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Session 6 a

MULTIRESOLUTION SATELLITE DATA FOR BOREAL FOREST CHANGE DETECTION MAPPING AND MONITORING

Erik Willén and Mats Rosengren[a] and Anders Persson[b]

[a] Metria Miljöanalys, P.O. Box 24154, SE-104 51 Stockholm, Sweden - (erik.willen, mats.rosengren)@lm.se

[b] National Board of Forestry, 551 87 Jönköping, Sweden - anders.persson@svo.se

ABSTRACT

The improved spatial resolution of new optical satellite data, such as SPOT-5, opens for improved forestry applications, such as improved cutting delineation, identification of soil scarification activities and for monitoring of the establishment of new forest stands. Since 1999, the Swedish National Board of Forestry (NBF) has extensively used satellite data from Landsat TM, ETM+ and SPOT in its operational work. Satellite data is used for change detection analysis, primarily to map and monitor forest cuttings as required in the Swedish Forestry Act and for mapping areas of different forestry activity needs.

This study has focused on evaluating the improved data quality from SPOT-5 in comparison and in combination with SPOT-4 and Landsat-7 data, for information concerning forest cuttings and factors of importance for the establishment of new forest stands by using multiresolution satellite data. Methods for enhanced change detection with combined use of the different resolutions of SPOT-5 multispectral bands were tested. Multiresolution, single band change detection between image pairs with pixel size differences of 2.5 – 30 m was evaluated. A method for multiresolution merging of panchromatic with all multispectral bands including SWIR applicable for boreal forestry was tested for this purpose. Examples from the use of SPOT-5 data for operational and recurrent national (Sweden) coverage are given.

Keywords: Remote Sensing, Forestry, Change Detection, Classification, Fusion, Satellite, Multiresolution, Optical.

1 INTRODUCTION

With the improved spatial resolution of SPOT-5 data (red, green and NIR –10 m, SWIR – 20 m and Pan - 5 and 2.5 m), new and improved forestry applications open up. SPOT-5 data can provide better information for improved cutting delineation, identification of soil scarification activities and for monitoring of the establishment of new forest stands. The introduction of SPOT-5 data, combining very high resolution with large scenes, is also of great importance for large area coverage, although there are operational limitations. Since 1999, satellite data from Landsat TM, ETM+ and SPOT have been extensively used by the Swedish National Board of Forestry (NBF) in its operational work. The satellite data is used for change detection analysis, primarily to map and monitor forest cuttings as required in the Swedish Forestry Act and for mapping areas of different forestry activity needs. For this purpose, user adapted methods for change detection and analysis were developed and implemented by Metria in the ENFORMA tool, in response to the user requirements of NBF.National satellite data coverages of Sweden, from SPOT-4 XI (1999) and Landsat-7 ETM+ (2000, 2001, 2002) have been acquired by NBF and are now used operationally in the daily work at the 100 forestry districts of Sweden. This study has focused on evaluating the improved data quality from SPOT-5 in comparison and in combination with SPOT-4 and Landsat-7 data, for new and enhanced information concerning forest cuttings and factors of importance for the establishment of new forest stands by using multiresolution satellite data. Better and more cost-effective data for visual interpretation is also an important and potentially widespread application for SPOT-5 data in addition to advanced image processing methods.

2 METHODS

2.1 STUDY AREA

The study are is situated in the southern part of Sweden in the forestry district of Nässjö. It has been used for several years for development of different forestry applications from optical satellite data.

The forest of this part of Sweden is owned by numerous private owners and the average size of the mapped clear cuts is between 1.5 and 2 hectares. Examples of applications tested in cooperation with NBF in the Nässjö district are refined clear cut mapping, mapping of seed trees left on felled areas, identification of regeneration activities such as soil scarification and also detection of regeneration failures.

2.2 DATA

Satellite data from Landsat TM and SPOT were used. The SPOT-5 data were made available by SpotImage for this project. Other data used included Digital map data from Geographical Sweden Data, GSD – digital topographic map database (National Land Survey of Sweden.) and DEM with 50m grid (base (National Land Survey of Sweden.)

Table 1 Satellite data used

Satellite	Date	Mode	Corrected by	Pixel size
Landsat-7	1999-09-04	MS	Metria	25 m
SPOT-4	1999-06-02	XI	Metria	20 m
SPOT-5	2002-08-19	XI	SpotImage	10 m
SPOT-5	2002-08-19	Pan	SpotImage	5 m
SPOT-5	2002-08-19	Pan	Metria	2.5 m
SPOT-5	2002-08-19	merged pan/ XS1,2,3	SpotImage	2.5 m
SPOT-5	2002-08-19	merged pan/ XS1,2,3,4	Metria	2.5 m
SPOT-5	2003-06-02	XI	SpotImage	10m

2.3 PREPROCESSING

Orthocorrected SPOT-5 data (10m multispectral, 5 m pan and 2.5 standard merged) and level 1A 2.5 m panchromatic were supplied by SpotImage. DEM data and GCPs measured from 1m resolution digital aerial orthophotos were provided by Metria. Landsat-7 ETM+ data, SPOT-4 data and the SPOT-5 2.5 m panchromatic data were orthocorrected by Metria. RMS- residuals for the SPOT-5 2.5 m panchromatic data were better than 3m

2.4 RESOLUTION MERGE

Resolution merging and data fusion techniques are commonly used for combining high-resolution single band images with colour images mainly for interpretation purposes. This is specifically useful when a satellite sensor system simultaneously acquires several spectral bands in different resolutions. In the case of SPOT-5, the multispectral bands 1-3 are imaged with 10m IFOV while the SWIR-band has 20m IFOV. All bands in the SPOT-5 multispectral products have 10 m pixel size. In parallel with the multispectral data, SPOT-5 is capable of simultaneously acquiring panchromatic data with 2.5 m or 5 m resolution. Resolution merging methods are needed, which can utilise the SPOT-5 multiresolution data in an efficient manner without deteriorating data quality, both for visual interpretation, and for classification and change detection. A variety of resolution merging techniques are available and described by several authors. The most common techniques are implemented in standard image processing software packages (IHS , PCA and Brovey transforms) The techniques can roughly be categorised into a limited number of main types (Pohl, C. 1999, Hill, J., Diemer, 1999, Bretschneider 2004). Transformation based methods are replacing the low-resolution "intensity" image with the high-resolution single band data. Examples of this are the IHS and PC transformations and is commonly used because the availability in standard image processing systems. Also examples for forestry applications are reported (Fritz, 1999). Addition and multiplication techniques are weighting a part of the panchromatic signal into the multispectral bands having a high correlation with the higher resolution panchromatic band. Filter fusion techniques are adding only the high frequency part of the high-resolution channel, by multiplication or addition, into the multispectral channels. Variants of this are the HPF, LMM and LMVM methods (de Béthune 1998a, 1998b) and the SFIM method (Liu, 2000). Wavelet decomposition fusion techniques are introducing the transformed high-resolution information into the multispectral image with different methods. For merging of the combined 10/20m resolution multispectral SPOT-5 data with the 2.5 or 5 m resolution panchromatic band with the purpose of enhancing the dataset for both interpretation and image analysis applications, the merging method should work on all spectral bands, including the SWIR-band, which is of high importance for boreal forest applications. The spectral properties should not be changed be the merging process. These requirements eliminate the addition/multiplication and transformation techniques. We have selected a modified filter fusion methods, which can be easily implemented before a more complex wavelet methods. The technique used is a normalised difference version of the high frequency modulation method (HFM).

Where H denotes high resolution, L = low resolution or low pass filtered version of the image and α is a gain factor defining the strength of the introduced high frequency component from the panchromatic image. The size of the low pass filter is defined by the ratio between multispectral pixel size and panchromatic pixel size.

2.5 CLEAR-CUT MAPPING METHOD

The SWIR band is the single most important spectral band for boreal forest applications. It contains information correlated to the density, timber volume, and tree height of the conifer forest. NDVI has very low correlation to the biomass of the conifer forest. In comparison with the red band (XS2), the number of digital levels within the forest is normally much higher in the SWIR band (standard deviation 8.7 vs. 22.8 in the SPOT-5 scene used). This is of great importance when mapping dark boreal forest in low illumination conditions. The clear cut mapping method developed by Metria and used operationally by NBF is a single band image difference method using the SWIR band when present in both scenes used for change detection, otherwise the red band may also be used but with less dynamic range in the resulting difference image. The SWIR bands from the old and new images are radiometrically matched using a linearised histogram matching method based on the histograms of the matched. Radiometric matching between the SWIR bands of the new and the old image is performed using only an area of interest defined by the forest mask from the digital topographic map, excluding areas with clouds or cloud shadows. A linearised histogram matching method is used between the percentiles 15% –85% of the 2 images. By using only the forest mask, variations in agricultural and other areas are removed from the matching and by cutting off the ends of the histogram, seasonal variations and changes from forestry activities are minimised. The same radiometric matching is also applied in order to produce an image mosaic in order to use for change detection.

2.6 MAPPING OF SEED TREES LEFT ON FELLED AREA

Seed trees are left on clear felled areas to enable the regeneration of new forest. The alternative is to replant within 3 years after the felling. NBF and the Regional Forest Boards are responsible for the legal supervising of the regeneration of new forest. If any areas are regrowing poorly, there is a demand for extra planting activities in order to fulfill the legal. NBF has a need for monitoring of recently clear-cut areas for the detection of indicators for activities to promote the regeneration of new forest is of interest from the NBF. Methods for detection of seed-trees left, soil scarification activities and if possible also detection of failed regrowth are of interest. A method for mapping of seed-trees left on new clear-cut areas was tested. The purpose of this method is to enable the planning and prioritising of field visits to the felled areas. There are no in situ data present at the time of the satellite image mapping. A simple thresholding method was evaluated for the purpose of mapping seed-tree density. The SWIR band of the newest scene was found to be most correlated to seed-tree density. The mapping was performed on SPOT-5 20m SWIR band data (10 m pixels) by simple thresholding in the SWIR band of the 2002 scene limited to the new clear cuts performed between 1999 and 2002. The 2.5 m merged colour image could be used as a reference for the development and calibration of the method. An alternative would have been simultaneously acquired aerial photos. In situ measurements were not feasible, as we had no advance knowledge where the areas were localised. The seed-trees could be visual interpretation in the merged images. Panchromatic 5 m data could also be used.

3. RESULTS AND DISCUSSION

3.1 RESOLUTION MERGE EXAMPLES FOR INTERPRETATION

Compared to Landsat-7 or SPOT-4 images, additional forestry features can be detected, identified and mapped in SPOT-5 data. The resolution merged colour images, both the standard merged 2.5 m product from SpotImage and the 2.5 m merged including the SWIR band, made by Metria, clearly shows the presence of seed trees left on the new clear cut area. Adapted contrast stretch for the purpose of identifying these areas should be used. This is shown in figur 6, where individual trees can be seen within the cut area. On the other hand, other types of forestry activities can be detected and identified in figure 2 and figure 3, where the line patterns in the right part if the image are thinnings performed by thinning harvester machines, and are easily clearly detected and identified in the high resolution panchromatic SPOT-5 data (2.5m, 5m) but can also be detected in the 10 m data with some difficulties.

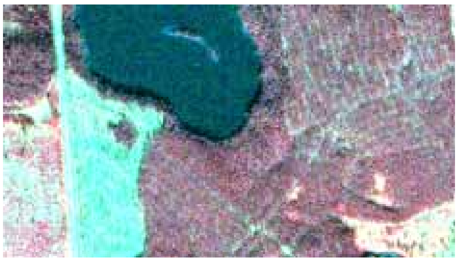

Figure 2. Resolution merge of SPOT-5 10m multispectral and 2.5m panchromatic data. Standard merged product from SpotImage. (Band 3=r, 2=g, 1=b)

Figure 3. Resolution merge of SPOT-5 10m multispectral and 2.5m panchromatic data using the normalised difference modified HFM technique including the SWIR band.
(Band 3=r, 4=g, 2=b)

3.2 CLEAR CUT MAPPING

An example of the single SWIR band difference image is shown in figure 4. In field validation campaigns performed, all areas mapped with a minimum size of 0.5 ha where found, although the area estimate error varies. The use of SPOT-5 merged data is clearly giving better area estimates, although this has not been validated by ground measurements at this time.

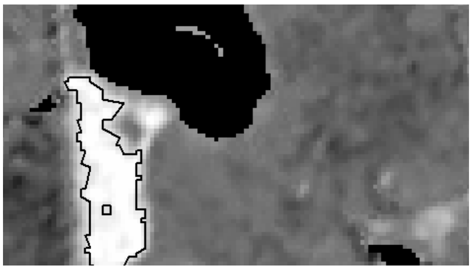

Figure 4. SWIR single band difference image between SPOT-5 2002 and Landsat-7 ETM+ 1999 scenes. Contour from threshold with 10m pixels.

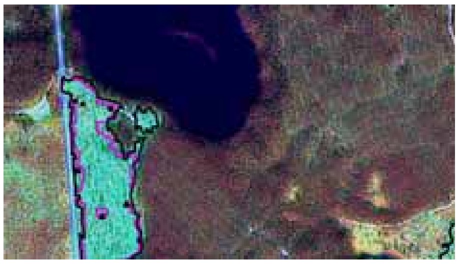

Figure 5. Mapping from SWIR single band difference image between 2.5 m resolution merged SPOT-5 2002 and Landsat-7 ETM+ 1999 scenes.

By utilising the resolution merged data with 2.5 m or 5 m pixel size, performing the change detection directly between the merged SPOT-5 SWIR band and Landsat-7, the contour of the clear cut area can be mapped more precisely. This is shown in figure 5. The black contour is mapped from 2.5 m data and is compared to the area mapped with 10 m pixels in purple.

3.3 SEED TREES MAPPING

Seed tree density classification was performed by thresholding in the SPOT-5 SWIR band, within the borders of the previously mapped clear cut areas. Panchromatic data were not used in this test. Seed trees can not be identified by visual interpretation in the 10m colour data, but the density of seed trees is correlated to the SWIR band intensity. As this information is intended to be used for stratification and planning of field visits, the validation was performed at object level. 6 shows the result of the classification and table 2 the validation matrix.

Figure 6 Density of seed trees left mapped in 3 classes.

