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An Information System for the Evaluation and Spatial Analysis of Forest Inventory Data

Ein Informationssystem zur Auswertung und räumlichen Analyse forstlicher Inventurdaten

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Summary

In the context of the project German Forest Sector under Global Change, forest inventory data of different sources with different resolutions were used to establish a Geographical Information System (GIS) for forest dynamics. The focus of the presented subtask was on the linkage of a single tree growth model to a GIS. Area-wide sample data on forest structure and production covering the whole of Germany provide the basis for the simulation of forest dynamics. The approach is based on the generation of representative three-dimensional forest stand information from sample data as a precondition for the simulation of future development by means of a growth model. Problems arising from the different hierarchies of spatial inventory data can be solved very user-friendly with the presented information system, which includes the automated handling of results from the simulator and the visualisation by thematic maps.

Keywords: Geographical Information System (GIS), simulation, growth model, inventory data stratification method

Zusammenfassung

Im Rahmen des Projektes „Wälder und Forstwirtschaft Deutschlands im Globalen Wandel“ wurden Daten verschiedener Datenquellen mit unterschiedlicher Auflösung verwendet um ein Informationssystem für forstliche Wuchsdynamik aufzubauen. Der Schwerpunkt des hier vorgestellten Teilprojektes lag in der Verknüpfung eines einzelbaumbasierten Wuchsmodells mit einem Geographischen Informationssystems. Flächendeckende Daten über die Struktur und Produktion der Wälder in Deutschland stellen die Grundlage für die Simulation der Wuchsdynamik dar. Der hier verwendete Ansatz basiert auf der Generierung von repräsentativen Beständen aus Stichprobendaten als Voraussetzung für die Simulation der zukünftigen Bestandesentwicklung mittels eines Wuchsmodells. Die Probleme, die durch verschiedene Ebenen räumlicher Inventurdaten entstehen, können mit dem hier vorgestellten Informationssystem, das die automatische Verarbeitung der Ergebnisse und die Visualisierung von thematischen Karten einschließt, benutzerfreundlich gelöst werden.

Schlüsselwörter: Geographisches Informationssystem (GIS), Simulation, Wuchsmodell, Stratifizierungsmethode von Inventurdaten

1 Introduction

One aim of German Forest Sector under Global Change (GFS) was the assessment of forest dynamics under global change. The focus of the presented subtask was the development of a software tool being able to utilise the existing pool of inventory data for generating input information, necessary to simulate forest development. These simulations were meant to be conducted on different spatial levels. A further intention was that the results of the simulations should be presented in a clear and comprehensive form to ensure that the model could be applied by persons who are not familiar with the interpretation of hardcore numerical output.

These specifications required the combination of a Geographical Information System (GIS) and a single tree growth model. In case of the single tree growth model the growth simulator SILVA was selected, which has been extensively tested and offers a highly flexible input interface (KAHN and PRETZSCH 1998, PRETZSCH 2002).

Two key features of the information system are the inventory data stratification method (ĎURSKÝ 1999) and the reproduction algorithms to generate different stands (POMMERENING 2000). Both methods in combination allow to construct representative forest stands from inventory data as start situations for simulations with SILVA.

The following section presents a short description of the data basis, followed by a specification of the stratification procedure and a description of the interface between GIS and growth simulator. The subsequent chapters deal with some exemplary simulation results and the visualisation of the model output for the inventory plot and for the regional scale.

2 Data base

Data from the Federal Forest Inventory (BWI) for former Western German federal states and from the "Datenspeicher Waldfonds" (DSW) for the newly-formed German states represent the data base for the nationwide model calculations. The inventory data of the BWI were harmonised with the results of the forest site mapping on plot-level. For the newly-formed German states, the DSW includes specification of stand and site conditions. This database contains only stand-based information, but no single tree data. Hence, to obtain data comparable to the BWI standard, a grid network is needed. This was available in terms of the so-called raster of the "Ökologische Waldzustandskontrolle" (ÖWK) of the former GDR. A combination of the ÖWK raster data with the data of the DSW then lead to the required data set (WOLFF 2002).

