edge parameters based on the weights for the attributes (Table 5). The experience with the field survey for the second NFI showed that the shelter belt width (MANTELBR) was very often difficult to determine and indicated that in three-quarters of all cases, the width was between 2 and 5 meters. The extreme case, namely the absence of a shelter belt, has already been taken into account by the parameter "structure of forest edge" (AUFBAU). Since little is known about the ecological relevance of the shelter belt width, this parameter was disregarded in the minimum structural diversity model (WRSTRUKM). This reduced structure model correlated better with the subjective structure assessment from the field test as well. The parameters for the structure models are explained in Table 5.

WRSTRUKT = AUFBAU + MANTELBR + STRABR + KRAUTBR + VERLAUF + DICHTE
WRSTRUKM = AUFBAU + STRABR + KRAUTBR + VERLAUF + DICHTE

AUFBAU: Structure of forest edge
MANTELBR: Shelter belt width
STRABR: Width of shrub belt
KRAUTBR: Width of herb border
VERLAUF: Shape of forest edge
DICHTE: Density of forest edge

On the 1,048 assessed forest edges, WRSTRUKM had a mean value of 12.4 (maximum 24), and WRSTRUKT had a mean value of 14.5 (maximum 28). Based on the validation of the model values by experts in the field, the values for WRSTRUKT, relative to the conservation requirements, can be interpreted as follows:

Up to 11	Low
12–14	Tends to be low
15–17	Moderate
18–21	Tends to be high
Over 21	High

On the same basis as above, three classes were derived for the result volume publication of the second NFI:

Up to 12	Low
13–15	Moderate
Over 15	High

3.8.3.3 Ecotone Value of the Forest Edge

The ecotone value of the forest edge (OEKOLFI2) is based on the criteria ligneous species diversity and structure diversity. Compared to the expert assessment of the field tests, as for the biotope value, the highest correlations were obtained when the structure diversity was weighted twice as high as the species diversity in the *standardized* model. Based on this, the mean values for the species and structure diversity were multiplied by 3.0, and 3.5 for the following *non-standardized* ecotone models.

OEKOLFI2 = WRARTEN + 3.0*WRSTRUKT
OEKOLFIM = WRARTEN + 3.5*WRSTRUKM

The less complicated ecotone model OEKOLFIM (without considering the shelter belt width) had a slightly higher correlation with the subjective general assessment than OEKOLFI2. Depending on the problem task, either model can be used.

Within the result volume publication of the second NFI, the model OEKOLFI2 was used. The observed values for this model ranged between 24 and 138 (mean 65.7). The value 138 was the result of the highest number of species and structure diversity achieved. The two to five best forest edges have ecotone values of 116 and 115. Since absolute judgement of the ecotone values are always debatable, the following relative classification in the second NFI is based on the 25% and 75% quartile for all 1,048 studied forest edges.

Up to 55	= Low
56–75	= Average
Over 75	= High

It is interesting to note that these statistical limits match exactly those that were derived earlier from the field assessment (Figure 4).

Applying the evaluation system of KRÜSI and SCHÜTZ (1994), the threshold for "good" forest edges is at an NFI2 ecotone value of approximately 100. This threshold is only reached by 2% of all studied cases. Forest edges can be considered "satisfactory" with an ecotone value of over 70, which corresponds approximately to the lower threshold for "high" forest edge quality according to the second NFI. Approximately 40% of all assessed forest edges reach this value. An "average" ecotone value, in accordance with the second NFI, corresponds to a rating of "unsatisfactory" according to Krüsi and Schütz. A "low" ecotone value definitely corresponds to the rating "poor".

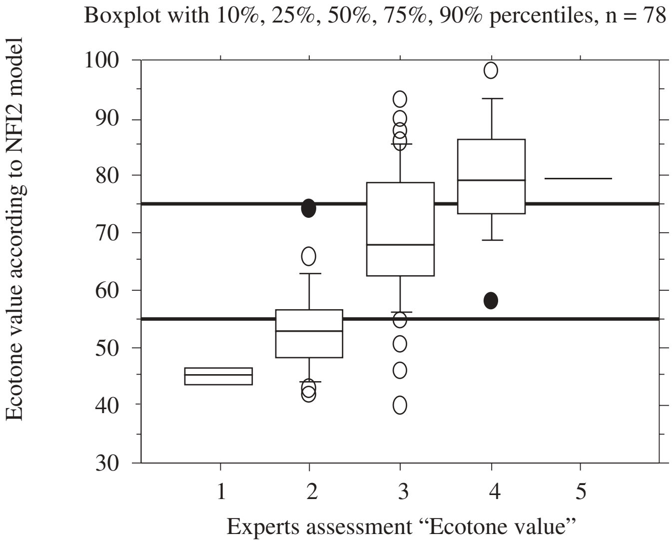

Figure 4. Relationship between the calculated model values and the ocular assessments for the "ecotone value." In the ocular assessment a value of 1 corresponds with the evaluation of "very low" and the value 5 with the evaluation "very high."

Acknowledgments

I would like to express my gratitude to the two forest engineers and former staff members of the NFI field survey, Meinrad Rettich and Christoph Dürr. They have searched the Swiss literature as well as the literature of the bordering countries of Germany and Austria for biotope value models and equivalent indicators. Their field assessments are the basis for the supplementary optimization of the models at the WSL. Moreover, they are the co-authors of the internal NFI work report, "Methodische Ansätze zur ökologischen Bewertung von Waldbeständen und Waldrändern im Landesforstinventar (LFI)" (BRÄNDLI *et al.* 1996). I would like to thank Ulrich Ulmer for his support during the additional model verification in the summer of 1996.

3.8.4 Literature

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4 Data Analysis

4.1 Database

Edgar Kaufmann

4.1.1 Storage of the NFI Data

The NFI data consists of four different types of data: 1) Terrestrial assessed raw data (assessments of site and stand attributes, and tree measurements); 2) Raw data that were assessed on aerial photographs (e.g., land-use categories, mean stand height); 3) Data from external data sources (e.g., maps); and 4) Variables that are calculated from raw data of diverse origin (e.g., site quality, stem volume).

The data required for the analysis of the first and second NFI inventory were stored in a relational database (ORACLE system). A relational database system ensures data integrity and provides various tools to describe and manage the data. It allows the user to conveniently access the data with the help of a user-friendly interface and an easy to comprehend query language (SQL). The relationships between all objects are clearly and precisely defined. The data description corresponds at any given time inevitably and completely to the data structure and is managed by the system itself. The high degree of transparency and the easy way to link objects with each other facilitates in checking the data considerably.

4.1.2 Architecture of Relational Database Systems

Data in relational databases are strictly recorded in two-dimensional tables (consisting of rows and columns). Each column of a table is reserved for one attribute (variable). Each attribute has a name and contains exactly one value per row. The number of attributes in a row (record) is fixed. A row consists of global attributes which have key functions and occur in several tables, and local attributes which only occur in one table (for the structure of tables in relational database see for example FLEMING and VON HALLE 1989). Tables are linked to one another by global key attributes which can be found in each of the linked tables (for an example of the rules of logical connection and so-called normalized relational database see KORTH and SILBERSCHATZ 1986).

A key is composed of one or several attributes and is used to either identify a row as a search key within a table, or to link tables. Local attributes depend clearly and completely on the value of the identification key of a table.

Each table has an identification key (primary key). A specific combination of attribute values of a primary key exists exactly once in a table. All attribute values of global attributes in a table also exist in hierarchically superordinated tables. If a primary key is composed of several variables, all of which must be exported into the tables intended to be linked, usually an artificial key in the form of a number is generated, which is exported instead of the entire set of variables.

A specific value of a search key, which is composed of global attributes and which can have more than one occurrence with the same key value in a table, exists exactly once in a hierarchically superordinated table.

Logical, physical, and external structures are separated from each other in a relational database system and can be changed independently from one another (see for example, YANNAKOUDAKIS 1988). Logical structures encompass, among other things, the description of tables, the relationship of tables to one another, definition of data types and the domain (valid range) of attribute values, the definition of key structures, and integrity criteria. Physical structures refer, among others, to the allocation of computer memory, physical data management, access algorithms and the corresponding address tables. The term "external structures" refers to special user views that are not implemented in the system and which are virtually generated (e.g., virtual placement of data elements that are actually located in several different tables into one table).

With the implementation of the database, a description of the data structure, the so-called "data dictionary" is created within the system itself (see for example WERTZ 1986). This description represents the condition of the database exactly and cannot be changed by the database administrator (who is responsible for the design and update of the database). Logical, physical, and external structures are stored in system tables and can be retrieved at any time. Categorical data are stored in the NFI database in coded form. The meaning of the codes for these variables is explained in separate tables. This part of the data description has to be managed by the database administrator.

The physical access to the data in a ORACLE database system is index sequential. Logical and physical addresses are managed with address tables (with binary tree structure, e.g., see KORTH and SILBERSCHATZ 1986). Such tables are explicitly generated by the administrator by indexing key variables. This significantly expedites the data access and is indispensable for an efficient data retrieval. Within an index sequential access, an entire block of data (usually substantially more than one individual record), which is stored physically close to each other, is retrieved. Thus, the access time is also decreased when records with logically related values of keys, which are often used for the access, are also physically stored close to one another.

4.1.3 Logical Structure of the NFI Database

Figure 1 shows the logical structure of the NFI database. The data can be divided into three hierarchical levels (I–III) with sub-levels (IIa, IIb, IIIa). Each box represents a table. A box contains the table name (in capital letters; for the content see Table 1), the global attributes of a table, which together form the primary key of the table (non-italic), and attributes, which represent an important search key (italic). Bold printed variable names refer to global key attributes (see Table 2), the other names refer to local key attributes (see Table 3). The levels have a "1 to mc" relationship to each other. This means that for each record ("1") in a table at a certain level, there exist several records ("m" for many), one record, or no records ("c" for conditional) in a subordinated table. Conversely, for each record in a table at a certain level, there exists exactly one record in a superordinated table. Hierarchical relationships are created using the tables in the dark-gray tables at the very left side. Through a dark-gray marked table, all tables in the lower level can be linked to one another. Cross-indexing at the same level is a "1 to c" relationship. For each record in the table on side "1" there exists one or no record on side "c" (i.e., the primary key values of the table on the "c" side are a subset of those in the table on the "1" side).

4.1.3.1 Data Levels

Level I contains data that do not depend on a certain inventory. They do, however, depend on the geographic location of a sample point and have one record per sample point. The tables in the sub-level Ia do not depend on the inventory either, but have many records per sample point.

Level II contains inventory specific sample plot data that have one record per sample point and per inventory. The tables in the sublevel IIa contain several records per plot and inventory (e.g., several young growth plots per sample plot, several timber extraction phases per sample point). The young growth data at the sub-level IIb have several records per sample point, inventory, and young growth plot. The young growth tables at the sub-level IIb are linked with the table JWSALFI (Figure 1 light-gray) at the sub-level IIa.

Level III contains individual tree data with one record per sample plot, inventory, and tree. The table "BA" is linked through the search key "clnr,invnr" to table "WA." It is linked through the primary key "invnr, banr" to table "TB" at the same level and to the tables on level IIIa. Level IIIa contains damages, remarks, and assortments with several possible records per tree.

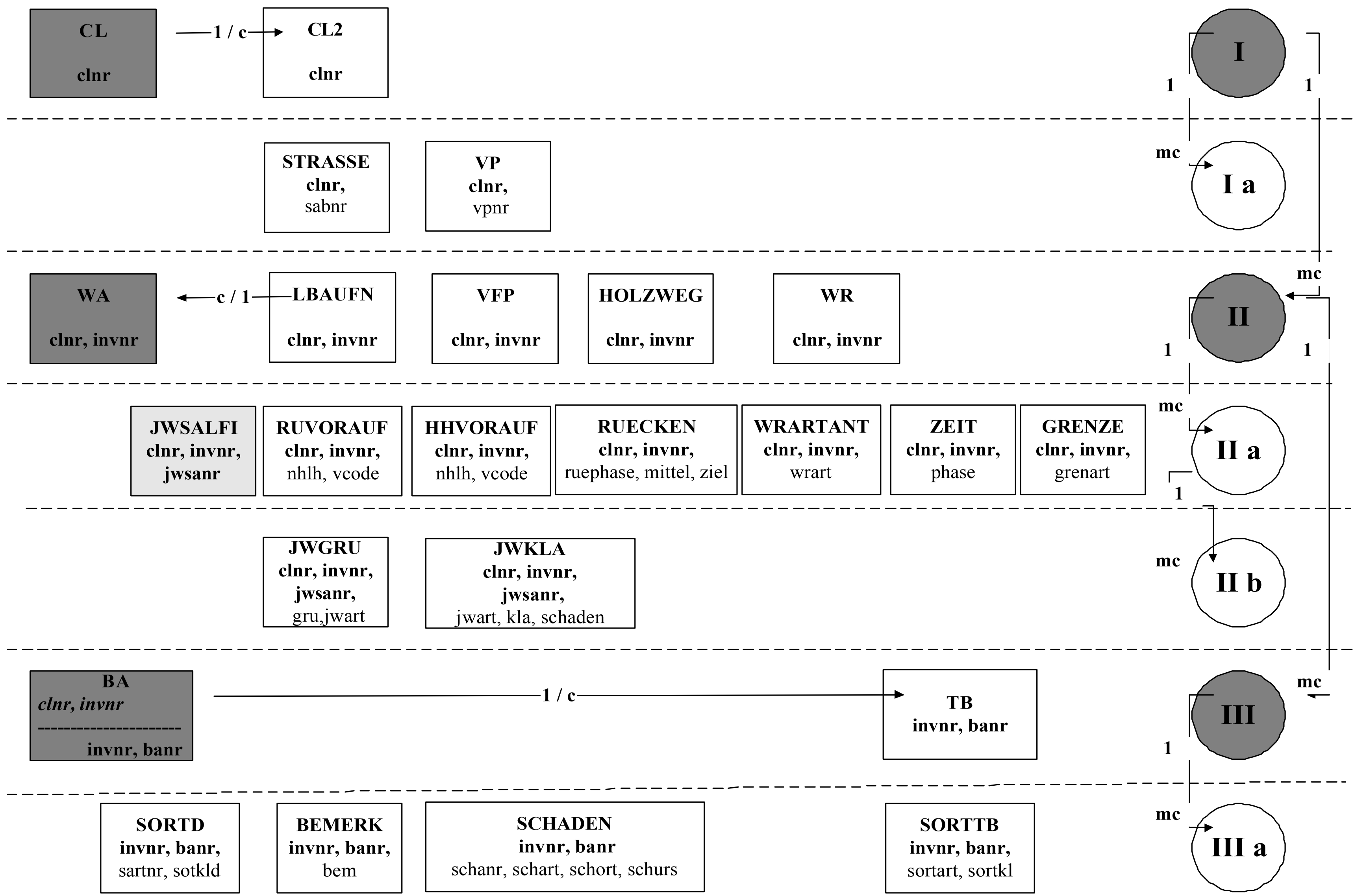

Figure 1. Logical structure of the NFI database. I-III: hierarchical levels. Ia, IIa, IIb, IIIa: sublevels. Capitalized letters: Table names (see Table 1). In bold small letters: global key attributes (see Table 2). In normal small letters: local key attributes. Italicize: Important search key.

Table 1. Tables of the NFI database

Name of table	Content
CL	Contains information that refers to a certain geographic location and that is independent of individual inventories (e.g., canton, elevation above sea level, x-coordinate, y-coordinate, production region). These are not project or NFI specific data. These data exist in the 500m-grid.
CL2	Contains mainly NFI specific attributes of the same type as in CL, often attributes that are derived from external data sources (e.g., site quality TI).
STRASSE	Contains information about the position, classification, and length of those roads relevant for the timber harvest in an area of 500 meters x 500 meters around the sample plot.
VP	Contains the permanently marked points for the terrestrial assessed permanent forest sample plots.
WA	Contains site and stand attributes of the terrestrial sample plots that are related to the sample plot and are specific to the inventory, information about timber harvest, and forest ownership. Contains also other attributes of the sample plot that are calculated from individual tree measures like timber volume per hectare and number of stems per hectare.
LBAUFN	Contains data assessed in aerial photographs, which are required for the NFI analysis. Contains stand information, information about the topography, and the position of the sample plot center.
VFP	Contains the permanently marked points of the terrestrial forested sample plots used in the inventory.
HOLZWEG	Contains data derived from the forest transportation survey (e.g., transport distance).
WR	Contains data that describe the forest edge.
JWSALFI	Contains sample plot related to young growth data, which were assessed for each young growth sample plot (e.g., type of regeneration).
RUVORAUF	Contains input data necessary to calculate the expenditure for timber removal as well as the calculated expenditure.
HHVORAUF	Contains input data necessary to calculate the expenditure for timber harvest as well as the calculated expenditure.
RUECKEN	Contains the information about timber removal from the enquiry at the forest service.
WRARTANT	Contains the proportions with which the different tree species occur at the forest edge.
ZEIT	Contains the time expenditure that was needed for the different work steps at the terrestrial sample plots.
GRENZE	Contains information about the position and the type of the borders that were assessed for the terrestrial sample plot.
JWGRU	Contains information about the crown closure of the young growth plots.
JWKLA	Contains the young growth – individual tree information.
BA	Contains for all trees with a DBH of at least 12 cm all individual tree information – the raw data, like the DBH as well as derived attributes, such as the stem volume. All trees that were assessed on the matched grid NFI1-NFI2 in the first as well as in the second NFI (with the code value for the variable HISTORY ranging between 1 and 6, see Chapter 3.2.5) have an occurrence for invnr = 100 (NFI1) and an occurrence for invnr = 210 (NFI2).
TB	Contains all individual tree information for the tariff sample trees.
SORTD	Contains assortment volume of the assortments in which an individual tree can be divided into.
BEMERK	Contains all remarks about the individual tree attributes.
SCHADEN	Contains all damages observed on the trees.
SORTTB	Contains assortment volumes of the assortments in which a tariff sample tree can be divided into.

Table 2. Global key variables for the NFI database.

Global key variable	Definition
CLNR	Artificial number, which identifies unambiguously a point that is defined by the X and Y coordinates of the Swiss Federal Office of Topography.
INVNR	Inventory number (invnr = 100 for NFI1; invnr = 110 for check assessment NFI1; invnr = 210 for field survey NFI2; invnr = 220 for check assessment NFI2; invnr = 230 for regional inventories).
JWSANR	Identification number of a young growth plot on a sample plot. The number is unambiguous for one sample plot.
BANR	Tree number. This number identifies a tree unambiguously in the entire database. If a tree dies, this number is not used any longer.

Table 3. Local key variables for the NFI database.

Locale key variable	Definition
SABNR:	Identification number of a road section. This number identifies a road section in the entire database.
VPNR:	Identification number for a permanently marked point. This number identifies a permanently marked point in the entire database.
NHLH:	Tree species group: Broadleaf or conifer.
VCODE:	Type of expenditure calculation.
RUEPHASE:	Phase of the timber extraction.
MITTEL:	Timber extraction method.
ZIEL:	Place to which timber is skidded after cut.
WRART:	Tree species for forest edge survey.
PHASE:	Work stage at the terrestrial sample plot.
GRENART:	Type of border (forest edge, accessibility boundary).
GRU	Denotation of a young growth group for the closure assessment.
JWART	Tree species for the young growth survey.
KLA:	Young growth class.
SCHADEN	Young growth plant damage (e.g., browsing).
SARTNR	Type of the timber assortment (short or longer stemwood).
SORTKLD	Assortment classes.
BEM	Remark.
SCHANR	Damage identification number (number unambiguous for one tree).
SCHART:	Type of damage.
SCHURS:	Cause of damage.
SORTART:	Type of the timber assortment (short or long stemwood).
SORTKL:	Assortment class

4.1.3.2 Tables and Key Variables

Table 1 gives an overview of the tables in the NFI database and of their contents. In Table 2, the global key variables and their meanings are listed. Table 3 lists the local key variables. The individual attributes of the tables and their meanings are presented in the variable documentation (Chapter 6).

4.1.4 Literature

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4.2 Analysis Software

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The inventory concept of the National Forest Inventory requires the analysis software to be highly flexible. The current value of various measures of the Swiss forests and their changes since the first inventory are of interest. A breakdown of the results into geographical units, such as production regions, cantons, or economic regions is just as important as the formation of assessment units, which allows further differentiation of the results according to categories, such as ownership or forest type.

For the design of the data storage and the analysis software, the following concept was pursued in order to permit the various analyses:

The attributes are stored in their original, non-aggregated form in a relational database (i.e., just as they were assessed) (see Chapter 4.1). The aggregation is conducted by special analysis software which ensures the correct access to the database and the right application of the analysis method. The results can be exported for the data exchange in table, graphic, or file format.

The data analyzed in the second NFI were: 1) assessed in the field by measuring the sample plots; 2) by enquiry; 3) obtained through interpretation of aerial photographs; 4) extracted using GIS analysis; or 5) generated by models. The analysis software can be interpreted as a “data warehouse” (MATTISON 1997). The software links data from different sources and information levels and provides aggregated or multi-dimensional data. This ensures a consistent foundation of data for all users.

The analysis software should enable a user to analyze National Forest Inventory data in a simple and fast manner. In order for a wide user group to carry out analyses independently the software, the statistical analysis methods, and the databank management should all be easy to use without any special training.

The double sampling for stratification was implemented in SAS (Statistical Analysis System), version 6.12. To ensure user friendliness and to avoid errors of the definitions for the input variables, a graphical user interface was developed for the access of analysis routines. The SAS system offers several different options for this. The module SAS/AF (SAS Institute 1989) together with the screen-control-language (SAS Institute 1990), was used for the NFI analysis software. It is possible to put together an analysis (parameterization) with only a few steps by using predefined, partially flexible selection lists and selection fields.

The database query and the calculation of the estimators can consume considerable amounts of database resources. Compared to this, relatively few resources are necessary in order to store the definitions of the query and the results of the analysis. The parameterization, the data analysis, and their presentations are, therefore, carried out separately. The parameter and the results of the analysis are stored in SAS data files, but not the raw data itself. This way it is possible to easily reproduce the analyses at a later time or to quickly visualize the results with different types of presentations (tables, graphics). The analysis in batch mode is possible as well.

The parameter definitions are managed within projects that encompass different inventories or thematic areas. Furthermore, analysis prototypes – organized in thematic catalogs – are provided which can be adopted and altered to individual parameter definitions.

A context sensitive online help function is available for explanations of the windows and entry fields. This function contains general remarks about the adjustments, the input of parameters, the information about options and their effects. For individual analyses different SAS modules such as SAS-Assist, SAS-Insight or the Program-Interpreter from SAS are available.

The NFI analysis software is arranged into four main areas:

1) The project management for managing the analysis definitions
2) The definition of an analysis (parameterization)

3) The analysis (databank query and calculations of the estimators)
4) The presentation of the results

In order to facilitate the work some programs for the control of the system and for data management were added as well.

