Assessment of Forest Quality in Southwestern Poland with the Use of Remotely Sensed Data[1]

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Abstract

A three-stage approach was applied to assess the quality of forests in southwestern Poland, which are heavily affected with air pollution and insect infestations. In the first stage a ground evaluation of spruce stands was done within the selected test areas. Three main characteristics of forest quality were determined as a result of these works: defoliation, discoloration, and vigor of trees. Next, aerial color infrared photographs were taken over the study area. They covered stands at different stages of forest decline. Detailed analysis of these photographs enabled discrimination of four levels of damage to spruce stands, as well as various phenomena, which accompany forest decline and transformation (loose canopy closure, windbreaks and windfalls, afforestations and regenerations). Results of analysis of aerial photographs and ground-truth information supported the main stage of the work: digital classification of Landsat Thematic Mapper (TM) satellite images. Digital classification of Landsat TM images can be useful for evaluation of forest quality and for rapid large-area assessment of forest changes, which accompany degradation processes. Different methods of analyzing satellite data were studied to obtain maximum information content. Supervised classification based on the TM3, TM4 and TM5 spectral bands was then applied. As a result of classifications for the test site, which is seriously affected with air pollution, three levels of forest damage were distinguished, as well as clear-cuts and vegetated openings accompanying forest decline. Comparison of two classifications performed on images collected in 1984 and 1990 revealed great changes in forest structure.

Introduction

Air pollution has been considered the main cause of damage and deforestation to forests in Europe. Air pollution increases along the direction of the prevailing wind from southwest to northeast so that pollution originating in southern and western Europe accumulates in Poland. This country itself contributes significantly to total air pollution, adding great amounts of pollutants from fuel and power industries, means of transport, and fossil fuel-heated homes.

Poland belongs to the group of most polluted nations because of the high concentration of SO_2. Limitation of the emission of sulphur compounds has not improved the situation considerably because about 50 percent of the total amount of SO_2 comes from neighboring countries.

The technology applied by foresters to determine forest damage has been based on analysis of the morphological changes in needles and tree growth. In the 1980's the Remote Sensing and Spatial Information Centre, OPOLIS, began to investigate the application of remote sensing to the detection and determination of damage to pine and spruce stands. At the beginning of the work, false-color aerial photographs were used to detect air pollution damage to pine stands. It was possible to distinguish between dead and dying trees based on changes in crown color as seen on aerial photographs. Five categories of damage to pine forest have been recognized by calculating the percentage of dead and dying trees in a given stand. A number of maps have been elaborated and published presenting the state of health of forests in different regions of Poland.

Damage to some Polish forests has been so extensive that it was decided to use satellite images in the investigation of the problem. The Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), SPOT images, and Cosmos space photographs have been applied in these works. After several attempts we found that the Landsat TM images have been the best source of information for this type of investigation.

This paper discusses a three-stage approach ground evaluation, aerial photograph analysis, and digital classification of satellite images — to assess the extent of air pollution to Polish forests.

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Study Area

The Sudety Mountains, where the damage to coniferous forests was one of the most serious in Poland, were chosen as a test site. This region, located at border areas of Poland, Germany, and the Czech Republic, has been highly affected by industrial activity and insect infestations. Concentration of industrial plants and coal mines within the region caused serious degradation of large forest areas. Extent and intensity of the damages are so significant that this area is currently treated as a region of ecological disaster and it has been called "Black Triangle."

The test area covers the western part of the Sudety Mountains, i.e., part of the Karkonosze and Izerskie Ranges, with dominating spruce stands forming a large forest complex. The most serious damage of coniferous stands, as well as different levels of forest transformation, occur in this region.

This differentiation of stands within the study area can support optimally the main aim of the studies; it enables one to determine, which stand characteristics, useful for large-area forest evaluation, can be derived from satellite data.

Materials and Methods

At the first stage of the work we decided to examine the usefulness of high-resolution satellite images for classifying health conditions of the forest, its species composition, and other forest phenomena. To fulfill this task, Landsat TM data collected in July 1984 and in August 1990, covering both test areas, were selected. The analysis was done with the use of ERDAS image processing system. This system enables interactive analysis of satellite images: radiometric and geometric correction, location of training areas on satellite images, determination of spectral signatures, and data classification.

Source Materials — Field Work and Aerial Photographs

To find relationships between field characteristics of stands and their signatures on satellite images, field evaluation of spruce stands was done at a preliminary stage of the works by using more than 500 test fields located at the Karkonosze, Izerskie, Sowie, and Stolowe Ranges. Field appraisal was performed on the basis of instruction prepared by the Forestry Research Institute. Each test field covered a homogeneous appraisal unit (1-10 ha), which was characterized through direct measurements and observations. The following information was collected during field work:

- Description of terrain conditions (type, relief, slope, aspect, type of cover and degree of coverage by rocks, stones, debris, etc.).
- Description of stand (structure, layer, species composition, age, form of mix ing, closure, average breast-diameter, mean height, height of crown base, number of trees per unit area, including dying and dead trees).
- Evaluation of damage of stand (defoliation — Df, discoloration — Dc, quality of trees — Dm).

Defoliation and discoloration was evaluated in accordance with International Cooperation Program on Assessment and Monitoring Pollution Effects on Forests (ICP) recommendations, while quality of trees was assessed on the basis of the state of assimilatory apparatus, height increments, and vigor of trees.

At first stage of the work numerous relations were studied between stand/terrain characteristics and spatial signatures of stands, derived from Landsat TM satellite images, including elevation/aspect information. The following conclusions were drawn from these studies (Zawila-Niedzwiecki 1994):

- The higher elevation above sea level, the lower height of trees and height of crown base; lower quality trees found more on a high elevation than less damaged trees.