Information about actual climate (from 1961 to 1990) and climatic scenarios, including the mean temperature and rainfall in the growing season, the length of the growing season and the annual temperature amplitude was provided by the Potsdam Institute for Climate Impact Research for each inventory plot (LINDNER and CRAMER 2002).

The data base also includes information concerning the individual forest ecoregions of Germany (WOLFF 2002).

3 Stratification

The stratification assigns a large number of inventory plots to a limited number of superior units (strata). Thus, stratification serves to reduce the complexity of an unmanageable diversity of site conditions, tree species mixtures, stages of development, and suchlike to a manageable number of planning units. In addition, the stratification here serves to prepare the simulation of the forest estate model (DUSCHL and SUDA 2002) and to derive different silvicultural treatment scenarios on stratum level (DÖBBELER and SPELLMANN 2002) with the aid of a GIS. Hence, stratification is, in this context, a two-dimensional classification of stands based on stand and site type (PRETZSCH et al. 1998).

A stand type comprises stands with the same or similar growing stock and comparable silvicultural treatment. It is described by the dominant commercial tree species and the most important commercial admixture species. Sites showing similar growth conditions were assigned to one site type. The inventory plots belonging to one stratum should show comparable nutrient and water supply and similar climatic conditions, which are assured through grouping by altitudinal zone and degree of continentality. To deduce the corresponding altitudinal zone and the degree of continentality, site data were linked with aggregated climate data and the forest growth regions. The altitudinal zone level was defined by the annual average of air temperature. The continentality level classes were assigned by the annual variation of the air-temperature and by forest growth regions (SCHLOTT and GUNDERMANN 2002).

Stand type and site type of the inventory plots were connected by means of a two-dimensional grid. This classification results in cross stratification units (Fig. 1). A sufficient number of stands per cross stratification unit must be ensured for a proper reproduction of representative stands for the strata. This requirement has a certain influence on the choice of classification boundaries. A too narrow definition of the boundaries leads to an inadequate representation of the single strata, whereas a too wide definition tends to blur the growth determining differences between the strata. These aspects have to be evaluated depending on the required level of detail and the resolution of data.

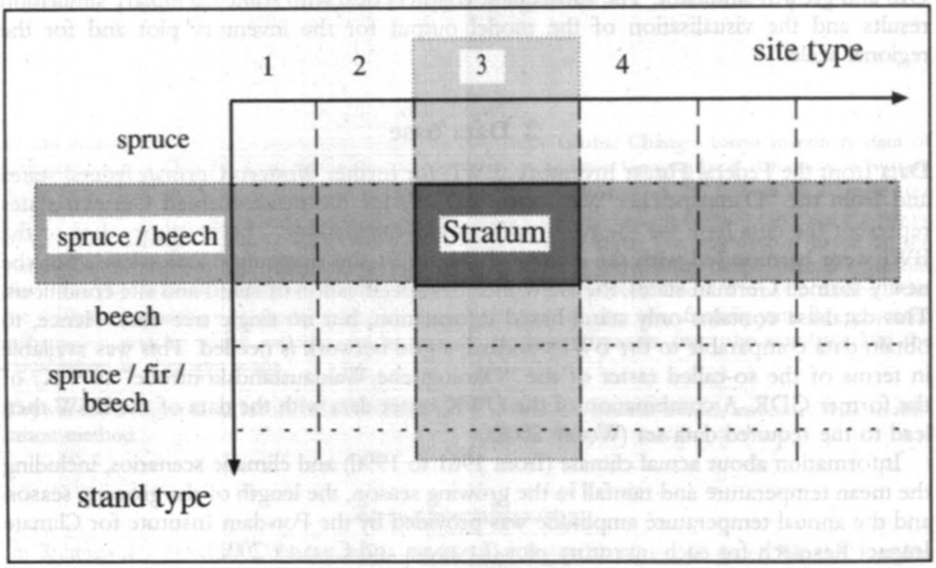

Fig. 1. Grouping forest stands by site conditions and stand types.