4.2.1 Parameterization of the Analysis

General

The organization of a correct parameterization is ensured in two different ways: First, the possible selections in lists and selection fields are adapted to the parameters set. Second, before a parameterization is recorded and stored, a list of tests are conducted which examine the validity of the parameter combination. Analyses that are methodologically incorrect are, for the most part, avoided.

The most important parameters and their effects on the analysis are presented briefly in the following. After the definition of the project, in which the desired subjects are managed or are newly included, the subject can be dealt with. An overview of all the entry fields can be found in Table 1.

Table 1. Content of the window “parameterization”.

Theme	Seven digit name of a certain data analysis (each theme is a record in a table containing the whole set of analysis parameters). A selection list that consists of theme definitions is displayed.
Description	Short description of the analysis, which is used as the title for tables and graphs.
Library	SAS-libref (library reference) defines the folder where the analysis results are stored.
Inventory perimeter	Determines the analyzed region. It is possible to select between 1) ”CH” (whole country) for the analysis of the NFI and 2) “canton” for the analysis of cantonal inventories. The other analysis options are adjusted to the selected perimeter.
Inventory cycle	It is possible to analyze the state (NFI1, NFI2) and change, or conduct an analysis on the joined grid.
Analysis unit	The analysis unit defines the underlying population (number of terrestrial sample plots) for the analysis. The analysis usually refers to the “accessible forest without shrub forest.”
inventory unit	The inventory unit is a geographically clearly defined area. The estimates are calculated separately for the individual inventory units. The overall estimate for the inventory perimeter of interest is the sum of the estimates from the individual inventory units.
Condition	Two conditional fields are available. For change analysis, the second conditions affect only the recent inventory. For state analysis, both conditions affect the selected inventory.
Target variable	From a menu list several variables can be selected or an alias can be entered for an SQL function. Options: In one of the two-option fields (1) the reference unit can be selected. In a sub-menu, it is possible to select whether the reference unit is calculated separately for each table cell or uniformly for columns, rows, or the entire table. It is also possible (2) to enter a function for changing/editing the target variable.
NVL	The two-digit input field determines the treatment of missing value or null values. By default they are replaced during the database query by the value zero.
Assessment unit	The smallest unit for the calculation of the estimators. If nothing is specified, the assessment unit and the inventory unit are identical. Several different options offer the possibility to create classes, or the integration of lookup tables etc.
Save	Saving the parameter and starts the analysis if desired.
End	Leaves the window without saving.

Inventory Cycle

Information from different inventory dates is stored in the databank. The field "inventory cycle" allows the user to select between state analysis (only one inventory) and a change analysis. The change can be calculated as the total change (difference between the two states) or as the mean annual change. Furthermore, it is possible to calculate the current values of both inventories on the joined grid. This is important for the analysis of ratio estimators. The individual options are listed in Table 2.

Table 2. Options for the inventory selection.

State	Analysis of data sampled at a certain inventory occasion. The inventory can be selected from a list.
Change	Analysis of change between two inventories. The initial state is selected from list 1; the final state is determined in list 2. Subject of the analysis is the difference between inventory 2 and inventory 1. By default, weighting and classification is carried out according to the current inventory data (difference class2). For special analysis it is possible to use both inventories for the classification (difference classes 1/2). For the classification of the difference, the option "classification difference" was created. In order to accomplish this, the difference of a continuous target variable is calculated first and the results are classified. See also: classification of the target variables. For the change analysis of proportions, the option "state / joined grid" exists. For this, a state analysis of the first and second inventory occasion is carried out and saved separately in the result table.
Reference period	The reference period determines whether changes are calculated for the entire inventory period or as annual change. This is especially important in case of varying length of inventory periods.

Analysis Unit

Selecting the analysis population determines the size of the sample. The population can refer to the entire 500-meter-grid (GIS data, air photo data) or to a sub-grid (terrestrial survey). The selection of the analysis population also effects the statistical analysis methods. Data from the entire grid are only analyzed in one phase, while data on the terrestrial grid is analyzed in two phases (double sampling) (see Table 3). The selection of the analysis population determines the target variables available for the analysis as well.

Inventory unit

The results are at first derived for distinct geographic subunits, such as production regions, economic regions, cantons, or forest districts. The total values for Switzerland or the cantons (for the cantonal analysis) are the sum of the individual results of the inventory units. The employment of different inventory units causes a slight difference between the total values. This is caused, on the one hand, by the calculation method and, on the other hand, by different total areas of the inventory unit. The total area for the cantons and the forest districts (4,128,419 hectares, derived from the municipal borders of the Swiss Federal Statistical Office GEOSTAT as of January 1, 1994) are seven hectares smaller than the area in the production regions, economic regions, and protection forest regions (4,128,426 hectares, derived from the partition of municipalities of the National Forest Inventory from 1985). The following inventory units can be selected:

Forest enterprise (only for special analysis in the cantons)
Forest district in the cantons (only for the cantonal analysis)
Forest compartment of the cantons (only for the cantonal analysis)
Canton
Production regions (standard setting)
Protection forest regions
Economic regions

Table 3. Definition of the analysis unit.

Analysis unit	Description	DS	Tables for the target variables	Condition
Total	All of the air photo samples and GIS data.	No	beo.cl, lfi2.cl2, lfi2.lbaufn, lfi2.strasse, lfi2.holzweg	none
Total forest	Aerial photography samples and GIS data for which the forest decision = forest.	No	beo.cl, lfi2.cl2, lfi2.lbaufn, lfi2.strasse, lfi2.holzweg	lbaufn. kombent = 2
Shrub forest	Aerial photography samples and GIS data for which the forest decision = shrub forest.	No	beo.cl, lfi2.cl2, lfi2.lbaufn, lfi2.strasse, lfi2.holzweg	lbaufn. kombent = 3
Terrestrial forest	Terrestrial survey without shrub forest, including inaccessible samples.	Yes	lfi2.wa, lfi2.ba, lfi2.schaden, lfi2.sortd, lfi2.bemerk, lfi2.hhvorauf, lfi2.ruvorauf, beo.ruecken (, lfi2.strasse)	lbaufn. kombent = 2
Accessible forest	Accessible terrestrial sample plots without shrub forest.	Yes	lfi2.wa, lfi2.ba, lfi2.schaden, lfi2.sortd, lfi2.bemerk, lfi2.hhvorauf, lfi2.ruvorauf, beo.ruecken (, lfi2.strasse)	lbaufn. kombent = 2 wa.zugang < 3
Wooded area	Accessible terrestrial sample plots without shrub forest, with utilization: "Forest in a strict sense."	Yes	lfi2.wa, lfi2.ba, lfi2.schaden, lfi2.sortd, lfi2.bemerk, lfi2.hhvorauf, lfi2.ruvorauf, beo.ruecken (, lfi2.strasse)	lbaufn. kombent = 2 wa.nutzkat >8
Young growth	Terrestrial young growth survey. Each young growth plot counts as a sample plot.	Yes	lfi2.jwsalfi2, lfi2.jwkla2, beo.jwgru	lbaufn. kombent = 2 jwsalfi2.jwlage in (1,2,4)
Forest edge	All terrestrial plots that intersect a forest edge.	No	lfi2.wr, lfi2.wrartant	lbaufn. kombent = 2

Conditions

For the analysis of certain subjects (for example, analysis of the timber volume, increments, and utilization) it is, at times, necessary to restrict the data which is to be analyzed. For the restriction, two separate conditions can be entered. These restrictions must contain valid variables from the database and must be correctly linked using ORACLE SQL.

For the analysis of current values both restrictions are equally treated and used. For the change analysis the first restriction is applied to the query of data for both inventories (see Table 4). The second restriction only affects the data query of the second inventory.

Table 4. Conditions for the change analysis.

Condition 1	Restrictions that refer to the target variable (e.g., elimination of sample plots with missing stability assessment for the analysis of the stand stability). Restrictions, like tree history for the analysis of growing stock and increment etc. Restrictions that refer to attributes that do **not** depend on the inventory occasion).
Condition 2	Restrictions that refer to the definition of assessment units (e.g., if the increment only for certain types of forests is of interest). For change analyses the second occasion value of the variable that determines the assessment unit is principally used. Restrictions for attributes which definitions or coding depend on the inventory (damage, etc.).

Target variable

The term "target variable" refers to the variable to be analyzed. The analysis is adjusted depending on the type (continuous or categorical) and the level (sample plot or subunit) of a target variable. The properties of the target variables must be manually adjusted. The following options are available:

– For the manipulation of the target variable it is possible to specify an SQL expression.
– The classification of the target variable
– Avoiding several identical data sets (example tree damage analysis)
For this the option DISTINCT should be selected.

Reference Units

The reference unit of the analysis is used for the calculation of ratio estimates (for example, volume per hectare) (KÖHL 1994). Several different reference units such as area in hectares, number of stems, timber volume, basal area, etc., or the target variable itself can be selected in order to calculate percentage values.

In the input field "weight," an SQL expression can be inserted for the weighting of the reference unit, starting with an operator (*, /, +, –). Furthermore, the type of reference unit table can be selected.

The possible options, depending on the level of the target variable and the assessment unit, are described in Figure 1.

Options:

– Reference to a cell	A reference unit is derived separately for each cell
– Reference to a column	A common reference unit is derived for each column
– Reference to a row	A common reference unit is derived for each row
– Reference to a table	A common reference unit is derived for each table

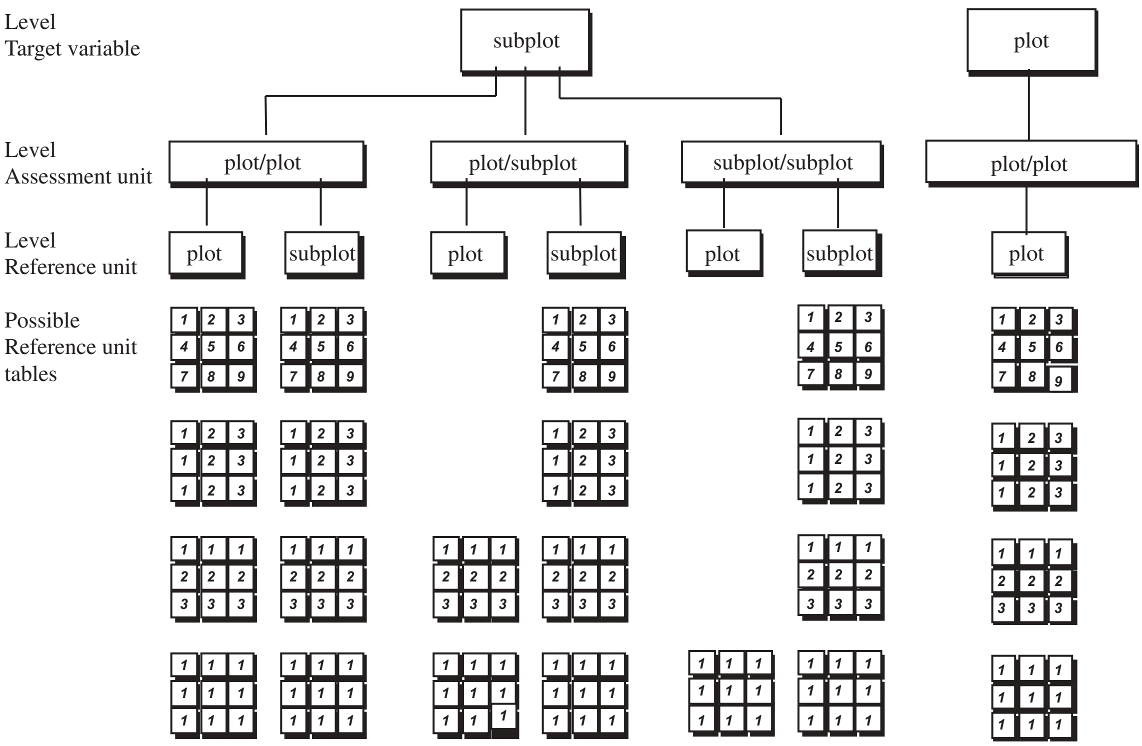

Figure 1. Schematic of possible reference unit tables.
Equal values per row or column mean that a unique value for the reference unit is applied.

Assessment Units

The analysis can be conducted separately according to categories of a certain attribute. The definition of these categories determine the number of rows and columns of the result table and thus the "thematic resolution" of the analysis. Five options are available for the manipulation of the group variables (see Table 5).

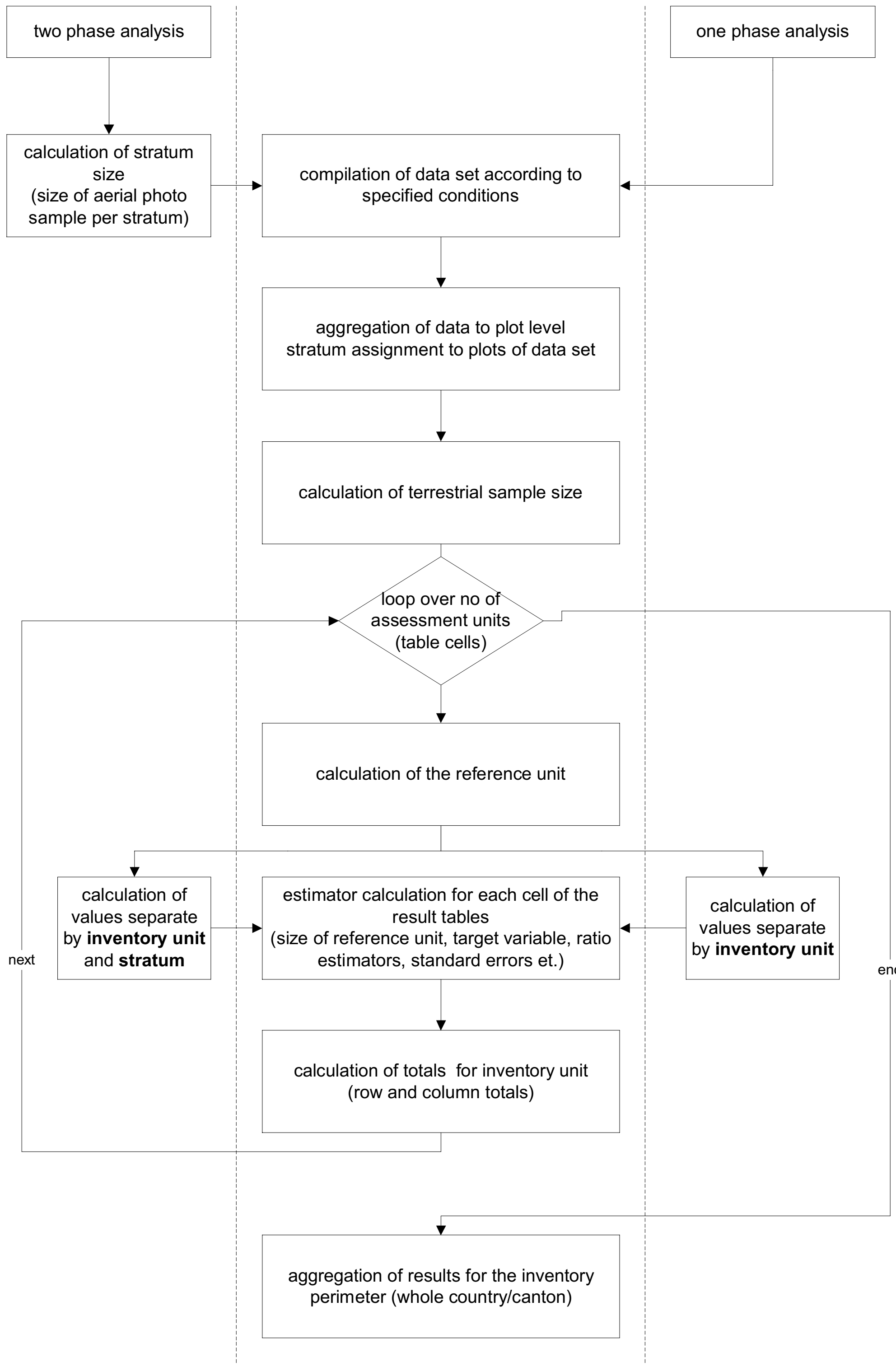

Figure 2. Flow chart of the analysis.

(Fictitious) example:
For the analysis of timber volume (level: subplot) by assessment units: 1) ownership (level: plot), and 2) tree species (level: subplot), the following several possibilities exist for the reference unit (a) hectare (level: plot) and reference unit (b) number of stems (level: subplot):

a) Reference unit hectares
   The timber volume per hectare can either be calculated for each type of ownership or for the entire forest area. Timber volume per hectare of forest area with occurrence of a certain tree species is, however, not very informative and results in non-additive tables.
b) Reference unit number of stems
   The number of stems allows for the selection of all possible table types. It is also possible to calculate the mean volume per tree according to: 1) ownership and 2) tree species. The remaining types of tables are mainly appropriate for the calculation of proportions.

Table 5. Options for the classification of assessment units.

CODE	Direct application of the codes for categorical variables
INTERVAL	For simple classification of continuous variables for an arbitrary number of classes.
CLASSES	For the classification of continuous variables in classes with a fixed reference point and class width or any classification by entering the class limits. For the classification two options area available: (1) Classifications with a fixed width for any reference point. Class width and starting point are defined. (2) Classification with arbitrary width. The desired number of classes and the class limits are defined. The classification table is stored in the result library under the corresponding variable name. For both types of classification, it is possible to treat the class limits differently. Either the lower or the upper limit (default) can be included in the class.
OTHERS	For arranging variables of any arbitrary scale (e.g., dividing ownership category in (1) public (2) and private. A key with the created code is generated and can be edited.
LOOKUP	With this option it is easy for the user to carry out complex manipulations of the assessment unit classification. It is possible to use additional information (e.g., from the GIS) in an analysis to change the original codes. The tables are linked by the cluster identification number. The following elements can be found in the window “look-up table”: OWNER: Selection list of the owner (ORACLE). TABLE: Selection list of the available tables. (ORACLE). CODEVARIABLE: Selection list for variables containing the new code to be assigned. FORMAT VARIABLE: Selection list for plain text variables. TABLE INFORMATION: This displays only the description of the selected elements and the content of the selected table. JOIN-TABLE: to which the lookup table is linked to. If an alias was specified as the assessment unit, the name of the appropriate table, to which the look-up table is linked to, has to be manually adjusted with the selection keys. CONDITIONS for lookuptable: The necessary conditions for the WHERE clause to link to the look-up table has to be specified here. It is important to correctly treat the NULL values. (e.g., AND NVL(ba.bart,0) = lfi2.nhlhlut.bart)

4.2.2 Process of the Analysis

After the parameters are stored the analysis can be started directly or in a batch mode. The process of the analysis is presented in a simplified form in Figure 2. For the one-phase analysis the estimates are derived separately for the inventory units. For the double sampling method the data need to be stratified. The calculation of the estimates is carried out for the assessment units of each stratum. They are then weighted according to the stratum size and are summarized to inventory units.

In both cases the values of the inventory units add up to total values for Switzerland or for the cantons, and are stored in the results file.

4.2.3 Presentation of the Results

Analysis

The window "analysis" is used for the output of the analysis results. The presentation of the results can be individually adjusted using different selection menus. The settings for each subject are stored in a separate file. If the subjects are selected, the parameters are loaded again. This facilitates the reproduction of tables and graphs.

Table 6. Menus and adjustments for the window: "analysis"(presentations of results).

Level	The level of aggregation can be selected in this window (Switzerland) inventory unit, ...).
Estimator	In this area the type of estimator can be selected (target variable, reference unit, ratio estimators). The target variable and reference unit is shown as estimates of totals. For non-continuous data, the frequency of the occurring code values is calculated (e.g., as the number of stems or area in hectares).
Standard error	The standard error is available as an absolute value and has the same units as the variable value (timber cubic meter solid, hectare, number of stems, ...). When displayed as a percentage value the standard error is calculated in percentage of the variable value.
Presentation	In the area of *presentation*, it is possible to select as the output either table or graphic. The arrangement of the values within the table of graphic can be adjusted.
Output	Possible output media area: Printer, computer screen, and file.
Table arrangement	The window *table arrangement* allows selecting the arrangement of the elements in a table. The arrangement of the grouping element can be selected individually. Example for grouping elements: Reference unit Inventory identification number Target variable Assessment unit 1 Assessment unit 2 The arrangement of the graphs is similar.

The overall concept of the database, analysis, and presentation is presented in Figure 3.

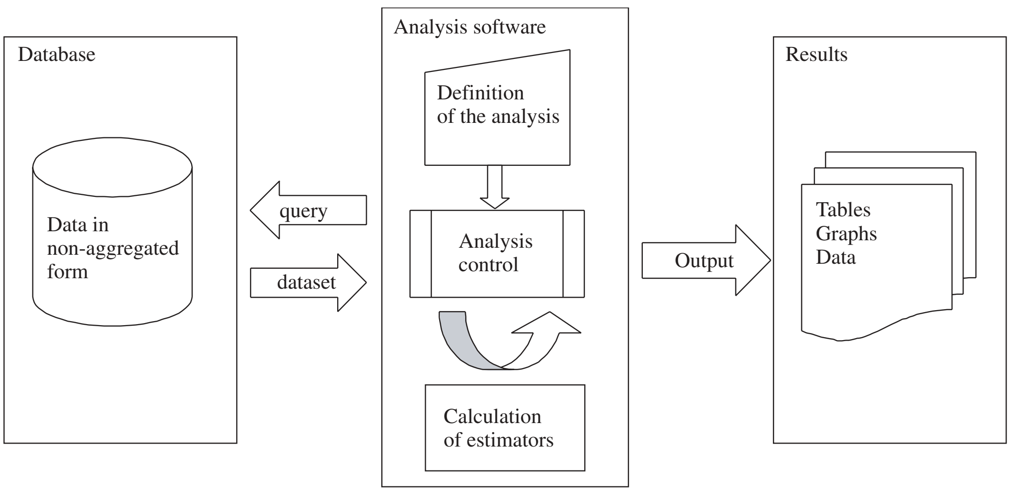

Figure 3. Analysis concept of the Swiss National Forest Inventory.

Other "Features" of the Analysis Software

Apart from programs for the file management within the SAS system and at the ORACLE or UNIX level, a data set can be generated according to the variables identified in the definition of the subjects. The results are: a) a comma delimited ASCII file and b) a temporary SAS file "WORK.AUSZUG." In order to work with these results in EXCEL the estimates and standard errors of the estimates can be exported. A semicolon delimited ASCII file is generated as an export file. For the structure of the data set and for the export file see Tables 7 and 8.

The batch mode makes it possible to conduct several analyses, one after the other. The batch can be run either with the user interface (online) or without the user interface (offline). The batch mode is started for the online mode directly from the analysis software. No other actions are possible until the end of the analysis. The systems messages appear in the LOG window.

Alternatively, it is possible to start the analysis without the window in the background. The system messages are then stored in a separate log-file. This file is overwritten each time a new analysis is run.

Table 7. Structure of the data set queried from the databank.