Table 2. Results from validation

Field result	Classification	
	Seed trees	No seed trees
Seed trees	35	4
No seed trees	6	93

3.4 CONCLUSIONS

The SPOT-5 10 m multispectral data and the 5 m and 2.5 m panchromatic data can be used for several new forestry applications within the boreal-forested area. Merging methods for utilising both the high resolution panchromatic and the multispectral in a combined manner is one way of improving the methods for change detection and monitoring of regeneration indicators on recently clear-cut areas. The delineation of the clear-cut areas can also be improved with SPOT-5 compared to SPOT-4 and Landsat-7 data.

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MAPPING CLEAR-CUTTING IN FRENCH FORESTS BY SATELLITE REMOTE SENSING

N. Stach[a] , M. Deshayes [b] and S. Durrieu[b]

[a] IFN, 32 Rue Léon Bourgeois 69500 Bron, France , email: nstach@lyon.ifn.fr
[b] Cemagref UMR TETIS, 500 rue J-F. Breton, 34093 Montpellier Cedex 5, France

ABSTRACT

Based on IFN and Cemagref research on change detection methods, IFN has developed an operational tool based on satellite imagery to map annual clear-cutting in Aquitaine maritime pine forest. Annual clear-cuts maps have been produced for the period 1990 - 1999 and integrated in a forest growth model to simulate wood resource evolution. The success of this application allowed IFN to propose an operational service of clear-cut mapping to the inter-professional regional forest organization to contribute to the sustainable management of forests. More recently, IFN and Cemagref have studied the adaptation of the method and its extension to more complex forest conditions (relief, species mixture). The positive results obtained clear the path for the development of an operational clear cut mapping service in other French regions.

Keywords: Clear cut, Change detection, Sustainable management, Maritime pine, growth model

1 INTRODUCTION

IFN and Cemagref have been working on forest applications of remote sensing for 15 years. They have focused their research on change detection methods and have tested them with success in different applications like forest maps updating, defoliation monitoring or deforestation mapping (Bartalev et al 1997; Durrieu & Boureau 1997). Clear cutting is one of the obvious changes that can be detected from satellite data. Moreover, clear cuts maps are not produced with another method and can be used in association with forest growth models to monitor wood resource evolution and update inventory results. With the development of forest certification, clear cut mapping can contribute to monitor the sustainability of forest management in relation with the Helsinki criteria.

2 MONITORING MARITIME PINE RESOURCE IN AQUITAINE

The first operational application of clear cut mapping on a large area in France was developed in the Aquitaine maritime pine massif. Three factors enabled the development of this application: the very favorable forest conditions for using remote sensing tools, a scientific context with numerous researches on remote sensing and forest modeling, and the need of local foresters for yearly updated data.

The aim of the project was to develop an integrated tool based on satellite imagery, inventory data and forest growth model to monitor maritime pine resource and its evolution.

2.1 AQUITAINE'S MARITIME PINE FOREST MASSIF

Aquitaine region is the first wooded area of western Europe. It represents 9 380 km² of regular maritime pine high forest on a flat area. The total wood volume reaches more than 145 million m3 and the annual yield is about 9.6 millions m3. The Aquitaine pine forest is privately at 94%. This forest is principally managed in a perspective of wood production. It provides the resource for a very large economic activity. In December 1999, Aquitaine's forest has been seriously affected by the Martin storm that blew down about 26 million m3 of wood in this region (about 170 million m3 in France).

2.2. CLEAR CUT MAPPING

The first component of the application developed in Aquitaine is clear cut mapping from satellite imagery.

2.2.1. Data and methods

The satellite images used are Landsat 5 TM and Landsat 7 ETM data as the quasi totality of the Aquitaine pine forest can be covered by one scene plus one scene quarter of these sensors.

The process is based on a change detection method using two images acquired at one year interval. The change detection method includes image georeferencing, relative radiometric normalization, image differencing and difference-image thresholding. All the processes are performed on the TM5 channel as coniferous clear cut detection performs better in SWIR spectral domain (Jolly *et al* 1996). Multispectral images are only used in color composition for visual control of the results.

Relative radiometric normalization of images is achieved with an original method developed at IFN (Durrieu and Boureau, 1997). A normalization model is calculated for each forest-type. For each Digital Count in the first image (DC Date 1), its target normalized value is defined as the modal value of the Digital Counts of the corresponding pixels in the second image (DC Date 2)(Figure 1).

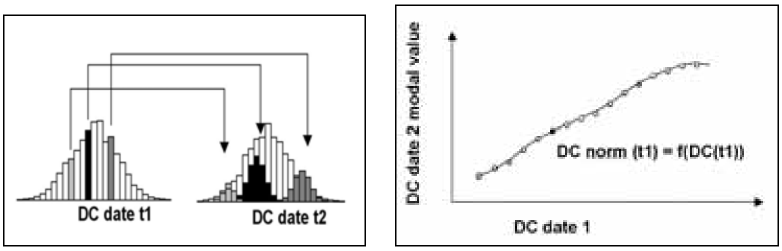

Figure 1. Relative normalization of an image channel

A difference-image is produced calculating the pixel to pixel difference between the second TM5 channel and the normalized first TM5 channel and centering the values on 128. A change probability image is then calculated by comparison of actual values frequencies of the difference-image and values frequencies of a theoretical no-change image. A theoretical frequency is calculated by fitting a Gaussian distribution function on the 6 values surrounding the mode of the real distribution (128). The probability of change is calculated for each pixel as the difference between real frequency and theoretical frequency divided by the real frequency (Fig. 2).

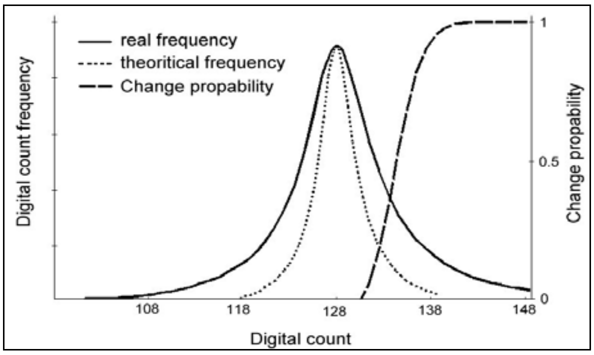

Figure 2. Digital count frequencies in difference-image and change probability

In order to avoid false detection in young plantations or recently logged stands, a second criteria is introduced in combination with change probability. Both images (date 1 and 2) are classified in 3 classes of crown cover (open, intermediate and closed stands) by thresholding TM5 band. The thresholds are determined from training stands operated by the national forestry board (ONF).

A multicriteria decision rule combining probability of change and crown cover in first and second images is applied to produce an initial classification with 3 classes : clear cut, uncertain clear cut and no clear cut. Morphological filters are applied to eliminate isolated pixels and to regroup contiguous certain and uncertain clear cut pixels in clumps. A second classification, at the clump level, is produced by classifying each clump in one of the three classes (clear cut, no clear cut or uncertain clear cut) depending on the clump shape and the proportion of “clear cut” pixels and “uncertain clear cut” pixels in the clump. At the end, a visual control using both original Landsat images in color composition allows to definitively affect "uncertain clear cut" clumps to "clear cut" or "no clear cut" class.

2.2.2. Implementation

Annual clear cut maps have first been produced with this method for the 1990 - 1999 period. In 2000, IFN adapted its method to map the damages caused by the December 1999 storms on the massif. In 2001 and 2002, the method was again used to map the windfall logging areas in the wind damaged areas at the behest of the Aquitaine timber industry. And for the 2003 - 2006 period the processing is to be carried over again at the request of the timber and forest industries, as an aid to a sustainable forest management within the framework of a PEFC approach. At the moment, the 2002/2003 clear cut map has been produced and the 2003/2004 map is in process.

The clear cut maps have been crossed over with IFN ground sample plots on which the tree ages are measured. For each detected clear cut with a sample plot, the age of the stand at clear cut has been calculated by incrementing the stand age when it was measured with the difference between the year of clear cut detection and the year of plot measurement.

2.2.3. Results

The mean annual clear cut area derived from satellite clear cut maps for the period 1990/1998 is 17 507 ha. It is very close to the area derived from IFN results for the period 1988/1996 which is 17 754 hectares. Accuracy assessment with ground reference data provided by the national forestry broad (ONF) and an industrial company (SMURFIT) revealed an omission rate varying from 5% to 7.5% depending on the year and a very low false detection rate (< 1%).

Beyond the estimation of global clear cut area, the rate of clear cut area depending on stand age is a major result of the clear cut mapping application as it is used as an input of the pine growth model. Fig. 3 presents the results of clear cut rates depending on age classes for the 1990 - 1994 and 1994 - 1998 periods.

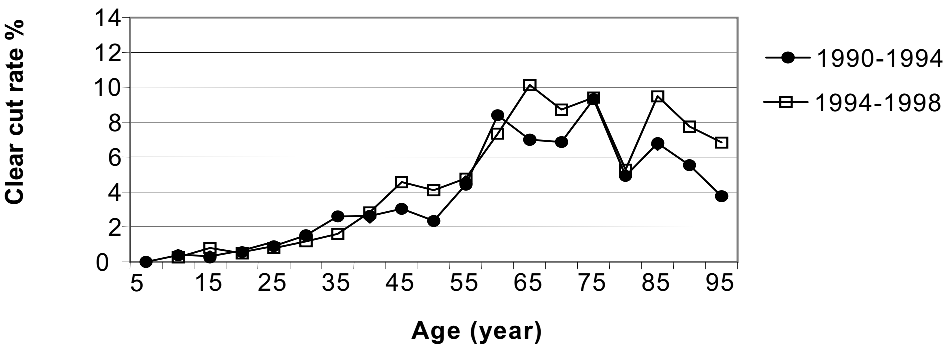

Figure 3. Clear cut rate depending on stand age derived from satellite clear cut maps and IFN sample plots

2.3 MARITIME PINE GROWTH MODELING AND SIMULATION

The second component of the project is modeling and simulation of maritime pine resource evolution. It aims at updating IFN results between two inventory cycles (made with a 10- to 12-year periodicity) and forecasting wood resource evolution in future years. To this aim, IFN has developed a simulator named *Pinastre 2001* based on a maritime pine growth model and sylvicultural scenarios.

2.3.1. Maritime pine growth model

The model used in the *Pinastre 2001* simulator is a stand growth model developed by Lemoine (Lemoine, 1991) for the maritime pine. First of all, the Lemoine model had to be calibrated as its parameters were determined from old measurements and did not reflect the increment of forest productivity observed in Aquitaine during the last decades. The calibration of the model was achieved with an empirical procedure minimizing the difference between the yield estimated from comparison of the 4th and the 3rd national forest inventory results and the yield simulated for the same period with the model.

2.3.2. Sylvicultural scenarios

Inputs of the simulator are the initial maritime pine resource and the sylvicultural scenarios including clear cut rates and thinning rates depending on age. Different approaches can be chosen to determine sylvicultural scenarios depending on the goal of the simulation: scenario from actual or recommended forest management practices, scenario derived from IFN results or from satellite clear cut maps.

2.3.3. Results

Several simulation of maritime pine resource with different initial situation and different sylvicultural scenarios have been produced. As an example, we can compare two simulations realized before and after the December 1999 storm in France. Both simulations use IFN results for thinning scenarios and satellite clear cut maps for clear cut scenario, but the first simulation considers 1996 IFN results for initial conditions while the second considers IFN results updated after the 1999 storm. Results of the two simulations are presented in Fig. 4 and show a long term deficit of mean annual harvesting due to the storm: a mean deficit of 720 000 m3 per year until 2020 when the annual harvesting reaches its before-storm level again (year 1999).

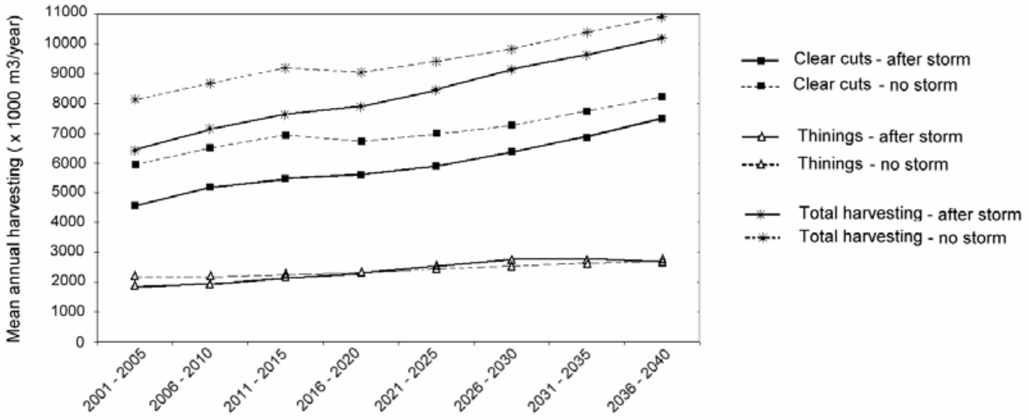

Figure 4. Mean annual harvesting simulations from *Pinastre 2001* simulator

3 EXTENSION OF CLEAR-CUTTING MAPPING IN OTHER FRENCH REGIONS

After the satisfactory results obtained on the Aquitaine maritime pine forest, IFN and Cemagref have studied the generalization of satellite based clear cut mapping on other French regions with more complex situations: presence of relief, mixture of species and forest structures. To this aim they studied the necessary adaptations of the method and tested it in various forest conditions.

3.1. STUDY AREAS

The first test site is the Corrèze '*département*', covering 5900 km² with more than 2600 km² of forest. It is an hilly region located on the western border of the Massif Central. Important plantations programs have been carried out in Corrèze since 50 years, mainly with conifers : douglas fir and spruce. Broad-leaved forests nevertheless still represent more than 75% of the forest, principally in coppices or mixed coppice and high forest stands.

The second test site is located in Ariège '*département*', in the Pyrenean mountain massif close to the Spain border. Its area is 1300 km² with a 280 km² forest area. Different forest types can be found: conifer high forest (26%), broad-leaved high forest (8%), mixed high forest (14%) coppice and broad-leaved high forest mixture (26%) and coppices (10%).

3.2. DATA AND METHODS

SPOT 1 to 4 images providing a full coverage of the Corrèze '*département*' were acquired for years 1991, 1994 and 1999 (10 scenes). Change detection was performed between 1991 and 1994 images and then between 1994 and 1999 images.

On the Ariège test site, the satellite data used are 2 SPOT 4 images from 1999 and 2000 and 2 SPOT 5 multispectral 10-meter images from 2002 and 2003.

Methodological investigations have concerned pre-processing with correction of topographic effects on radiometry , adapting multicriteria detection rules to SPOT1 to 3 data (without SWIR band) and adapting morphological filters to the highest resolution data (SPOT 5, 10 meters).