- High correlations (R^2>0.90) were found between spectral response in Landsat TM bands and some indices of quality of stands (Df, Dc, Dm). The strongest relations exist for defoliation and quality index, while discoloration is less correlated. Usually the relations are defined through multiple regression, which involves use of 2 to 4 spectral TM bands (most commonly visible near infrared and middle infrared bands).
- Loose canopy closure disturbs relationships between ground parameters and spectral signatures of stands, so if it exists on a larger area, this information should be taken into account in the process of supervised classification.

Analysis of the Karkonosze — Izerskie Ranges Test Area

Aerial false-color photographs taken in July 1984 were the supplementary source of information on the state of forests within the study area. The map of the health status of forests, prepared on the basis of these photographs, was the reference material for making appropriate selection of training and test areas, which was used further in the process of supervised classification of satellite data.

At the first stage of analysis the rectification of a satellite image was performed, through its transformation to the Gauss-Kruger projection system, which is commonly used for medium-scale topographic maps in Poland (1942 system). Next, correlation analysis was done for all seven bands of Landsat TM, in order to choose the three least-correlated channels. As a result of this analysis the following TM spectral bands were selected: TM3, TM4, and TM5. This choice is consistent with the other studies conducted at the European and American remote sensing centres. These studies revealed high usefulness of the mentioned spectral bands for classifying forest areas (Horler and others 1986, Kadro 1988, Rock and others 1986). According to these studies TM4 and TM5 give the best information for vegetation analyses, while TM3 combined with the latter ones forms a color composite that emphasizes spectral differences within vegetation classes. TM5 is especially useful for examining damage caused by loss of water in plant tissue and characterizing vigor of vegetation. In the case of forests at the Sudety Mountains, we found as a result of preliminary analysis that coniferous forests can be delineated with TM3, while TM4 differentiates grasslands, deciduous and mixed forests. TM5 allows different levels of defoliation to be discriminated, as well as clear-cut areas.

After preliminary analysis of color composite images, eight forest categories were selected:

1. Slightly impaired spruce stands
2. Heavily impaired spruce stands
3. Dying and dead stands
4. Young spruce stands
5. Openings with vegetation cover
6. Clear-cuts
7. Deciduous and mixed stands
8. Dwarf mountain pine.

Training areas representing these categories were transferred to the satellite image; next, spectral separability analysis was done to determine those categories that could be classified with the acceptable accuracy (exceeding 80 percent). We found that all selected classes, except dwarf mountain pine, were spectrally separable. So, seven forest categories were finally selected for classification, while areas of dwarf mountain pine were transferred from topographic map.

After selecting the classes, supervised classification of the Karkonosze-Izerskie Ranges test area was performed by using the 1984 image. Next, the same process was repeated for the 1990 image by using the analogue set of training areas. Results of both classifications were printed in the form of color maps. Finally post-classification accuracy assessment was done for both classification images by using the set of test fields distributed randomly throughout the study area.

Discussion

Comprehensive analysis of Landsat TM satellite images, conducted on two test areas for two dates of image acquisition, proved that spectral differentiation of spruce stands in this region enables the discrimination of a maximum of three classes of forest quality. Class No. 1 includes healthy and slightly impaired stands, with up to 30 percent loss of assimilatory apparatus. Initial phases of spruce damages cannot be separated from healthy stands with the use satellite data. So training fields located at the stands with 0-30 percent loss of assimilatory apparatus should be treated as representatives of one forest category.

Accuracy of discriminating on satellite images the other classes of spruce damage (more than 30 percent) depends on local conditions: canopy closure, soil cover, understory vegetation, etc. For instance, if stands with loose canopy closure contain openings with vegetation cover, spectral signature for these stands changes towards a class of better quality. Generally, there is the possibility to distinguish heavily impaired stands with 30-60 percent loss of assimilatory apparatus, as well as dying and dead stands that have lost more than 60 percent of needles.

Young coniferous stands were delineated well on the satellite image from 1984. This class includes mainly spruce stands (and partly pine stands) at ages of 7-25 years, covering 9 percent of the Karkonosze and Izerskie Ranges test area. The other classes, which are usually hardly discernible on satellite images (i.e. grasslands and afforestations) were quite well discriminated. As afforestations cover about 7 percent of the total classified area, this class significantly characterizes structure of the studied forests.

Main forest categories — three levels of damage of spruce forests and deciduous/mixed forests — were classified with accuracy exceeding 80 percent. By considering complex natural phenomena that existed at the studied region, the obtained results should be treated as fully satisfactory. They characterize both structure and health conditions of forest existing at the Sudety Mountains with acceptable accuracy.

Comparative analysis of two classified images from 1984 and 1990 enabled evaluation of qualitative changes that occurred during 6 years within the study area. The main observed phenomena were as follows (Zawila-Niedzwiecki 1994):

- An increase of the area comprising impaired spruce stands by 30 percent.
- A decrease of the area of dying and dead trees from 15 percent to 5 percent.
- An increase of the area of openings and clear-cuts from 8 percent to 15 percent with domination of vegetated openings in 1990.

Comparison of the classified image with forest maps revealed satisfactory consistency between classes determined from satellite data and stand characteristics contained at forest maps. Thus, characteristics of stands, obtained as a result of classification of Landsat TM images for the Karkonosze and Izerskie Ranges region, are suitable for large-area description of health conditions and structure of stands in this region. Landsat TM satellite images, then, enable evaluation of general characteristics of health conditions and structure of stands and thereby permit rapid evaluation of degradation processes.

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