Variable	Definition
x	X-coordinate
y	Y-coordinate
clus	Identification number of the sample plot.
aussage	inventory unit
<befundeinh.1>	1. Assessment unit
<befundeinh.2>	2. Assessment unit
zielvariable	Coded target variable for categorical data; continuous value for the target quantity.
wicht	Weighting factor for the target variable.
begro	Reference unit

Table 8. Structure of the export files.

Variable	Definition
invnr	Inventory identification number
aussage	inventory unit
<befundeinh.1>	1. Assessment unit with formatted values.
<befundeinh.2>	2. Assessment unit with formatted values.
zielvariable	Formatted target variable for categorical data.
gy	Estimator total of the target variable.
sgy	Standard error for the target variable absolute.
psgy	Standard error for the target variable percentage.
gx	Estimator total of reference unit.
sgx	Standard error for the reference unit absolute.
psgx	Standard error for the reference unit percentage.
r	Ratio estimator.
sgr	Standard error of the ratio absolute.
psgr	Standard error of the ratio percentage.

4.2.4 Literature

KÖHL, M. 1994: Statistisches Design für das zweite Schweizerische Landesforstinventar: Ein Folgeinventurkonzept unter Verwendung von Luftbildern und terrestrischen Aufnahmen. Mitt. Eidgenöss. Forsch.anst. Wald Schnee Landsch. 69 (1):141.

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SAS INSTITUTE, INC. 1989. SAS/AF(R) Software: Usage and reference, Version 6. 1 ed. Cary, NC: SAS Institute, Inc. 245 p.

SAS INSTITUTE, INC. 1990. SAS(R) Screen Control Language: Reference, Version 6. 1 ed. Cary, NC: SAS Institute, Inc. 464 p.

4.3 Error Sources and Their Influence on the NFI Inventory Results

Michael Köhl

Despite the efforts to achieve high quality data and to use efficient statistical estimators, the results of the NFI are not free of errors. A complete census of the Swiss forests is impossible due to the necessary costs, the available personnel, and the required time from the beginning of the survey up to and including the publication of the results; thus no other alternative to a sample based approach for the NFI exists. In a sample based survey a small portion (sample) is selected from the entire population of the Swiss forests. The selected elements (trees or sample plots) are precisely assessed. The elements included in the sample are then used to draw an inference about the entire population. Inferring about the entire population (e.g., Swiss forests) based on the sample has its roots in theoretical probability assumptions. Simply spoken, the probabilities with which the individual population elements are selected for the sample are taken into account during the derivation of the statistical parameters (e.g., mean values, proportions, and totals). For the inference, the statistical parameters that were calculated using the sample data are applied to the entire population.

Since only some of the population elements are used for the derivation of the statistical parameters, the derived values for the entire population are not the "true values," but rather "estimates." These estimates are subject to errors – the so-called estimation error or sampling error. The reason for these errors is the fact that it is possible to select exactly $\binom{N}{n}$ samples of size n out of a population of size N[1], and that the samples show random variation. Inferring about the entire population based on the sample involves this random component and makes it possible to not only calculate the estimates but also their estimation errors.

The calculation of estimation errors is based on the assumption that an observation of a selected element corresponds to its actual (true) value. Deviations of observed and true value can occur due to measurement errors or the wrong assignment of attributes (e.g., tree species). If the population parameters are derived with the help of functions or models, prediction errors can also influence the reliability of the results. These errors are called non-sampling errors, in contrast to the sampling error. This includes errors during the data collection as well.

Sampling and non-sampling errors can influence the results in two different ways: accuracy and precision. Accuracy refers to the systematic deviation between the estimated value and the true value; precision refers to the size of the deviation of the estimate when the sampling procedure is repeatedly applied to the population (Cochran, 1977). The combined effect of both of these components on the reliability of estimates is illustrated in Figure 1.

An estimate can be precise or imprecise, biased or unbiased. With increasing sample size, the sampling error decreases (i.e., the results become more precise). Biases can occur as a result of measurement errors or model errors, but can also occur because of statistical methods. An example for bias could be an interpreter for a Forest Condition Monitoring Program, who systematically overestimates crown transparency by 10%. Independent of the number of assessed trees, the estimated mean crown transparency will always be 10% too high. The bias is not considered for the calculation of the sampling errors, so that even biased results can suggest very reliable results due to a low sampling error.

The objective of a sample based inventory is to obtain a true representation of the target population. Errors that occur during the different steps of an inventory and can have different sources, lead to a different representation of the reality and influence the reliability of the results. For this reason the non-sampling and sampling errors were thoroughly studied during the preparation for the second NFI (GERTNER and KÖHL 1992; 1995; KÖHL 1991; 1993; 1994; KÖHL and KAUFMANN 1993; KÖHL *et al.* 1994; KÖHL and ZINGG 1996).

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[1] This holds for random sampling without replacement.

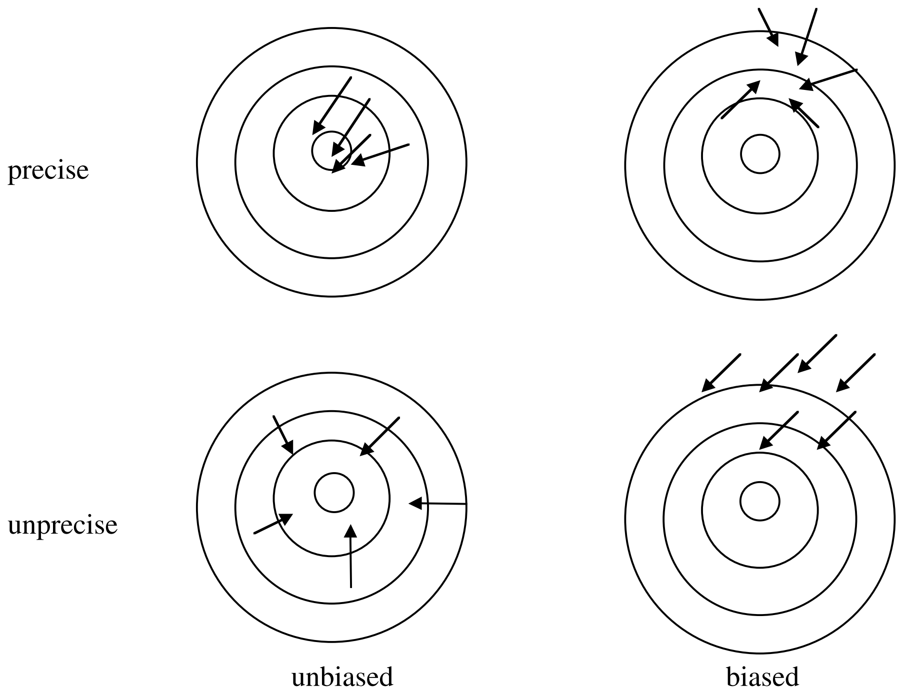

Figure 1. Precision and accuracy of estimators.

An important objective for the method development of the second NFI was to keep the overall error of the estimates as low as possible. Based on the data and check assessments of the first NFI, different potential error components were studied and their proportion of the total error quantified. Methods were finally sought that would reduce the overall error. An important tool for this was the derivation of error budgets, in which several different sources of error could be combined. The analysis of the error budget led, for example, to a revision of the methods for the volume calculation of individual trees (Chapter 3.2). Furthermore, the studies emphasized the necessity of high data quality for the assessment on the forest sample plots and aerial photographs (see also Chapter 2.8 to 2.9 and Chapter 4.4).

The properties of the statistical estimation procedures are especially important in the analysis of the data. In the following, the statistical estimation procedures applied in the second NFI are examined with respect to their bias, efficiency, consistency, and their suitability for employment in the NFI. After that, the example of the volume estimation in the first NFI is used to illustrate the employment of an error budget.

4.3.1 Sampling Error and Bias

A measure to evaluate the quality of an estimator is the mean squared error (MSE, see page 15, COCHRAN 1977).

$$\mathrm{MSE}(\hat{\mu}) = E(\hat{\mu} - \mu)^2 = (\text{variance of } \hat{\mu}) + (\text{bias})^2 \qquad (1)$$

where $\hat{\mu}$ is an estimate for the true mean value μ and the bias is the deviation of a calculated mean value m from μ. The MSE consists of two different components which describe the adequacy of an estimate: 1) the precision, given by the variance of $\hat{\mu}$, and 2) the accuracy given by the bias.

The verification of the estimation procedures introduced in Chapter 2.1 was an important step during the development of the sampling designs in the second NFI. Based on a test data set, the MSE of the combined ratio estimators was studied using the Jackknife method. The test data set was compiled from data obtained from the first NFI survey and the National Forest Condition Survey 1990. A total of 723 sample plots were used.

COCHRAN (1977) and SUKHATME et al. (1984) describe Jackknife methods which improve the variance estimation of ratios. The Jackknife estimator was introduced by QUENOUILLE (1956) as a method for bias reduction. TUCKEY (1958) suggested using this method for variance estimates and coined, in unpublished papers, the name of this method (MILLER 1974). MILLER (1974) provides an overview of the Jackknifing.

The basic principle of the Jackknifing is to derive estimates for a sample that is of reduced size. Suppose $X_1,...,X_n$ is a sample of independent and identically distributed random variables. Suppose, furthermore, that $\hat{d}$ is an estimate for the population parameter δ that is derived from the sample of size *n*. If the sample of size *n* is divided into *g* groups of size *h*, so that *n* equals *gh*, it follows that $\hat{d}_{-i}$ is a corresponding estimate, which is based on a sample of size *(g-1)h* in which the i^{th} group was deleted. The estimate $\hat{d}_{Ji}$ is defined as follows:

$$\hat{d}_{Ji} = g\hat{d} - (g-1)\hat{d}_{-i} \tag{2}$$

Tuckey introduced for $\hat{d}_{Ji}$, the term “pseudo value” (MILLER 1974). The Jackknife estimate is:

$$\hat{d}_J = \frac{\sum \hat{d}_{Ji}}{n} \tag{3}$$

with the variance $v(\hat{d}_J)$

$$v\left(\hat{d}_J\right) = \frac{\sum\left(\hat{d}_{Ji} - \hat{d}_J\right)^2}{n(n-1)} \tag{4}$$

The most common form of the Jackknife estimator uses a group size *h=1*, which implies that *n=g*. Thus, the pseudo values are calculated by leaving out the i^{th} observation for the calculations. This is also assumed in the following presentation:

The Jackknife ratio estimator follows from Equation (3) and is:

$$\hat{R}_J = \frac{\sum \hat{R}_{Ji}}{n} \tag{6}$$

with the pseudo values

$$\hat{R}_{Ji} = n\hat{R} - (n-1)\hat{R}_{-i} \tag{7}$$

and the variance

$$v(\hat{R}_J) = \frac{\sum\left(\hat{R}_{Ji} - \hat{R}_J\right)^2}{n(n-1)} \tag{8}$$

For the calculation of $\hat{R}_{Ji}$, a combined ratio estimator with double sampling $\hat{R}_{ds}$ was used.

$$\hat{R}_{ds} = \frac{\hat{Y}_{ds}}{\hat{X}_{ds}} = \frac{\hat{\bar{Y}}_{ds}}{\hat{\bar{X}}_{ds}} \tag{9}$$

In a Monte-Carlo simulation study $\hat{R}_{ds}$ was compared to the Jackknife estimator (KÖHL 1994). Since the bias of the ratio estimator is of order 1/n, which implies that bias should especially be expected for small sample sizes, the sample size was chosen to be n=50 and n=100. The number of sample units within the production regions was selected to be proportional to the size of the production regions. In order to obtain a data set for the selection of the samples that was as extensive as possible, and to avoid empty strata as much as possible, the estimator was not separately derived for the production regions. Due to the enormous computing time, the simulation study was limited to 100 iterations.

Conducting a simulation study with a double sampling ratio estimator requires determining the sample sizes in both the first and second phase. Since the main focus of the study was on the behavior of the estimator for small sample sizes in the second phase, the sample size in the first phase, with 2,500 samples, was chosen to be relatively high, and the simulated second phase sample sizes were chosen to be constant with n=50 and n=100.

The number of stems and timber volume per hectare, which were determined using the double sampling ratio estimator for the test data set with n'=2,500 observations in phase one and n=723 observations in phase two are presented in Table 1.

Table 1. Double sampling ratio estimator for the test data set (n = 723, n' = 2500).

	N/ha [m^3/ha]	V/ha [n/ha]
R	429.07	310.88
s(R)	9.91	7.01

Table 2 contains the summarized results of the simulation study. The results show that the Jackknife estimator (Jackknife $\hat{R}$) and the double sampling ratio estimator $\hat{R}_{ds}$, with a sample size of n=100, lead to practically the same results for the estimation of stem number as well as for the estimation of timber volume. For a sample size of n=50, differences between both estimators can be observed. The Jackknife estimator leads to lower ratios. The difference between the procedures is, however, relatively low and amounts to approximately 1.5% for the estimation of stem number.

Table 2. Results of the Monte-Carlo simulation study (mean of 100 iterations).

	n=50		n=100	
	N/ha [m^3/ha]	V/ha [n/ha]	N/ha [m^3/ha]	V/ha [n/ha]
$\hat{R}_{ds}$	433.36	314.09	431.01	312.07
Jackknife $\hat{R}$	427.14	312.45	432.06	312.76
s($\hat{R}_{ds}$)	35.90	24.75	25.92	17.81
Jackknife s($\hat{R}$)	42.90	29.73	28.43	19.69

Jackknifing results in a higher standard error in comparison to the double sampling ratio estimator. However, for the 100 iterations that were conducted, the Jackknife procedure has a higher variance of the standard error than the double sampling ratio estimator, which can, therefore, be considered to be more stable. The standard error for the double sampling ratio estimator is for a sample of size n=50 approximately 20% lower than for the Jackknife procedure, and for a sample of size n=100 approximately 10% lower as well. The conservative estimation for the standard error by Jackknifing observed here is known and is, among others, described by EFFRON (1982). The mean bias of the 100 iterations (see Table 3) also varies for the double sampling ratio estimator for both procedures in the same range and is between -0.45% and +1.0%.

Table 3. Mean bias of the double sampling ratio estimator (values in parentheses: deviation from the value for the total population in percentage).

	n=50		n=100	
	N/ha [m^3/ha]	V/ha [n/ha]	N/ha [m^3/ha]	V/ha [n/ha]
$\hat{R}_{ds}$	4.29 (1.0%)	2.21 (0.71%)	1.94 (0.45%)	1.19 (0.38%)
Jackknife $\hat{R}$	-1.93 (-0.45%)	1.57 (0.51%)	2.98 (0.69%)	1.88 (0.60%)

The sample size of the simulation study was kept low on purpose and corresponds with samples that each represent 100 hectare to a reference unit of 5,000 ha and 10,000 ha. No results had to be derived in the NFI for such small areas (i.e., the sample size is usually significantly larger for the analysis of subunits). The combined ratio estimator and the Jackknife estimator had similar results in the simulation study presented here. Thus, it can be assumed that the estimation method used in the second NFI does not lead to a systematic error (bias), and that the sampling error is low even for small sample sizes. The method is therefore appropriate for the use in the NFI and can replace the Jackknife estimator which requires considerably higher computing time.

4.3.2 Nonsampling Error and Error Budget

During the preparation for the second NFI GERTNER and KÖHL (1992) studied the influence of non-sampling errors on the reliability of the inventory results. The objective was to identify error sources that have a substantial influence on the reliability of the results and to minimize these error sources by the revision of the inventory manuals and models.

The sensitivity of the first NFI results were investigated with the help of so-called error budgets. A model was constructed initially for each individual error source in order to quantify the error (Figure 2). For this, random and systematic errors had to be distinguished. The construction and application of the error budget is illustrated in the following for volume estimation of spruce from the first NFI. This shows how, based on the data of the first NFI, the necessity to revise the volume prediction of individual trees was recognized (see Chapter 3.2).

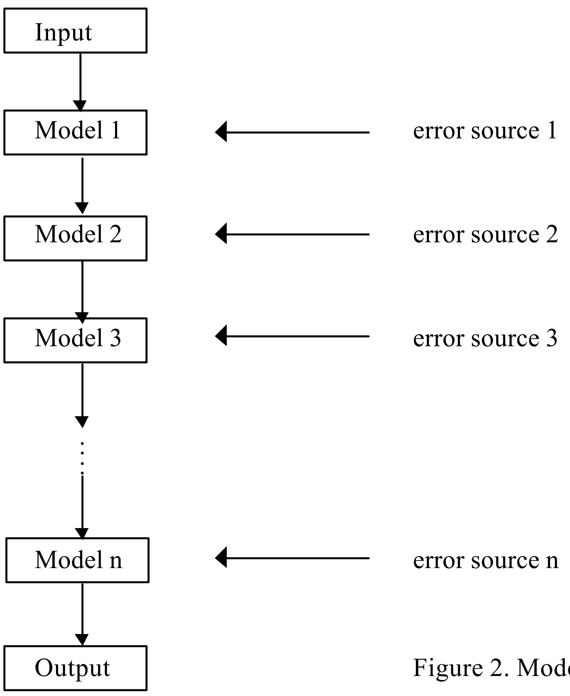

Figure 2. Model used to derive the error budget.

In the first NFI the individual tree volumes were derived using tariff functions. At first, the individual tree volume was determined with the help of volume functions for all trees on which the diameters in height 1.3 meters and 7 meters and total tree height were measured. The individual tree volumes, which were only available for a subsample (the so-called tariff sample trees), were used for the construction of tariff functions. For the tree species spruce, 19 different tariff functions were derived that depended on stand classification attributes, development stage, stand structure, and stand density (KAUFMANN 1991). Independent variables for the calibration of the tariff function included, for example, the DBH, slope of the plots, site index, tree crown position, and the presence of stem forks. For the construction of the error models of the tariff functions the following different error sources were considered:

- The variance of the tariff functions, assuming that the tariff functions are free of error
- Measurement errors of the variables used for the calibration of the tariff function (e.g., measurement errors in the DBH)
- Errors of the discrete variables used for the calibration of the tariff function (e.g., wrong assignment of the crown position)
- Errors that occurred during the assessment of attributes used to select the tariff function (stage of development, stand structure, and stand density)

The errors of these individual sources increase the variance of the volume predicted with the tariff function $var_{tariff}(v)$. Instead of the true volume of individual trees the values predicted by volume functions were used for the construction of the tariff functions. These predicted volumes are smoothed estimates and do not contain the variability of the true individual tree volumes. If the true tree volumes had been used for the derivations of the tariff functions, the variance of the residuals would have been larger than the ones used for the individual volumes estimated with the volume functions. Since the volume functions were developed independently of the NFI survey (HOFFMANN 1984), a general model which was introduced by KISH (1965) for summarizing several different sources of error could be applied and the variance of the volume functions $var_{function}(v)$ could be added to the variance of the tariff function.

The individual tree volumes of the trees that were selected in the NFI, which were estimated using the volume functions, include potentially a bias which depends on systematic errors that arise from measurements of the independent variable in the volume function (e.g., DBH, height). In contrast to the bias of the independent variables within the tariff function, this bias is not adjusted through the calibration. Thus, the bias of the volume function $bias_{function}(v)$ leads to a bias in the tariff function $bias_{tariff}(v)$.

The total error of the individual tree volume that was derived using the tariff functions $var_{tariff}(v)$, for which the measurement errors of the independent variable as well as the errors in the volume function were accounted for is:

$$var_{tariff}(v) \cong var_{function}(v) + var_{tariff\ error}(v) \tag{10}$$

where $var_{tariff\ errorr}(v)$ the variance of the tariff function and the variance of the different above mentioned errors of the calibration variables, as well as the attributes used to select the tariff function, are all included. The bias of the tariff function is:

$$bias_{tariff}(v) \cong bias_{function}(v) \tag{11}$$

The individual tree volumes, which were determined by using the tariff functions, are expanded in the NFI to a per hectare basis. The bias $bias_{tariff}(v)$ and the variance $var_{tariff}(v)$ were similarly expanded to a per hectare basis.

For the derivation of the estimates, the individual tree volumes are accumulated for each sample plot to a sample plot volume Y_i (see Chapter 2.1.4). The variance of the sample plot volume $var_{sample}(\bar{Y})$ was calculated in the first NFI using the equations of the random selection (see page 18 and following, COCHRAN 1977). Since the smoothed individual tree volumes from the tariff functions were used, the errors of the tariff function given up to this point are not implicitly accounted for. The variance of the sample plot volume can, however, be traced back to one important source of error. A large portion of the NFI sample plots is situated in inclined terrain and requires correcting for the slope. In the NFI, sample plots on slopes were sampled with concentric circles, which when projected on the horizontal plane were elliptical with a certain defined area (200 m^2 and 500 m^2). The radius of the sample plots on a slope depends on the defined area and the angle of the slope on the plots. An error in the measured angle of the slope will cause an error in actual area of a plot on the horizontal plane and can be either random or systematic. The radius of the sample plots on slopes depends on the defined horizontal plane and the angle of the slope. An error in the measured slope will cause an error of the actual area on the horizontal projection and can be either random or systematic. Thus, the error is described with $var_{slope}(\bar{Y})$ and $bias_{slope}(\bar{Y})$. These errors were accounted for in the construction of the error budget.

The estimated bias, the variance, the mean square error, as well as the percent root mean square error, $bias_{total}(\bar{Y})$, $var_{total}(\bar{Y})$, $mse_{total}(\bar{Y})$ and $prmse_{total}(\bar{Y})$ respectively, are calculated as:

$$bias_{total}(\bar{Y}) \cong bias_{tariff}(\bar{Y}) + bias_{slope}(\bar{Y}) \tag{12}$$

$$var_{total}(\bar{Y}) \cong var_{tariff}(\bar{Y}) + var_{sample}(\bar{Y}) + var_{slope}(\bar{Y}) \tag{13}$$

$$mse_{total}(\bar{Y}) \cong var_{total}(\bar{Y}) + (bias_{total}(\bar{Y}))^2 \tag{14}$$

$$prmse_{total}(\bar{Y}) \cong 100\frac{\sqrt{mse_{total}(\bar{Y})}}{\bar{Y}} \tag{15}$$

Based on the data of the first NFI, it was possible to derive an error budget for the different attributes with this approach. The example of Norway spruce (*Picea abies* (L.) Karst.) is used here to illustrate the error budget for volume estimation. An error budget displays the effects of measurement errors of individual attributes and groups of attributes on the reliability of overall estimates. The amount of measurement errors entered into the error budget was either taken from the analysis of the check assessments of the first NFI (WINZELER 1989) or was determined based on expert opinion. The coefficient of variation due to the measurement errors was 2% for the DBH, 4% for the d_7, 7% for the tree height, 20% for the site index, and 5% for the slope. All independent variables were considered to be unbiased. The classification error, which occurred by selecting the wrong tariff function, was determined using a simulation study (GERTNER and KÖHL 1992).

