SMALL SCALE FOREST CLASSIFICATION AND EVALUATION OF WOOD RESOURCES IN THE UKRAINIAN CARPATHIANS

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ABSTRACT

A project for investors in wood industry was conducted to evaluate the standing timber volume, its geographical distribution and the harvest potential of the Ukrainian part of the Carpathian Mountains. Based on these needs, remote sensing and GIS are suitable tools to derive the required information. The special challenge of this project was the absence of any detailed ground truth information and also no possibility to fall back on aerial imagery as well as the short time frame available. Therefore a procedure had to be designed, which allows to derive useful information for a large area based on satellite data and a very limited field work only. The setup is based on area-wide multi-temporal LANDSAT data and samples of recent IKONOS scenes. LANDSAT data from three epochs were used: images from the beginning 90ies, the 'main' data coverage from 2002/3 and a recent coverage of the SLC_OFF LANDSAT scenes from 2004/5. The 2002/3 data was used for the basic classification. A forest mask was derived taking into account all three time frames. IKONOS data (7x7km chips) were selected representatively over the area in order to effectively collect training data for the classification. To be able to derive training sites from the IKONOS scenes, an interpretation key was derived by field work. The result comprises a map of the main forest types and four age classes. The accuracy from the basic classification (2002/3 data) showed an average classification accuracy for the tree species classification of 90%. The classification of young development stage yielded 84% correct and for older stocks 79%. This is not the final quality, since the additional multi-temporal analysis is not yet included. The final classification result was visually compared to the IKONOS images and showed an improved quality compared to the initial mono-temporal classification. Based on the classification and existing data from the literature, the standing timber volume and yield conditions of each forest type could be estimated for each pixel. The whole project was conducted within four months, which was only possible by accelerating the remote sensing component using IKONOS data as ground truth.

Keywords: forest inventory, wood industry, satellite imagery, classification

1 INTRODUCTION

The utilization of forest resources over large areas is often a cumbersome and cost intensive task. In order to reduce the costs for this task, there is a need to optimise harvesting procedures and transportation logistics. For this purpose some key information is necessary, which encompass the allocation of timber volume, forest species composition, the distribution of age classes, information on growth and potential harvest volume. For the current case a large area in the Carpathian Mountains in the Ukraine (almost 35.000 km²) was analysed. The derivation of the required information from terrestrial observation is clearly not feasible over such a large area in a reasonable time. In addition, large parts of the investigation area are located in steep and inaccessible areas further preventing intensive field measurements. Based on these restrictions, remote sensing and GIS form an appropriate alternative to obtain the required information.

The forest types classified from remote sensing data were combined with data on standing timber volume and growth conditions from existing scientific sources. The knowledge on the spatial distribution of the forest resources together with other geographical data on traffic connections (roads, railway) led to proposals for the localisation of new wood industry plants. This article focuses on the forest resources assessment part.

2 METHODOLOGY

The project encompasses two topics: first, the derivation of forest parameters by means of satellite imagery and second, on this basis the assessment of wood resources at a watershed level. For the first topic LANDSAT TM scenes were used, pre-processed and a supervised classification was applied. The preprocessing steps of the LANDSAT images comprised geocoding, followed by a topographic normalization and a radiometric calibration. Based on the preprocessing results, a forest mask was derived by threshold operations and visual correction. Within this forest mask, the main forest parameters, as there are species type, age classes and crown coverage, were computed. A combination of IKONOS satellite imagery and a short field trip was used to derive the interpretation key and thus generate training data necessary for the classification. The timber volume was then calculated by synchronizing the forest types from satellite data classification with data on timber volume per forest type from literature: Ministery of Education and Science, 2004, further referred to as "Scientific Study". All other results were reached by using GIS procedures. Figure 1 shows a graphical overview of the project.

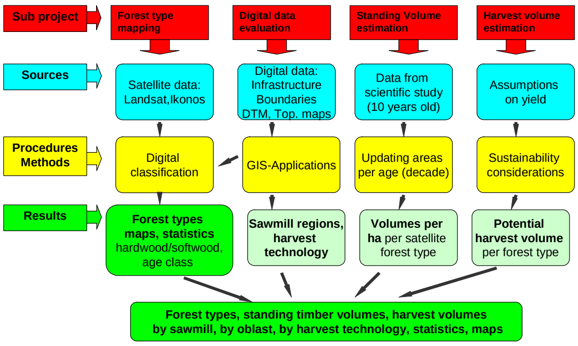

Figure 1. Graphical overview of the project.

