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# FUSION OF DIFFERENT DATA-LEVELS WITHIN GEOGRAPHIC INFORMATION SYSTEMS

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**ABSTRACT:** In this document methods for the fusion of different GIS-data with remote sensing data will be demonstrated and discussed by the help of a practical example of its application. The objective of the project has been on one hand to develop methods for a remote sensing-based inventory of forest decline and on the other hand the establishment of a Forest Information System (FIS). The investigation in the context of the Forest Information System on which results the following explanations concentrate, has been the conception of a GIS-data-set containing the relevant basic informations for the environmental planning processes. For this reason, besides thematical maps and the digital height model, the results of a forest decline classification on the base of Landsat Thematic Mapper data have been implemented as the actual level of knowledge inside the Forest Information System. Following now, the working steps and the methods for the **capture** and the **integration** of the different data-levels in the Forest Information System will be summarizingly demonstrated. Besides that **methods for the fusion** of data levels as well as the resulting possibilities for planning processes will be demonstrated by the help of an example for the GIS-supported judgement of nature proximity of forest stands. The studies have been conducted in the context of the project „Monitoring of forest decline in the western Harz by the help of remote sensing methods and GIS“ at the Technical University Berlin, sponsored by the BMBF.

## 1. BACKGROUND

The objective of data fusion is to combine data sets from multiple sources into a single set of meaningful information. The availability of digital data sets is significantly growing and thus available for processing and combining by data fusion methods. State of the art GIS-systems are capable of combining data in various different representation forms. By means of these systems, continuous raster data, e.g. digital terrain models, polygon vector layers, e.g. soil maps, point measurements, e.g. meteorological observations can be combined within data fusion models. Besides the information sources mentioned above, results from satellite remote sensing increasingly gain importance in GIS-systems. By these means, informations can be extracted out of satellite data, which aren't either available at all or which can only be found in maps or other information resources of a scale unconvenient for research on a small scale. Moreover, the results from remote sensing also offer themselves as the actual GIS-level and they prove especially indispensable when regarding monitoring aspects where the dynamic of the development of vegetation surfaces has to be investigated. Whereas this information up to now has been collected on an irregular basis mostly by the means of initiatives of local inventories and monitoring programs, there is an increasing demand for a more standardised approach to such inventories which can be applied across wider areas. Here, satellite remote sensing has an important role to play in that it can provide a data source which has the advantage of being continuously collected over wide areas, repeated coverage in certain time intervals, in a standard format and accessible to everybody.

However, the integration of remote sensing data and other relevant data layers demand appropriate data fusion methods. Only if these methods are available, increasing amount of new information resulting from complementary information content of the various different data layers can be optimally utilised. For all that, many restrictions on the data fusion methods have to be taken into consideration for practical applications. These restrictions as well as opportunities of data fusion methods will be treated in this study.

## 2. TEST SITE

The Harz - one of the most severely damaged regions in Germany - is located between Hannover, Magdeburg and Göttingen. Its forest area comprises 94,000 ha. The Harz was selected as an important test area in several major experiments on national and international level. The main tree species of the test site are spruce (Picea abies), occurring in the higher regions of the Harz and beech (Fagus sylvatica) growing in the lower parts. In the higher regions the silvicultural treatment is particularly performed as a group selection felling system, thus resulting in multi-layered stands of different ages. With these few exceptions the stands mainly occur as homogeneous stands and in the lower parts they are harvested by clear felling. The pure spruce stands are the most frequent results of silviculture in the former mining area of the Harz.

The Harz shows very different climatic conditions. All climatic stages from collin to sub-alpine, oceanic to continental can be found. The highest mountain, the Brocken, 1142 m asl., and characterizes the natural timber line. Rainfall varies from 400 to 600 mm per year in the eastern parts up to 1400 mm per year in the higher regions. The site-characteristics of the area are extremely diverse with practically all variations from dry lime soils in the south-western parts to well drained brown soils and podzols. In higher regions peat-bogs in different stages of development can be found. The water supply of the forest stands is very variable, due to the differing site and climate conditions.

The forest decline symptoms have been clearly identified since 1980 and they spread alarmingly until now, particularly in the higher regions. The forest stands show a variety of forest decline, ranking from almost intact in the lower regions to most severe damages, like opening-up of stands and deforestation symptoms, in the higher regions. The strongly affected stands are additionally damaged by storm and beetle calamities (Ips typographus).

## 3. DATA CAPTURE - CONSTRUCTION OF THE FOREST INFORMATION SYSTEM

The geographic information system Arc/Info has been used as GIS-database. The used geodetic reference-system was Gauss-Krüger. The different components of the Forest Information System are shown in table 1.