Table 4 shows the error budget when these measurement and classification errors were used. The mean total stem volume was 267.35 m^3/ha, which amounts to a percent root mean square error of 1.28%. The sampling error is the most important source of error and the tariff functions are the second most important source of error. Random measurement and classification errors were of minor importance. Even if random measurement errors were doubled, in terms of the continuous variables, the coefficient of variation would not change significantly.

Control surveys have shown that the probability of systematic measurement errors in the NFI is very low because every precaution has been taken to avoid systematic errors. In order to understand how sensitive the sampling design of the first NFI was in regard to systematic errors, an error budget was prepared assuming that the measurable variables DBH, d_7, tree height, and slope were biased by one percent. The relatively small bias causes a very drastic increase of the mean squared error (see Table 5). This is particularly true for the d_7. The coefficient of variation increased by about four percent. The main reason for this strong increase is the very large sample size. An increasing sample size reduces the variance due to the sampling error, the random measurement errors, and the prediction errors; however, the increasing sample size does not effect the bias of the volume estimation. Thus, the weight given to the bias increases with increasing sample size.

Error budgets were used to develop the inventory methods of the second NFI in order to demonstrate the influence of different attributes on the reliability of the inventory results. The design of the first NFI is very sensitive to systematic biases. As a consequence, the methods for the volume prediction (i.e., the volume and tariff functions) and the assortment tariffs were completely revised (see Chapter 2.1, Standing Timber, Increments and Utilization).

Table 4. Error budget for spruce in Switzerland (according to GERTNER and KÖHL, 1992). Measurement error from the check assessment. Values in parentheses are the percentage change of the MSE with respects to the corresponding error source.

	Variance of the stem volume $[m^3/ha]^2$		Bias of the stem volume $[m^3/ha]$
Sampling error		11.5196 (98.416%)	0
Function error			
Volume function	0.0025 (0.0213%)		0
Tariff function	0.1219 (1.1033%)		0
Subtotal		0.1316 (1.1246%)	0
Measurement error			
DBH	0.0000 (0.0000%)		0
Height	0.0017 (0.0145%)		0
d_7	0.0276 (0.2361%)		0
Site class	0.0003 (0.0028%)		0
Slope (%)	0.0008 (0.0066%)		0
Subtotal		0.0304 (0.2600%)	0
Assignment error			
Crown class	0.0090 (0.0768%)		0
Tariff function	0.0143 (0.1225%)		0
Subtotal		0.0233 (0.1993%)	0
Total		11.704 (100%)	0

Table 5. Error budget for spruce in Switzerland with bias of the measurable attribute 1 (according to GERTNER and KÖHL, 1992). Measurement error from the check assessment. Values in parentheses are the percentage change of the MSE with respects to the corresponding error source.

	Variance of the stem volume $[m^3/ha]^2$		Bias of the stem volume $[m^3/ha]$	
Sampling error		11.5196 (9.427%)		0.00 (0.000%)
Function error				
Volume function	0.0025 (0.0020%)		0.00 (0.000%)	
Tariff function	0.1219 (0.1057%)		0.00 (0.000%)	
Subtotal		0.1316 (0.1077%)		0.00 (0.000%)
Measurement error				
DBH	0.0000 (0.0000%)		2.72 (40.796%)	
Height	0.0017 (0.0014%)		1.75 (27.616%)	
d_7	0.0276 (0.0233%)		5.53 (70.120%)	
Site class	0.0003 (0.0003%)		0.00 (0.000%)	
Slope (%)	0.0008 (0.0006%)		0.50 (8.484%)	
Subtotal		0.0304 (0.0256%)		10.51 (147.016%)
Assignment error				
Crown class	0.0090 (0.0074%)		0.00 (0.000%)	
Tariff function	0.0143 (0.0117%)		0.00 (0.000%)	
Subtotal		0.0233 (0.0191%)		0.00 (0.000%)
Total		11.7049		10.51

4.3.3 Literature

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4.4 Propagation of Data Uncertainty through Models

Heike Lischke

In the NFI2, several different models were used to assess how far certain forest functions, beyond timber production, were fulfilled. The forest functions included, for example, the protection against natural hazards, the preservation of the biodiversity, and the availability of recreational space. Furthermore, a model for classifying different forest types was used. The employed models contain, as does every model, different types of uncertainties. These uncertainties can be due to underlying assumptions, chosen model structures, values of the model's parameter, and only imprecisely given input values (see as an example the research of uncertainty analysis of models conducted by JOHNSON 1987 and PAHL-WOSTL *et al.* 1997). The uncertainties in the models themselves have been discussed in the appropriate chapters. This chapter tries to analyze how uncertainties of the input data can affect the outcome of the models.

These data uncertainties can be caused by systematic errors in measurements (for metric data) or in ratings of attributes (for nominal and ordinal data). Apart from this, continuous data can be randomly scattered around a mean value. Ordinal and nominal data can also have different outcomes for the same attribute when they are assessed repeatedly.

Such uncertainties of the assessed attributes, which enter the model, were determined by assessing the data a second time ("check assessment," "second survey" in Chapter 2.9) on approximately 600 sample plots in addition to the normal assessment of the NFI2 data ("first survey" in Chapter 2.9). This made it possible to determine how often the control team assessed a certain outcome of an attribute when the (first) survey team had decided upon another outcome. The results of this check assessment are presented in contingency tables (Tables 2 and 3 in Chapter 2.9). For most of the attributes, the assessments of the control team varied around the value of the first survey team (i.e., the maximum values in the contingency tables that are along the diagonal). For some of the attributes however (e.g., the attribute "stand structure," Chapter 2.9, Table 3, at the top), two outcomes were frequently mixed up (e.g., "cluster structure" and "multi-layered").

It is not possible to examine the propagation of such asymmetric uncertainties in the input data through models, which consist of many arithmetic and logical operations with the methods discussed in Chapter 4.3.2. The reason for this is because, apart from continuous data, nominal and ordinal data enter these models as well. Furthermore, the models consider many different input variables with even more case differentiations. Hence, any theoretical derivation of the model's uncertainties involves – depending on the uncertainties of the input variables – computing intense analyses and is consequently very time consuming and prone to errors, even when symbolic calculation software is used (e.g., MAPLE). The Latin-hypercube-method (JOHNSON 1987), the calculation of the model's outcome of all possible input variable combinations with the appropriate probabilities, could not be used since some input variables were continuous measurements. Furthermore, some unrealistic combinations of input variables would have occurred. The uncertainties of the results from the model were, therefore, determined using Monte-Carlo simulations (e.g., JOHNSON 1987), which are based on numerous repeated calculations with different values which were produced by a random number generator.

4.4.1 Methods

4.4.1.1 Approach

Figure 1 gives an overview of the approach of the uncertainty analysis. A detailed account can be found in the following sections. Randomly selected data from NFI sample plots were used as one group of input data. They were first assumed to be certain. From the check assessment, the uncertainty distributions of these original input data were determined. Using these distributions, several uncertain input data were generated for each original datum. The original data, as well as the associated uncertain data, were used as input data in the models. By comparing the results of the models that were simulated with the original input data and with the uncertain input data, the uncertainty distributions of the results from the models were determined. These uncertainty distributions were then used to study how data uncertainties affect the relative areas of the model results determined in the inventory.

The term “certain” refers to values that are assumed to be without any variability. “Uncertain” values are, therefore, values that include certain variability.

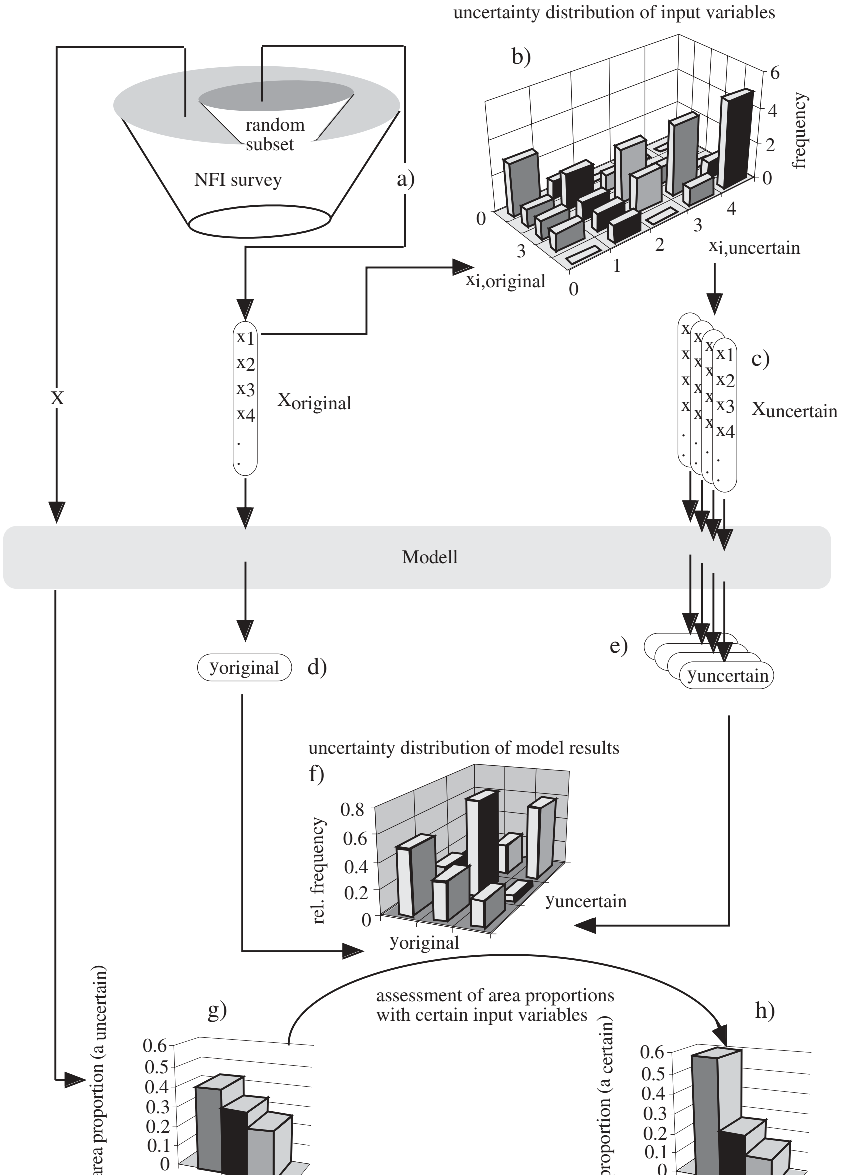


Figure 1. Study of the uncertainty propagation using Monte-Carlo simulations. For each set $X_{original}$ of input variables, which was determined from a randomly selected subset of the NFI survey (a) several sets $X_{uncertain}$ (c) are randomly selected from a given empirical uncertainty distribution (b). The model is used to calculate the results $y_{original}$ (d) and $y_{uncertain}$ (e) with the help of the input data sets $X_{original}$ and $X_{uncertain}$, respectively. By repeating this simulation many times (indicated by the different layers), the uncertainty distribution of the results (f) is determined. Together with the area proportions of the model results determined from all NFI sample plots (g), the uncertainty distribution is then used to assess what the area proportions of the results would have been if the input data had been certain (h).

4.4.1.2 Examined Models

The uncertainty propagation was studied in the models for:

1. The stability of the protection forest (protection forest model, see "Stability Standards in the Protection Forest", Chapter 3.6)
2. The ecological quality of forest areas (biotope model, version BIOLFI2, see Chapter 3.8)
3. The ecological quality of forest edges (ecotone model, version OEKOLFI2, see Chapter 3.8)
4. The recreational quality of forests (natural characteristic model, version ERHNAT3, see Chapter 3.7)
5. The determination of the forest type (EAFV 1988)

The structure of the models is described in the appropriate chapters and literature; the input variables that enter the individual models are presented in Table 1.

Table 1. Models and attributes used in the uncertainty analysis. For a precise explanation, see the model descriptions or documentation of the variables in the appendix. "Fixed" means that no check assessment was available for this attribute. It was therefore not changed. "Uncertain" means that it was changed based on the uncertainty distribution of the check assessments.

Model	Input variable	Definition	Fixed	Uncertain
Protection forest Chapter 3.6	STRUK	Stand structure		x
	VERJDG	Closure of regeneration		x
	SCHLUSSG	Crown closure		x
	KROLAE	Crown length		x
	KROFRM	Shape of crown		x
	BHD	Diameter at breast height		x
	BHOHD	Derived tree height		x
	PROB1-3	Probability of VUNIT1-3	x	
	VUNIT1-3	Most probable PNV	x	
Forest type according to (EAFV 1988)	STRUK	Stand structure		x
	EST	Stage of development		x
	WTYP	Type of forest		x
	WFRM	Origin and management type of forest		x
	NUTZKAT	Utilization category	x	
Biotope rating Chapter 3.8	STRUK	Structure		x
	EST	Stage of development		x
	SCHLUSSG	Crown closure		x
	BHDGT50	% trees with DBH > 50	x	
	BSTSGRAD	Degree of damage	x	
	WARA	Forest edge present?	x	
	BESTGRE	Stand edge		x
	LUECKEN	Type of gap		x
	STRADG	Closure of shrub species		x
	BEERDG	Closure of berries		x
	STOECKE	Stumps		x
	DUERRSTA	Standing dead trees		x
	AHAUFEN	Heaps of branches		x
	BWNATURN	Biotope rating closeness to nature	x	
	BWARTEN	Biotope rating species	x	
Ecotone value Chapter 3.8	WRARTEN	Species at forest edge	x	
	AUFBAU	Type of forest edge (vertical)		x
	MANTELBR	Width of forest edge		x
	STRABR	Width of shrub belt at forest edge		x
	KRAUTBR	Width of herbals belt at forest edge		x
	VERLAUF	Type of forest edge (horizontal)		x
	DICHTE	Density of forest edge		x
	WRUMG	Surrounding of forest edge		x
Natural characteristics Chapter 3.7	BODENVEGDG	Closure of ground vegetation		x
	STRUK	Stand structure (vertical layers)		x
	EST	Stage of development		x
	STRADG	Closure of shrub species		x
	WRUMG	Surrounding of forest edge		x
	LUECKEN	Type of gaps		x
	ERHARTEN	Species important for recreation	x	

4.4.1.3 Original Input Values

The original input values (i.e., the values of the attribute x_i that are assumed to be known as certain) were first generated by a random number generator. It was assumed that the attributes were uniformly distributed over the range of all possible NFI values and that they were independent. However, this led to many unrealistic attribute combinations and to biased result distributions. Thus, in the final simulations, the original input values were determined from a randomly selected subset of NFI samples, so that the resulting combinations were realistic.

4.4.1.4 Uncertainties of the Input Variables

The uncertainty distributions of the input variables of the models (see Table 1) were derived from the control study that was conducted between 1993 and 1995 (see Chapter 2.9). During the study, some of the sample plots were assessed twice. The results were presented in contingency tables (Chapter 2.9, Table 2 and 3) which indicated how often the control team decided upon the value $x_{i,j}$ for the attribute x_i when the survey team had chosen $x_{i,k}$.

In this study, the term “uncertainty” is used for such deviations instead of the term “error.” The reason for this is because the check assessment is not an assessment of the error in the strict sense, since it is not possible to determine the deviation of the survey from a fixed true value. The contingency tables reflect the variability of the assessment between teams. The true variability must be assumed to be slightly lower than the variability of the contingency tables, since the latter combines the variability of the survey team with the one from the control team. This should be taken into account for the evaluation of the results.

Neither the uncertainty distributions of the input variables nor those of the model results changed significantly if the marginal distributions of the columns in the contingency tables were used instead of the marginal distributions of the rows (e.g., Chapter 2.9, Table 3). In other words, if the survey from the control team was used as a reference value instead of the survey from the first team. The final study was conducted using the marginal distributions of the rows.

An example for the uncertainty distribution of discrete attributes (see Table 1) is given in Figure 2. The distributions for the stand structure and regeneration coverage assessed by the control team are plotted as frequency distributions of the differences to each of the possible outcomes assessed by the survey team.

The uncertainties of the continuous DBH measurement proved to be symmetric in the 1993 check assessment. Thus, it was assumed that the DBH followed a normal distribution with mean 0 and standard deviation (measurement error) 0.7 cm, as determined by the check assessment.

The tree height (BHOHD, see variable documentation, Chapter 6.1) was estimated with an empirical model that used the DBH (Chapter 3.2). Its (random) model error (i.e., the standard deviation of possible results from the model around the mean model function, which is estimated with a regression analysis) amounts to 3.8 m. This model was calibrated with the measured height against the measured DBH. The measured height, in itself, contains a random error (standard deviation) of 1.5 m. This results in an overall error (standard deviation) of

$$\sqrt{3.8^2 + 1.5^2} \cong 4.$$

The most probable potential natural vegetation unit (VUNIT1, see variable documentation, Chapter 6.1), an input variable of the protection forest model, was determined using the potential natural vegetation (PNV) models of BRZEZIECKI, KIENAST and WILDI (see also Chapter. 3.1, BRZEZIECKI *et al.* 1993; 1995; KIENAST *et al.* 1994; KIENAST *et al.* 1996). This model provides for each sample point, depending on the site conditions that exist there, the three most probable forest communities together with the probability of occurrence.

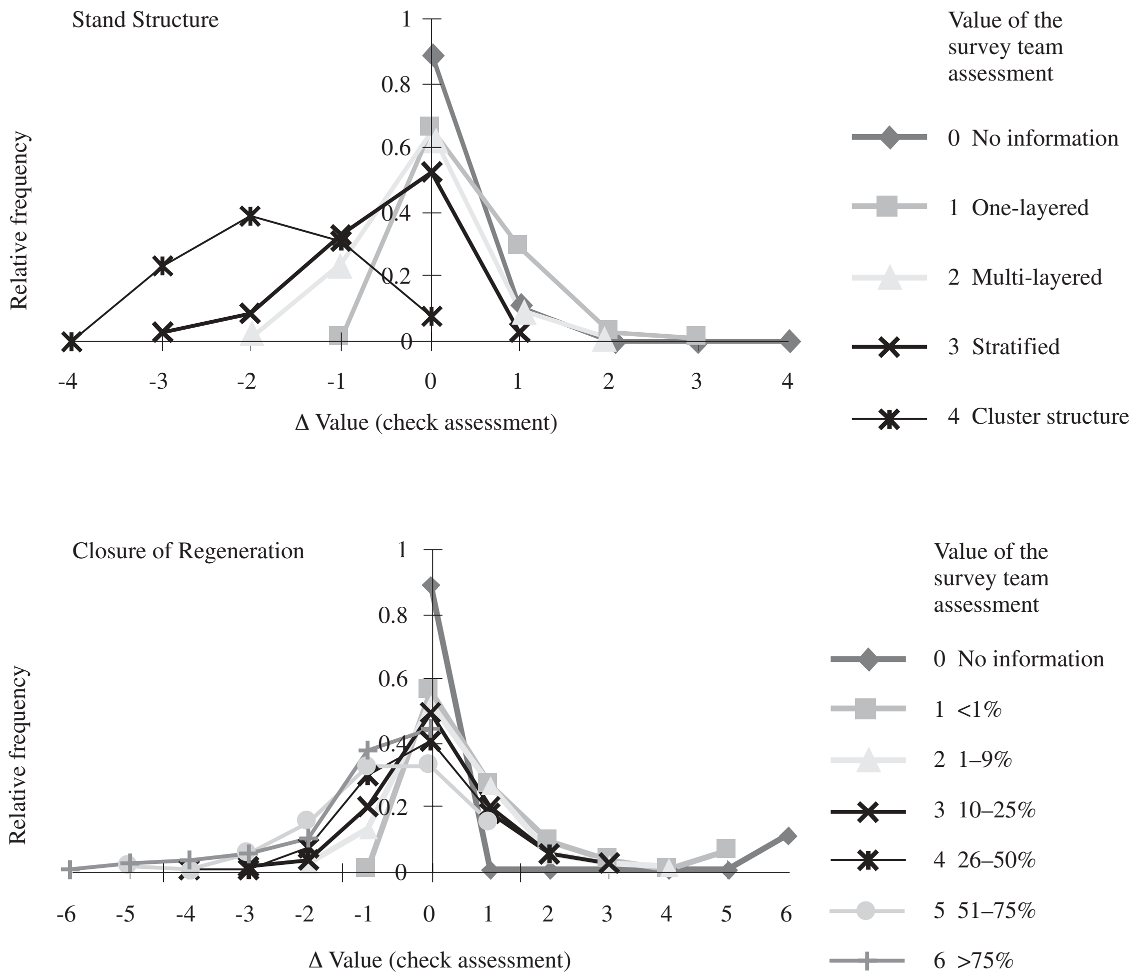


Figure 2. Uncertainty distribution of the input variables from the check assessment, using the example of stand structure and closure of regeneration. The relative frequencies of the differences between the assessment of the control team and the survey teams are presented. Each line represents an attribute value selected by the survey team. For example, if the survey team assessed the stand structure as 4 (cluster structure), the control team assessed, in 40% of the cases, the same stand with the decision 4-2 = 2 (multi-layered).

This model also contains uncertainties which are, for the most part, due to the insufficient quality and quantity of the underlying data in some regions. In order to estimate the influence of such uncertainties of the simulated PNV on the protection forest simulation, the probability $P_{vunitMod}$ was introduced for the confidence of the PNV model results. With this probability $P_{vunitMod}$, one of the three most probable forest communities was selected. Within these three forest communities the probabilities calculated by the PNV model were used for the selection. With the probability $1\text{-}P_{vunitMod}$, however, *any* forest community was randomly selected. During a sensitivity analysis, the $P_{vunitMod}$ varied between 0.5 and 1.

For variables where no check assessments were conducted, the values assessed in the NFI were used (i.e., they were assumed to be certain) (“fixed” in Table 1).

4.4.1.5 Monte-Carlo Simulation

The four examined models were programmed in Modula-2. From 600 randomly selected NFI sample plots, the outcome was determined and used as the input variable. For each set of “original values” $X_{original}$, 100 additional sets with “uncertain values” $X_{uncertain}$ were selected with the help of a random number generator from the empirical distribution of the check assessment.

The random selection from an empirically determined discrete distribution of the attribute *m* with the probability density *f(m)* and the cumulative distribution function *F(m)* is illustrated in Figure 3. Using a random number generator, a value *u* is selected from a [0,1] uniform distribution (in the example 0.55) and determined in which interval of the cumulative distribution function *F(m)* *u* falls. The corresponding *m*-value (in example 2) is then selected.