After testing different topographic correction models proposed by different authors (Riaño *et al*, 2003), the statistical empirical model from Teillet (Teillet *et al* , 1982) was found to be the more efficient and the more robust.

The expression of normalized reflectance is $L_H = L_T - (a \cos i + b) + \overline{L}_T$, where L_T is the original reflectance, i is the local incidence angle and a and b are two parameters to be determined from image data.

3.3. RESULTS

Bad results were obtained on the Ariège test site. These disappointing results are not only due to the significant relief in this mountainous area but rather to the type of logging that is realized: clear cutting is very rare while most of the logging is done through thinning or progressive regeneration feelings. Most of these partial fellings can be easily seen in very high resolution SPOT 5 images but the method adapted to clear cut mapping fails to detect them.

Satisfactory results were obtained on the Corrèze test site. The total clear cut area derived from satellite imagery for the 1991/1999 period is 12884 ha whereas it was estimated to 13975 ha by IFN inventory results, showing an underestimation of about 7.8%. The accuracy assessment was realized with ground reference data provided by forest owners (CRPF) and a sample of reference clear cuts delineated on aerial photos. It shows an omission rate (non detected clear cut area divided by the reference clear cut area) of 15% and a commission rate (falsely detected clear cut area divided by the total detected area) of 13%.

4 CONCLUSION AND PERSPECTIVES

Clear cut mapping from satellite imagery was first developed and validated in Aquitaine maritime pine forest massif in order to monitor maritime pine resource evolution. After the satisfying results obtained in a first methodological stage, an operational service is provided to the local forest owners and forest industries to contribute to monitoring the sustainable management of the massif in a Pan European Forest Certification Process.

The satisfying results obtained in Corrèze '*département'* with non optimum data (SPOT1 to 3 without SWIR band) let envisage the development of operational applications in several hilly French regions with an emerging forest resource resulting from 50 years of intensive plantation programs. Clear cut mapping in these areas could help to monitor the evolution of this resource and could contribute to guaranty its sustainable management. A clear cut mapping service has already been proposed to Limousin forest companies in the context of the ESA GMES Forest Monitoring initiative.

ACKNOWLEDGMENTS

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INTEGRATION OF DEM DATA WITH SATELLITE IMAGERY FOR FOREST CHANGE DETECTION

M. F. Álvarez, J. R. Rodríguez and A. Asenjo

IPR Research Group. Universidad de León, Avd. Astorga s/n 24400 - Ponferrada, León. (Spain)
email: flor.alvarez@unileon.es

ABSTRACT

In a standard supervised classification, increases in land cover map classification accuracy have been obtained by including topographic attributes as inputs to the classification algorithm. In this study we investigate the potential of such data as a means to increase the accuracy of supervised forest change detection using Landsat 5 imagery in a target area located in El Bierzo (León). *Pinus radiata* plantations are the most important forest stands in this area, concerning stocks and the economic interest of the owners and timber purchasers. Variations in agricultural policies and the ageing of the rural population have caused continuous and dynamic land use changes, mainly from the farming uses to radiata pine plantations. The aim of this paper it is not only improving the quantitative detection of changes, but also the qualitative approach, a key factor for the management and monitoring of these stands. Once the quantitative change was identified using difference in Landsat TM Wetness Index, the nature of the change was settled by image classification. An accurate land use classification was needed for each image, so that three classification trials were completed: (*a*) using a standard approach without the addition of topographic attributes, (*b*) using elevation data as an additional input to (*a*), (*c*) using elevation and slope data as an additional input to (*a*). The second classification trial (*b*) provided the highest overall accuracy at 90.21%, improving the standard methodology (a) result, which produced in an overall accuracy of 83.92%.

Keywords: remote sensing, qualitative change detection, DEM, *Pinus radiata.*

1 INTRODUCTION

More frequent updates of information on changes in land use are required as part of land management policies, mainly those referred to changes from farming to forest uses, due to their environmental and socioeconomic repercussions in rural areas. The comparison of two or more remotely sensed images of the same geographic area permits the study of temporal change. Good change detection research should provide the area change and change rate, spatial distribution of changed types, change trajectories of land cover types, and accuracy assessment of change detection results (Lu *et al.,* 2004). The hybrid change detection method combines the advantages of the threshold and classification methods. The threshold method (e.g. image differencing) is used to detect the changed areas, then classification methods are used to classify and analyze detected change areas. These methods are based on the classified images, in which the quality and quantity of training sample data are crucial to produce good quality classification results. The major advantage of these methods is the capability of providing a matrix of change information and reducing external impact from atmospheric and environmental differences between the multi-temporal images (Rogan & Chen, 2004). However, selecting high-quality and sufficiently numerous training sample sets for image classification is often difficult. Petit *et al.* (2001) used the combination of image differencing and postclassification to detect detailed 'from–to' land cover change in south-eastern Zambia and such a hybrid change detection method was regarded as better than post classification comparison techniques. Foody (2001) found that post-classification comparison underestimated the areas of land cover change, but where the change was detected, it typically overestimated its magnitude.

Changes in the Tasselled Cup Transformation (TCT) (Kauth & Thomas, 1976) indices may be used to identify changes in land use, especially regarding forest characteristics. Franklin et *al.* (2000a) reported that the accuracy of partial harvest change detection using Landsat imagery approached 71% over a full range of forest change conditions in southeastern New Brunswick (Canada) using the TM Tasseled Cap transformation (Crist & Cicone, 1984) and classifying the brightness/greenness/wetness difference images. Franklin *et al.* (2002) enhanced the difference between wetness indices for several near-anniversary TM dates over a 15-year period and established a threshold for changes associated with clear-cut, partial harvesting, and silviculture in highly variable forest stands. The image data were first atmospherically corrected, transformed into the TCT wetness component, differenced, and then enhanced for computer display and thresholding. Three classes (light, moderate, severe change) were mapped using standard supervised classification with 100% producer's accuracy. Differences in TCT indices have been also used in forest environments for modeling fire hazards (Patterson & Yool, 1998), estimating forest stand density (Horler & Ahern, 1986), structure (Hansen *et al*., 2001), age (Cohen *et al.*, 1995) and tree mortality (Collins & Woodcock, 1996; Skakun *et al.,* 2003).

In order to provide quantitative change information accurate classifications of imagery are required. Additional ancillary data can be used to increase supervised land cover classification accuracy. In many environments, digital elevation models (DEM) are used in classification of land cover, as discrimination of cover types whose distributions are influenced by variation in elevation is improved with the inclusion of the DEM in the classification (Franklin *et al.,* 2000b). One approach is to use the DEM data, or derivatives such as aspect and slope, as supplemental logical channels in the classification input data (Strahler, 1981); another is to stratify the image data using the DEM (Skidmore, 1989); another is to modify classifier prior probabilities (Strahler, 1981); another is to employ rule-based or expert systems logic; and still another is using classification trees (Rogan *et al.,* 2003). Improved classification accuracies have been reported with the direct incorporation of a DEM into an unsupervised classification approach. Elumnoh and Shrestha (2000) used an ISODATA algorithm with 13 land cover classes in forested highlands and agricultural lowlands in Thailand. Classification accuracy improved from 65.3% (without the DEM) to 72.4% (with the DEM). The largest improvement was found in discriminating lowland agriculture fields from highland forest. Wulder *et al.* (2004) found that the prestratification of an image into areas of shadow and nonshadow prior to clustering in conjunction with the use of elevation data as an input to the clustering process increased classification accuracy in areas of high relief where topographic shadow is problematic.

The purpose of this research is to examine the increase in classification accuracy that can be obtained by including a DEM or its derivatives in a supervised classification as a part of a hybrid method for change detection in radiata pine stands in a very fragmented area in El Bierzo (León, Spain). In addition, another objective of this study is to test the suitability of the TM Tasseled Cap transformation Wetness index differencing to detect changes, mainly in areas where radiata pine plantations are concerned.

2 STUDY AREA

The study area comprises 700 km^2 in western León, Castilla y León, Spain, approximately 100 km west of León. The elevation varies from 450 to 1,752 m. Natural vegetation depends on bioclimatic conditions, so that in the peripheral mountains dominant tree species are beech (*Fagus sylvatica*), birch *(Betula* sp.), chestnuts trees *(Castanea sativa*) and oaks (*Quercus pyrenaica*, *Querqus ilex*), following a pattern of decreasing precipitation. Shrubs are also common as secondary succession series and as a result of forests degradation. The area is in a Mediterranean continental climatic environment, characterized by moist, mild winters with warm, dry summers. Mean annual precipitation is 720 mm and mean annual solar radiation ranges reaches 2,100 sun hours, which are very suitable conditions for radiata pine growth.

3 IMAGERY AND ANCILLARY DATA

A Landsat 5 TM image (path 203, row 22) acquired on 25 June 2000 was geometrically registered to the UTM Zone 30 WGS84 projection with 92 ground control points at key road intersections dispersed throughout the scene with less than 0.85 pixel root mean square error (RMSE). A second Landsat 5 TM scene (path 204, row 31) acquired on 13 July 2004, was registered to the UTM Zone 30 WGS84 projection with less than 0.64 pixel RMSE using 85 ground control points at key road intersections dispersed throughout the scene. A nearest neighbour algorithm was used to resample both images with an output 30 m grid. Atmospheric corrections were not necessary because simple image subtraction was use to detect changes and the qualitative assessment of changes was achieved by post-classification comparison.

Orthophotographs scale 1:10,000, 0.7 x 0.7 m pixel size, acquired in 2001 were used in the training areas location and for the accuracy assessment, required for the supervised classification. These data were checked by field work in July-August 2004.The digital elevation model (DEM) for the area of interest was generated by spatial interpolation of contour lines from 1:10,000 scale topographic vector maps. The output grid spacing was 30 m. Slope (in degrees) was derived from this DEM using standard methods included in the software ArcGIS™.

4 METHODS

The Wetness component of the Tasseled Cap transformation was calculated for each Landsat 5 image using the coefficients proposed by Crist and Cicone (1984). Wetness has been applied because of the strong relationship between reflectance in bands 5 and 7 and moisture content of vegetation and soils, helping in land use change identification (Lu *et al.*, 2003). The final image processing step was to convert the wetness index from each of the two dates (2000 and 2004) to a difference image for that index. Simple image subtraction was used because the high degree of confidence in the geometric correction of the imagery enabled a suitable overlay of the image data and the minimum area of change of interest was several pixels in size.

Supervised classification was performed using Landsat TM images. Therefore as first step a legend with the land use covers to be identified was defined. The following land covers were defined for the study area: agricultural lands (grasslands, vineyards, farming areas) (A), water (W), broadleaved forests (B), shrubs (S), other conifer forests (*Pinus pinaster, Pinus sylvestris*) (C), areas with low canopy cover or without canopy cover (newly afforested areas, unproductive areas, urban areas, roads, mining areas) (LCC), and *Pinus radiata* stands (PR). The second step consisted of selecting training samples which were representative and typical each land cover class, in order to generate the class signatures. For radiata pine 555 pixels were selected in the image from year 2000 and 1,509 in the image registered in 2004. The following step was performing the classification of the Landsat image from 2004 using the maximum likelihood algorithm. This image was selected instead of the 2000 one because field data was gathered in 2004. The strategy for testing the improvement in classification accuracy obtained by including a DEM or its derivatives in the supervised classification resulted in the completion of three classification trials. The initial classification trial (*a*) was the control and had 7 Landsat TM optical channels. The second trial (*b*) used identical methods to those in the first trial, however elevation data were added as input to the classification process as a channel. For the third classification trial (*c*) elevation and slope data were added to the optical channels to be considered in the classification. Accuracy of the classified image was assessed through analysis of a confusion matrix which was generated using the validation areas and through the calculation of the kappa statistic for each class. The best method (*a, b* or *c)* was used to classify the image from 2000; the results were validated with ground truth points identified on the orthophotographs. Both classified images were exported to vector files and intersected using a Geographic Information System (ArcGIS™), so that the obtained polygons had information of land cover in 2000 and 2004. Thus, polygons without/with changes were identified, and detailed 'from–to' land cover changes were detected. Changes detected by overlaying and the 2000 and 2004 classifications were compared to the changes detected by Wetness differences between the images. The resulting post-classification changes were considered as actual changes. Therefore, it was checked the agreement between actual changes and changes predicted from radiata pine land cover to other land covers and vice versa using differences in Wetness and three different thresholds (I, II, and III).

5 RESULTS AND DISCUSSION

Using the standard methodology in the first classification trial (*a*) for the 2004 image resulted in an overall accuracy of 83.92% and an overall kappa statistic of 0.80 for the 7 target classes. The second classification trial (*b*) which added elevation data as an input, resulted in a 90.21% overall accuracy and 0.88 overall kappa statistic, while the third one (*c*) resulted in a 89.16% overall accuracy and a 0.87 overall kappa statistic. Table 1 shows the producer's and user's accuracy for each land cover class for each classification trial, as far as the conditional Kappa for each category. For all the categories the best results were obtained from the second trial, adding elevation data to the spectral data. Producer's accuracy for radiata pine increased from 88.64% to 95.45% when including topographic attributes in the classification, regardless it was elevation or slope. Broadleaved forests and agricultural lands classifications were reasonably improved in trials *b* and *c*. Comparing trials *b* and *c*, better accuracies and kappa statistics were achieved by including only elevation data in the classification, therefore the Landsat 5 Tm image from year 2000 was classified using the trial *b* methodology. This result agrees with the results obtained by Wulder *et al.*(2004), whose land cover classification using elevation data as an additional input and prestratifying the image into shadow and nonshadow areas prior to clustering using trials provided the highest level of overall attribute accuracy at 80.1%, improving the approach using only the spectral information (68.7%).

Table 1. Producer's and user's accuracy for each land cover class for each classification trial for Landsat 5 TM image (2004), as far as the conditional Kappa for each category. Classification trial (*a*): optical channels as input data; trial (*b*): optical channels and elevation as input data; trial (*c*): optical channels, elevation and slope as input data. Land cover classes: agricultural lands (A), water (W), areas with low canopy cover or without canopy cover (LCC), broadleaved forests (B), shrubs (S), other conifer forests (C), and *Pinus radiata* stands (PR).