Abb. 1. Stratifizierung der Waldbestände nach Standorts- und Bestandestypen.

4 Composition of the information system

The information system within the scope of the GFS study consists of a database and a forest growth simulator (Fig. 2).

The database is compiled in MS Access in the environment of Desktop GIS ArcView 3.1. It contains the inventory data of BWI and DSW, including information about the location of individual forest ecoregions of Germany (WR). Furthermore information about actual climate (from 1961 to 1990) and climatic scenarios (LINDNER and CRAMER 2002) are linked to respective inventory plots in the database. All this information is connected to a spatial information system, which is set up in ArcView 3.1. The database is composed of main themes concerning the inventory plots and the forest ecoregions and of derived themes concerning the forest estate model (BRD200), which will be described later in more detail (see section 5.3), and the actual climate as well as the climatic scenario. A short description of the different thematic topics, which are called themes follows:

The topic *inventory plots* implies plot locations described by geographical coordinates. The data attributes from the database of inventory plots (BWI, DSW) are joined to the layer of each topic.

The topic *forest ecoregions* contains the areas of the different forest ecoregions of Germany. The information about forest ecoregions from the database is joined with the

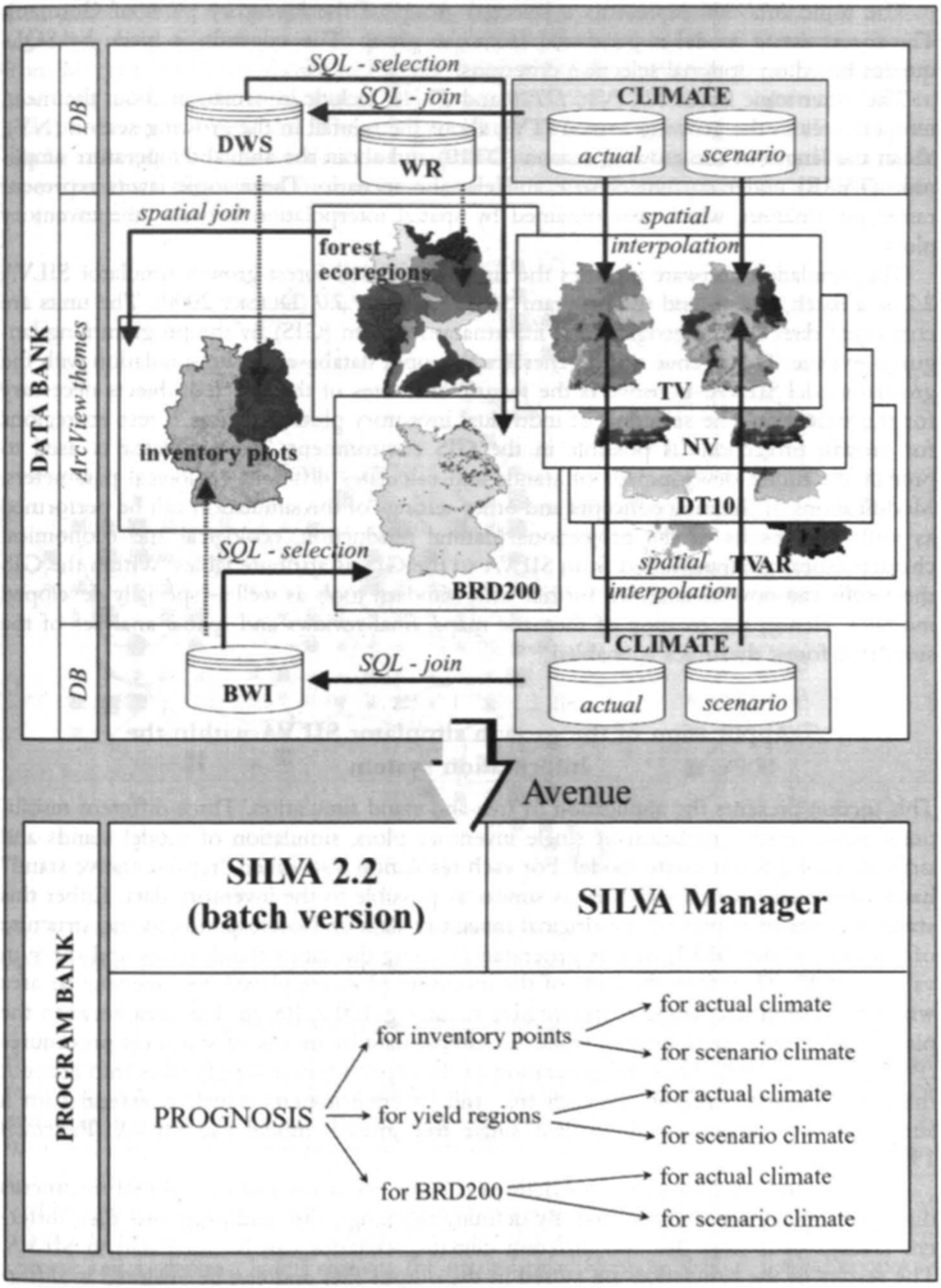

Fig. 2. Scheme of the developed information system.

Abb. 2. Aufbau des entwickelten Informationssystems.

theme. This theme is an overlay to the previous theme by spatial join, hence the identification of the inventory plots, which are located inside an individual forest ecoregion, is possible.

The topic *BRD200* represents a selected group of the inventory plots of Germany. The forest estate model is generated from the group. The selection is made by SQL-queries based on optional selection criterions.

The other topic layers *TV, NV, DT10* and *TVAR* include information about the mean temperatures in the growing season (TV), about the rainfall in the growing season (NV), about the length of the growing season (DT10) and about the annual temperature amplitude (TVAR) under current climate and climatic scenario. These topic layers represent raster information, which was obtained by spatial interpolation between the inventory plots.