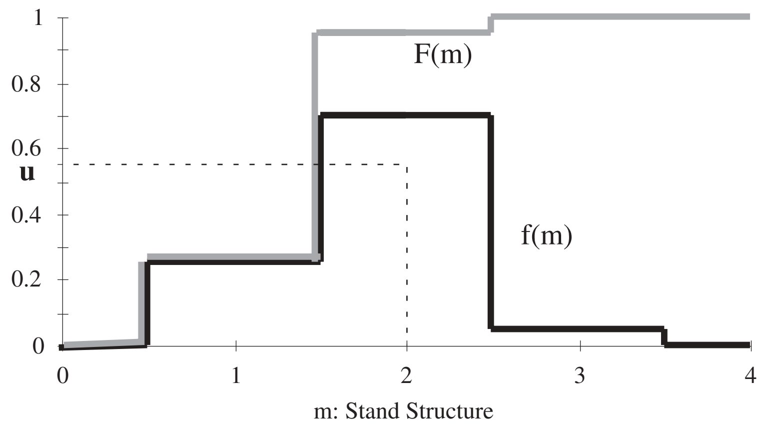


Figure 3. Random selection from a discrete, empirical distribution *p*. The example here is the empirical distribution f(stand structure) when the original value of the stand structure is 2 (multi-layered) (see Figure 2). The cumulative distribution function *F* is calculated from the empirically determined density function *p*. Using a random number generator, a number *u* is randomly selected from a uniform [0,1] distribution (here: 0.55). The next step is to determine in which interval of *F* *u* falls. The stand structure associated with this interval (here: 2) is selected.

The models were applied using the original ($X_{original}$) input variables and the uncertain ($X_{uncertain}$) input variables associated with them. This led to original result values and to 100 uncertain result values $y_{uncertain}$ for each $y_{original}$. It was then determined how frequently each $y_{uncertain}$ was obtained for a certain $y_{original}$ (see example in Table 2).

At the end of the simulation, the relative frequencies of the uncertain results per original result value were determined. This resulted in the matrix *U* of the uncertainty distribution (Table 3). The relative frequencies in the rows of *U* indicate for a certain original value how frequently the same or other (uncertain) values resulted. In this form they can be used for a-priori uncertainty estimations; in other words, they indicate how a (hypothetical) true result, which is based on certain input data, would be distorted by the uncertainty of the input data.

Table 2. Absolute frequencies of the model results from the Monte-Carlo simulation with the example of the protection forest model. Presented are the proportions of fulfilled criteria for a sufficient stability of the protection forest, which were calculated with original data and with data determined with the uncertainty distribution.

$y_{unsicher}$ $y_{original}$	alle	≥2/3, <1	>1/3, <2/3	≤1/3	∑
alle	92	59	19	1	**171**
≥2/3, <1	42	118	54	1	**215**
>1/3, <2/3	19	71	112	5	**207**
≤1/3	1	1	3	2	**7**
∑	**154**	**248**	**189**	**9**	**600**

Table 3. Uncertainty distributions (matrix *U*) for the model's results, referring to results calculated with the original data for the example of Table 2.

$y_{unsicher}$ / $y_{original}$	alle	≥2/3, <1	>1/3, <2/3	≤1/3	∑
alle	0.538	0.345	0.111	0.006	**1**
≥2/3, <1	0.195	0.549	0.251	0.005	**1**
>1/3, <2/3	0.092	0.343	0.541	0.024	**1**
≤1/3	0.143	0.143	0.429	0.286	**1**
∑	**0.968**	**1.380**	**1.332**	**0.320**	**4**

Table 4. *A-posteriori* probability distribution (Matrix U^{-1}) for the model results of the example in Table 2 (see equation 2).

	alle	≥2/3, <1	>1/3, <2/3	≤1/3	∑
alle	2.445	-1.740	0.346	-0.051	**1**
≥2/3, <1	-0.977	3.283	-1.390	0.084	**1**
>1/3, <2/3	0.255	-1.877	2.837	-0.215	**1**
≤1/3	-1.116	2.045	-3.734	3.805	**1**
∑	**0.607**	**1.710**	**-1.941**	**3.624**	**4**

4.4.1.6 Uncertainties of the Area Proportions

The analysis of the normally assessed NFI data that used different models showed the area in which a certain result category was obtained; separately for each larger region and for all of Switzerland. According to the protection forest model, approximately 38% of the area in protection forest regions (Chapter 3.6) meet all of the criteria for sufficient stability of the protection forest; 27% meet between one and two-thirds of the criteria; and only 2% meet less than one-third of the criteria.

These numbers seem to contradict the column margins in Table 2. However, it is important to note that the 600 NFI sample plots, which were used to generate the original data for this analysis, originate from all over Switzerland, while the analysis of the protection forest model only refers to those regions in which the forest fulfilled a certain protective function. Despite this, the uncertainty matrices that were determined using these data are still generally valid, since they only contain the proportion of the uncertain results (i.e., the column margins are not important).

Under the unrealistic assumption that these area proportions are the result of the model's analysis using "certain" input variables, it is possible to find out, with the help of the uncertainty distribution matrix *U* determined in Chapter 4.4.1.5, how these uncertainties affect the area proportions in the result categories. In order to accomplish this, the areas associated with the result categories (vector $a_{certain}$) are newly distributed according to the matrix *U* into the category.

$$a_{uncertain} = \begin{pmatrix} a_{uncertain,1} \\ \vdots \\ a_{uncertain,n} \end{pmatrix} = \begin{pmatrix} u_{1,1} & \cdots & u_{1,n} \\ \vdots & \ddots & \vdots \\ u_{n,1} & \cdots & u_{n,n} \end{pmatrix} \cdot \begin{pmatrix} a_{certain,1} \\ \vdots \\ a_{certain,n} \end{pmatrix} = U \cdot a_{certain} \qquad (1)$$

Example 1: In the example of the protection forest with *U* from Table 3, 38% of the area with the category "all stability criteria fulfilled" is newly distributed with 0.345*38%=13.11% in the category "more than 2/3 of the stability criteria fulfilled;" with 0.111*38%=4.218% in the category "between 1/3 and 2/3 of of the stability criteria fulfilled;" and with 0.006*38%=0.228% in the category "less than 1/3 of the stability criteria fulfilled." Only 0.538*38%=20.44% remain in the category "all stability criteria fulfilled."
The new area proportions result then by newly distributing the area proportions of all categories and adding them up.

The NFI surveys are subject to the variability of the survey teams; thus, the input variable and the results from the models, as well as their area proportions, must be considered uncertain (i.e., $a_{uncertain}$ denotes the uncertain, but known, results of the survey). Therefore, it is of interest to estimate in retrospect (*a posteriori*), how the results and their area proportions $a_{certain}$ would have been if the results had been certain (i.e., if the survey teams would have assessed the attributes in the same way). For this (1) is solved for $a_{certain}$:

$$\begin{aligned} & U \cdot a_{certain} = a_{uncertain} \\ \Leftrightarrow\ & a_{certain} = U^{-1} \cdot a_{uncertain} \end{aligned} \tag{2}$$

For the example of the protection forest model U^{-1}, the inverse matrix of U is given in Table 4.

The uncertainty distribution of the results from the models and the *a-posteriori* area proportions calculated with (2) are presented in the following.

4.4.2 Results

The results of the uncertainty analysis are given in Figures 4 through 11. The first figure for each model shows the uncertainty distribution of the results from the models as the difference to the results of the original values.

> Example 2: If in Figure 6, the biotope rating of original data takes on the value 4 (category "high," a curve with solid squares), the biotope ratings for 60 % of the uncertain data also have the value 4, i.e., Δbiotope rating = 0; in 40% of the cases they have the value 3 ("tends to be high"), i.e., Δ biotope rating = –1. Values of 2 and 1 (category "tends to be low" and "low") do not exist at all, i.e., Δ biotope ration = –2 and –3.

The second figure shows the assessed area proportions together with the a-posteriori area proportions.

Table 7 shows for all models the mean value of the attribute category that was determined with the area proportion – with and without variability.

4.4.2.1 Protection Forest Model

Figure 4 describes the uncertainty distributions of the proportions, in which the stability criteria of the protection forest are fulfilled, for three different values of $P_{vunitMod}$ (i.e., the confidence of the PNV model). The difference between the three simulations is small, which indicates that the uncertainty of the PNV model has only a very small influence to the overall result. If less than a third of all stability criteria are fulfilled by simulations that have "certain" original values (category 4, curves with solid squares), then the uncertainty distribution is shifted strongly in the direction of the higher proportions (smaller categories). For the other values that were generated with the original data (other curves), the value itself was selected with a probability of about 0.6; whereas, the neighboring values were selected with a probability of 0.2 to 0.4. The area proportion (Figure 5) for "less than two-thirds of the stability criteria fulfilled" increased slightly. The area proportion for "all of the stability criteria fulfilled" strongly increased at the expense of the area proportion, for "more than two-thirds of the stability criteria fulfilled."

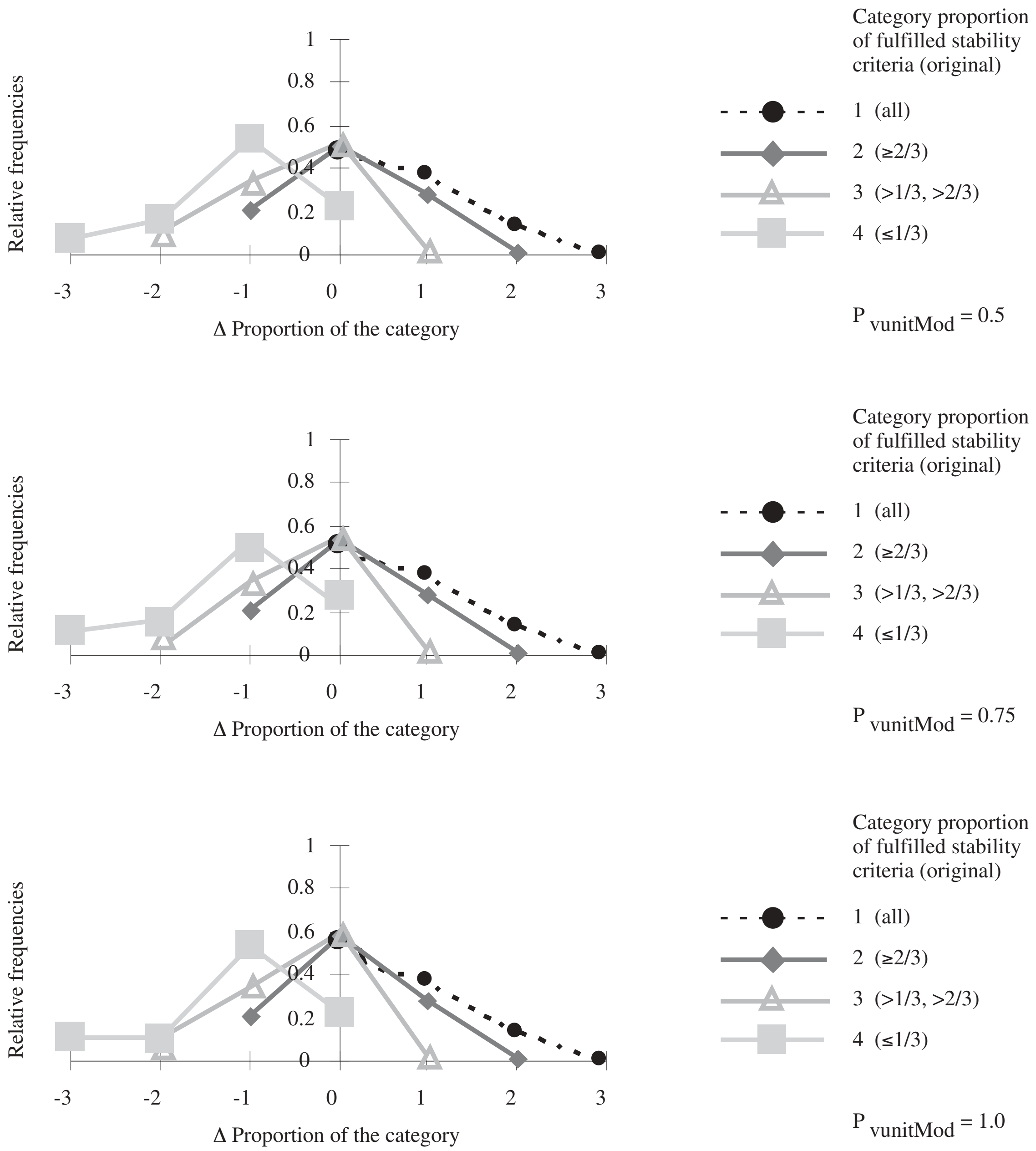


Figure 4. Uncertainty distribution for the proportion of fulfilled stability criteria according to the protection forest model. (The proportions were given in discrete categories). Plotted are the relative frequencies of the deviations between the proportions that were calculated from input variables of randomly selected NFI sample plots (“original”), and the proportions calculated with “uncertain” values of the input variables. The “uncertain” input was determined by selecting from the corresponding uncertainty distribution (e.g., Figure 2, Table 2 and 3 in Chapter 2.9). Each curve represents a proportion that is based on original data. The x-axis represents the differences of the “uncertain” proportions to the original proportions. $P_{vuniModt}$: Confidence of the PNV model.

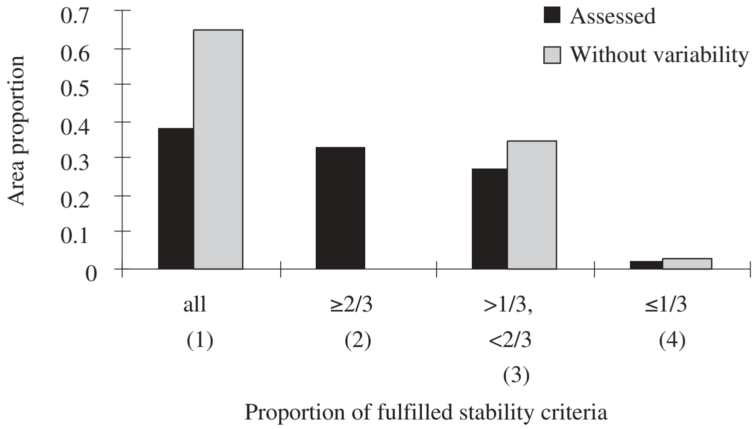


Figure 5. Area proportions for different proportions of fulfilled stability criteria in all of Switzerland. The area proportions were determined (a) with the protection forest model with assessed (i.e., variable, uncertain) data and (b) corrected with the inverse uncertainty distribution. The corrected distribution corresponds to the distribution which would occur if the data did not have any variability, i.e., would have been certain ($P_{vunitMod}$=0.75).

4.4.2.2 Biotope Model

Figure 6 shows a low sensitivity of the biotope rating model with respect to the uncertainty of the input variables, which is also reflected in the small change of the area proportion as seen in Figure 7.

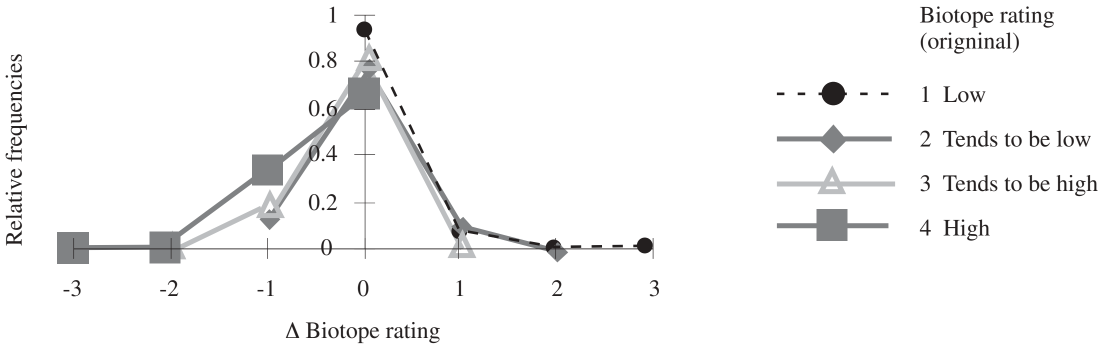


Figure 6. Relative frequencies of the deviations of the biotope rating according to the model BIOLFI2. Plotted are the relative frequencies of the deviations between the biotope ratings that were calculated from input variables of randomly selected NFI sample plots (“original”), and the biotope ratings calculated with “uncertain” values of the input variables. The “uncertain” input was determined by selecting from the corresponding uncertainty distribution (e.g., Table 2 and 3 in Chapter 2.9). Each curve represents a biotope rating that is based on original data. The x-axis represents the differences of the “uncertain” to the “original” biotope rating.

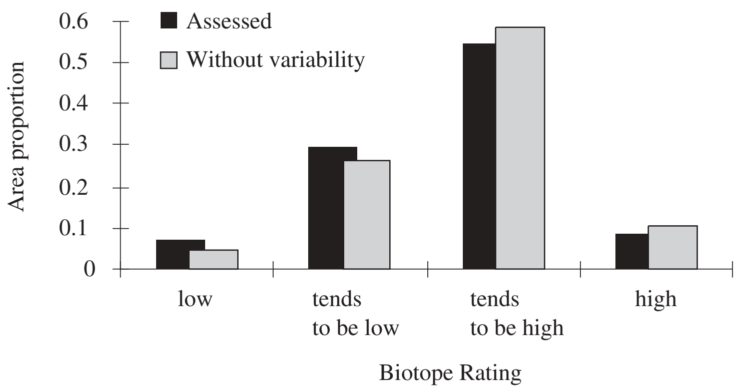


Figure 7. Proportions of the area representing different biotope ratings in all of Switzerland. The area proportions were determined (a) with the biotope rating model with assessed (i.e., variable, uncertain) data and (b) corrected with the inverse uncertainty distribution. The corrected distribution corresponds to the distribution, which would occur if the data did not have any variability, i.e., would have been certain.

4.4.2.3 Ecotone Model

The ecotone model reacted with slightly more sensitivity to the uncertainty of the input variables (Figure 8). The area proportions (Figure 9) were shifted from the lower to the higher ecotone values.

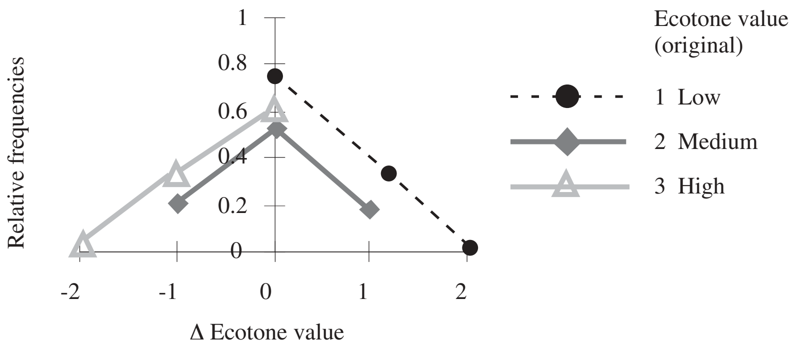
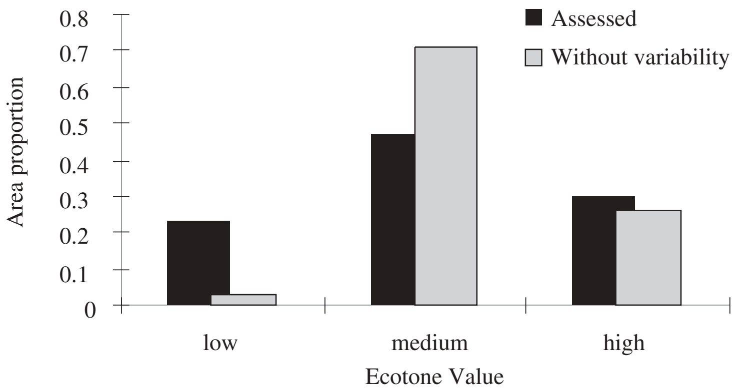


Figure 8. Relative frequencies for the deviations of the ecotone values according to the model OekoLFI2. Plotted are the relative frequencies of the deviations between the ecotone values that were calculated from input variables of randomly selected NFI sample plots ("original"), and the ecotone values calculated with "uncertain" values of the input variables, which were determined by selecting the input variables from the corresponding uncertainty distribution (e.g., Table 2 and 3 in Chapter 2.9). Each curve represents an ecotone value that is based on original data. The x-axis represents the differences of the "uncertain" to the "original" ecotone values.

Figure 9. Proportion of the area representing different ecotone values in all of Switzerland. The area proportions were determined with the ecotone model with assessed (i.e., variable, uncertain) data and (b) corrected with the inverse uncertainty distribution. The corrected distribution corresponds to the distribution, which would occur if the data did not have any variability, i.e., would have been certain.



4.4.2.4 Natural Characteristics

The uncertainty distribution for the natural characteristics' model (Figure 10) was shifted from "low" natural characteristics to "tends to be low" natural characteristics. The area proportion (Figure 11) increased for the categories "high" and "tends to be low" at the expense of the category "low" and "tends to be high."

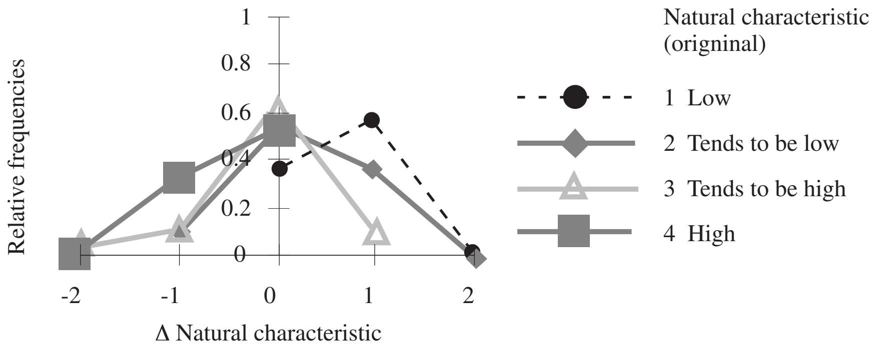


Figure 10. Relative frequency for the deviations of the natural characteristics according to the model NATUERH3. Plotted are the relative frequencies of the deviations between the natural characteristics that were calculated from input variables of randomly selected NFI sample plots (“original”), and the natural characteristics calculated with “uncertain” values of the input variables, which were determined by selecting the input variables from the corresponding uncertainty distribution (e.g., Table 2 and 3 in Chapter 2.9). Each curve represents a natural characteristic that is based on original data. The x-axis represents the differences of the “uncertain” to the “original” natural characteristics.

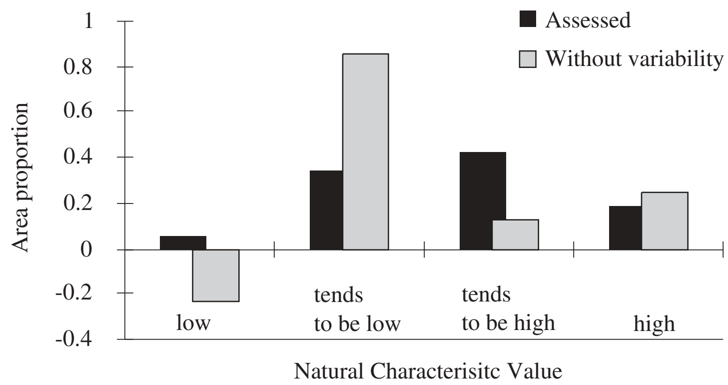


Figure 11. Proportion of the area representing different natural characteristics in all of Switzerland (a) with assessed (i.e., variable, uncertain) data and (b) corrected with the inverse uncertainty distribution. The corrected distribution corresponds to the distribution, which would occur if the data did not have any variability, i.e., would have been certain.

