1 Introduction

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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.

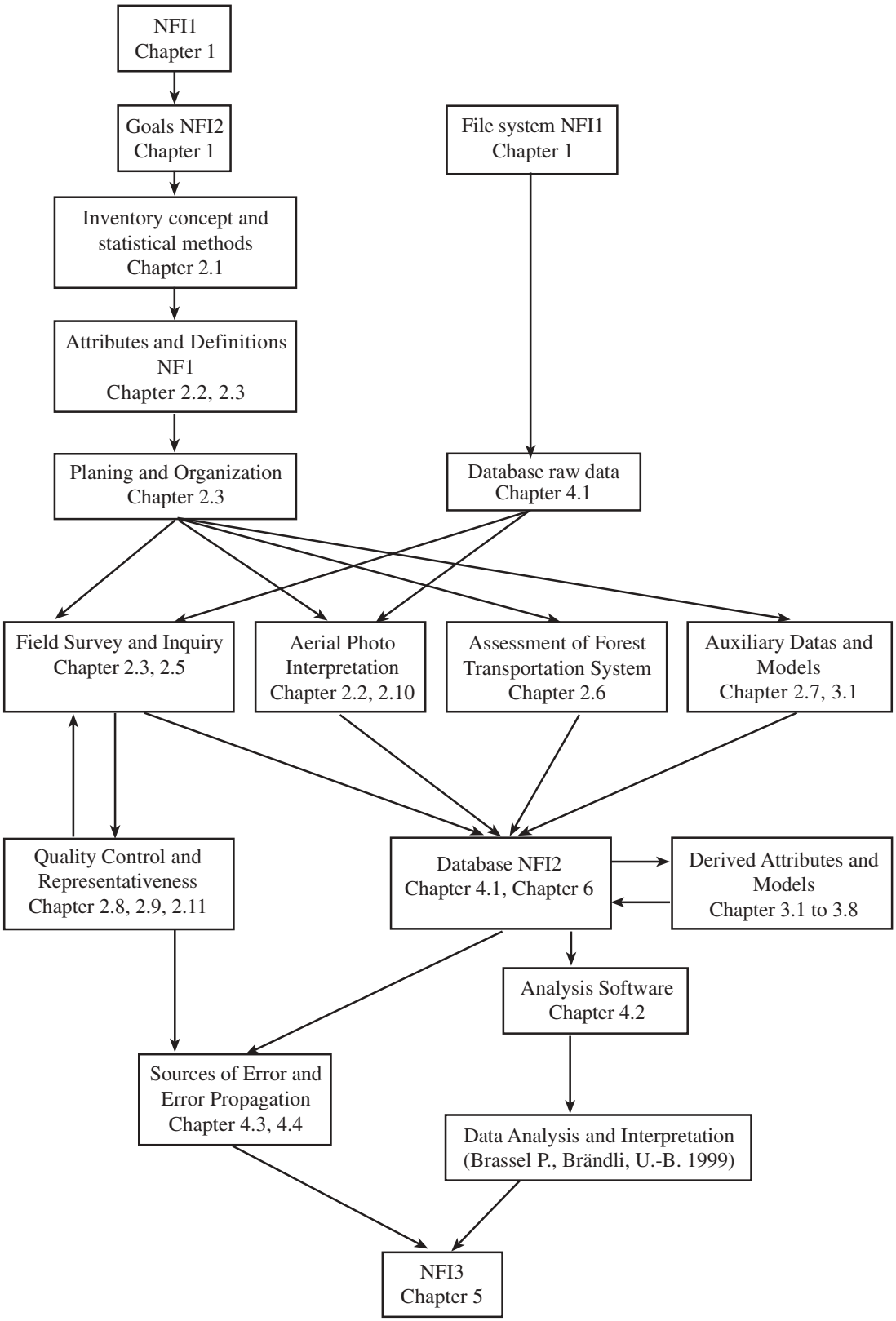

Figure 1. Flowchart NFI2.

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 inven-

tory. 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.

M**ain 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.

1.6 Literature

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