Land cover class	Trial *a*			Trial *b*			Trial *c*		
	Accuracy (%)		Kappa	Accuracy (%)		Kappa	Accuracy (%)		Kappa
	Producers	Users		Producers	Users		Producers	Users	
A	84.34	97.22	0.9609	91.57	97.44	0.9639	90.36	97.40	0.9634
W	100.00	100.00	1.0000	100.00	100.00	1.0000	80.00	100.00	1.0000
LCC	88.37	66.67	0.6077	90.70	70.91	0.6576	90.70	70.91	0.6576
B	75.86	93.62	0.9199	86.21	96.15	0.9518	86.21	94.34	0.9290
S	80.00	55.56	0.5130	84.00	75.00	0.7261	84.00	70.00	0.6713
C	88.89	82.76	0.8096	92.59	96.15	0.9575	88.89	96.00	0.9558
PR	88.64	97.50	0.9705	95.45	100.00	1.0000	95.45	100.00	1.0000

The high accuracies achieved in the classifications resulted consequently in accurate land cover maps for 2000 and 2004: thus forest change detection was improved. The areas concerning radiata pine stands (changes due to new plantations, harvesting, no changes) were mapped in a GIS and the differences in Wetness overlaid. Therefore, the proposed method is very useful to monitor changes in radiata pine stands. The results of the analysis of means showed that there are significant differences among the differences in Wetness index depending on the class of land cover change concerning radiata pine stands. The percentages of agreement comparing actual changes to the predicted using three different thresholds (I, II, and III) are showed in Table 2.

The most interesting changes (regarding their occurrence) are those from agricultural uses and low canopy cover to radiata pine land use. If these changes are correctly detected, an increase (gain) in biomass should be registered. Using the threshold III (which classifies as decrease in radiata pine land use (lost) a difference in wetness lower than -8, and as an increase in radiata pine plantations (gain) a difference in wetness higher than 8), 88% of the pixels which changed from agricultural to radiata pine use were properly detected. Low canopy cover areas reforested between 2000 and 2004 are detected in 69 out of 100 cases using same threshold; 30% of the reforestations are not detected because the change in canopy cover (change in wetness) is not high enough. Changes from radiata pine land use to low canopy cover imply harvested or disturbed (e.g. forest fire) areas; 61% of these areas where detected using the difference in Wetness and the threshold III. Some shrub areas where radiata pine was the previous land cover, are due to forest fires, which explains the fact that increases in land cover were detected by the wetness difference, because small pine plantations were affected by forest fires and in two or three years a dense shrub canopy covered the affected area. Areas where radiata pine is maintained as the main use are mainly classified as non-change areas using the three thresholds, with accuracies of 86.9% to 92.8%. Using the threshold III several areas were identified as areas where biomass had increased, therefore forest growth can be detected when the upper value of the threshold decreases. Even when a simple threshold was selected, changes such as clearcutting and forest growth were successfully detected in radiata pine stands. Threshold III is recommended if interested in detecting this kind of changes. However, more research is needed to define accurately the thresholds for each kind of change.

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Table 2. Percent of agreement between land cover changes regarding radiata pine stand using post-classification results and changes detected by differences in Wetness index using thresholds I, II and III. Land cover classes: see Table 1.

Land Cover (Year)		Agreement between post-classification land cover change and changes predicted by differences in Wetness (2004 - 2000) (%)								
		(I) Loss <-13; Gain>10			(II) Loss <-8; Gain>10			(III) Loss <-8; Gain>8		
2000	2004	Loss	Equal	Gain	Loss	Equal	Gain	Loss	Equal	Gain
A	PR	0.00	15.71	84.29	0.00	15.71	84.29	0.00	11.97	88.03
LCC	PR	0.19	36.36	63.44	1.06	35.49	63.44	1.06	29.69	69.25
S	PR	0.00	63.72	36.28	0.00	63.72	36.28	0.00	46.98	53.02
PR	A	73.78	24.22	2.00	78.00	20.00	2.00	78.00	19.11	2.89
PR	LCC	48.48	47.38	4.14	61.45	34.40	4.14	61.45	32.13	6.41
PR	S	22.79	75.66	1.55	41.59	56.86	1.55	41.59	55.53	2.88
PR	PR	0.40	92.84	6.76	1.24	92.00	6.76	1.24	86.99	11.76

RATES AND PATTERNS OF FOREST COVER CHANGE SINCE MID-1980s IN THE EASTERN BALTIC REGION, EVALUATED WITH MULTITEMPORAL LANDSAT IMAGERY

Urmas Peterson[a,b], Jaan Liira[c] and Kersti Püssa[c]

[a]Tartu Observatory, Tõravere 61602, Tartumaa, Estonia, email: urpe@aai.ee
[b]Faculty of Forestry, Estonian Agricultural University, Tartu, Estonia
[c]Institute of Botany and Ecology, Tartu University, Tartu, Estonia

ABSTRACT

A series of Landsat TM and ETM+ late winter images covering an area of Estonia, Latvia and Russia was used to classify forest from non-forest and to examine forest change resulting from clearcutting. The data set consisted of images from mid-late 1980s (1985-1987), mid 1990s (1996) and early 2000s (2001-2003). Landscape patterns of forest patches were quantified for the administrative districts of Estonia, Northern Latvia and western regions of Pskov guberniya and Leningrad oblast in Russia. Approximately 10% of the forest area was disturbed overall, translating into annual disturbance rate of 0.6 %. The general rates and patterns of clearcutting within the last two decades were found to be rather similar in Estonia and in Latvia but were more modest in the territory of Russia. Clearcuting resulted in increased forest fragmentation. Mean forest patch size and patch core area decreased, edge density increased as a result of clearcuts. In addition there was a negative relationship between distance from major roads and the number of clearcut patches within the territory of Russia. The increase of forest fragmentation has accelerated since mid 1990s and particularly in private forests. While the rates of disturbance are not markedly higher than those recorded from other temperate forests there has recently been a large alteration in the disturbance regime which will lead to a general transformation of forest age structure in the Eastern Baltic area if the trend continues. In general forest cover decreased throughout the region and throughout the period. The effects of land-use changes, abandonment of agriculture on forest cover throughout the region have not resulted the net increase of forested area.

Keywords: Forest fragmentation, clearcutting, Landsat TM winter images, Eastern Baltic region

1 INTRODUCTION

Clearcutting alters the structure of forests by reducing the amount of mature forest cover, increasing edge density and isolating mature forest stands (Franklin and Forman 1987; Reed et al. 1996; Tinker et al. 1998). Recent political and economic changes in the Eastern Baltic region have opened access to those forests that are now in private ownership and large-scale exploitation of their timber resources has started in mid 1990s. According to the popular opinion forests in the region are severely overcut. However there have been relatively few quantitative assessments of the extent and rate of forest fragmentation by clearcutting in the area.

We used Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) images, forestry database data and national base map orthophotos to compare the effects of clearcutting on the landscape pattern in the Eastern Baltic region covering territories of Estonia, Northern Latvia and western regions of Pskov guberniya and Leningrad oblast in Russia. The data set consisted of images from mid-late 1980s, mid 1990s and early 2000s. Landsat TM images from late winter – a non-traditional season for forest mapping were used. Winter in boreal and hemi-boreal latitudes is the season with the greatest target to background contrast on predominantly two-class images composed of forest and non-forest classes. In winter, forest patches are surround on all sides by open areas with bright snow cover. Our previous experience has demonstrated that forest mapping with winter images can give rather accurate results, with overall accuracy exceeding 90% when compared with forest boundaries derived from a co-registered map with forest boundaries delineated from orthophotos (Peterson 2003).

We used administrative regions as analysis units for the evaluation of forest clearcutting pattern. Administrative units have well-defined and temporally relatively stable, although generally not natural boundaries. The results san be compared across broad spatial scales by aggregation of local administrative units of communes (several hundreds of square kilometers) into administrative districts (several thousands of square kilometers). Both the local communes and the administrative districts are of comparable size in the three neighbouring countries due to the common periods in recent history.

Forest map was generated by thresholding winter images into two classes 'forest' and 'non-forest' (Peterson et al. 2004). Forest harvesting activity was mapped in a straightforward manner using an image differencing algorithm (Coppin et al. 2004).

The objectives of this study were set to: 1) quantify rates of change in forest cover for the period between mid-late 1980s and early 2000s for the Eastern Baltic region; 2) describe the fragmentation pattern of public and private forest land.

2 MATERIAL AND METHODS

2.1. STUDY AREA

The study region is bounded by 56 30'N and 59 30'N latitude and 22 E and 30 E longitude and spans an area that extends about 300 km south from the southern shore of the Gulf of Finland and about 400 km east from the eastern shore of the Baltic Sea (Figure 1). The forest is dominated by boreal and boreo-nemoral forests. Clearcut timber harvesting has been a major use over the last tens of years, and has resulted in a mosaic of regenerating clearcuts within a matrix of uncut forest over most of the region. The dominant land cover in the region is forest (52% forested in Estonia 48% in Latvia), pastureland, cropland and wetland. About half of the forest area in Estonia and Latvia is under public ownership, the other half is under private and corporate ownership.

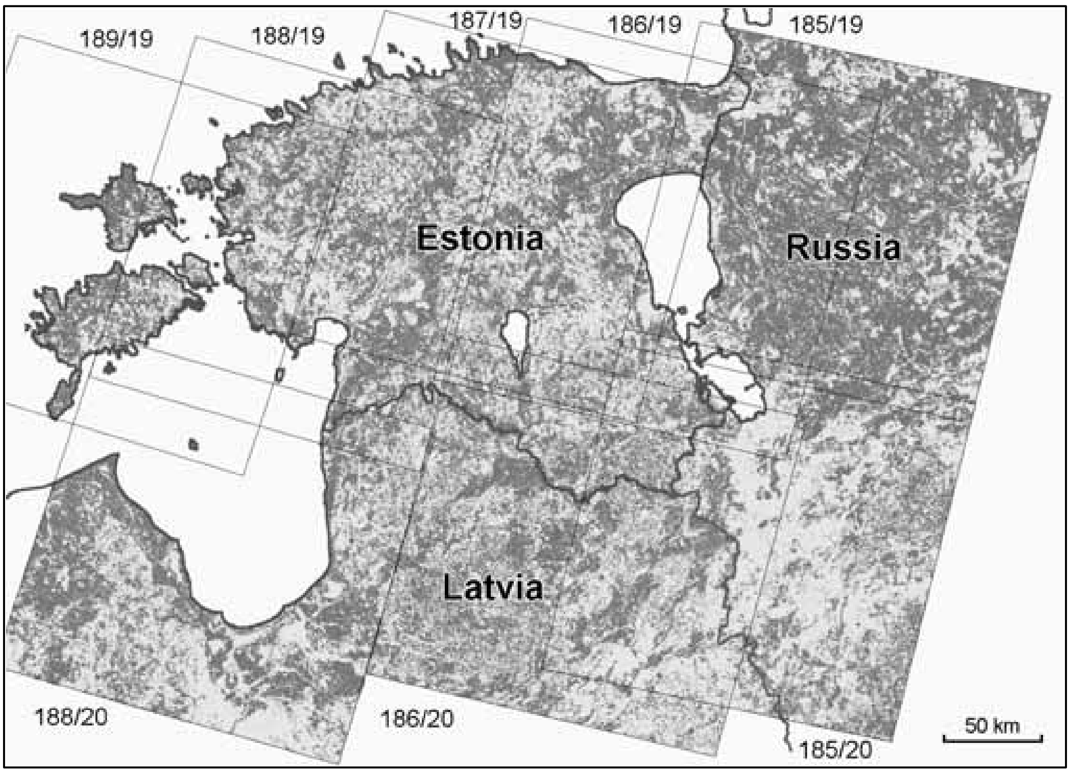

Figure 1. A forest map of the Eastern Baltic area mosaicked from classified satellite images. Landsat Worldwide Reference System nominal scene locations used in the study are shown with frame rectangles together with the respective path and row numbers.

2. 2. SATELLITE DATA AND IMAGE PROCESSING

The data set consisted of Landsat TM and Landsat ETM+ images from three time periods: mid-late 1980s (1985-1987), mid 1990s (1996) and early 2000s (2001-2003). Image processing included two separate steps: 1) forest map generation and 2) forest clearcut mapping. Image processing steps in forest map generation are described in detail by Peterson (2003) and Peterson et al (2004) and included thresholding of winter images and post-classification removal of "forest" patches from urban areas. The classification of satellite images was supported by orthophotos and 1:10 000 scale national basic map in vector format for Estonia, National 1:50 000 base map for Latvia and russian military topographic maps in scale 1:50 000 and 1: 100 000 for Russia. Forest was defined as area with 30 % or more tree cover with minimum patch size over 0.5 ha.

The change detection method used for clearcut mapping was image differencing (Coppin et al 2004). The images were analysed as separate date-pairs, the results of which were merged into a final harvest map. The errors in a clearcut harvest map derived from Landsat data were characterized with a comparison with a vector database containing forest stand historical information. For comparing the harvest map with vector database we used the method described by Cohen et al 1998). The centroids of the harvest polygons from the vector database were extracted, overlaid on the harvest map and counted the number of patches containing a centroid, the number of patches not containing a centroid and the number of centroids not falling within a patch. This procedure allowed for slight misregistration errors between the data sets. Agreement was characterized in two ways; based on overall area harvested and based on patch by patch comparison using a map overlay operation. All images were processed separately using Idrisi software with mosaics being produced from the results. The classified images were analyzed and forest patch metrics describing forest patch size, edge density and core area were calculated for administrative districts.

3 RESULTS AND DISCUSSION

The administrative regions differed widely in forested area, the number and density of clearcuts (Figure 2). The overall accuracy of the forest-to-non-forest classification was better than 90%. Harvest activity was also mapped using merged differencing with greater than 90 % accuracy.

The first obvious trend is a gengerally increasing amount of temporally non-forest (clearcut) areas over time in forests in all ownership types. Approximately 10% of the forest area was disturbed overall, translating into annual disturbance rate of 0.6 %. The second trend in forest-cover patterns is the consistent difference of clearcutting between forest ownership types in the areas where it was possible to be differentiated (in Estonia and in Latvia) (Figure 3). The general rates and patterns of clearcutting within the last two decades since 1985 were found to be rather similar in Latvia and in Estonia. The annual rate of cutting has increased both in private and in state-owned forests in these two countries if the yearly average rates of late 1980s and early 2000s are to be compared. While the rate of cutting has remained more conservative in state-owned forests, that on lands now in private possession has increased by five to seven times if averaged over a commune area. This situation has supported the dominating public opinion that the forests in the Baltic states are severely overcut. Though the annual average rate of clearcutting has not exceeded 1 % of the total forest area in most of the communes, thus still supporting a hundred year long rotation period. Within these prevailing average rates of clearcutting forests from different growing conditions are harvested with different intensity. Forests in the studied areas of North-Western Russia have been cut to a lower rate than in the neighbouring Baltic states with the pattern of the clearcut area distribution dependent on the network of roads. Forest-cover dynamics in private forests in Estonia and in Latvia during the last decade of the twentieth century was affected by a low amount of forest clearing during the preceding four decades and decline in the agricultural economy after collapse of the Soviet Union.