The simulation software includes the single-tree-based forest growth simulator SILVA 2.2 as a batch version and the program *SILVA Manager 2.0* (ĎURSKÝ 2000). The units are connected directly to a geographical information system (GIS) by the programming language Avenue. The Avenue script generates the input database for the simulation with the growth model SILVA. It converts the feature attributes of the selected objects necessary for the simulator. The selection of individual inventory plots or whole forest ecoregions for growth projections is possible in the GIS environment. The simulator is used to predict the future development of stands and calculates different ecological parameters. Modifications of thinning concepts and other settings of the simulation can be performed as well. The results of the projections (natural production, ecological and economical characteristics) are transmitted from SILVA to the GIS as attribute tables. Within the GIS the results can now be analysed further with standard tools as well as specially developed modules. Hence, the creation of thematic maps, final reviews and spatial analyses of the simulated forest dynamics is enabled.

5 Application of the growth simulator SILVA within the information system

This section presents the application of tree and stand simulation. Three different resolutions are covered: simulation of single inventory plots, simulation of model stands and simulation of a forest estate model. For each resolution a so-called "representative stand" has to be created with a structure as similar as possible to the inventory data. Either this stand consists of copies of the original inventory data and corresponds to the structure of the sample plot (BWI) or it is generated by using the mean stand values and the sum values (DSW). Therefore, the trees of the inventory plots are placed on a rectangular area which is equal in size to the representative stand, e.g. 100 × 100 m. The area between the plots is filled with trees, created from the sample data by means of statistical procedures (POMMERENING 1998). Thus the generation of the representative stands takes into account the correct spatial structure of each tree and its environment, which is essential for a simulation with a position-dependent single tree growth model like SILVA (PRETZSCH 1993, 1997).

On the stand level the effects of defined climatic scenarios and silvicultural treatments on stand production are simulated. By defining thinning-, site- and prognosis files, different management strategies and different climatic scenarios can be simulated in SILVA. The results of the simulation are stored in the output files and can be analysed in different ways.