4.4.2.5 Forest Type Model (According to Report 305)

Table 5 demonstrates that, due to the uncertainties in the input variables, some systematic uncertainties in the determination of the forest types arise. Some of the forest types (namely 6, 10, 11, 14, and 16) are frequently classified as medium timber (type 15). Plantations are not clearly recognized and are wrongly identified as uniform high forests. The types coppice forest and coppice with standards are being confused or are classified as pole wood. Plenter type high forests have a high chance of being classified as irregular high forests or as young or medium timber. The classification of young, medium, and old timber is not well defined. In the area proportions (Figure 12) the uncertainties affect the transition from pole wood to timber in particular. For certain input data, area proportions of pole wood would decrease at the expense of the young and medium timber. Especially drastic is the influence of the uncertainties for irregular high forests. If “certain” input data would be used, the area proportion of this forest would completely change to the plenter high forest.

Table 5. Relative proportion of forest types determined from the uncertain input data (rows) per forest type determined from the original input data (columns). Proportions over 0.3 (in this example only on the diagonal) have a black background; proportions between 0.2 and 0.3 are framed bold; and proportions between 0.1 and 0.2 are framed. The codes are defined in Table 6.

Unsicher Original	0	3	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0.90	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.05
3	0.01	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.01	0.00	0.00	0.48	0.00	0.01	0.01	0.04	0.08	0.03	0.07	0.05	0.12	0.09	0.01
7	0.01	0.00	0.00	0.04	0.51	0.00	0.00	0.02	0.19	0.02	0.04	0.06	0.06	0.05	0.01
8	0.00	0.00	0.00	0.04	0.00	0.40	**0.21**	0.01	0.02	0.03	0.25	0.02	0.00	0.01	0.01
9	0.01	0.00	0.00	0.03	0.00	0.19	0.38	0.01	0.07	0.02	0.15	0.07	0.04	0.02	0.00
10	0.01	0.00	0.00	0.03	0.01	0.00	0.01	**0.25**	**0.20**	0.03	0.08	0.11	0.16	0.09	0.03
11	0.02	0.00	0.00	0.03	0.01	0.00	0.01	0.05	0.42	0.04	0.07	0.09	0.17	0.09	0.01
12	0.02	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.06	0.73	0.04	0.02	0.02	0.02	0.05
13	0.02	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.05	0.03	0.74	0.06	0.01	0.01	0.02
14	0.02	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.06	0.02	0.17	0.50	0.15	0.02	0.01
15	0.02	0.00	0.00	0.03	0.01	0.00	0.01	0.02	0.11	0.00	0.01	0.12	0.53	0.14	0.01
16	0.01	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.05	0.04	0.01	0.00	0.19	0.63	0.01
17	0.01	0.00	0.00	0.03	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.04	0.01	0.85

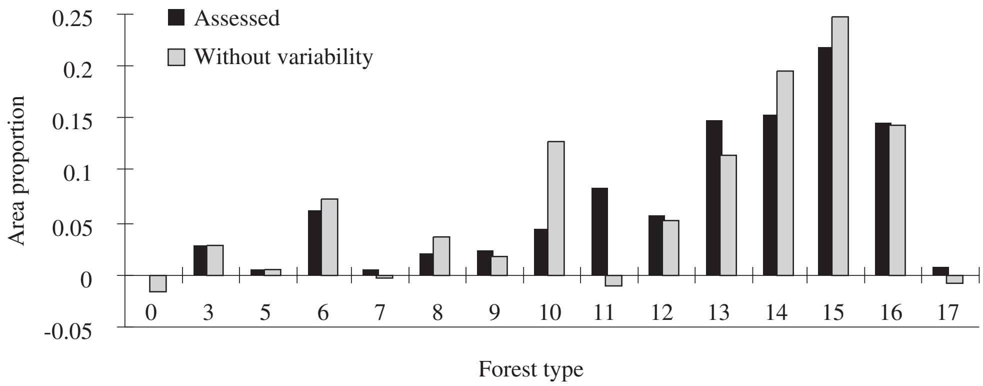


Figure 12. Proportion of the area representing the types of forest determined with (a) assessed data and (b) corrected with the inverse uncertainty distribution. The corrected distribution corresponds to the distribution which would occur if the data did not have any variability , i.e. would have been certain. Definition of the codes, see Table 6.

Table 6. Code for the forest types

0	Missing	10	Plenter high forest
3	Permanently unstocked	11	Irregular high forest
4	Temporary unstocked	12	Young growth/thicket
5	Ride and slopes	13	Pole wood
6	Permanently open	14	Young timber
7	Chestnut and other plantations	15	Medium timber
8	Coppice forest	16	Old timber
9	Coppice forest with standards	17	Incomplete description

Table 7. Swiss mean result values of models. They were determined with the area proportions based on (a) assessed data and (b) corrected with the inverse uncertainty distribution (see Figures 5,7,9,1, and 12).

	Category proportion of fulfilled stability criteria	Biotope rating	Ecotone value	Natural characteristics	Type of forest
Assessed	1.93	2.64	2.07	2.75	12.74
Without variability	1.76	2.74	2.24	2.84	12.84

4.4.3 Discussion

This study investigated how uncertainties in the input variables of several different models employed in the NFI affect the outcome of these models. The study is based on the contingency tables of the check assessment. These do not provide a distribution of errors around the true value, since the qualitative assessments do not present an objective true reference value. The distributions reflect only the dispersion of the subjective assessments. However, this is not very important for the quality of the models, as long as the same mean subjective assessment enters the model. This is true for the investigated models, since the developers of the models participated in the survey, the training, and the check assessment, and consequently were very familiar with the survey.

The contingency tables can only present the variability of the same attributes within the survey. They combine the variability of the first team and the control team. The distribution contains, as a consequence, a much higher dispersion than the actual uncertainty distribution of the survey teams. It is to be expected that the uncertainty distributions of the results from the models also have a lower dispersion; therefore, the shift of area proportions would be less. For example, negative area proportions should not occur any further if the actual uncertainty distribution can be used.

On the other hand, not all uncertainty distributions of all input variables were known. In addition, the variables presently assumed to be certain also contain a particular variability, which in turn should have led to an increase in the result variability.

4.4.3.1 Consequences

The examined models show a significant, but not aggravated sensitivity towards the data uncertainties at the magnitude they occurred. The uncertainty distribution of the result values suggests, at first glance, that the results from the models are not very reliable. This is certainly true for individual sample plots. The goal of a sampling inventory, however, is not to provide information about individual plots, but rather to present information about larger units. A relatively small deviation between the area proportion as well as the mean values (Table 7) indicate that the deviations compensate each other.

Due to the uncertainties of the input data, the models for the qualitative evaluation of the forest functions, namely the models for the protection forest, biotopes, ecotones, and natural characteristics, estimate the output variables slightly too negatively. The proportion of fulfilled stability criteria, as well as biotope and ecotone values seem, on average, to be too small. This is reflected in the average values determined from the area proportions (Table 7). Thus, the statements given in the result volume publication for the second NFI should be considered as conservative.

The misclassification of the forest types (Table 5 and Figure 12), in particular plenter forests and irregular forests, could in some cases be of importance, since some analyses in the NFI use this attribute as a stratifying attribute.

4.4.3.2 Outlook

The software developed in this study for the uncertainty analysis using Monte-Carlo simulations provides an instrument which allows efficient uncertainty analyses of other models that use the data from current and future inventories.

In order to estimate model uncertainties comprehensively, check assessments with other important attributes should be conducted during the next inventory. Especially desirable is to establish the error distribution. This could be achieved if the check assessment would be conducted by a particularly well-trained expert group, which would ideally be involved in the analysis later on. Another possibility consists in multiple surveys (more than ten surveys) of a subset of all samples. The most frequently selected outcome of an attribute would be considered the true outcome.

The sensitivity of the model towards data uncertainties, as they were shown by this study, leads one to consider that the models also react sensitively to uncertainties within the structure and the models' parameters (e.g., the interval limits within the decision trees). It is advisable to assess the influence of uncertainties with respects to model structures and parameter values, and for the classification of the result values using a sensitivity analysis (see for example BUGMANN 1994; LISCHKE 1992), if these models are used further or new models of this type are developed. The method introduced here provides the necessary instruments for this as well.

4.4.4 Literature

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5 Visions

Peter Brassel, Michael Köhl

5.1 Introduction

The attitude of society towards forests has changed. Today, forests are no longer primarily considered as a source of raw material, but are appreciated as one of the last close-to-nature landscapes. The function of forests as a source for recreation, as protection against erosion, avalanches, rockfall, noise and flooding, as habitat for animals and plants, as well as for the improvement of air and water quality, is rated higher in several different regions of Switzerland than timber production. Just as the demands on the forest have changed, so have the informational needs of society. Inventories contribute decisively in obtaining the information needed in order to allow for sound political decisions. The change of informational needs is reflected, for example, in the main focus of the first and second Swiss NFI. The first Swiss NFI focused clearly on the timber production function, while the focus in the second Swiss NFI changed towards non-wood goods and services.

The demands for inventories are high. They should cost little, and at the same time should satisfy all current informational needs. They should be conducted with the most up-to-date methods and technologies, and should provide scientifically sound estimates of the target parameters (LUND 1998). The translation of the informational needs into suitable methods and attribute catalogs, the evaluation of appropriate sources of data, and the study of the inventory perimeter is a continuous process, which is essential for scientifically sound inventories. Without research, it is not possible to achieve the high standards set for inventories. The development of methods for the third NFI is being conducted in the following four activity fields: 1) Inventory design and statistical methods, 2) survey techniques and attribute catalogs, 3) modeling and prognosis tools, and 4) implementation and extension services.

5.2 Inventory Design and Statistical Methods

The sampling design, the assessment rules, and the statistical analysis methods are the center of any sample based environmental observation. The development of methods must comply with the informational needs, the objectives of the inventory, the availability of suitable data sources and auxiliary information, and it must meet the long-term objectives. Last but not least, it should be compatible with inventories on successive occasions.

In large-scale forest inventories, the further development and changes of methods from one inventory to another is more the rule than the exception. For example, today's inventory design of the Swedish National Forest Inventory does not have much in common with the first national forest resources assessment conducted in the 1920's. Their commonality is that both times information was gathered about the forests, and that the terrestrial assessment remained the most important data source.

Methodological changes made it possible to apply the newest development in sampling theory, computer science, and remote sensing in the Swiss NFI, and thus utilized all possibilities to increase the accuracy and to decrease the inventory costs. The savings of variable cost are best realized by reducing relatively expensive components, such as expenses for field assessments. One way of cost reduction is to increase the extensive utilization of remote sensing data. In addition to the introduction of double sampling for stratification, it is conceivable to extend the attribute catalog and the sampling intensity of the aerial photography interpretation. This would render the further reduction of estimation errors and cost possible.

Updating of the existing data sets offers another possibility to reduce expenses. Similar to the increment models, which are used in the second NFI, methods for updating other attributes should be developed and applied. The choice of such an approach to describe changes resulted, for example, in a considerable cost reduction to forest inventories in the United States (HAHN and HANSEN 1983).

The optimization of inventory cost can only consider variable costs that are dependent on sample size and occur during the field survey, aerial photography interpretation, and the map survey. The most important cost factor, which cannot be reduced, however, is the method development itself in a broader sense, due to changing demands. Identifying informational needs and transferring them into measurable attributes, statistical design, evaluation of data sources, and development of feasible assessment methods and programs, software for the database and analysis, interpretation of the results, implementation of the information, infrastructure, and general knowledge about inventories are the indispensable basis for national inventories.

The reduction of the field assessments by employing statistical models for updating stand developments, or by the extensive utilization of remote sensing data, conflicts with the current and future informational needs. Many of them require intensive observations in the forests and on individual trees. For example, monitoring species diversity or regeneration can only be carried out through field assessments.

The objectives of the second Swiss NFI were to provide reliable information on current state and changes for entire Switzerland and the five productive regions. These objectives could be met by a cost-efficient inventory design. By intensifying aerial photo interpretation and employing a double sampling for stratification design, it was possible to reduce the number of field plots by roughly fifty percent and maintain the sampling errors of the first NFI. If results are to be presented for units of reference on a level smaller than the productive region, i.e., cantonal or community level, the sample size of the NFI might not be sufficient to provide results with an adequate reliability, since sampling errors may become too large for decision making.

For the third NFI, the sampling intensity of both aerial and field samples must be evaluated in the scope of the then valid inventory objectives. The NFI-design is, however, open for a local intensification of the sample grids by regionally or locally increasing the number of aerial or terrestrial plots by additional assessments in order to maintain both satisfaction of informational needs and cost-efficiency. Thus, reliable information could be provided for specific regions of interest or hot spots. The assessment and estimation procedures and the analysis software can still be applied in those situations.

In the future, aerial photographs will still be an important data source for the NFI, as long as aerial photographs with complete coverage are available without charge. However, the analysis does not necessarily have to be carried out using an analytical method with aerial photography interpreters, as in the current survey. Developments in the area of digital photogrammetry open up new possibilities for future employment of aerial photographs in obtaining information for the NFI (OESTER and KÖHL 1995). Digital photogrammetry offers the measurement of structural attributes which could replace qualitatively assessed information such as development stage, stand structure, or crown closure.

In the future, remote sensing will gain in importance as an option in obtaining current, up-to-date and geo-referenced data with complete coverage. The utilization of satellite imagery, however, still needs to overcome some obstacles, of which the insufficient classification accuracy of different forest types is the most serious (BODMER 1993; KELLENBERGER 1996). Satellite remote sensing is described in several publications as an ideal method to assess forest resources; the classification accuracy mentioned in these publications are, however, difficult to achieve with the heterogeneous forest structure and topography of Switzerland. Nevertheless, the technology of satellite remote sensing is currently developing so fast that it might be an operational tool at the time of the third NFI. Aerial photography and terrestrial surveys could be supplemented by digital satellite images or by radar (SAR) data. One important field for the application of satellite remote sensing could become the classification of forest areas and the preselection of spots on which field surveys will be conducted.

NFI methods and information are increasingly used for reports at the cantonal level. Some cantons built up on the information provided by the NFI and intensify the sampling grid on the cantonal level. This approach results in a sound information basis for multi-purpose forest planning at the regional level. A side-effect of this synergism is that expensive forest inventories for larger forest enterprises can be replaced, and information on both public and private forests is available. The current NFI-design and the NFI data base management system enables the establishment of an integrated forest information system that combines information assessed on the national, cantonal, regional and even local levels.

The importance of computer science will increase even more in the future. The database should be developed further and optimized. The complexity of the structure and the size of the database will drastically increase with additional inventories. This will increase considerably the access time for joins and queries. Maintaining and optimizing the database will be essential in order to allow the information of the NFI to be widely used. The programs for gathering data directly in the forest and in open fields with a laptop computer must be adjusted to the new technology, operating systems, and interfaces. Software for the data assessment of aerial photographs and satellite images has to be evaluated and further developed. Finally, the analysis software has to be provided.

5.3 Survey Techniques and Attribute Catalog

The survey technique is, and will remain, an essential prerequisite to the NFI. On the one hand, the technique fits in with already existing inventories in order to ensure that results can be compared; on the other hand, it complies with the new needs for information. By translating these needs into measurable and reproducible attributes, one of the most important basics for the entire inventory system is established. Apart from the attributes used today, other ones will be required in the future. These include attributes for the vegetation survey, the soil parameter, the intensive survey of the forest structures in the montane forests to evaluate the protection function, and the extended young growth inventory to evaluate the forest and game problem. Although the number of terrestrial sample plots does not necessarily have to be increased, the surveys on the individual sample plots will be more extensive and intensive, and will require highly qualified field survey equipment.

The recreational space required by humans, and the space needed for animal and plant habitats is not limited to forests alone, but encompasses the entire landscape; especially the extensively used areas. For many problem tasks, it is not possible to evaluate the forest separately from other biotopes (e.g., alpine meadows, pastureland). This requires an expansion of the inventory perimeter to the entire extensively used terrestrial ecosystem.

Up until today, the Swiss forest periodically was surveyed in a ten-year cycle. Apart from the indisputable advantages, this approach has several disadvantages, such as the relatively long period of time that must pass until new attributes can be introduced, or the decrease in the up-to-dateness of the results between two surveys. One alternative to the periodic surveys in a ten-year interval appears to be the permanent survey (Scott *et al.*, 1999, Schreuder *et al.*, 1999). For this, every year a tenth of the inventory quota is assessed either per region or in systematic sub-grids, which cover all of Switzerland every year. If the survey would be conducted per region, it would be possible to publish annual results for the region or canton that was surveyed. However, for the summary of the inventory data in a form comparable to the current result reports, the ten-year survey period would require that the individual tree and sample plot data must be updated too. If the data would not be updated, it would not be possible to determine which “current” state the NFI results would reflect.

The necessity to update the area and tree data for permanent inventories leads inevitably to complex statistical algorithms. A preliminary study conducted during the preparation for the third NFI (Scott *et al.*, 1999) showed that the estimation procedures would make it impossible to analyze the NFI data with standardized analysis methods as they are currently used for the NFI. In addition to this, the result tables would not be additive any longer and the results of the NFI analysis would not be intuitively comprehendible.

In the future, the NFI will have to comply with international standards and definitions. Currently, all European countries employ for their own national forest inventories a system of nomenclature and definitions that historically grew out of specific national conditions, but which only partially allow for a comparison between different countries. Several international organizations (EU, UN-ECE, and UN-FAO) are currently attempting to harmonize the most important key parameters for forest inventories and develop mandatory definitions and consequently international standards.

The NFI has been actively involved in the development of a harmonic nomenclature (KÖHL and PÄIVINEN 1996) and will have to comply with the international conventions in the future. However, this should not effect the comparison of the current NFI results with earlier surveys.

5.4 Modeling

The NFI data are suitable as a basis for modeling the forest development and for the derivation of cause and effect relationships. Ecosystems are strongly influenced by their abiotic and biotic environment. The information about the states and the developments in the landscape and in the forest could be combined with relevant environmental data. This could allow for the derivation of hypotheses about cause and effect relationships, and could improve the understanding of the interaction between forest and landscape on the one hand and influence factors on the other.

Since all of the NFI data have a spatial reference, it is easily possible to combine them with geo-referenced environmental data. For the preservation of the biological diversity in ecosystems, it is possible to combine the data with other inventories, for example, the inventory of lowland moors that are of national importance (BROGGI 1990). Apart from the modeling, it is feasible to use different techniques such as conventional analysis systems, GIS, knowledge-based systems, fuzzy techniques, or neural networks within the scope of an environmental system research.

The interest will further shift from a pure account of the current state (first NFI) and the registration of changes (second NFI), to scenarios of future development (third NFI) (e.g., climatic changes). This requires a better understanding of relationships in the ecosystem forest, the impact to the ecosystem, the effects and function of the forest, as well as the instruments used for predictions and for assessing the risk.

An important part of such instruments are models that allow hypotheses to be tested with regard to the cause and effect relationship, and which allow the simulation of future developments of forests and landscapes. These could include statistical models that are derived directly from the NFI data or mechanistic ecosystem models.

Statistical models can be derived directly from the NFI data and provide reliable empirical estimates (e.g., relationships between DBH and tree volume, see Chapter 3.2 or for short to medium-term developments of the forest, see Chapter 3.3).

Mechanistic ecosystem models, by comparison, cannot be directly derived from the NFI data, since they require detailed knowledge on a smaller spatial, temporal, and structural scale. The NFI data provide, nonetheless, an excellent opportunity to initialize, standardize, and validate existing (BUGMANN 1996; LISCHKE *et al.* 1998) and newly developed models (e.g., based on Chapter 3.4), which are built upon the knowledge and assumptions about the processes that take place in the forest system. Such models could then predict long-term changes in the Swiss forest as a reaction to different environmental conditions (for example see LISCHKE 1998) and could test hypotheses about cause and effect relationships. These models will, for example, allow finding areas in which the sustainability would be not ensured under certain environmental scenarios (e.g., continued climate change or increased browsing intensity).

The significance of the raw material wood by itself, the high increase of the timber volume that was determined with the second NFI, and the resulting risk for the sustainability of forest effects have become a high priority in solving the problem of “timber, biomass, and CO_2 sink.” The interactions between timber volume, increment, sites, and management (utilization) are crucial to forest effects. The modeling of these forest developments, which depend on management (see utilization scenario in Chapter 3.3), will make it possible to predict the future state of the forest, timber volume, CO_2 sinks, and possibly timber production, as well as to assess the risks involved. Based on such modeling studies, important information can be provided for political decisions.

The NFI provides information to evaluate the forest effects at a national and regional level. The question now is whether the Swiss forest is currently able to fulfill the functions that are demanded of it now as well as in the future. In order to answer this question, more must be known about forest structures and their influence on the forest effects; about stand stability and its development; and about forest regeneration as the basis for the sustainability of the forest effects.

With an increasing number of completed inventory cycles, the NFI will provide data to model changes and the development of forests. The NFI offers the advantage to assess representatively all forest structures in Switzerland in the future and, thereby, allows the derivation of models that are valid over a wide range of values.

Many of the current available models are based on data that reflect only a relatively small part of the entire spectrum of the Swiss forest and are, therefore, only valid for this narrowly defined range. For example, the range of the Swiss yield tables should, strictly speaking, include only approximately 18% of Swiss forest area (KÖHL *et al.* 1995). The data from the NFI offer a possibility to supplement intensive but spatially limited studies, such as researching long-term forest ecosystem areas, and to define the valid scope of these studies.

5.5 Implementation

Utilizing the knowledge, methods, and data of the NFI for local and strategic decisions and for understanding forest ecosystems is an important objective. An active implementation is important for the success of the long-term NFI project. Clarifying future information needs is essential in defining the objectives of subsequent inventories. By building a forest information and communication system, a close link between decision makers on the local, regional cantonal and national level and the NFI will be established. The information and communication system will be engaged in transferring adequate, comprehensive, up-to-date and reliable information and technology between applied forestry, politics, research, teaching, and the NFI.

Future developments will lead to changes, not only in gathering and analyzing the data, but also for the dissemination of the results. The increasing access to the Internet and recent developments such as open GIS or platform independent software tools will open up new possibilities and challanges to make the latest results and special analysis available for a wide audience.

5.6 Conclusions

The NFI has become an instrument that can provide extensive information with respect to the Swiss forest. By applying environmental statistical methods and environmental data processing using the existing NFI data and appropriate links with other databases, the NFI offers an important contribution to environmental analysis. The NFI satisfies, therefore, all prerequisites to become a powerful national forest information and communication system, which provides a sound information background for decision makers in the forestry, environmental and political sector.