**Table 1:** Components and information content of the Forest Information System

| Components | Information Content |
|---|---|
| **Forest maps**<br>scale 1:10.000<br>in vector-format | Forest parameters such as<br>• tree species, tree age<br>• stand structure<br>• timber volume<br>• a.s.o.<br>(more than 15.000 stands) |
| **Soil maps**<br>scale 1:10.000<br>in vector-format | Pedological features such as<br>• soil moisture<br>• soil type<br>• nutrient supply<br>• soil depth<br>• a.s.o |
| **Topographical maps** in raster format (1:25.000 - 1:100.000) | Topographical features such as<br>• streets<br>• lakes<br>• buildings<br>• a.s.o. |
| **Terrain model**<br>in raster-format | Terrain features such as<br>• slope<br>• aspect<br>• illumination |
| **Height zones**<br>in raster format | Height zones<br>• colline<br>• submonatane<br>• montane<br>• subalpin<br>• a.s.o |
| **Satellite classification**<br>in raster-format | Forest parameters<br>• crown closure<br>• forest damage |
| **Aerial photo inter-pretation**<br>in vector-format | Forest parameters<br>• crown closure<br>• needle loss<br>• vertical stand structure<br>• a.s.o |

A. Digital forest maps

Forest maps are to be seen as a central element of the Forest Information System. In order to integrate stand parameters such as tree age, tree species and stand structure, the forest management plans (70 map sheets consisting of over 15.000 planning units) of the complete western Harz Mountains have been digitized. Because of the insufficient geometrical accuracy of the forest survey (gaps and overlapping of neighbouring map sheets of up to 100 meters) each map had to be geometrically corrected in Arc/Info using a rubber-sheet algorithm and pass points derived from topographical maps. After the geometrical correction, the digitized map sheets were merged together to one forest map containing the complete forest area of the Harz mountains.

As attribute data, the digital stand description of the forestry administration could be used. The attribute data containing about 100 different stand parameters were prepared due to the requirements of satellite classifications and computer-aided forest management plannings. By combinations of the attribute data and the digitized forest maps the planning units can be stratified according to single parameters or different combinations of the stand parameters. The stratifications result in example maps demonstrating the distribution of different e.g. age classes, tree species, tree heights or diameter classes.

B. Digital soil maps

Digital soil maps also create a central component of the Forest Information System. Together with the digital terrain model, forest management maps, and the forest decline classification, these maps were used for feasibility studies of the Forest Information System according to forestry management plannings. The soil maps have been digitized by the Institute of Soil Science of Niedersachsen.

C. Digital topographical maps

Digital topographical raster maps have been integrated in the Forest Information System in order to automate the process of geometrical correction of the digitized forest management maps. These maps have been made available by the Surveying Administration of Niedersachsen.

D. Digital terrain model (DTM) and height zones

A digital terrain model is integrated into the FIS first of all to eliminate the negative influence of topographical parameters in the satellite image (Schardt 1987, 1990) and secondly to derive information of growth conditions of the forests.

A map of the height-zones was calculated using the topographical parameters elevation, slope and aspect from the DTM. The DTM and the height-zone map were geometrically adapted and superimposed to the satellite data, too. The spatial differences between the DTM and the satellite data reach up to about 15 meters due to the y- and x- axis and less then 5 meters due to the z- axis (height above sea-level) which is highly satisfactory for classification purposes on a scale of less than 1 : 50.000.

E. Classification Results from Satellite Data

The satellite image was classified by the following stand parameters:

- needle loss
- crown density
- total needle loss, resulting from needle loss and reduction of crown density

The parameters listed above could not be derived from existing information such as forest maps. Nevertheless the availability of these parameters was necessary to evaluate the condition of the forests and thus had to be assessed by means of satellite remote sensing methods.

For the classification Thematic Mapper data of the year 1991 have been used. The satellite images were rectified into the Gauß-Krüger coordinates using the pass point method. The RMS-Error of the geometrical correction reaches up to 18 m. For the evaluation of the satellite images the Image Processing System ERDAS has been used. The classification was carried out for the class definitions set up in this project by a simple threshold method using the bands 4 and 5 (near and middle infrared) and the maximum likelihood method using the bands TM2,3,4 and TM5. In order to integrate illumination and tree age into the classification, the entire Harz was stratified into two age and three illumination classes using the digital terrain model and the digitized forest management plans.

The comparison of the classification results with the results of the aerial photo interpretation shows the following correspondences: stand density categories can be classified in intervals of 10% with an average accuracy of over 90%. The negative influence of ground vegetation on the classification of stand density is not as high as expected. The accuracy of the classification of 4 needle loss categories (C0-C3) is very low and doesn't exceed 65%. This is due to the high influence of stand density on the signature masking the signature differences caused by different needle loss symptoms. The classification of needle loss in stands with low density has even to be regarded as impossible. The classification of the category resulting from both stand density and needle loss of remaining trees provides satisfactory results. 5 classes could be devided with an accuracy of about 85%. More details on the classification and accuracy assessment can be found in SCHARDT et al. 1995 and KENNEWEG et al. 1993.