5.1 Simulation for inventory plots – (inductive simulation)

The application of the information system offers the option to use single inventory plot data to simulate tree growth as stated above. First of all, the plots for the generation are selected by choosing an area on the map or with a filter defining a range of certain site and stand properties. The three-dimensional structure of every chosen inventory plot is then generated by the program SILVA-Manager. Thus a representative stand is created according to the information on each single plot. Two examples of simulation results from MÜLLER (2000) are shown in Figures 3 and 4. Figure 3 presents the actual stock per inventory plot, which characterises the actual condition. The future increment for ten years is shown in Figure 4. Using this procedure, all information of each individual plot can be utilized. The characteristics of the stand structure are better preserved by a simulation, in which silvicultural treatment and stand structure interact than in a deductive way of simulation.

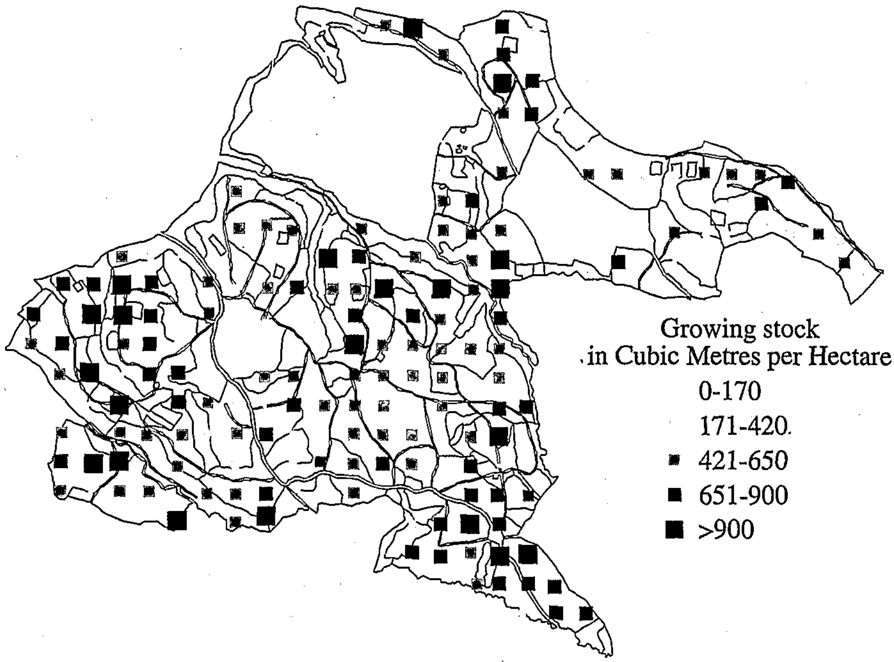

Fig. 3. Actual stock per inventory plot in cubic meters per hectare.
Abb. 3. Aktueller Vorrat pro Inventurpunkt in Vorratsfestmetern Derbholz pro Hektar.

5.2 Simulation for forest ecoregions (model stand)

By simulation on the scale of a forest ecoregion a representative stand has to be created for every forest ecoregion. The representative stand is generated from the data of the inventory plots of the most frequent site and stand type of each region (s. chapter 3). With this type of simulation the possibility exists to simulate forest dynamics with a larger spatial reference.

The simulation was carried out for actual and changed climatic conditions with all other conditions remaining constant. Thus, for the single growth regions for the present climate and a scenario based climate, the natural production as well as further economic and ecological indices were calculated and compared. The two maps shown in Figure 5 represent actual condition and the development of the stand under specific climatic conditions for each ecoregion. As a description factor the stumpage value is used. The darker the colouring the better are the proceeds.