5.7 Literature

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6 Appendix

6.1 Variable Documentation

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The variable documentation provides information about the attributes that were used in the second National Forest Inventory. The documentation is intended to give a rough overview. A detailed description of the individual attribute values and code definitions is therefore not given at this point. With abbreviated names and the name of the table, it ensures that the attributes are clear and the reference to the database of the second NFI is given. The data for the individual attributes are stored in a relational database in thematic tables and can be linked with the help of key variables (which are not listed here) for the analysis. The list at hand is sorted by themes (=tables) and abbreviated names.

Table	**Theme**
BA	Individual tree data
BEMERK	Remarks on special features of sample tree
CL2	Geographic data of the sample plot
HHVORAUF	Timber harvest expenditure
HOLZWEG	Forest transportation system
JWKLA2	Young growth
JWSALFI2	Young growth (area = plot)
LBAUFN	Aerial photography interpretation
RUVORAUF	Expenditure for timber extraction
SCHADEN	Damage
SORTD	Timber assortment
STRASSE	Forest transportation system
WA	Area data for the forest survey
WR	Forest margin

1) **"Origin"** denotes the data source:

	1	Terrestrial inventory
	2	Aerial photography interpretation
	3	Map or GIS
	4	Derived attribute

2) Category **"used as"**: The number of "used as" refers to the chapter in the result volume publication of the second NFI.

Table of contents of the result volume publication NFI2 “Swiss National Forest Inventory; results of the second survey 1993 to 1995.”

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
ZWANUANT	WA	Proportion of unregulated fellings, in percentage of the total utilization	%	0	100		*	1	9.2		*	AH	
ZWANUURS	WA	Cause of unregulated fellings	Code	1	10	10	*	1	9.2		*	AH	
LETZTENU	WA	Number of years since last silvicultural treatment	Number	0	99			1	9.2		*	AH	
NUART	WA	Type of last silvicultural treatment since the first NFI	Code	1	11	11	*	1	9.2		*	AH	
PLAN	WA	Kind of management plan that was valid during the time of the survey	Code	1	4	4	*	1	9.2		*	AH	
PLANJAHR	WA	Year when management plan was created	Year	1900	1995			1	9.2		*	AH	
EGART	WA	Type of next required silvicultural treatment	Code	1	7	7	*	1	9.2	*	*	AH	125
EGDRING	WA	Urgency of next silvicultural treatment	Code	1	5	5	*	1	9.2		*	AH	
EBSGRAD	BA	Degree of damage of the sample tree	Code	1	6	6		4	9.3	*	*	AH	
SANZAHL	BA	Number of damages on the sample tree	Code	0	3	4		4	9.3		*	AH	
HSCHURS	SCHADEN	Indicator if recorded damage is the main cause	Code	0	1	2		4	9.3	*	*	AH	
SCHANR	SCHADEN	Damage identification number	Code	1	14	6		4	Auxiliary variable		*	AH	
SCHART	SCHADEN	Type of tree damage	Code	11	199	31	*	1	9.3	*	*	AH	
SCHURS	SCHADEN	Cause of damage	Code	2	115	20	*	1	9.3	*	*	AH	
SCHORT	SCHADEN	Location of damage at tree	Code	1	4	4		1	9.3		*	AH	
BESTSTAB	WA	Mechanical stability of stand	Code	1	10	10		1	9.4	*	*	AH	154
BSTSGRAD	WA	Degree of stand damage	Code	1	6	6		4	9.3	*	*	AH	
FONUFL	WA	Management intensity	Code	1	3	3		4	9.2	*	*	AH	
HANDBDF2	WA	Fulfillment of the stability requirements for protection forests, only NFI2	Number	0	1			4			*	AH	
HANDVAR2	WA	Number of defined variables for HANDBDF2	Number	3	5			4	Auxiliary variable for HANDBDF2			AH	
NUJRLFI2	WA	Number of years since last silvicultural operation, if missing in NFI2: updated	Number/ code	-99	110			4	9.2	*	*	AH	
SCHUWIRL	WA	Protection effect of the forest against the fracture of avalanches	Code	1	3	3		4	13.3		*	AH	
SCHUWIRS	WA	Protection effect of the forest against the hazard "rockfall"	Code	1	4	4		4	13.3		*	AH	
STABHDST	WA	Stability requirement for protective forest with respects to the DBH dispersion	Code	0	1	2		4	13.3		*	AH	
STAKRONE	WA	Stability requirement for protective forest with respects to the crown form and length	Code	0	1	2		4	13.3		*	AH	
STAMISCH	WA	Stability requirement for protective forest with respects to the mixture proportion	Code	0	1	2		4	13.3			AH	
STASLKGR	WA	Stability requirement for protective forest with respects to the slenderness	Code	0	1	2		4	13.3		*	AH	
STASTRUK	WA	Stability requirement for protective forest with respects to the stand structure	Code	0	1	2		4	13.3		*	AH	
STAVJDG	WA	Stability requirement for protective forest with respects to the closure of regeneration	Code	0	1	2		4	13.3		*	AH	
STZGE16	WA	Number per ha of trees with DBH >= 16 cm	Number	0	2050			4	Auxiliary variable for SCHUWIRL			AH	
STZGE40	WA	Number per ha of trees with DBH >= 40 cm	Number	0	536			4	Auxiliary variable for SCHUWIRS			AH	
WIWATYP	WA	Forest type classification with respects to winter canopy (e.g. deciduous forest, mixed forest)	Code	1	5	5		4	Auxiliary variable for SCHUWIRL			AH	
AZI	BA	Azimuth of a sample tree, measured from the sample plot center	gon	0	400			1	Diverse			BT	
AZI	CL2	Derived aspect for the calculation of the total increment (TI)	gon	0	999			4	Auxiliary variable for TI			BT	
EX	CL2	Derived aspect class (north/south aspect) to derive the TI and HOESTUF	Code	N	s			4	Auxiliary variable for TI and HOESTUF			BT	
FLAECHE	CL2	Indicator variable, all aerial photo samples in the 500-m-grid receive the value 1	ha	1	1			4				BT	
TERRNET	CL2	Indicator variable, identifies the assignment to the terrestrial grid of NFI2	Code	0	1	2		4				BT	
TERRNETK	CL2	Indicator variable, identifies the assignment to the terrestrial grid of the first occasion of forest inventories in the regions	Code	0	1	2		4				BT	
DG	HHVORAUF	Diameter of the mean basal area tree used for the derivation of the timber harvest expenditure	cm	8.660254038	175			4	Auxiliary variable for HHVORAUF			BT	
JAHR	HHVORAUF	Reference year, auxiliary variable, input variable in simulation studies	YY	85	95			4	Auxiliary variable			BT	
MENGE	HHVORAUF	Harvest volume / standing gross volume separate by broadleaf and conifer tree species (derived attribute used in timber harvest expenditure)	m3/ha	0.95	1638.89			4	Auxiliary variable ?			BT	
NHLH	HHVORAUF	Classification of the tree species in conifer and broadleaf trees	Code	1	2	2		4	Diverse?			BT	
STZ	HHVORAUF	Total number of stems per hectare and tree species group (broadleaf, conifer) used for the calculation of the timber harvest expenditure		20	2962			4	Auxiliary variable for timber harvest			BT	
VCODE	HHVORAUF	Code for timber extraction method, used for the expenditure calculation of carrying out the timber harvest	Code	1	13	20		4	Auxiliary variable?			BT	
KOMBENT	LBAUFN	Combined (=edited) forest decision from the aerial photography interpretation (default) and the terrestrial survey (verification)	Code	1	4	4		4	Diverse			BT	
RPLB	LBAUFN	Weight factor for the expansion of the aerial photography interpretation area to hectare values		4	4			4	Auxiliary variable ?			BT	
SPANNHOE	LBAUFN	Range of the tree height, derived from the aerial photography interpretation (lbrast.kronhoe)	Meters	0.6	139.7			4	Auxiliary variable?			BT	
ANFALL	RUVORAUF	Estimated total timber for cable crane on the accessible area	m3	35	3439			4	?			BT	
JAHR	RUVORAUF	Reference year, auxiliary variable as an add-on for the inventory number of the simulation study	YY	95	95			4	Auxiliary variable			BT	

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
MENGE	RUVORAUF	Harvested volume in Efm/ha and tree species, calculated using the assortment volumes	m3	0.75	1419.959			4	?			BT	
NHLH	RUVORAUF	Classification of the tree species in conifer and broadleaf trees	Code	1	2	2		4	Diverse			BT	
STKMIDM	RUVORAUF	Mean assortment diameter per tree species	cm	10	48.2			4	?			BT	
TRSPEZ	RUVORAUF	Code for timber extraction using a tractor	Code	1	3	3		4	?			BT	
VCODE	RUVORAUF	Code for timber extraction method, used for the calculation of timber harvest expenditure.	Code	2	26	20		4	Auxiliary variable?			BT	
FLAECHE	WA	Indicator variable, all accessible terrestrial sample plots receive the value 1		1	1			4	Auxiliary variable			BT	
LBNEIG	WA	Slope of the interpretation area in the aerial photo	%	0	364			2	Diverse?			BT	
NEIGUNG	WA	Slope of the terrestrial sample plot	%	0	202			1	Diverse?			BT	
ASTDH	BA	Estimated volume of branches (diameter >=7cm)	m3	0	13.0374			4	11		*	EK	
BAL	BA	Basal area of all trees on the sample plot with larger d1.3	m2/ha	0	222.1			4	6		*	EK	
BASF	BA	Basal area	m2	0.01	3.11			4	6		*	EK	
BHDKL	BA	DBH class	Code	0	4	5		4	Diverse		*	EK	
BHOHD	BA	Individual tree height predicted with tariff function	Meters	0	45			4	6		*	EK	
D13	BA	Measured DBH, with calliper or measuring tape	cm	0	199			1	6		*	EK	
D7D	BA	D7 predicted with tariff function	cm	0	97			4	6		*	EK	
DUERR	BA	Health condition of the sample tree	Code	1	11	4		1	6		*	EK	
HBART	BA	Main tree species	Code	1	12	13		4	Diverse	*	*	EK	360
HISTKT	BA	Tree history for regional inventories	Code	-1	-1	9		4	Auxiliary variable		*	EK	
HISTORY	BA	Tree history for national inventory (e.g., survivor, ingrowth, ongrowth, cut tree)	Code	1	9	9		4	Auxiliary variable		*	EK	
IMMERTOT	BA	History of the health condition for the national inventory	Code	0	3	5		4	6		*	EK	
LBHNDH	BA	Broadleaf or conifer	Code	1	2	2		4	Diverse	*	*	EK	361
NADELN	BA	Needle weight	kg/m2	1.3	1293.8			4			*	EK	
OBIO	BA	Above ground biomass	m3	0.016	33.834			4	11		*	EK	
REISIG	BA	Branchwood	m3	0.0011	8.9781			4	11		*	EK	
RPSTZ	BA	Expansion factor from single tree value to per ha value	n/ha	0	300			4	11/diverse	*	*	EK	365
TARNR	BA	Tariff number	Code	201	230			4	6		*	EK	
TARWAHL	BA	Selected as tariff sample tree	Code	0	2	3		4	6		*	EK	
TOTKT	BA	History of the health condition for the regional inventories	Code	-1	-1	5		4	Diverse		*	EK	
VLOKAL	BA	Stem volume, estimated with locale tariff function	m3					4			*	EK	
VMRD	BA	Stem volume over bark, estimated with tariff	m3	0	24.856			4	6/diverse		*	EK	
VORD	BA	Stem volume under bark, estimated with tariff	m3	0.012	22.014			4	6		*	EK	
VPPS	BA	Bias correction for the tariff function in the national inventory	m3	-9.948	20.517			4	6		*	EK	
VPPSKT	BA	Bias correction for the tariff function in the regional inventory	m3	0	0			4	6		*	EK	
WURZELN	BA	Root weight	kg/m3	4.8	16115.5			4			*	EK	
BEM	BEMERK	Remarks	Code	1	18	18	*	1	Auxiliary variable		*	EK	
EFMD	HHVORAUF	Timber volume in cubic meters of timber harvested	m3	0.75	1419.959			4	Auxiliary variable		*	EK	
HBART	JWKLA2	Main tree species	Code	1	12	13		4	Diverse		*	EK	
RPSTJ	JWKLA2	Expansion factor from single tree value to per ha value for regeneration plot data	n/ha	708.24	3183.1			4	13	*	*	EK	452
SCHADEN	JWKLA2	Type of damage at young growth tree	Code	1	9	10		1			*	EK	
JAZIABBR	JWSALFI2	Stopped counting at azimuth in the first NFI	gon					1			*	EK	
MISTKINH	RUVORAUF	Average volume per piece	m3	0.0075	5.0844			4			*	EK	
MITDMD	SORTD	Estimated mean assortment diameter	cm	0	154			4	11		*	EK	
SORTART	SORTD	Type of assortment	Code	A	T	4		4	11		*	EK	
SORTKLD	SORTD	Estimated class of assortment	Code	1	10			4	11		*	EK	
SORTVD	SORTD	Estimated volume of assortment	m3	0.001	21.43			4	11		*	EK	
ALTERD	WA	Estimated age using tree-ring based model	Years	30	350			4	6		*	EK	
BASFPH	WA	Basal area per ha	m3/ha	0.57	143.27			4	6		*	EK	
DDOM	WA	Mean diameter of the 100 thickest trees per hectare	cm	0	132.5			4	6		*	EK	
DMPH	WA	Sum of all tree diameters (per hectare) of all standing and living trees on the sample plot	cm/ha	0	56257			4			*	EK	
EFMD	WA	Cubic meters of timber harvested per hectare	m3/ha	0	1454.568			4	Auxiliary variable		*	EK	
KFM	WA	Diameter corresponding to mean basal area	cm	0	175			4	11		*	EK	
NPH	WA	Number of stems per hectare for all standing and living trees	n/ha	20	2962			4	6/diverse		*	EK	
RVMRD	WA	Volume over bark per ha of standing and living trees	m3/ha	0	1638.89			4	6/diverse		*	EK	
VEGPER	WA	Number of growing seasons since first NFI		7.26	12.75			4	6		*	EK	
BART	BA	Tree species	Code	1	118	98	*	1	7.5	*	*	HST	340
BHD	BA	Diameter at breast height	cm	12	121			1	7.3/7.5	*	*	HST	341
BSTAT	BA	Status of the tree (e.g., present in NFI1 and NFI2)	Code	1	5	5		1	Auxiliary variable		*	HST	
GRUND	BA	Reason for trees present in first assessment not found in second assessment	Code	1	4	4		1	Auxiliary variable		*	HST	
KROFRM	BA	Shape of crown	Code	1	3	3	*	1	Auxiliary variable		*	HST	
KROLAE	BA	Crown length	Code	1	3	3	*	1	Auxiliary variable		*	HST	
RINGE	BA	Number of year rings	Number	33	33			1	Auxiliary variable		*	HST	
SCHICHT	BA	Layer to which sample tree belongs	Code	1	4	4		1	Auxiliary variable	*	*	HST	344
SOZSTEL	BA	Social position of sample tree in forest stand	Code	1	5	5		1	Auxiliary variable		*	HST	
UMFANG	BA	Circumference of the sample tree in 1.3 meter heights	cm	33	628			1	Auxiliary variable		*	HST	
ZWIESL	BA	Tree has a bifurcation	Code	0	1	2	*	1	Auxiliary variable	*	*	HST	363
ANZAHL	JWKLA2	Number of stems in regeneration class	Number	1	216			1	8.2		*	HST	
ALTERMET	WA	Method for estimating stand age	Code	1	3	4		1	Auxiliary variable		*	HST	
AZIEXPOW	WA	Azimuth of the terrestrial sample plot aspect	gon	0	400			1	Diverse	*	*	HST	81
BESTALT	WA	Stand age	Years	1	400			1	7.4	*	*	HST	248
BESTGREN	WA	Stand boundary	Code	1	2	2		1	Auxiliary variable	*	*	HST	
BODVEGDG	WA	Closure of ground vegetation	Code	0	6	7		1	12		*	HST	
BRAND	WA	Traces of fire	Code	1	2	2		1	5	*	*	HST	88
DATUMU	WA	Date of enquiry	Date	07-MAY-93	22-MAY-96			1	Auxiliary variable		*	HST	

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
DATUMW	WA	Date of sample plot assessment	Date	06-MAY-93	27-OCT-96			1	Auxiliary variable		*	HST	
DG	WA	Crown closure in percentages	%	0	100			1	Auxiliary variable		*	HST	
EST	WA	Stage of stand development	Code	1	6	6		1	7.3	*	*	HST	101
EXPO	WA	Aspect determinable?	Code	1	2	2	*	1	Auxiliary variable	*	*	HST	82
KRFLGR	WA	Reduced area of the large plot (for plots at forest boundary)	m2	1	500			4	Auxiliary variable	*	*	HST	
KRFLKL	WA	Reduced area of the small plot (for plots at forest boundary)	m2	1	200			4	Auxiliary variable	*	*	HST	
MISCHG	WA	Mixture proportion of needle and deciduous trees	Code	1	4	4	*	1	Diverse	*	*	HST	121
NUTZKAT	WA	Utilization class of forest land (e.g., forest stand, road, meadow)	Code	1	12	12		1		*	*	HST	
PFRAGR	WA	Radius of 500 m2 field plot (horizontal: 12.62m)	Meters	12.62	17.83			1	Auxiliary variable	*	*	HST	
PFRAKL	WA	Radius of 200 m2 field plot (horizontal: 7.98m)	Meters	7.98	11.28			1	Auxiliary variable	*	*	HST	
PFSTAT	WA	Status of field plot (e.g., found, not found, assessed for the first time)	Code	1	8	8		1	Auxiliary variable		*	HST	
RELIEF	WA	Type of relief	Code	1	5	5		1	Diverse	*	*	HST	83
STOECKE	WA	Stumps present or not	Code	1	2	2		1	12		*	HST	
STRADG	WA	Closure of shrub species	Code	1	6	7		1	12		*	HST	
STRUK	WA	Stand structure (vertical layers)	Code	1	4	4		1	7.3	*	*	HST	123
VORHERBA	WA	Dominant tree species	Code	1	12	13		4	7.5		*	HST	
WFRM	WA	Origin and management type of forest	Code	1	5	5		1	7.3	*	*	HST	100
WNWENT	WA	Forest/non-forest decision	Code	1	11	11	*	1	Diverse	*	*	HST	70
WTYP	WA	Forest type	Code	1	4	4	*	1	7.3	*	*	HST	99
ZUGANG	WA	Accessibility of sample plot	Code	1	7	7	*	1	Diverse	*	*	HST	69
BEFAHRB	CL2	Trafficability of soil according to the soil suitability map (Frei et al., 1980)	Code	0	5	6		3	None	*		IP	52
BONUKAT	CL2	Land-use categories of the area statistics (BFS, 1992), 69 classes	Code	10	99	69		3	Auxiliary variable		*	IP	
DURCHL	CL2	Soil characteristic "water permeability" according to the soil suitability map (Frei et al., 1980)	Code	0	6	8		3	5	*	*	IP	50
ENTWREG	CL2	Regions of the land-use planning and promotion of mountain regions	Code	1	55			4	Diverse	*		IP	11
GRUEND	CL2	Soil characteristic "depth" according to the soil suitability map (Frei et al., 1980)	Code	0	6	8		3	5	*	*	IP	46
HERKEX	CL2	Source of origin for aspect	Code	1	4	4		4	Auxiliary variable			IP	
HERKREL	CL2	Source of origin for relief	Code	1	3	3		4	Auxiliary variable			IP	
HUEM	CL2	Elevation above sea level from aerial photo/terrain models	Meters	174.2	4501			2	Diverse	*	*	IP	3
KAFO	CL2	Combined key of canton and forest districts	Code	100	2603			4	Diverse		*	IP	
LANUKL17	CL2	Simplified land-use categories according to area statistics (BFS, 1992) with 17 classes	Code	1	17	17		4	Diverse		*	IP	
NAEHRSP	CL2	Soil characteristic "nutrient content"	Code	0	6	7		3	None	*		IP	49
RASTFLAE	CL2	Actual area of the quadratic sample plot (500 x 500 m) around the sample plot center (smaller at Swiss border)	ha	5.724	25			3	10.2		*	IP	
RPGIS	CL2	Weight factor of the sample plot for GIS-variables	Number	0.04	1.831501832			4	Diverse		*	IP	
RUSACK	CL2	Soil characteristic" risk of rock/ soil slides" as determined from the simplified geotechnical map	Code	1	5	5		3	5		*	IP	
SKEL	CL2	Soil characteristic "skeleton content" according to the soil suitability map (Frei et al., 1980)	Code	0	5	6		3	5	*	*	IP	47
SOILTYPE	CL2	Type of soil according to the soil suitability map (Frei et al., 1980) (letters)	Code	A1	Z5			3	5		*	IP	
VERNAESS	CL2	Soil characteristic "soil moisture" according to the soil suitability map (Frei et al., 1980)	Code	0	4	6		3	5	*		IP	51
WAFLAE	CL2	Forest area on the 25 ha sample of the pixel map	ha	0	25			4	10.2		*	IP	
WALDANT	CL2	Forest area proportion on the 25 ha sample of the pixel map	Number	0	1			4	10.2		*	IP	
WASSP	CL2	Soil characteristic "water storage capacity"	Code	0	6	7		3	5	*	*	IP	48
NEIG	HHVORAUF	Slope of the interpretation plot (from aerial photo)	Per-centage	0	182			2	Diverse		*	IP	
TE0	HOLZWEG	Theoretical transport distance to the next forest road	Meters	0	297761.8227			3	10.2		*	IP	
TEM	HOLZWEG	Horizontal transport distance to the next forest road	Meters	0	13665			3	10.2		*	IP	
TES	HOLZWEG	Oblique distance to the next forest road	Meters	0.141	19677.028			3	10.2		*	IP	
DIST	BA	Distance of tree from plot center, measured at 1.3 meter heights	Meters	0	17.6			1	Diverse	*	*	JZ	342
TRAEMGEB	CL2	Indicator whether the assortments are short timber or long timber, determined from the enquiry NFI2	Code	1	2	2		4	Auxiliary variable		*	JZ	
HHABSMAS	HHVORAUF	Felling expenditure per sample plot and type of timber for machines except chain saw	min	0	1792.752			4	Auxiliary variable for timber harvest		*	JZ	
HHABSMS	HHVORAUF	Felling expenditure per sample plot and type of timber for chain saw	min	0	26979.221			4	Auxiliary variable for timber harvest		*	JZ	
HHABSP	HHVORAUF	Felling expenditure per sample plot and type of timber for personnel	min	0	78074.093			4	Auxiliary variable for timber harvest		*	JZ	
HHAUFWA	HHVORAUF	Felling expenditure in Swiss francs per sample plot and type of timber	Fr/ha	0	55909.23813			4	Auxiliary variable for timber harvest		*	JZ	
HHMAS	HHVORAUF	Felling expenditure in Swiss francs per m3, sample plot, and type of timber for machines except chain saw	min/m3	0	16			4	Auxiliary variable for timber harvest		*	JZ	
HHMS	HHVORAUF	Felling expenditure in minutes per m3, sample plot, and type of timber for chain saw	min/m3	0	81			4	Auxiliary variable for timber harvest		*	JZ	
HHP	HHVORAUF	Felling expenditure in minutes per m3 sample plot, and type of timber for personnel	min/m3	0	220			4	Auxiliary variable for timber harvest		*	JZ	
WEGLAE	HOLZWEG	Length of roads important for forestry as determined with the digitized roads	Meters	0	3609.716334			4	10		*	JZ	
JWART	JWKLA2	Tree species (including shrubs) in the young growth	Code	1	118	98		1	Auxiliary variable	*	*	JZ	
JWSANR	JWKLA2	Identification number of regeneration plot	Code	1	2			4	Auxiliary variable		*	JZ	
KLA	JWKLA2	Size class (trees<10-130 cm height) or diameter class (trees >0.1-12 cm diameters) of trees on the regeneration plots	Code	1	7	7		1	Auxiliary variable		*	JZ	
WURST	JWKLA2	Indicator whether the young growth plant is a living tree (regeneration without shrubs and dead trees)	Code	0	1	2		4	8.2		*	JZ	