2.1 DATA COLLECTION

Six LANDSAT ETM+ scenes were selected, considering the best scene properties according to cloud coverage, acquisition time (date and hour) and season. This main data coverage was acquired in 2002/3 at three different dates: path 186 (1 image): 19.08.2002, path 185 (3 images): 27.05.2003 and path 184 (2 images): 21.08.2002 (see Figure 2). All scenes are SLC_ON data. After 2003, the LANDSAT SLC mode failed and only SLC_OFF data was available for more recent acquisition dates. Although SLC_OFF data cannot be used for detailed classification, such a data set (2004/5) was acquired to update major changes, like clear cuts. They have been derived from the 2004/5 data sets and consequently integrated into the classification result. In addition, older LANDSAT data (ca. 1990) was used to differentiate between spectrally similar classes.

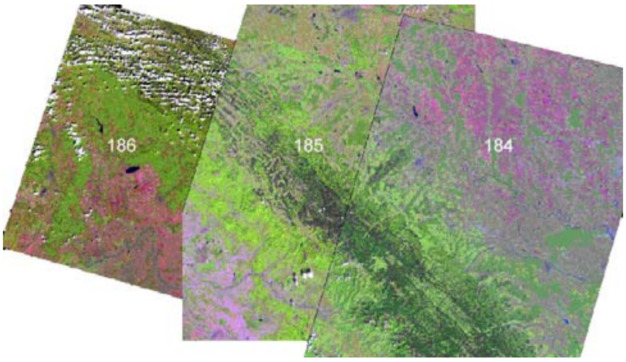

Figure 2. LANDSAT images covering the testsite.

For the preparation of the interpretation key and the training data 11 IKONOS data sets (7x7 km) were ordered from EURIMAGE. This (pansharpened) type of satellite data offers a spatial resolution of 1 m in four spectral bands including the near infrared. Following aspects were considered for the selection of these scenes in order to be representative:

- Well balanced distribution across the whole project area
- Well balanced distribution across the 2002/3 LANDSAT ETM+ scenes
- Coverage of all classes from the nomenclature (age and tree species)

The data on the timber volume per forest type were taken from the mentioned scientific study.

2.2 NOMENCLATURE FOR CLASSIFICATION

The nomenclature was elaborated according to the user requirements and the potential of LANDSAT data. Following parameters have been defined:

1. Forest area (forest mask):
    - Crown coverage > 30 %
    - Potential forest growth > 7 m
    - Minimum area > 5000 m²
2. Forest types:
    - Predominantly broadleaf (> 90 %)
    - Predominantly coniferous (> 90 %)
    - Broadleaf-dominated mixed forest (broadleaf share 50 % - 90 %)
    - Coniferous-dominated mixed forest (coniferous share 50 % - 90 %)
3. Growth classes:
    - Open areas (clear cuts)
    - Closed young forest, thicket and pole
    - "Timber" and "strong timber"
    - Old aged forest (rule based derivation)

Additionally the parameter crown coverage was derived for two classes, namely less than and more than 50 %.

2.3 GEOCODING

The images of each path of the 2002/3 LANDSAT data were treated jointly and orthorectified using the RSG (Remote Sensing Software Package Graz, JOANNEUM RESEARCH, 1998), the in-house software of the Institute of Digital Image Processing. Due to mountainous terrain it was necessary to perform a DEM (Digital Elevation Model) based geocoding. The DEM has been derived from SRTM (shuttle radar topographic mission) and shows a ground resolution of 90 m. Based on ground control points, the images were geocoded maintaining the original resolution of 28.5 m. The geocoding accuracy is less than 1 pixel root mean square error.

2.4 TOPOGRAPHIC NORMALISATION

The strong relief does not only affect the geometric properties of an image but also has a significant impact on the illumination and the reflection of the recorded area. This effect is caused by the local variations of view and illumination angles due to terrain, and thus, is particularly critical for applications in high mountain regions (Colby; 1991; Meyer et al, 1993). Therefore, identical forest types might be represented by significantly different intensity values depending on the slope orientation and on the position of the sun at the time of data acquisition. Thus, it was a prerequisite to apply a topographic correction on the data.

Based on the experience of several projects in the alpine region, the Minnaert correction model was selected and applied. For estimating the Minnaert constant (K value), two types of forested areas were used: pure spruce and pure broadleaf forest, which fulfill both following requirements: (i) crown cover more than 80 % and (ii) growth class “timber”.

The successful application of the correction is displayed in Figure 3, where it can clearly be seen that the shadowed slopes are equalized and the resulting image appears plain.