5.3 Simulation for the forest estate model Germany

The simulation of the forest estate model Germany connects the two presented model resolutions. Different inventory plots are combined with the stratification. Altogether, the

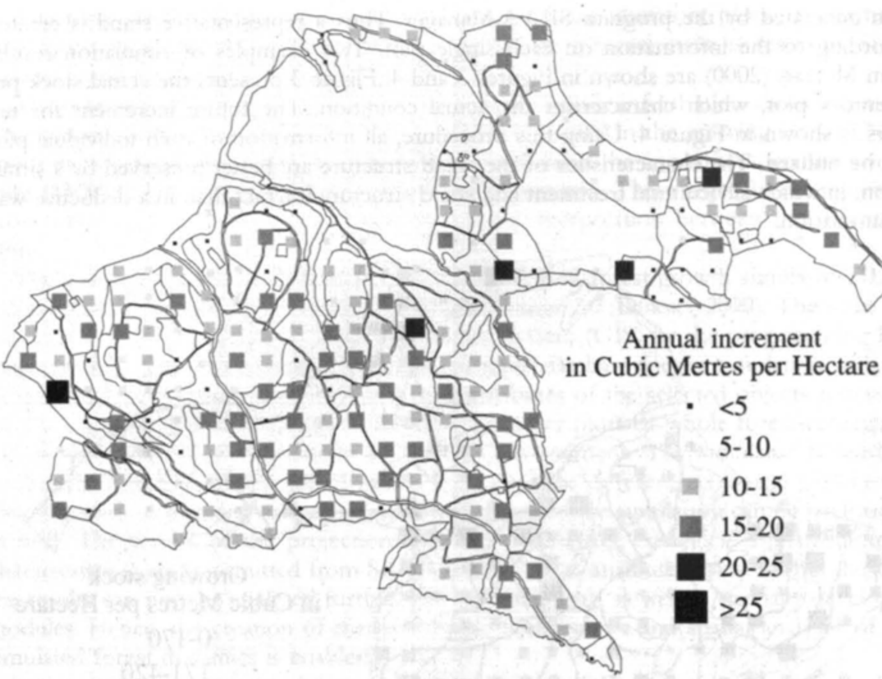

Fig. 4. Increment-simulation for the future ten years of each inventory plot (in cubic meters per hectare).

Abb. 4. Zuwachsprognose pro Inventurpunkt für das kommende Dezennium in Vorratsfestmetern Derbholz pro Hektar und Jahr.

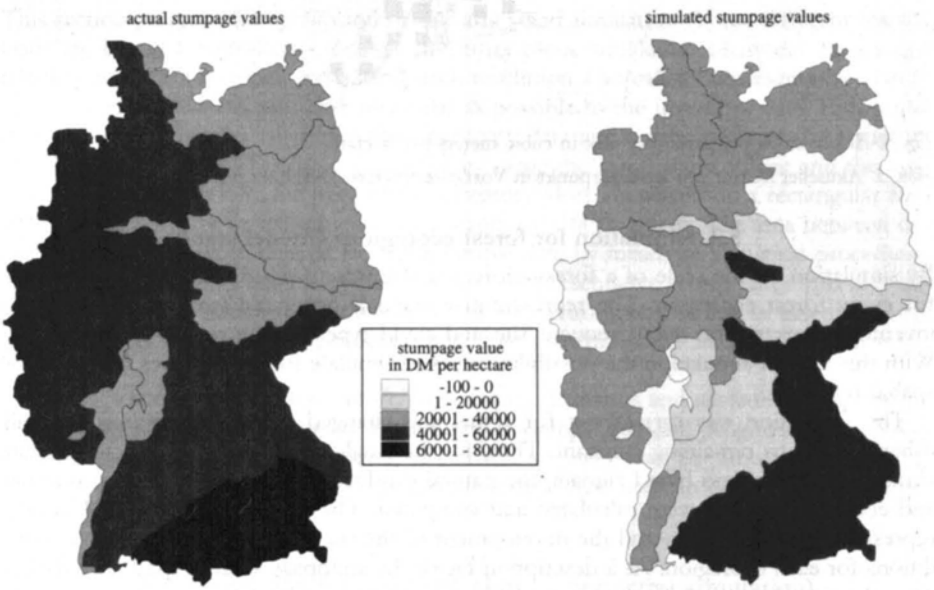

Fig. 5. Stumpage value per forest ecoregion, on the left side the actual conditions are shown and on the right side the simulated values under defined climatic conditions are presented.