F. Results of areal photo interpretation

The results of areal photo interpretation have been integrated into the Forest Information system in order to compare these results with those derived from satellite remote sensing. Aerial infrared photos on a scale of 1 : 6.000 and 1 : 7.000 have been taken for small and representative areas of the Harz Mountains. They were used to estimate the crown density and the percentage distribution of the different needle loss classes. For the estimation of the crown density, a 1mm x 1mm grid (6m x 6m on the ground) was superimposed to the aerial photos. The relation between grid points covering a tree and those covering a gap between trees can be defined as the crown-cover percentage. The percentage of the different needle-loss classes was estimated by the interpretation of 3 trees per sample plot on a 30m x 30m grid. The interpretation has been carried out using the AFL interpretation key (VDI-Richtlinie 1990).

## 4. FUSION OF INTEGRATED DATA FOR EVALUATION OF NATURAL PROXIMITY

By the help of an example for the judgement of nature proximity of the forest stand, in the following the methods will be described that have been used for the merging of the various informations as mentioned above. The application example „nature proximity of forest stands“ has been elected for all information levels of the Forest Information System could be taken into account and thus various aspects of data fusion could be explained in this complex subject (see figure 1). The judgement of nature proximity represents moreover an important information resource which will be required for the realization of the ecological objectives in the Harz area.

### Methodical approach

For the judgement of nature proximity of forest stands the actual potential natural vegetation (hnpV) was compared with the actual forest stand. For the judgement of the status of the actual forest stand, in addition to the informations directly extracted out of forest maps, results from remote sensing have been integrated into the judgement of nature proximity. As smallest reference unit for the judgement of nature proximity, the forest stand respectively the sub-area of the digital forest map has been chosen. This is due to the fact that forest stand represents the unit of silvicultural activities and thus the results can be directly transfered for planning purposes. In the following, the methods used for the merging and standwise integration of the different data-levels will be explained. More detailled information on the methodical approach can be found in FABER et al. (1994).

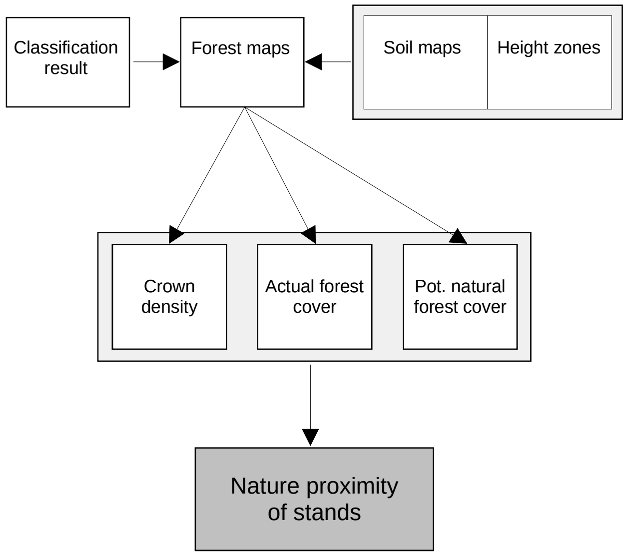


**Figure 1:** Fusion of different data-levels for the judgement of nature proximity of forest stands

### 4.1. Integration of the classification result into the FIS on stand level

The classification results were integrated into the Forest Information System on stand level according to the vectorized digital forest maps on raster level. For this purpose different steps of data processing were performed: In order to avoid overlapping errors at the stand boundaries, the digital forest maps were buffered in a first step with a distance of +/-30m which corresponds to the spatial resolution of the Thematc Mapper data. In a second step the buffered forest maps were converted into raster-format. This way individual grey values (from 1-16.000) were allocated to each of the stands. In a third step the classification result was masked by the rastered forest maps (fusion on raster level). This masking procedure results in an ASCII-table which provides different statistical parameters such as mean value, standard deviation or median value of the classified forest parameters "needle loss", "stand density" and "total needle loss" for each stand. In a last step the ASCII-table was linked to the attribute table in Arc/Info and used as an additional parameter of the digital vector forest maps.

### 4.2 Assessment of potential natural forest cover and integration into the FIS on stand level

A. The presence of a potential natural forest cover is mainly defined by the topographic height-zone and the soil-conditions. The potential natural forest cover could therefore be derived by the means of merging the rastered soil-map with the height-zone map derived from the digital terrain model (see chapter 3D). The fusion of the soil map with the height-zone map, at hand in raster format, occured on the raster-level, thus analogous to the method already used in chapter 4.1 at the integration of the classification results in the digital forest map. A buffering of border lines of different soil units hasn't been necessary in this case, for the height zones represent vast homogenous areas and therefore the error of merging, resulting from a poor geometric correspondence of the data-levels to be merged is regarded as neglectable. When soil units reside in an adjacent area of two height zones, the height zone with the highest pixel number has been integrated into the attribute table of the soil map.