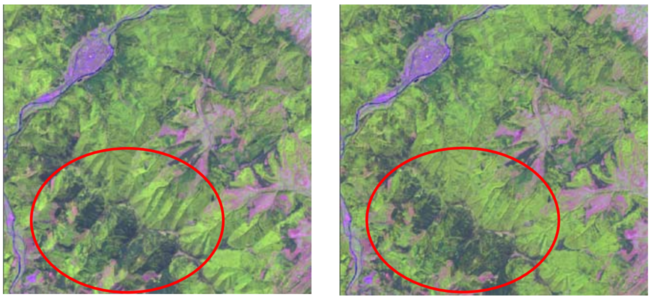

Figure 3. Left: original image; right: topographically corrected image.

2.5 RADIOMETRIC CALIBRATION

Radiometric calibration allows the handling of different scenes like one single image, and thus minimizing the effort of obtaining training data sets. A procedure based on regression analysis was performed for the overlapping strip between the western project area (path 186) and the centre area (path 185, see Figure 2). The part from path 186 belonging to the investigation area could be successfully adjusted to the radiometrical properties of path 185 and therefore 185 and 186 could be mosaicked and jointly treated in the following classification. The same procedure was also tested for the overlap between path 185 and path 184. However, the radiometric calibration for this part could not be performed with adequate accuracy. Therefore, two separate data sets (185/186 and 184) were classified.

2.6 FOREST MASK

The forest mask generation consisted of various processing steps. First, thresholds were derived from the LANDSAT ETM+ data from 2002/3 for each of the two strips separately. Ambiguous reflectance values between broadleaf forest and cultivated crops in the northern areas made exclusion based on additional thresholds for different parts of the strips necessary. Finally, the forest mask from both strips were checked visually and revised by on-screen interpretation integrating also the data from the two other epochs in order to guarantee a high quality result.

2.7 SUPERVISED CLASSIFICATION

In order to reduce the effort of obtaining training data from field work, a two stage procedure was developed (see Figure 4). Based on the interpretation key derived in the field and by means of IKONOS data, additional training area could be identified in other IKONOS images. This approach saves a lot of time, because signatures, which are once clearly defined and checked in the field, can be found easily in the IKONOS data in other areas again. These training data was then transferred to the LANDSAT images and after an extensive signature analysis supervised classification using the Maximum Likelihood (ML) classifier was applied. ML proved to be useful for forest parameter classification in earlier studies (Schardt 1997, Granica et al. 2005, Schardt et al. 2005). However, not all classed could be derived with the required accuracy, therefore additional procedures were needed. For the differentiation of the growth class “old aged forest”, a rule based approach was used integrating the crown coverage classification. The differentiation of young coniferous-dominated stands and old deciduous-dominated stands required a multi-temporal analysis using the LANDSAT data from the 1990ies.

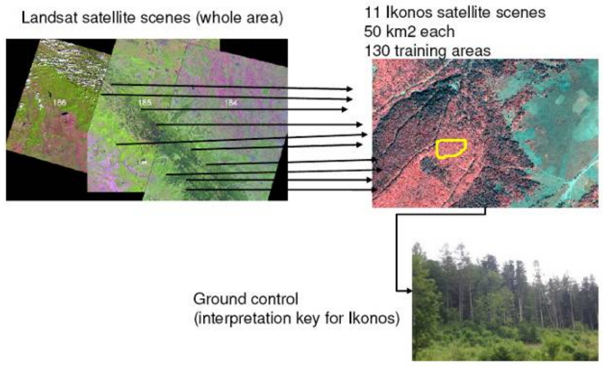

Figure 4. Two-stage procedure for the classification.

2.8 UKRAINIAN SCIENTIFIC STUDY

This study (Ministry of Education and Science, 2004) is a comprehensive source on the forest conditions in the Ukrainian Carpathian Mountains based on statistical data. The spatial relations are poor and the data on areas are more than ten years old and as such out of date. Legal and illegal harvest, hazards and pests have changed the situation of the forests. This was one reason to conduct a remote sensing project. However, the information of that study on standing timber volumes by forest type and age class and the growth models are still valid. Therefore, this information was used to calibrate the new areas per forest types from the remote sensing project.

3 RESULTS

The achievements during this project are discussed in the following for three main topics: the small-scale satellite classification, the assessment of wood resources and the localization of potential wood industry plants by applying GIS tools.

3.1 SATELLITE CLASSIFICATION

The forest parameters as described in the nomenclature were derived. An example of the signatures in the LANDSAT data is displayed in Figure 5: with respect to **tree species** separation, broadleaf and coniferous forests could be distinguished with a very high accuracy; the two mixed forest classes (dominant broadleaf and dominant coniferous) are overlapping and therefore less separable than the pure classes. However, this is obvious, since the classes are transition classes and the class borders defined in the nomenclature (see above) are artificial borders. However, the averaged classification accuracy for all species classes showed 90 % correct.