Abb. 5. Holzerntekostenfreie Erlöse je Wuchsregion, links für den aktuellen Zustand und rechts unter definierten Klimabedingungen prognostiziert.

forest estate model consists of 200 representative stands in overall 15 strata (DUSCHL 2001). The number of stands per stratum is weighted depending on the frequency of the incidence of the strata in Germany. This forest estate model is the most important link to socio-economic investigation (DUSCHL and SUDA 2002) and a timber market model (BARTELHEIMER 2002).

5.4 Visualisation of results

This section displays maps with the results of a sensitivity analysis (PRETZSCH and ĎURSKÝ 2002) for each region typical stands on typical sites were simulated. These maps represent the synopsis of multiple simulation calculations.

Figure 6 shows the calculated site index and the basal area per hectare per region for the tree species spruce. The darker the colouring, the better the site class, respectively the higher the basal area. With the bar chart information between the tree species spruce, pine, beech and oak can be composed and the tree species with the best growth production of the region can be recognized in an easy way. In the map on the right the proportions of the basal areas of the tree species indicate the common tree species of the region.

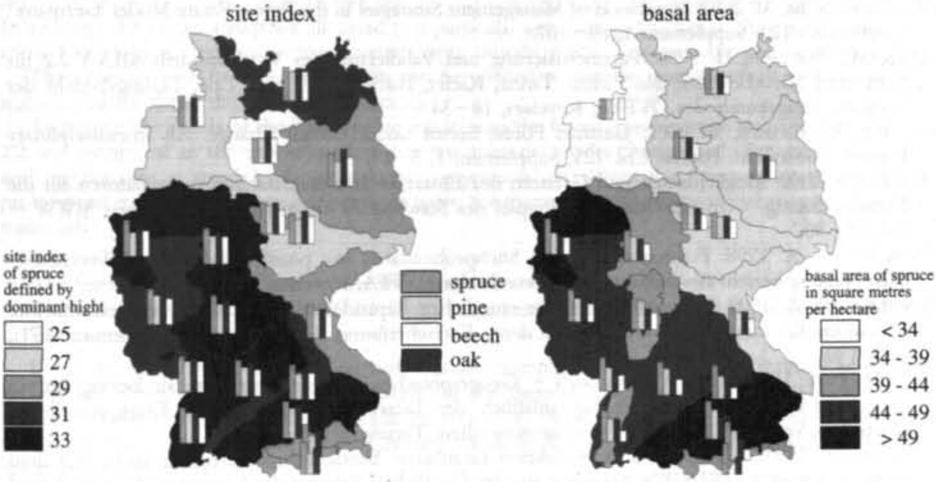

Fig. 6. Distribution of the site indices and the basal areas of each forest ecoregion for the tree species spruce (left hand: site indices right hand: basal areas). The bar chart indicates the proportions for different tree species per forest ecoregion.

Abb. 6. Verteilung der Werte der Bonitäten und Grundflächen je Wuchsregion für die Baumart Fichte (links: Bonitäten, rechts: Grundflächen). Die Balkendiagramme zeigen die Verhältnisse der jeweiligen Werte für unterschiedliche Baumarten je Wuchsregion.

6 Conclusion

In the scope of this project an information system for different questions of the impact of a changing climate on forestry was developed. The questions can be answered with the aid of new technologies. A Geographical Information System offers the user extensive possibilities to evaluate geographical data while growth models like the single tree growth model SILVA cover the aspects of the ecology and structural development of the flora. But up to now a lot of aspects of information on the landscape have rarely been used in combination. Existing approaches of integrating GIS and simulation data have been based on just a few facets (POTT 1998). The presented approach offers the operator an automated way of integrating data from different sources in a user-friendly way. The Geographical Information System is used to manage the information system and to visualise the results on different scales. Hence a comparison of the results can be improved and the spatial analysis is considerably easier. The single tree growth model SILVA permits a temporal solution for the simulation. The idea to combine a Geographical Information System and a single tree growth model enables studies on different spatial and temporal resolutions.

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