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
ESTJ	JWSALFI2	Development stage of the stand in which the regeneration plot is located, if regeneration plot center is in a different stand than the main sample plot center	Code	1	6	6		1	Auxiliary variable		*	JZ	
GESAMTDG	JWSALFI2	Closure of regeneration on regeneration plot	Percent	0	100			1	Auxiliary variable		*	JZ	
JWLAGE	JWSALFI2	Position of the regeneration plot with respects to properties (stand, accessibility, etc.) of the NFI-sample plot center	Code	1	4	4		1	Auxiliary variable		*	JZ	
JWRAGR	JWSALFI2	Radius of the regeneration plot for class 2-7, with slope	Meters	2.12	3			1	Auxiliary variable		*	JZ	
JWRAKL	JWSALFI2	Radius of the regeneration plot for class 1, with slope	Meters	1	1.41			1	Auxiliary variable		*	JZ	
SCHLUSGJ	JWSALFI2	Crown closure of the stand in which the regeneration plot is located if regeneration plot center is in a different stand than the main sample plot center	Code	1	8	55		1	Auxiliary variable		*	JZ	
SCHUTZ	JWSALFI2	Type of protection measures of regeneration against game browsing	Code	1	3	3		1	8		*	JZ	
VERJART	JWSALFI2	Origin of the regeneration in the regeneration plot (planted, natural regeneration, mixed)	Code	1	4	4		1	Auxiliary variable		*	JZ	
VERYBEST	JWSALFI2	Stands for which the regeneration is silviculturally important	Code	1	4	4		4	8		*	JZ	
RI	RUVORAUF	Direction of timber transport = direction with longest timber transport	Code	0	3	3		4	Auxiliary variable		*	JZ	
RUABSMAS	RUVORAUF	Extraction expenditure in machine minutes per sample plot and type of timber	min	1.5	195058.4			4	Auxiliary variable		*	JZ	
RUABSP	RUVORAUF	Extraction expenditure in person minutes per sample plot and type of timber	min	0	412696.93			4	Auxiliary variable		*	JZ	
RUAUFWA	RUVORAUF	Extraction expenditure in Swiss francs per sample plot and type of timber	Fr/ha	0	488395.1373			4	Auxiliary variable		*	JZ	
RUDIS	RUVORAUF	Timber extraction distance, total distance of the procedure without skidding	Meters	0	80000			4	10		*	JZ	
RUMAS	RUVORAUF	Extraction expenditure in machine minutes/m3 per sample plot and type of timber, depending on the tools used for timber harvest	min/m3	1	1840			4	Auxiliary variable		*	JZ	
RUP	RUVORAUF	Extraction expenditure in person minutes/m3 per sample plot and type of timber, depending on the tools used for timber harvest	min/m3	0	3893			4	Auxiliary variable		*	JZ	
ZUZUG	RUVORAUF	Distance of pre-skidding	Meters	0	800			4	Auxiliary variable		*	JZ	
LTYP	STRASSE	Road type of the forest transportation roads	Code	1	8	8		3	Auxiliary variable		*	JZ	
STRKLASS	STRASSE	Road class according to Swiss Federal Office of Topography	Code	0	6	7		3	Auxiliary variable		*	JZ	
STRLAE	STRASSE	Road length according to the GIS	Meters	0.125973	3410.808143			4	Auxiliary variable		*	JZ	
STRWO	STRASSE	Type of surrounding of the forest transportation roads	Code	1	4	4		3	Auxiliary variable		*	JZ	
TUNNEL	STRASSE	Road in tunnel or gallery	Code	0	9	2		3	Auxiliary variable		*	JZ	
AUFWA	WA	Total expenditure in Swiss francs/ha per sample plot, without debarking expenditure	Fr/ha	0	524471.447			4	Auxiliary variable		*	JZ	
AUFWAM	WA	Total expenditure in Swiss francs/m3 per sample plot, without debarking expenditure	Fr/m3	14.78333333	4725.366667			4	Auxiliary variable		*	JZ	
ERKONZ	WA	Concept for the timber harvesting and transportation system of the forest districts	Code	1	5	6		4	Auxiliary variable		*	JZ	
ERNTART	WA	Tools for timber harvest at the present time	Code	1	5	5		1	Auxiliary variable		*	JZ	
ERNTAUSF	WA	Timber harvest carried out by external enterprise or with own personnel	Code	1	7	7		1	Auxiliary variable		*	JZ	
GESDIS	WA	Total transportation distance (timber extraction + pre-skidding)	Meters	0	80290			4	Stratifying variable		*	JZ	
HHAUFWA	WA	Felling expenditure in Swiss francs/ha per sample plot, without debarking expenditure	Fr/ha	0	55909.23813			4	Auxiliary variable		*	JZ	
HHAUFWAM	WA	Felling expenditure in Swiss francs/m3 per sample plot, without debarking expenditure	Fr/m3	0	162.8666667			4	Auxiliary variable		*	JZ	
HOHAUEIN	WA	Constraints for timber harvest (e.g. settlements)	Code	1	5	5		1	Auxiliary variable		*	JZ	
HOHAUHIN	WA	Obstacles for the timber harvest on the interpretation area	Code	1	4	4		1	Auxiliary variable		*	JZ	
HOLZMECH	WA	Level of mechanization of the timber harvest	Code	1	5	5		4	10		*	JZ	
RUAUFWA	WA	Timber extraction expenditure in Swiss francs/ha per sample plot	Fr/ha	0	495974.8523			4	Auxiliary variable		*	JZ	
RUAUFWAM	WA	Timber extraction expenditure in Swiss francs/m3 per sample plot	Fr/m3	0	4678.566667			4	Stratifying variable		*	JZ	
RUEDIS	WA	Total timber extraction distance per sample plot	Meters	0	14800			4	Stratifying variable		*	JZ	
RUEMIEIN	WA	Constraints for extraction method	Code	1	4	5		1	Auxiliary variable		*	JZ	
RUEMIT	WA	Main timber extraction method	Code	1	4	5		1	Auxiliary variable		*	JZ	
SANR	WA	Identification number of plots within the cluster		1	1			1	Auxiliary variable		*	JZ	
SCHLUSSG	WA	Crown closure	Code	1	8	8		1	Auxiliary variable		*	JZ	
SCHUTZ	WA	Protection measures in the stand against game browsing	Code	1	3	3		1			*	JZ	
TRAELANG	WA	Utilized timber, sorted as shorter or longer stemwood	Code	1	2	2		1	Stratifying variable		*	JZ	
TRANSDIS	WA	Total pre-skidding distance per sample plot	Meters	10	80000			4	10		*	JZ	
VERJART	WA	Origin of the regeneration in the relevant stand (e.g., natural, planted)	Code	1	3	4		1	8		*	JZ	
VERJDG	WA	Closure of regeneration	Code	1	6	7		1	8		*	JZ	
VERYBEST	WA	Stands for which the regeneration is silviculturally important	Code	1	4	4		4	Auxiliary variable		*	JZ	
ABKGRUND	LBAUFN	Reason for terrestrial verification of forest/non-forest decision from the aerial photo	Code	0	5	6		2	Auxiliary variable for KOMBENT		*	MK	
AUFOP	LBAUFN	Initials of the last aerial photo interpreter		hd	vm			2	Auxiliary variable for aerial photograph		*	MK	
AUFOPN	LBAUFN	Number of the last aerial photo interpreter	Number	0	123			2	Auxiliary variable for aerial photo		*	MK	
AUSSBAUM	LBAUFN	Tree species of stocks outside of the forested area	Code	-1	7	8		2	4.6		*	MK	
AUSSGEHO	LBAUFN	Type of woody plant stocks outside of the forested area	Code	-1	9	10		2	4.6		*	MK	
AUSSWALD	LBAUFN	Indicator for stocks outside of the forested area	Code	-1	3	5		2	4.6		*	MK	
BAUMANZ	LBAUFN	Number of trees for stocks outside the forested area		0	99			2	4.6		*	MK	
BESTGR	LBAUFN	Stand edge within the 500 m2 sample plot	Code	-1	2	3		2	Auxiliary variable for aerial photo		*	MK	
DGRAD25	LBAUFN	Crown closure determined with 25 grid dots	%	-1	100			4	Auxiliary variable		*	MK	

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
DGRAD9	LBAUFN	Crown closure determined with 9 central grid dots	%	-1	100			4	Auxiliary variable		*	MK	
FLUGJAHR	LBAUFN	Flight year when the aerial photo was taken	YYYY	1987	1995			2	Auxiliary variable for aerial photo		*	MK	
GEHOLANG	LBAUFN	Length of wooded area for stocks outside of the forested area	Meters	0	129.4			2	4.6		*	MK	
GWART	LBAUFN	Species of shrub forest	Code	-1	3	4		2	Tree species		*	MK	
GWTYP	LBAUFN	Type of shrub forest (e.g., pure shrub forest, mixed with forest trees)	Code	-1	2	3		2	Forest type		*	MK	
INSDATUM	LBAUFN	Date of the first interpretation of the aerial photo	Date	28-Feb-93	27-Jun-96			2	Auxiliary variable for aerial photo		*	MK	
INTBED	LBAUFN	Conditions for interpretation of aerial photo	Code	1	3	3		2	Auxiliary variable for aerial photo		*	MK	
LBANR	LBAUFN	Identification number (foreign key) of aerial photo sample	Number	3948	243154				Auxiliary variable		*	MK	
LBEST	LBAUFN	Stage of development in forest stand determined with aerial photo	Code	-1	6	7		2	Auxiliary variable		*	MK	
LBEXPO	LBAUFN	Aspect determined in aerial photo	Code	-1	9	11		2	Auxiliary variable		*	MK	
LBMISCHG	LBAUFN	Mixture proportion of conifers and deciduous trees determined with aerial photo	Code			5		2	Auxiliary variable			MK	
LBREL	LBAUFN	Relief determined in aerial photos	Code	-1	7	9		2	Auxiliary variable			MK	
LBWNWENT	LBAUFN	Forest/non-forest decision determined in aerial photos	Code	1	4	4		2	4.2			MK	
LUWAHOKL	LBAUFN	Forest height classes	Code	1	5	5		4	Double sampling stratification		*	MK	
MODNR	LBAUFN	Identification number of stereo model (foreign key)		18	999999						*	MK	
MWNWENT	LBAUFN	Manual acceptance or rejection of automatic forest/non-forest decision	Code	-9	2	3		2	4		*	MK	
PFZLAGE	LBAUFN	Location of plot center in aerial photo inside or outside forest	Code	-1	1	3		2	Auxiliary variable for KOMBENT		*	MK	
SCHLGRD	LBAUFN	Crown closure of the stand in the aerial photo	Code	-1	10	11		2	Auxiliary variable		*	MK	
STEIGX1	LBAUFN	X-coordinate for the highest point of the gradient vector	Meters	0	831998			2	Auxiliary variable for aerial photo aspect		*	MK	
STEIGX2	LBAUFN	X-coordinate for the lowest point of the gradient vector	Meters	0	832020			2	Auxiliary variable for aerial photo aspect		*	MK	
STEIGY1	LBAUFN	Y-coordinate for the highest point of the gradient vector	Meters	0	295000			2	Auxiliary variable for aerial photo aspect		*	MK	
STEIGY2	LBAUFN	Y-coordinate for the lowest point of the gradient vector	Meters	0	294995			2	Auxiliary variable for aerial photo aspect		*	MK	
STEIGZ1	LBAUFN	Z-coordinate (elevation) for the highest point of the gradient vector	Meters above sea level	0	2295			2	Auxiliary variable for aerial photo aspect		*	MK	
STEIGZ2	LBAUFN	Z-coordinate (elevation) for the lowest point of the gradient vector	meter above sea level	0	2276			2	Auxiliary variable for aerial photo aspect		*	MK	
TERABKL	LBAUFN	Aerial forest/nonforest decision to be verified by terrestrial assessment – yes/no	Code	1	2	2		2	Auxiliary variable for KOMBENT		*	MK	
UPDATUM	LBAUFN	Data of the last interpretation	Date	28-Feb-93	22-Apr-96			2	Auxiliary variable		*	MK	
WALDRD	LBAUFN	Existence of forest edge	Code	-1	3	4		2	Forest edge		*	MK	
WBREITE	LBAUFN	Forest width	Meters	-1	1564.3			2	Auxiliary variable for KOMBENT		*	MK	
WRABST	LBAUFN	Distance sample plot center – forest edge	Meters	-1	499.6			2	Forest edge		*	MK	
Z	LBAUFN	Elevation of the sample plot center (measured in the aerial photos)	Meters above sea level	174.2	4501			2	Diverse		*	MK	
KROKLA	BA	Crown class estimated from leaf/needle density and crown form	Code	1	3	3	*	1	Only LFI1	*		PB	
ACIDIT	CL2	Acidity according to classification by Keller (1978, 1979)	Code	1	2	2		4	Auxiliary variable for GWL	*	*	PB	
GEOLOG	CL2	Geology according to Keller (1978, 1979)	Code	0	3	4		4	Auxiliary variable for GWL	*	*	PB	
GWL	CL2	Site index according to Keller	kg	-1	6432			4	5.3	*	*	PB	
HDOMBU	CL2	Site index for beech according to Keller (1978, 1979)	Meters	0	22.5			4	5.3	*	*	PB	
HDOMFI	CL2	Site index for spruce according to Keller (1978, 1979)	Meters	0	27.2			4	5.3	*	*	PB	
HDOMKI	CL2	Site index for pine according to Keller (1978, 1979)	Meters	0	25.2			4	5.3	*	*	PB	
HDOMLAE	CL2	Site index for larch according to Keller(1978, 1979)	Meters	0	31.5			4	5.3	*	*	PB	
HDOMTA	CL2	Site index for fir according to Keller (1978, 1979)	Meters	0	26.1			4	5.3	*	*	PB	
BGRAD	LBAUFN	Crown closure	%					2	Auxiliary variable	*		PB	
POTWALD	CL2	Potential forest area derived from area statistics (BFS; 1992)	Code	1	3	3		4	4.3		*	TS	
BESTOCK	LBAUFN	Type of stock, determined in aerial photos	Code	1	6	5		4	4.6		*	TS	
EIGENKAT	WA	Ownership public/ private	Code	0	2	3		1	4.2/diverse	*	*	TS	156
EIGENTUM	WA	Ownership	Code	1	7	8	*	1	4.2	*	*	TS	79
HOESTUF	CL2	Altitudinal vegetation zones	Code	2	7	8		4	Diverse	*	*	UBB	38
LWSPS	CL2	Avalanche protection forest for settlements	Code	0	8	2		4	13.2		*	UBB	
LWSPV	CL2	Avalanche protection forest for traffic	Code	0	16	2		4	13.2		*	UBB	
SCHUREG	CL2	Protection forest regions	Code	1	6	7		4	13		*	UBB	
STSPS	CL2	Rockfall protection forest for settlements	Code	0	5	3		4	13.2		*	UBB	
STSPV	CL2	Rockfall protection forest for traffic	Code	0	10	3		4	13.2		*	UBB	
VUNIT1	CL2	Most probable potential natural vegetation as derived by PNV model (Brzeziecki et al., 1993)	Code	-99	71	76		4	Diverse		*	UBB	
VUNIT2	CL2	Second most probable potential natural vegetation as derived by PNV model (Brzeziecki et al., 1993)	Code	-99	71	76		4	BWNATURN		*	UBB	

Abbreviated name	Table	Description (in the NFI1: Long name)	Unit	Minimum	Maximum	Number of Codes	Definition of code differently for each inventory	Origin 1)	Used as 2)	NFI1	NFI2	Author	NFI1-Var. No.
VUNIT3	CL2	Third most probable potential natural vegetation as derived by -PNV model (Brzeziecki et al., 1993)	Code	-99	71	76		4	BWNATURN		*	UBB	
AHAUFEN	WA	Heaps of branches present	Code	1	2	2		1	12.2		*	UBB	
ANZARTB	WA	Number of woody plants in stand		1	9			4	12.2		*	UBB	
ANZARTJW	WA	Number of woody plants in regeneration		1	19			4	12.2		*	UBB	
ANZARTPF	WA	Number of woody plants in the sample plot (total)		1	20			4	12.2		*	UBB	
BEERART	WA	Main berry species	Code	120	128	98		1	12.2		*	UBB	
BEERDG	WA	Closure of berry plants	Code	0	6	7		1	12.2		*	UBB	
BHDGT50	WA	Basal area proportion of trees with DBH > 50	%	0	100			4	12.2		*	UBB	
BIOLFI1M	WA	Biotope rating NFI1 (minimum-model)		0.726190476	3.523809524			4	12.2		*	UBB	
BIOLFI2	WA	Biotope rating NFI2 (maximum-model)		0.535714286	3.214285714			4	12.2		*	UBB	
BWARTEN	WA	Woody plant diversity in the stand		1	7			4	12.2		*	UBB	
BWNATURN	WA	Closeness to nature of the conifer proportion	Code	0	5	6		4	12.2		*	UBB	
BWSTRU1M	WA	Structural diversity of the stand (for BIOLFI1M)		3	17			4	12.2		*	UBB	
BWSTRUKT	WA	Structural diversity of the stand (for BIOLFI2)		4	41			4	12.2		*	UBB	
DUERSTA	WA	Dead standing trees present	Code	1	2	2		1	12.2		*	UBB	
ERHOLUNG	WA	Infrastructure for recreation	Code	1	6	6		1	12.4		*	UBB	
EROSION	WA	Erosion caused by water	Code	1	4	4		1	5.2		*	UBB	85
GEOMORPH	WA	Geomorphologic objects	Code	1	11	11		1	5.3/12.2		*	UBB	
LUECKEN	WA	Type of gaps	Code	1	8	8		1	12.2		*	UBB	
RUTSCH	WA	Traces of landslide	Code	1	3	3		1	5.2	*	*	UBB	84
SCHNEE	WA	Damage caused by snow	Code	1	2	2		1	5.2	*	*	UBB	87
SDI	WA	Stand Density Index (stand density)	Number	0	2607			4	12,13		*	UBB	
SPEZORT	WA	Special sites	Code	1	10	10		1	5,12		*	UBB	
STEIN	WA	Traces of rockfall	Code	1	2	2		1	5.2		*	UBB	86
TOTHOLZP	WA	Basal area proportion dead wood	%	0.6	100			4	12.2		*	UBB	
TOTVOLUP	WA	Volume proportion dead wood	%	0.3	100			4	12.2		*	UBB	
TROCKMAU	WA	Dry walls and heaps of stones present	Code	1	2	2		1	5.3/12.2		*	UBB	
TYP30517	WA	Forest type according to (EAFV, 1988) (17 classes)	Code	1	17	18		4	Diverse		*	UBB	159
TYP30563	WA	Forest type according to (EAFV, 1988) (63 classes)	Code	1	63	64		4	Diverse		*	UBB	160
UEBERBEL	WA	Traces of heavy utilization and disturbances	Code	1	7	7		1	9.2/12.2		*	UBB	
VEGLOS	WA	Patches without vegetation present	Code	1	2	2		1	BWSPEZ		*	UBB	
WARA	WA	Forest edge present	Code	1	2	2		1	12.3		*	UBB	
WEID	WA	Type of grazing	Code	1	6	6		1	9.2		*	UBB	
WEIDINT	WA	Intensity of grazing	Code	1	4	4		1	9.2	*	*	UBB	89
AUFBAU	WR	Type of forest edge (vertical)	Code	1	7	7		1	12.3		*	UBB	
DICHTE	WR	Density of forest edge	Code	1	4	4		1	12.3		*	UBB	
KRAUTBR	WR	Width of herbal belt at forest edge	Code	1	5	5		1	12.3		*	UBB	
MANTELBR	WR	Width of forest edge	Meters	0	50			1	12.3		*	UBB	
OEKOLFI2	WR	Ecotone value of the forest edge		24	138			4	12.3		*	UBB	
STRABR	WR	Width of shrub belt at forest edge	Meters	0	60			1	12.3		*	UBB	
VERLAUF	WR	Type of forest edge (horizontal)	Code	1	5	5		1	12.3		*	UBB	
WRANZART	WR	Total number of woody plants at the forest edge		1	28			4	12.3		*	UBB	
WRARTEN	WR	Species diversity at the forest edge		1	57			4	12.3		*	UBB	
WRDORN	WR	Proportion of briar species at the forest edge		1	11			4	12.3		*	UBB	
WREXPO	WR	Azimuth of the aspect	gon	0	399			1	12.3		*	UBB	
WRGREN	WR	Border at forest edge (e.g., road, fence, river)	Code	1	10	10		1	12.3		*	UBB	
WRSTRUKM	WR	Structural diversity at the forest edge (without the width of forest edge)		6	24			4	12.3		*	UBB	
WRUMG	WR	Surrounding of forest edge	Code	1	11	11		1	12.3		*	UBB	
WRWEICH	WR	Proportion of softwood and special species at the forest edge		1	28			4	12.3		*	UBB	
WRZUST	WR	Condition of forest edge	Code	1	8	8		1	12.3		*	UBB	
ERHARTEN	WA	Basal area proportion of tree species important for recreation		0	5			4	ERHANATU3		*	UBB	
ERHNATU1	WA	Natural characteristics in the recreational forest 1		2	8			4	12.4		*	UBB	
ERHNATU3	WA	Natural characteristics in the recreational forest 2		8	42			4	12.4		*	UBB	
ERHOLNA	WA	Weighted recreational demand		1	42521			4	12.4		*	UBB	
ERHWALD	WA	Importance of the forest for local recreation	Code	1	4	4		4	12.4		*	UU	
ERSCHINF	WA	Accessibility and infrastructure for recreation	Code	1	4	4		4	12.4		*	UU	

6.2 Literature

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Korrigendum S. 192:

$$V = \pi \sum_{i=1}^{q} \int_{x=h_{i-1}}^{h_i} \left[f(x) + g(x) - r(x) \right]^2 \times dx \tag{32}$$