Multi-date satellite images have been widely used to estimate disturbance rates in forest ecosystems. In a 250 000 forested area in Oregon, USA, Spies et al (1994) detected a 0.95% disturbance rate for public and 2.14% for private land over a 16-year period. Cohen et al (1998) found an annual disturbance rate of 0.82% per year between 1972 and 1992 also in Western Oregon on an area partly covered by the study of

Spies et al. Hall et al (1991) investigated annual disturbance rates in mixed and coniferous forests in Northern Minnesota, USA The respective disturbance rates were 2.7% and 1.8%. Luque et al (1994) measured disturbance rates of 1.5% per year for mixed deciduous forest and 2.2% per year for pine-oak lowland forest in New Jersey, USA. Disturbance rate of 0.66% per year was recorded in the Russian far East in the Central Sikhote Alin mountains by Cushman and Wallis (2000). Over the 20-year time period between 1972 and 1992 an annual disturbance rate of 0.53% in Klamath-Siskiyou ecoregion in southwest Oregon and northwest California USA (Staus et al 2002).

Disturbance rates in our study area (0.6 %) per year fall toward the lower end of the range reported for temperate forests. While the rates of disturbance are not markedly higher than those recorded from other temperate forests there has recently been a large alteration in the disturbance regime which will lead to a general transformation of forest age structure in the Eastern Baltic area if the trend continues. In general forest cover decreased throughout the region and throughout the period. Forest cover decreased across the area in all municipalities (counties) and in all forest ownership types, though there was a notable difference in rates of change.

Clearcutting is associated with predictable changes including a decrease in core area, an increase in edge density and decrease in the size of remaining forest patches. The results of these analyses reveal that fragmentation increased over the 18-year time span covered by Landsat images, but the isolation of fragments did not change substantially. The analysis of perimeter to area ratio reveal a general trend in increasing edge habitat from 1985 to 2003. The effects of land-use changes, abandonment of agriculture on forest cover throughout the region have not resulted the net increase of forested area.

ACKNOWLEDGMENTS

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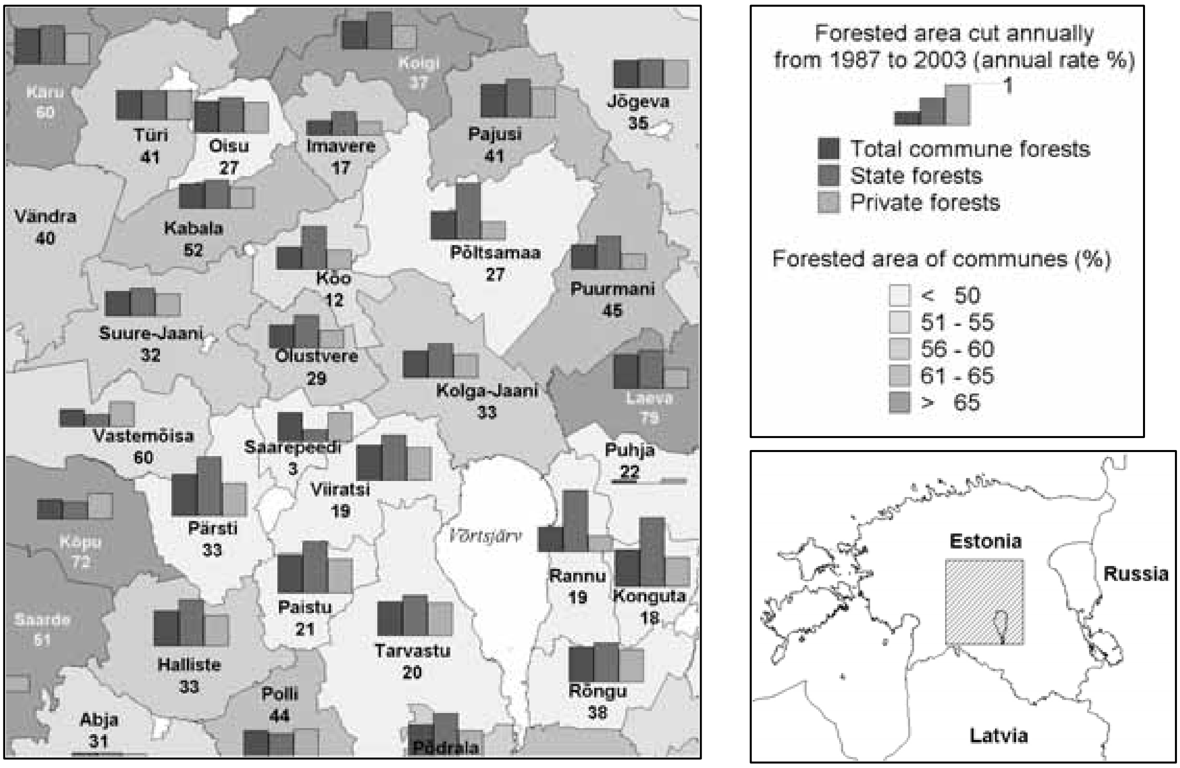
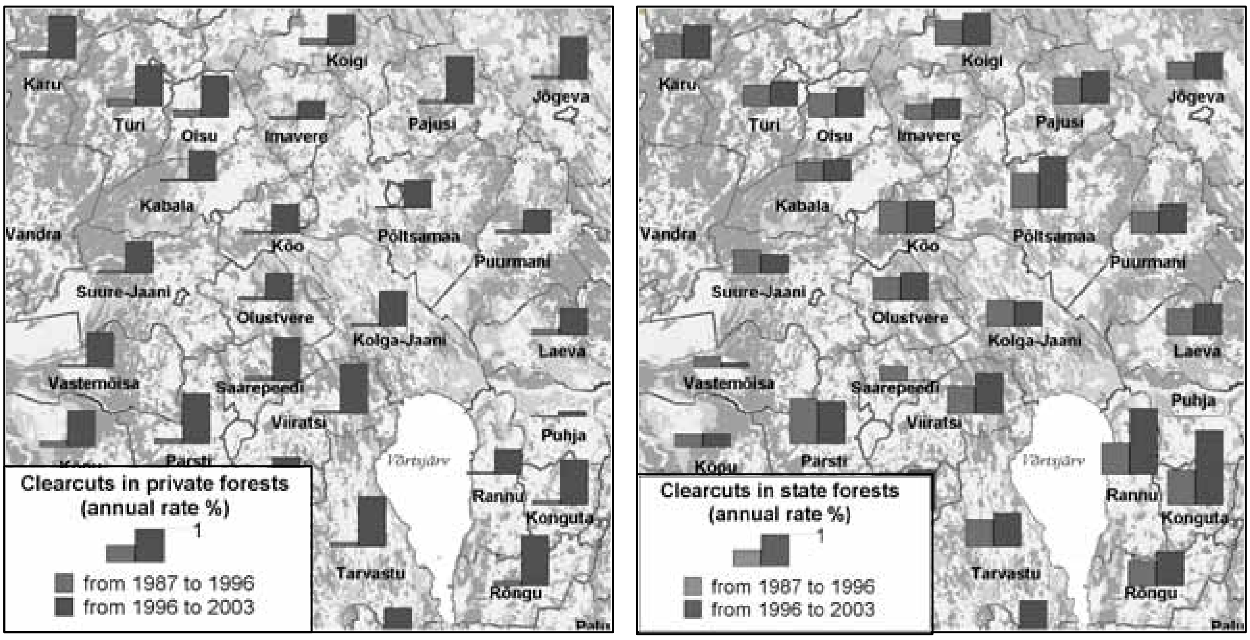


Figure 2. Forest clearcuts in the communes in South-Central Estonia, a sample of the study area. The proportional area covered by forests is indicated with greylevel tones. The share of state-owned forests in communes (per cent) is indicated with numbers. The proportional area of forests cut annually (per cent) from 1987 to 2003 is indicated with the height of the bars. The proportional amount of forests cut in a commune (the left-most bar), in state owned forests (central bar) and in private forests (right-most bar) are shown with separate bars.



a b

Figure 3. Change of annual cutting rates in private (a) and state-owned (b) forests. The sample area is the same as in Figure 2. Cutting rates are shown as average per cent of the respective commune forest area cut annually. Average cutting rates are shown for two periods: from 1987 to 1996 (left bars) and from 1996 to 2003 (right bars). Distribution of forests is shown with grey tones.

A POST-FIRE ANALYSIS OF VEGETATION DYNAMICS IN SEMI-FORESTED AREAS USING MULTI-TEMPORAL REMOTE SENSING IMAGERY

A. Maltese[a], B. Blanca[a], G. Ciraolo[a], E. Cox[a] , G. La Loggia[a] and D.S. La Mela Veca [b]

[a] Dipartimento di Ingegneria Idraulica ed Applicazioni Ambientali - Università di Palermo. Viale delle Scienze 90128 – Palermo, Italy, email: giuseppe@idra.unipa.it

[b] Dipartimento di Colture Arboree - Università di Palermo. Italy

ABSTRACT

The general aim of this paper is to present the results of an application of remote sensing techniques in order to assess and analyse vegetation re-growth in a burned forest in a semi-arid area (Sicily). The study area is located in the North Eastern part of Sicily, it is partly forested and completely destroyed by an extensive fire in September 1987. In order to monitor the regeneration of the vegetation, a set of six Landsat images acquired in the period between July 1986 (before the fire) and July 2002 has been processed. Each image has been georeferenced, corrected for the atmospheric influence and radiometrically calibrated. In order to delimitate the burned area, a comparison between the vegetation index of the 1986 image (before the fire event) and the 1988 image (after the fire event) has been performed. Several vegetation indices have been calculated in order to evaluate the vegetation dynamics in the period under analysis (17 years). Some of these indices have resulted to be more sensitive to such changes than others. The analysis of the evolution of the vegetation indices over time has shown that the original conditions were restored after 7-10 years, however some of the original vegetation species have been replaced by others.

Keywords: Vegetation indices, regeneration, fire.

1 INTRODUCTION

Fire is a crucial environmental factor for life and evolution in natural ecosystems in arid areas. The combustion of the organic substance determines a release of carbon dioxide and nitrogenous gas into the atmosphere and an accumulation of minerals more soluble than organic content in the ground. The availability of these elements, after the passage of the fire, allows the new vegetation to immediately use them. However, when the fire is intense, the soil structure can be modified causing increased erosion and decreased soil infiltration capacity. These conditions do not permit the growth of new vegetation. This degradation is particularly serious in several Mediterranean zones characterised by modest soil thickness, irregular morphologies, slopes and intense rain in brief periods.

Vegetation growth is influenced by several factors: climate, soil characteristics, and interactions with other species. One of the methods used to analyse the influence of climate in the regeneration process is insolation. The solar radiation directly influences the temperature and evapotranspiration phenomena.

Vegetation indices retrieved from multispectral imagery are widely used to monitor vegetation dynamics in burned areas. Viedma et al. (1997), for example, monitored the vegetation regeneration process in a burned area of Spain using a multitemporal series of satellite images. Other authors developed specific vegetation indices for burned areas. Miller and Yool (2002) implement the NBR (Normalized Burn Ratio) in order to delimit burned areas.

The main aim of this research is to evaluate the vegetation dynamics in burned areas using multispectral satellite images. We tried to find a correlation between quantity of solar energy, reaching a specific point on the ground, and the regeneration dynamics of vegetation in order to determine whether, in semi-arid zones, solar energy affects the vegetation re-growth.

2 STUDY AREA AND DATASET

The study area selection was performed by analysing several fires occurring during the last 20 years in Sicily. The main characteristics of the area should be: **1)** the area has been completely destroyed by a fire;

2) the burned area extension is big enough; **3)** the fire is enough old to permit the (partial) regeneration of the vegetation, but not before 1986 because our image dataset starts in this year.

On the basis of these criteria, the selection was performed using the fire database of the Regional Forest Agency. The selected area is located in the northern part of Sicily (Fig. 1), in the San Mauro Castelverde area. On 25th September 1987, this area was burned by a big fire, in total the burned area was 2,000 ha (1,400 ha of woodland and 600 ha of not forested area).

The main natural plant communities are Cork Oak forest (*Quercus suber L.*), Mediterranean Garigues and grasslands, although there is also agricultural land including olive and almond groves in the area. When fires occur, Maquis or low Garigues replace Cork Oak forest stands. If the fire occurs again after a short time (one or few years), the Maquis is replaced by perennial or annual grasslands.

A dataset of multispectral satellite images has been used to study the vegetation dynamics (Tab. 1). All the images were recorded in the summer (July or August) from 1986 to 2002.

A Digital Elevation Model (DEM) has been used for the calculation of insolation. The elevation grid was extracted from the DEM of Sicily (20 m spatial resolution, 1 m accuracy) produced by the Sicilian Regional Environmental Agency. The subset DEM of the study area was resampled in order to obtain a 30 m grid in order that the spatial resolution of the Landsat images and the DEM are homogeneous.

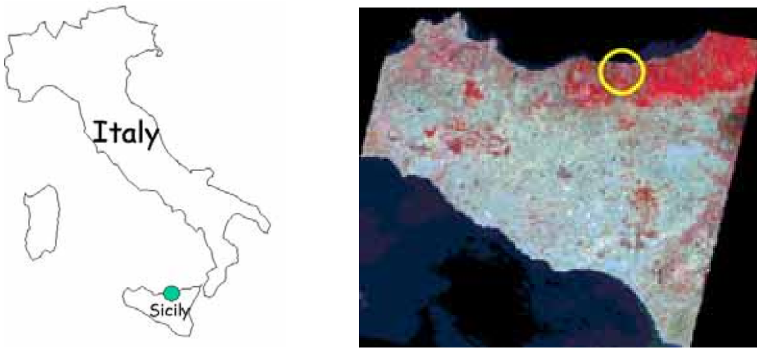


Figure 1. The Study Area. On the right a Landsat TM false colors composite (4,3,2) of Sicily; the circle indicates the area under investigation.

2 METHODS

All the Landsat TM images have been calibrated to radiance and then to reflectance using the Epema (1990) method. The thermal band has been calibrated to temperature values. In order to correct for the atmospheric influence on the visible and near infrared recorded data, an evolution of the "relative scattering model" (Chavez, 1988) has been applied.