B. As a fusion result a soil map is now available which offers for each soil unit the additional parameter "height zone". The deduction of the present potential natural forest cover is now possible by the use of classification rules "soil condition" <-> "height zone" on the level of the soil units within the attribute table of Arc/Info (fusion on data base level). The employed classification rules have been developed by the forest planing administration of Niedersachsen (NMELF, 1992 und Schwietert, 1989).

C. In order to grant an automatic judgement of nature proximity on stand level, the information on potential natural forest cover derived for the area units of the soil-maps have been merged with the forest maps. The fusion of both maps was carried out on vector level using Arc/Info routines. If more than one potential natural forest vegetation society exists within one forest stand, the forest vegetation society representing the largest sub-area has been considered deputizingly.

### 4.3 Assessment of actual forest type on stand level

In order to facilitate a comparison between the actual forest cover with the present potential natural forest cover, the forest society of the stands have been derived from the forest map. Therefore the standwise forest inventory data stored in the attribute table of the forest map had to be transferred into the actual forest society. This was necessary because this information could not be directly derived from the attribute table. The fusion of informations was performed within the attribute table of Arc/Info. The classification of forest stand types into potential natural forest cover has been oriented according to the tree species composition of the natural forest society as described by the plant sociology (e.g. ELLENBERG, 1978). Characteristics of vegetation such as species and composition of the ground-vegetation couldn't be taken into consideration, for this sort of information doesn't show up in the attribute table of the forest maps. A distinction of forest vegetation societies, comparable because of their tree-species composition, but different because of varying ground vegetation is therefore impossible.

## 5. RESULT OF THE JUDGEMENT OF NATURE PROXIMITY

The basis for the judgement of nature proximity of the forest stands have been the information, integrated in the forest map for each stand concerning „actual forest stand“ (chapter 4.3), the "potential natural forest cover" (chapter 4.2) as well as the results of the classification of the satellite images (chapter 4.1). The merging of these data levels, derived from different information sources, occurred by the fusion of the enhanced attribute table of the digital forest map (data base level). The judgement of the proximity of forest stand was carried out by comparing the actual forest stand with the potential natural forest cover on stand level. The result of this comparison was that only some spruce stands of the upper regions and some beech stands of the lower parts of the Harz were classified into the category "high nature proximity". Whether or not these stands belonged also because of their ground vegetation or side-tree species to the characteristic potential forest composition couldn't be investigated. This is due to the fact that, as mentioned above, no information on ground vegetation was available in the attribute table of the forest map. Apart of this restriction such a result offers however a reliable clue concerning the nature proximity of the forest stand and therefore a precious assistance for forest planning.

For the judgement of the condition of the selected forest stands the results of the satellite classification which were integrated into the forest map have been used. For this purpose the information on crown density has been chosen since this parameter is best suited for the assessment of stand stability. The fusion of the new information level strengthens the fact that nearly all spruce stands with a high nature proximity in the upper regions are severly deforested (cover less than 60%) and thus no longer to be classified with a high nature proximity in every respect. This example demonstrates that remote sensing in a spatial information system can furnish, as an actual source of information, important and supplementary information.

## 6. SUMMARY

From the results of this study it is to be inferred that the FIS can offer an effective mean of assistance for planning tasks. The GIS-based method shows the advantage that once the data exists in digital form, planning tasks can be solved fast and flexibly. The therefore necessary fusion of various data-levels of a spatial information system can be effected by the use of different fusion-methods. The choice of the method depends hereby on the specific problem and most important on the sort of data used.

In addition to the spatial component, also the temporal component of planning can be considered. On this occasion various scenarios can be considered by the automated extrapolation of single data-levels. These can be then illustrated fast and cost-effectively in cartographic form or as area-balances. A further advantage of GIS-based methods is the relatively unproblematic integration of results from remote sensing. By the help of this, already available informations can be actualized and involved in the planning process.

Examples for further employments, exceeding the applications mentioned above are:

- Use for the integration of results from remote sensing-based monitoring-projects
- Use for the modeling of effects of climate changes on forest ecosystems
- Use for forest inventory and map continuation

A disadvantage that arouses from the use of GIS methods is the enormous amount of time and costs that is connected with the capture of data. Regarding the fact however, that in the future an increasing amount of data will be available in digital form and will be used by different users from various faculties this multiple use of the data will strongly reduce the expenditures.

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