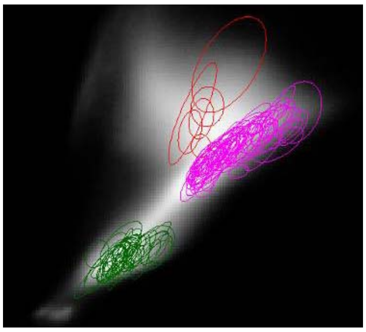

Figure 5. Feature space image showing signatures of spruce (green), openings (red) and broadleaf (magenta) stands.

The derivation of the **age classes** proofed to be more difficult than tree species. Young and old stands of pure tree species could be well distinguished, but the growth classes of mixed stands were quite difficult to classify. The most frequent error was that young areas (mainly coniferous-dominated mixed stands) were often classified as old deciduous-dominated stands. One reason is that partly bare soil is visible in the young stands. This spectral mixture generates a response similar to the signal of older, mainly deciduous-dominated stands. In order to overcome this problem, a multi-temporal approach was applied. LANDSAT ETM+ data from 1989-1992 was used to map harvested areas back then (mainly clear cuts). In a second step, this information was superimposed with the previous classification from 2002/3 and all those pixels classified in the original classification as “old” were then assigned to the class “young”, if they have been classified as “harvested areas” in the 1990ies images.

In an additional step, all most recent clear cut areas not inherent in the 2002/3 data were extracted from the SLC_OFF LANDSAT data from 2004/5 and integrated in the final classification.

The old aged forest class has been derived applying a combination of the tree species class timber/strong timber with a canopy closure value less than 0.5. This procedure is of course only valid for coniferous forests, as broadleaved old stands still show a high canopy closure. According to the nomenclature, all pixels classified as pure coniferous forest, growth class timber/strong timber and crown coverage less than 0.5 were selected and combined in a separate class called “probably old aged forest”.

A post-processing step was performed for the age classification result. A majority filtering using a 3x3 window was applied on the age classification to minimize the so called “salt-and-pepper effect”. The effect of the majority filter is depicted in Figure 6.

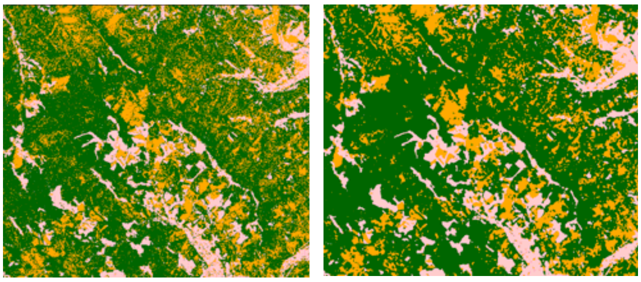

Figure 6. Left: age classes before majority filtering; right: the same result after the majority filtering.

3.2 STANDING TIMBER VOLUME AND YIELD ESTIMATION

The forest types by species combination and age classes as result from the remote sensing project component were synchronized with the data from the "Scientific Study". The data from that study were by more detailed forest types (tree species) and age classes in decades. Therefore the more detailed data from the "Scientific Study" was grouped according to the broader classes from the remote sensing project. Thus, a standing timber volume per ha could be attributed to each forest type from the digital satellite data classification. Assumptions on yield per forest type and sustainability considerations led to a potential harvest volume.

3.3 SAW MILL LOCATIONS

Based on the information on forest resources and additional spatial information on transportation conditions (roads, railway access) and considering other economic aspects, concrete proposals for new wood industry plants were developed. For this purposes GIS procedures were used.

4 CONCLUSIONS

The operational performance of this project shows that the assessment of wood resources over a large region can be only be achieved on a time and cost effective way if satellite remote sensing data are combined with existing information.

The whole project area of approximately 35.000 km² could only be processed in that short time and in a cost-effective way using large-area covering satellite data. For this purpose the LANDSAT system with its 185 km orbit strip proved to be the most appropriate choice. A combination of IKONOS images and a very short field trip allowed deriving the needed training data. Based on this supervised ML classification and the additional multi-temporal and rule-based improvements, the results show a good quality for the estimation of the spatial distribution of the forest types. The use of IKONOS data as ground truth speeded up the project to one third of the duration such projects normally need. This is a contribution to make remote sensing more operational and attractive to commercial use.

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