The relative scattering model is an evolution of the simple dark object subtraction method introduced by the same author, in order to represent the real atmospheric conditions at the moment of the image recording, and the relationship between the values to be subtracted from each spectral band. One of the problems in applying this method is how to set the correct scattering model: in other words, how to understand whether atmospheric conditions are clear or foggy. In our application we follow the indication of Fallah-Adl *et al.* (1997), based on *in situ* measurements, to calculate the atmospheric condition exponential value. For the sake of brevity, we report only the results of the application of this method (Tab. 1). High α coefficient values stand for clear atmospheric conditions.

Table 1. The satellite images dataset, including atmospheric conditions

SATELLITE	DATE	α
Landsat 5 TM	19/07/1986	6,2
Landsat 5 TM	24/07/1988	5,2
Landsat 5 TM	04/08/1992	5,6
Landsat 5 TM	28/07/1995	5,3
Landsat 5 TM	20/07/1998	2,0
Landsat 7 ETM+	07/07/2002	3,3

The thermal band has been corrected for atmospheric influences in order to retrieve the Land Surface Temperature (*LST*) using a single channel correction method (Qin et al., 2001),

$$LST = [a_6(1-C_6-D_6)+(b_6(1-C_6-D_6)+C_6+D_6)T_6-D_6T_a]/C_6$$

where the subscript 6 refers to the sixth Landsat spectral band, T_6 is the brightness temperature, a_6 e b_6 are the authors constants, C_6 and D_6 depend on distribution of: the surface thermal emissivity ε_6 [adim], the atmospheric transmittance (mainly a function of the atmospheric water content w [g/cm^2]) and the air mean temperature T_a [°C].

The ε_6 maps have been produced using the NDVI method (Sobrino and Raissouni, 2000):

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s(1-P_v) + d\varepsilon$$

which considers ε to be linearly dependent on the vegetation index, through the fraction cover P_v, in the range of NDVI between 0.2 and 0.5. Below this range ε is assumed to be that of bare soil (ε_s), while above this range, it is assumed to be that of dense vegetation (ε_v). The term $d\varepsilon$ considers heterogeneity and roughness effects: in the case of forests this term is not negligible.

T_a and w maps for the dates of satellite acquisitions have been retrieved using climatic data.

Several Vegetation Indices (VI) have been tested in order to understand the most sensitive index for our analysis. The VI calculated for our case study are: **1)** *NDVI* (Normalized Difference Vegetation Index); **2)** *NDVIc* (Corrected Normalized Difference Vegetation Index); **3)** *MSAVI* (Modified Soil Adjusted Vegetation Index); **4)** *WDVI* (Weighted Difference Vegetation Index); **5)** *TVI* (Triangular Vegetation Index); **6)** *NBR* (Normalized Burn Ratio); **7)** *T/NDVI* Ratio.

The *NDVI*, introduced by Rouse (1974), was designed to separate vegetated areas from water bodies and bare soil:

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$

where R_{NIR} is the near infrared reflectance and R_{RED} is the red reflectance.

This index is widely used because it minimises topographic effects and produces a linear scale, ranging from –1 to +1 where 0 and negative values indicate non vegetated areas.

Following the *NDVI* formulation, Nemani *et al.* (1993) formulated the *NDVIc*, which includes the mean infrared reflectance (R_{MIR}):

$$NDVIc = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \cdot \left(1 - \frac{R_{MIR} - R_{MIRmin}}{R_{MIRmax} - R_{MIRmin}}\right)$$

where: R_{MIRmax} is the maximum reflectance value in the mean infrared on vegetated areas and R_{MIRmin} is the minimum reflectance value in the mean infrared on vegetated areas.

The *MSAVI* (*QI et al.*,1994) is defined by:

$$MSAVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \cdot (1+L)$$

where L is a correction factor ranging from 0 (in case of dense vegetation) to 1 (in case of sparse vegetation). L can be calculated using:

$$L = 1 - (2 \cdot \gamma \cdot NDVI \cdot WDVI)$$

where γ is soil line slope and $WDVI = R_{NIR} - \gamma \cdot R_{RED}$.

The *TVI* (Broge and Leblanc, 2000) was developed following the idea that energy absorption from the canopy is a function of the relative distance of red, infrared and green reflectances. The index is defined by the area of the triangle (ABC) given by the green reflectance peak, the minimum in the red and the peak in the near infrared (Fig. 2). When the vegetation cover increases, the red reflectance decreases and the near infrared reflectance increases: this means that the triangle area increases.

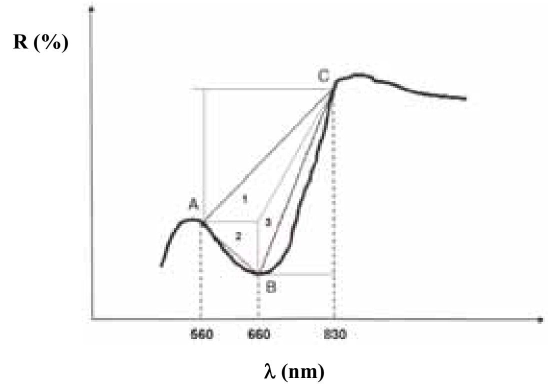


Figure 2. Area of triangle ABC that defines the *TVI* index

The *NBR* (Key and Benson, 1999) formulation is similar to *NDVI*:

$$NBR = \frac{R_{NIR} - R_{MIR}}{R_{NIR} + R_{MIR}}$$

This index was designed to be applied in burned areas, because it uses only infrared information.

A new VI, called *T/NDVI ratio*, has been defined during this research to take into account the increase in the pixel temperature when vegetation disappears.

$$T / NDVI = \frac{T}{NDVI_{0-1}}$$

where *T* is the soil temperature and $NDVI_{0-1}$ is the *NDVI*, normalised to assume values in the 0–1 range. This index is always positive and represents the temperature per unit of VI.

Finally, very complex calculations were performed in order to calculate the mean annual insolation for each point of the study area. The Liu and Jordan (1960) approach has been applied. This method uses the experimental values of mean daily radiation, for each month, on a horizontal surface: in our application, we used values measured in Palermo and Messina. The mean daily radiation of our study area has been obtained applying an interpolation weighted on latitude positions. To take the morphology into account, an exposition and a slope map have been generated, using the Digital Elevation Model. The horizontal mean daily radiation has been recalculated introducing illumination (direct and diffuse) geometry. The final product of this elaboration is a map of the mean annual insolation. In this way, it is possible to differentiate the most exposed zones from the insolation.

All the calculations described above (VI and insolation) have been implemented using *Model Maker* in *Erdas Imagine* software. In order to delimitate the burned area, a difference between the VIs calculated using the 1986 image (one year before the fire) and the VI calculated using the 1988 image (one year after the fire) was determined. The evolution over time of the mean VI on the delimited burned area, has been represented in order to try to retrieve the number of years sufficient for the initial vegetation conditions to recover.

Finally a cross correlation analysis over time of mean annual solar insolation and VIs has been performed in order to evaluate the correlation between the vegetation re-growth and exposition to solar radiation.

3 RESULTS AND CONCLUSIONS

The best delimitation of the burned area was obtained using the *WDVI* distribution because this index takes the influence of the surrounding soil when the vegetation disappears into account.

Within the burned area the mean value of the VIs defined above has been calculated for all the available images. This allows us to analyse the vegetation recovery, in terms of biomass, over time. The most sensitive VI in describing the fire effect is the *NBR* although it shows a "salt and pepper" noise that degrades the accuracy in burned area delimitation. Among the normalised VIs *NDVI* shows the most variability. After the event (1988) all the VIs show the absolute minimum. The *T/NDVI ratio* shows specular behavior due to its definition. *NDVI* and *NDVIc* reach the original value after 5-8 years, while *TVI*, *NBR* and *T/NDVI ratio* reach the original value after 8-11 years.

A spatial cross correlation analysis between mean annual insolation and VIs has been performed in order to understand the influence of radiative incident energy on vegetation re-growth. A significative negative correlation of insolation has only been found with *NDVI*, *NDVIc*; a positive correlation has been found with *T/NDVI ratio*. This means that where insolation values increase, vegetation fraction cover decreases. From 1986 to 1992 the correlation increases reaching a maximum absolute value of 0.43. In areas characterised by steep slopes, the correlation shows the same trend over time reaching a maximum value of 0.62. The negative correlation should suggest that the surplus of incident energy causes a vegetation sufferance, although this hypothesis is not supported by the correlation values that remain negative even after 1992, when we recognise that the vegetation recovers its original status in terms of biomass.

This means that insolation plays a weak role in the vegetation re-growth process and this suggests that, in semi-arid zones, other factors have to be considered in the analysis (mainly soil water content and nutrient availability).

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Session 6b

USING REMOTELY SENSED INFORMATION TO VERIFY BASIC LEGALITY AND SUSTAINABILITY IN REMOTE FOREST AREAS NOT READY FOR CERTIFICATION

L. Laestadius

World Resources Institute, 10 G. St. N.E., Washington, DC, 20002 USA, larsl@wri.org

ABSTRACT

An important enabling condition for unsustainable and/or illegal forest management is the combination of poor information and insufficient transparency. The overwhelming majority of the world's forest landscapes, most of which are not certified as being sustainably managed, are characterized by gaps in information and transparency. Many obstacles stand in the way of eliminating these gaps, including difficulty of access to remote forest areas and lack of resources, will, and incentives. Satellite imagery is an increasingly accurate and cost-effective public source of information with the potential to overcome these obstacles. This potential needs to be captured in a set of tools that combine technical accuracy and ease of use with stakeholder relevance and credibility. Tools worthy of consideration include (1) a forest change tool that provides information on the location, time and type of recent discrete changes, (2) a forest condition tool that provides spatially explicit information on the species/age matrix, (3) tools that provide information on the location of ecologically and socially sensitive areas, and (4) tailor-made tools for systems and organizations working to expand the area of certified sustainable management. Global Forest Watch intends to use Russia as a laboratory for developing and testing such tools in collaboration with interested stakeholders.

Keywords: Illegal logging, certification, remote sensing, transparency.

1 PROBLEM

1.1 GAPS IN INFORMATION AND TRANSPARENCY

An important enabling condition for unsustainable and/or illegal forest management is the combination of poor information and insufficient transparency. This condition prevails in the overwhelming majority of the world's forest landscapes, most of which are not certified as being sustainably managed. To improve forest management, these gaps in information and transparency must be eliminated. Some of them are of particular significance for the forest industry:

Information on what is happening in the forest landscape. Any stakeholder intent on dealing with the complex problem of illegal logging needs to have a firm and detailed grasp of what is happening where and when. The current absence of such information is a major obstacle to positive action. Forest authorities cannot verify the legality of unknown operations. Forest companies cannot track the flow of wood from such operations. Civil society organizations cannot ask questions about them.

Information on the status of the forest landscape. Sound plans for future management, including business decisions to expand and invest, require relevant, accurate, and recent information about the condition of the forest landscape (including forest composition and age). Currently available information is often of dubious or poor quality, which allows unsustainable practices to go unnoticed and also causes other problems. Examples include over-harvesting, which erodes the capacity of the forest landscape to sustain its population and keep it out of poverty, poor or unsuitable regeneration, and poor or lacking silviculture. Forest companies find it risky to plan expansion into new areas and difficult to determine the proper price for user rights.

Information on the ecological and social sensitivity of the forest landscape. Policies for responsible management and wood purchasing require that the exact location of different types of sensitive areas (e.g. high conservation value areas) be known. Existing maps typically do not allow producers to achieve FSC certification, or purchasers to implement policies on corporate responsibility. Better maps of sensitive areas are needed to design and implement policies that integrate proper concern for these areas in forest management.

1.2 CHARACTERISTICS OF NON-CERTIFIED AREAS

Gaps in forest landscape information and transparency typically occur in areas which are not certified as being sustainably managed. Improving information and transparency in these areas is important and urgent but faces some formidable obstacles. These obstacles become evident when non-certified areas are compared to certified areas:

- Management problems occur in greater number and are more serious. Illegal or destructive logging and over-harvesting may be among them.
- The area is much greater (certified area remains a small proportion of the total forest area of the world) and often more difficult to access.
- The risk of encountering false or misleading information is greater (poor or illegal producers may wish to misrepresent their practices)
- The *ability* to pay for information and transparency is much less. Management in these areas is either unprofitable or wishes to hide its profits.
- The *willingness* to pay for information and transparency is also less. No market advantage will be received in return for such an investment unless it leads to certification.

2 A STRATEGY FOR NON-CERTIFIED AREAS

The difficulty of providing information and transparency for non-certified forest landscapes is daunting. A feasible system must be cheap, robust and simple. It must allow large areas to be assessed annually at a much lower cost than through field verification, and with much greater reliability than through self reporting. It must be independent of the willingness of the forest manager or land owner to participate. It must thus focus on actual (rather than planned) practices and not require physical access (a practical impossibility in many areas). It must be pragmatic and incorporate the 80/20 rule, as perfection will be impossible to achieve. It must be useful and complementary to systems for sustainability certification without competing with them. It must be recognized as being reasonable and fair by major stakeholders.

A promising possibility is to build a system that combines two features:

- Heavy reliance on remotely sensed information. Satellite images provide a source of public information that is increasingly accurate, cost-effective and available to different stakeholders including civil society.
- Engagement of multiple stakeholders. The system should be developed in consultation with an advisory group, which should also be invited to endorse the results.

3 TOOLS TO IMPROVE FOREST INFORMATION AND TRANSPARENCY

Satellite imagery appears to have the potential to overcome the difficulties of non-certified areas. This potential needs to be captured in a set of tools that combine technical accuracy and ease of use with stakeholder relevance and credibility. Tools of several types are needed to fill the different information and transparency gaps identified above.

3.1 A FOREST CHANGE TOOL

A forest change tool will provide information on the boundaries of discrete recent changes in the forest landscape, the type of change (e.g. clearcuts and fires) and the time of occurrence. This information should be shown on top of a topographical map that is detailed enough to allow users to understand the precise location and relate it to their own context. Other information, such as jurisdiction, tenure, forest management boundaries such as the *kvartal* grid (in Russia), and boundaries of protected or otherwise sensitive areas, will also be shown. Figure 1 indicates the kind of information that this tool will provide.

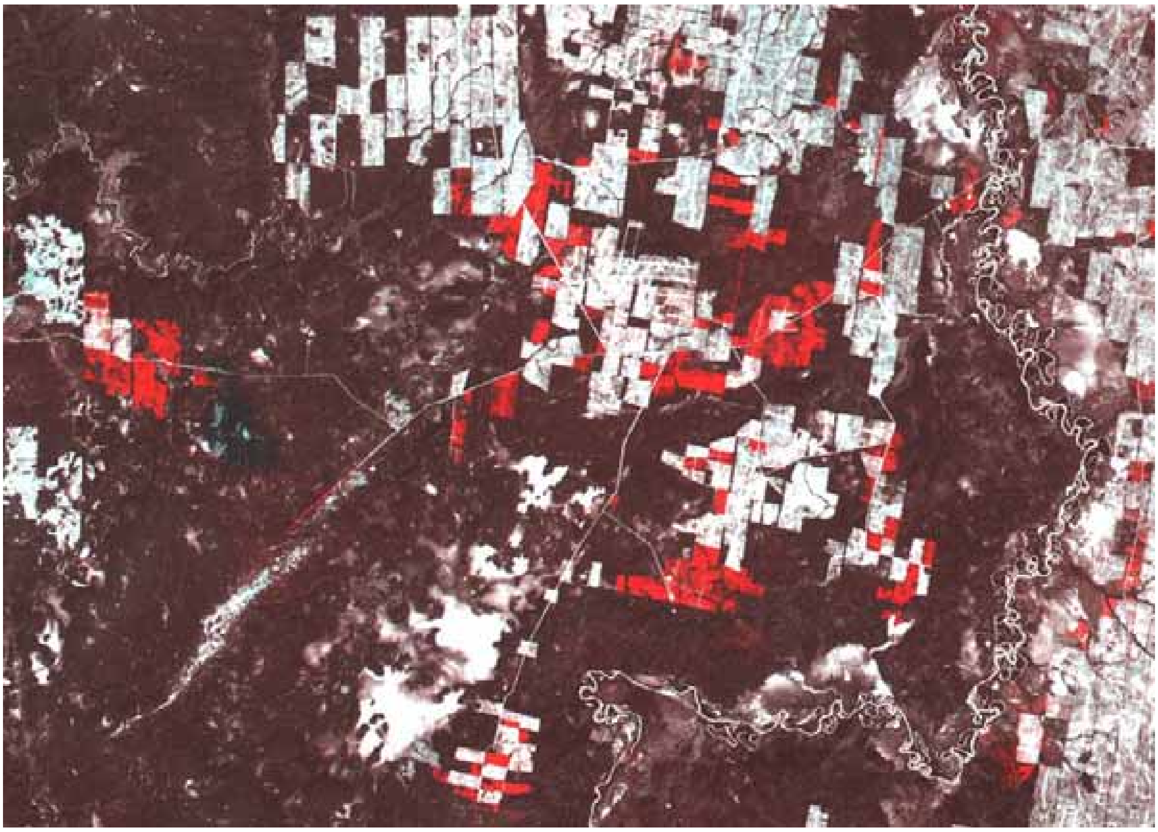

Figure 1. The forest change tool will provide stakeholders and the public with a detailed picture of individual logging sites. This will allow them to identify and follow up on illegal or inappropriate activities. Clearcuts made after 2000 are shown in red. (IRS)

A possible strategy is to compare inexpensive images of high temporal resolution (MODIS, at 250m spatial resolution, or possibly IRS AWiFS at 55m resolution) from different points in time to detect changes, while images of higher spatial resolution (possibly IRS, at 6m and 23m resolution) will be custom ordered to provide the necessary detail for chosen sites.

The tool will not distinguish legal activities from illegal or good ones from bad. Stakeholders, including government authorities, the forest industry, and environmental organizations, are in a much better position to make this assessment on the basis of additional non-public and/or local knowledge. The tool works by providing them with the detailed and easy-to-use evidence that they need to do this and take action as needed. To be effective, it must be designed so that no special software or computer skills are required of the user.

3.2 A FOREST CONDITION TOOL

A forest condition tool will provide information on the condition of the forest landscape. A tentative list includes the following characteristics:

- Location of infrastructure (roads, railroads, pipelines, etc), and change over time. Fragmentation.
- Location (spatial distribution) of forest area classified by species group (pine, spruce/fir, mixed, deciduous) and age class (mature/old-growth, clearcut, young forest, medium-age forest), and change over time.
- Location of clearcuts by species group and period of occurrence.
- Location of fire scars and other disturbances by species group and period of occurrence.
- Reforestation patterns on recent clearcuts by period of occurrence.
- Location and change of sensitive areas, such as protected areas and intact forest landscapes.

This information will be up-to-date and spatially explicit. Other information, such as jurisdiction, tenure, and the *kvartal* grid (in Russia), will also be shown. Figure 2 indicates the kind of information that this tool will provide.

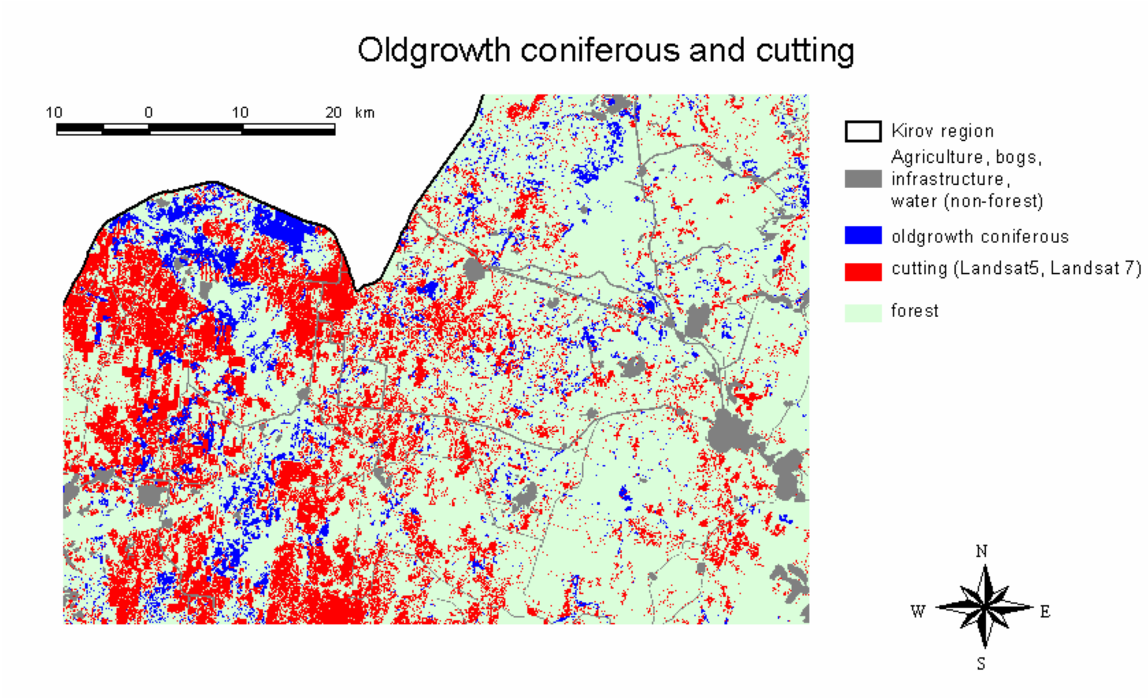

Figure 2. The forest condition tool will give the forest sector an objective, detailed and recent picture of the forest at the regional level. Recent clearcuts (red) and remaining mature/old-growth forest (blue) in Kirov oblast. (Landsat).

A possible strategy is to begin from a comparison of Landsat imagery from approximately 1980, 1990, and 2000 (30m resolution), making it possible to capture the dynamics of forest change in ten-year intervals for at least two decades. Other imagery (possibly IRS LISS-3 MSS at 23m resolution) will be used to bring the analysis up to date.

The tool will present objective biophysical information without any sustainability assessment. It seems likely, however, that the tool can be used as a basis for assessing basic aspects of sustainability.

3.3 FOREST SENSITIVITY TOOLS

Forest sensitivity tools will show the location of bio-physical characteristics that are relevant to ecological and social sensitivity, such as the high conservation value forest concept. The purpose is to create broad awareness of the location of such characteristics, so that stakeholders can make well-informed decisions about the formulation and implementation of policies.

An example of a tool for ecological integrity is shown in Figure 3. Intact forest landscapes were defined as natural mosaics of ecosystems in the forest landscapes which are unfragmented by infrastructure, virtually unaffected by industrial landuse, and greater than 50,000 hectares in size (Yaroshenko, Potapov and Turubanova, 2001; Aksenov, *et al*. 2002).. Topographical maps and satellite imagery (Resurs, Landsat) were used to identify and eliminate areas with infrastructure and signs of industrial landuse. This tool is currently used by many forest companies in Russia to define and implement policies on sensitive areas.

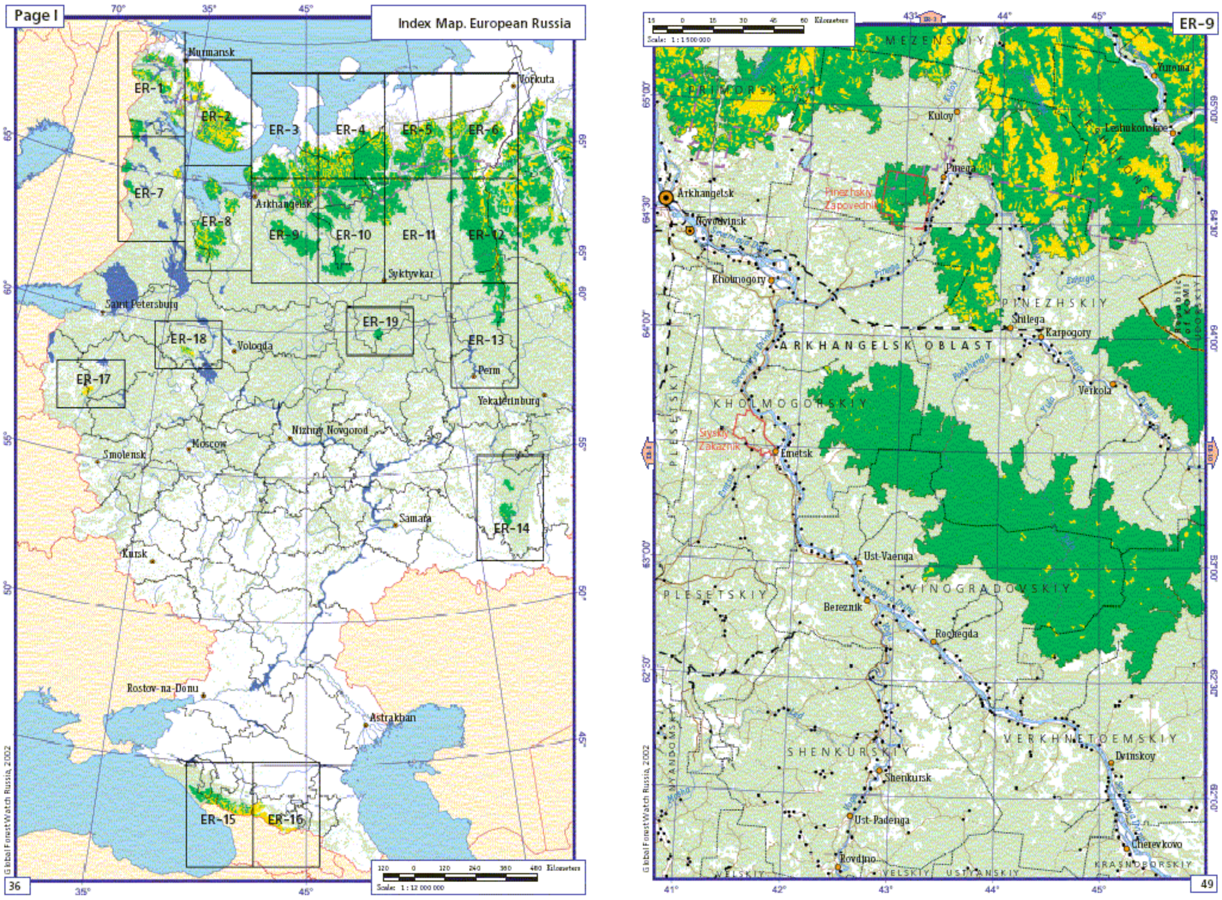

Figure 3. Intact forest landscapes in Russia (shown in bright colors). To the left an index map of European Russia, to the right a detailed map for the Arkhangelsk region (the scale is 1:1.5 million). (Aksenov, *et al*. 2002.)

3.4 TAILOR-MADE TOOLS

The above-mentioned tools can be combined in different ways to serve systems and organizations that work to expand the area of certified sustainable management and therefore need information about non-certified areas. These include the Global Forest and Trade Network as well as different certification systems.

4 NEXT STEPS

Global Forest Watch plans to use Russia as a laboratory for designing and testing forest landscape information and transparency tools of the type exemplified above. Russia was chosen because of its importance to forest ecology, economy and policy, and because it has taken the initiative to an intergovernmental process on forest law enforcement and governance (FLEG) centered on Europe and Northern Asia. The ambition and hope is to develop tools that can later be applied in other forest countries.

ACKNOWLEDGMENTS

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MAPPING HIGH CONSERVATION VALUE FORESTS AND ANTHROPOGENIC DISTURBANCES ANALYSIS OF FOREST ECOSYSTEMS OF PRIMORSKY KRAY, RUSSIAN FAR EAST, USING LANDSAT TM / ETM+ DATA

D. E. Aksenov[a], M. Yu. Dubinin[b], M. L. Karpachevskiy[c], N. S. Liksakova[d], V. E. Skvortsov[e], D. Yu. Smirnov[f], T. O. Yanitskaya[g], L. Laestadius[h], V. Roshchanka[i], S. Minnemeyer[j]

[a] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: picea@online.ru
[b] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: m_a_x_d@mail.ru
[c] Biodiversity Conservation Center, Vavilova 41, 117312 Moscow Russia, e-mail: forest@biodiversity.ru
[d] Botanical Institute, Saint Petersburg, Russia, e-mail: nliks@mail.ru
[e] Biodiversity Conservation Center, Vavilova 41, 117312 Moscow Russia, e-mail: v-sturnus@yandex.ru
[f] World Wide Fund for Nature (WWF) Russia, Far Eastern Branch, Vladivostok, Russia, e-mail: dsmirnov@wwfrfe.ru
[g] Biodiversity Conservation Center, Vavilova 41, 117312 Moscow Russia, e-mail: tyanitskaya@biodiversity.ru
[h] World Resources Institute, 10 G Street NE Washington, DC 20002 USA, e-mail: larsl@wri.org
[i] World Resources Institute, 10 G Street NE Washington, DC 20002 USA, e-mail: volha@wri.org
[j] World Resources Institute, 10 G Street NE Washington, DC 20002 USA, e-mail: susanm@wri.org

ABSTRACT

Primorsky Kray hosts one of the most diverse forest ecosystems in Russia. Forest ecosystems here conserve great deal of the regional biodiversity. But historic and current development rates in the region raise questions about its conservation value in future. To understand better conservation strategy for the region, update protected areas system and help identify high conservation value forests (HCVF) a project was initiated for mapping such forests. The research was carried out in several steps. On the first step – topographic information was used for creation of buffer zones and sorting them out from the territory of interest, on the next step remote sensing data was used to identify infrastructure not present on available topographic data, this infrastructure includes logging roads, clearcut areas, high-graded forests, areas converted into agricultural lands, areas of mining and other elements of human caused disturbances. As a separate agent burned areas were also delineated to be excluded to get low-fragmented areas. Image interpretation was carried out using Landsat-7 ETM+ data and Landsat-5 TM data. Results show that most fragmented forest formation in Primorsky Kray is mixed broadleaf formation, Manchurian fir dominated formations also fragmented to high degree particularly in comparison to the relatively small area they occupy.

Another step is an identifying and mapping of the HCVF itself. It was implemented using topographic maps, forest inventory data and space images simultaneously. HCVF were identified in all main forest formations of the area, as well as some rare forest communities and some rare plant species stands were mapped. All these kinds of HCVF together if protected can support the biodiversity of forest vegetation in Primorsky Kray.

Keywords: High Conservation Value Forest (HCVF), Intact Forest Landscapes, biodiversity, conservation, disturbance, fragmentation, Russian Far East, Russia

1 INTRODUCTION

Primorsky Kray (or Primorye) is rich in ecosystems that support unique species, such as the Amur Tiger (*Panthera tigris altaica*) and Far eastern leopard (*Panthera pardus orientalis*), ginseng (*Panax ginseng*) and Asian devil's-club (*Oplopanax elatus*). For millennia, these ecosystems have remained in their natural state, however within the last decades many types and species became endangered as a result of human activity. Loss of a few key ecosystems would mean loosing dozens of species associated with them. In many cases, their survival depends on the condition of biodiversity of the forest ecosystems in the region.

The highest conservation priority should be given to those ecosystems that are most endangered, such as for example the least disturbed forests, the area size of which diminishes every year. In this research, we focused on the following categories of forest ecosystems:

- Less disturbed forest tracts
- Naturally rare and unique forest communities
- Habitats of rare and endangered plant species

While mapping high conservation value forest (HCVF) in Primorye, we focused on identifying those forests that are important for preservation of natural vegetation and its biodiversity. To a large extent, animal biodiversity would also be represented inside the delineated forest communities. Although this assumption might not always hold true, especially as far as large and mobile animal species are concerned, the survival of many animals depends on preserving natural vegetation – their habitat. We did not consider economic, cultural, and social values in this analysis, since their identification requires a different approach and an enormous amount of fieldwork. However, it should be remembered that the location of forest with different high conservation values often overlaps.

2 LESS DISTURBED FOREST TRACTS

To map *less disturbed forest tracts*, we combined the results of two separate analyses: one to identify the degree of human-caused transformation of different forest ecosystems and another to determine the degree of fragmentation of the natural forest landscapes (Figure 1).

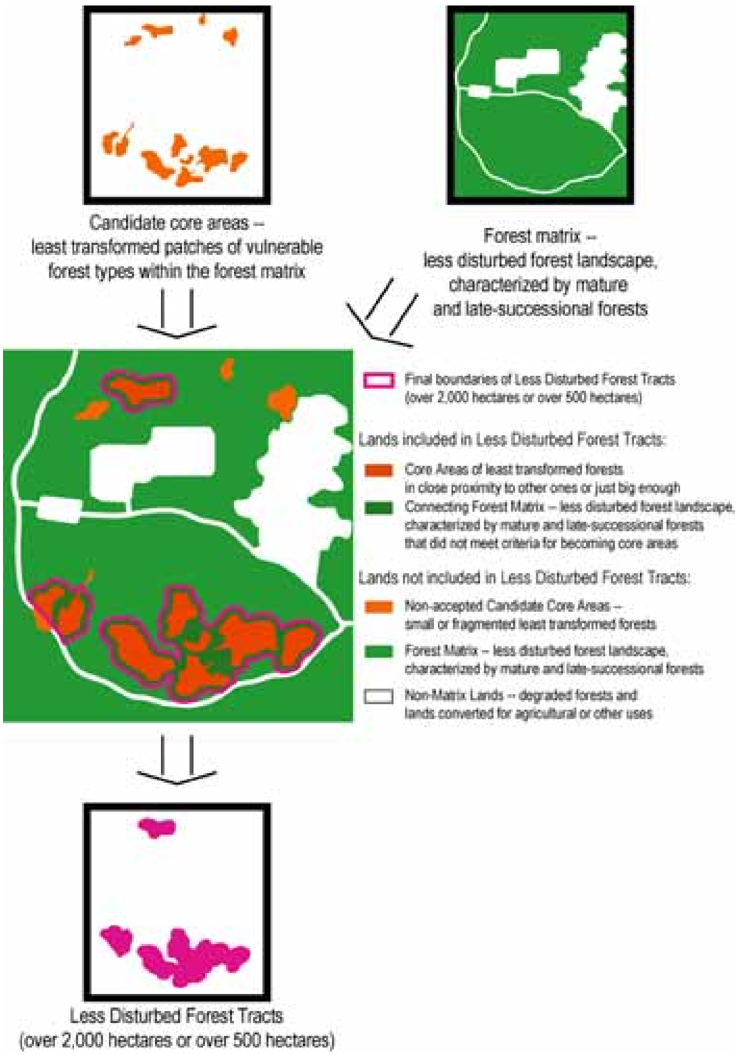

Figure 1. Steps in identifying Less Disturbed Forest Tracts.

In the *transformation analysis***,** our approach was the opposite of the one we used to map intact forest landscapes. We identified intactness features, such as tree species composition and advanced age, and mapped the least anthropologically transformed forests areas without mapping disturbed areas. This approach is commonly used to map intactness and biodiversity values. For example, we used it in 1995-1998 to map old-growth forest in Karelia Republic and Murmansk Oblast. Our Finnish colleagues used a similar approach to map old-growth forest in their country, although in association with extensive field verification. A group of scientists used a similar methodology in Primorsky Kray in 1999 but with different criteria (Dyukarev *et al.*, 1999). However, we believe that in many cases this approach alone is insufficient to identify low-disturbance forests and therefore in our research was considered to be only a step. The output of this step was the location of a set of *candidate core areas* – least transformed patches of vulnerable forest types.

We classified the forest landscape into forest types, using a common Russian forest classification system (Rozenberg and Vasiliev, 1969). Forest types that were difficult to distinguish both on satellite images and in forest inventory data were grouped into one category. From this list we selected those forest types that are native to the region and vulnerable to human activities. Thus, we analyzed five forest types:

- Korean pine forest (Korean pine, *Pinus koraiensis*, in mixture with other coniferous, except forests with Manchurian fir, *Abies holophylla*, see below, or deciduous species);
- Manchurian fir forest (forests with the Manchurian fir, *Abies holophylla*);
- dark coniferous forest (mixed Yezo spruce, *Picea jezoensis,* also called *P. ajanensis*, and East Siberian fir, *Abies nephrolepis*);
- mixed noble hardwood forest (Japanese elm, *Ulmus japonica,* and Manchurian ash, *Fraxinus mandshurica,* dominated hardwoods); and
- riparian poplar forest (a mixture of *Populus coreana, P. maximoviczii, P. suaveolens*, and *Chosenia arbutifolia* with presence of conifers).

We then attempted to locate the least anthropologically transformed parts of each sensitive forest type. In Primorye, different types of least transformed forest showed different degrees of human impact due to differences in their accessibility and economic value. While highland dark coniferous forests are well-preserved in northern Primorye, Manchurian fir forests are heavily affected by humans. We were barely able to find any patches of Manchurian fir forest without traces of recent human disturbance. Therefore, we used different transformation criteria for each forest type, using less stringent criteria for more disturbed forest types, which nonetheless preserve their natural plant diversity.

Technically, the transformation analysis included the following steps:

1. First, using state forest inventory data, we located forest stands, which fulfill our criteria for candidate least-transformed forests. Forest inventory data can be unreliable and must be used with precaution. We relied primarily on data on age and dominant tree species as these are usually accurately recorded in our experience and adequately represent the true state of the forest. Our selection criteria relied on empirically established relationships between age and dominant tree species on the one hand, and the diversity of the natural plant community on the other. We could only locate *candidate* areas of least-trans-formed forests in this step.
2. Then we located highland and bottomland forest that included flat sections of river valleys wider than 2 kilometers. For this step, we used digital elevation model that we derived from topographic maps. We overlaid these with data on forest type distribution to locate high-elevation spruce-fir forests, as well as riparian forests, which tend to have characteristic biodiversity.
3. Using satellite images, we corrected and updated the boundaries of the forest stands located in the previous steps. If an adjacent area had the same spectral and textural characteristics on the satellite images as the ones identified through the forest statistics, this area was included in the core. We also made sure that our boundaries reflected the most recent changes in the forest by excluding areas recently disturbed. Spruce-fir forests on slopes, which connect highland and riparian ecosystems were also included.

These identified territories were termed *candidate core areas* – patches of a certain forest type that are least transformed by humans and are most biologically diverse. We did not include “secondary” forest – post-fire or post-cleacut forest – in the candidate core areas, nor did we include forest with clear evidence of multiple ground fires, often indicated by an abundance of Mongolian oak, *Quercus mongolica*. Such forests usually do not have long continuity, are not threatened by modern human impact, and do not represent any flora communities that are specific to them.

In the *fragmentation analysis*, similarly to the approach we used to map intact forest landscapes, we assumed at the outset that the entire research area was intact unless otherwise proven by adequate information. This information included basic infrastructure maps, satellite images, and official forest inventory data, showing evident human disturbances. Such disturbed areas were mapped and excluded from further study.

Technically, the fragmentation analysis was carried out in three steps:

1. We eliminated major elements of human infrastructure using topographic maps. Built-up areas, croplands, railroads, paved roads, gravel roads, and smaller roads, if they connected two populated areas, were assigned a buffer with a width of 50-100 meters (500 meters for urban settlements). Dirt roads, including most small logging roads, small (local) powerlines, and selective logging were not regarded as sufficient fragmentation and were not excluded. Also, the buffer assigned to linear features like pipelines, powerlines, quarries, and other types of mining activity was smaller.
2. We eliminated areas that have been completely transformed by humans, identifying them through satellite images. These areas included built-up areas, croplands and quarries that had not eliminated in the previous step, wide roads that were not indicated on topographic maps (mainly big logging roads). These areas were buffered and eliminated from further analysis.
3. Using satellite images, we excluded areas with visibly transformed vegetation caused by clear-cutting, catastrophic fires and often ground forest fires during the last decades. We also eliminated abandoned agricultural areas, which we identified by characteristics like shape, drainage system, and road network. All areas affected by forest fires, whether of natural or anthropogenic origin, were excluded along with all forest regarded as “secondary” (i.e. all early stages post-fire and post-logging succession).

Our objective in the fragmentation analysis was to eliminate areas not capable of maintaining the ecological connection between the least transformed forest patches. The remaining area was called the *forest matrix* – less disturbed forest landscape, characterized by mature and late-successional forests.

To locate Less Disturbed Forest Tracts, we *combined the results of the transformation and fragmentation analyses*, identifying clusters of candidate core areas and eliminating fragmented areas.

This analysis included the following steps:

1. The region was divided into small rectangular blocks, 30 x 30 meters. A circular area with a radius of 2,000 meters was investigated around each block. Blocks that had more than half of their surrounding area as candidate core areas were joined into plots, representing a high-density zone of candidate core areas. In this way, clusters of small candidate core areas were unified into larger plots, and candidate core areas, whether clustered or individually large enough, were provided with a surrounding buffer zone. Isolated small candidate core areas, as well as very narrow ones, were eliminated.
2. Areas with a high density of candidate core areas were overlaid with the result of the fragmentation analysis – with the forest matrix. Thus, we eliminated lands located close to candidate core areas but occupied by clear-cuts, post-fire forests or croplands. We also eliminated smaller candidate core areas located close to each other if divided by significantly transformed land. In this case, candidate core areas would not have ecological connectivity between them.
3. We checked the geometrical shape of the remaining areas and eliminated parts (“appendices”) if less than 1 kilometer wide.
4. The remaining areas with a high density of core areas were classified by size. Areas smaller than 2,000 hectares were eliminated. The rest were called Less Disturbed Forest Tracts (Figure 2).
5. For some of the most threatened forest types, such as Manchurian fir forests, mixed noble hardwood forests, and riparian dark coniferous forests, we used a smaller threshold – 500 hectares. Minimum width criteria were not applied to these areas.

Figure 2. The final map of the Less Disturbed Forest Tracts (in dark green).

3 NATURALLY RARE AND UNIQUE FOREST COMMUNITIES

We used the publication by Krestov and Verkholat (2003) to identify a list of naturally rare communities. However, we excluded several communities, the uniqueness of which is in doubt.

There are also some forest communities that have become rare due to human impact. Examples include forests with Manchurian fir and some types of noble hardwood forests with Korean pine). Some of them are globally rare and/or endemic to the region. However, those forests were not analyzed separately as they make up a part of the category called Less Disturbed Forest Tracts (see previous section).

The naturally rare communities we analyzed can be grouped as follows:

1. Forests with the rare or endemic tree species: forests with Japanese yew (*Taxus cuspidata*); forests with iron birch (*Betula schmidtii*); forests with castor aralia (white nut, *Kalopanax septemlobus*); Japanese red pine forests (beauty pine, *Pinus funebris, Pinus densiflora*); forests with Daimio oak (dentate oak, *Quercus dentata*); Manchurian apricot forests.
2. Forests with the rare or endemic dominant species in undergrowth or grass: mountain dark coniferous forests (Yezo spruce, *Picea jezoensis* and East Siberian fir, *Abies nephrolepis*) with bergenia (*Bergenia pacifica*); mountain dark coniferous forests (Yezo spruce, *Picea jezoensis* and East Siberian fir, *Abies nephrolepis*) with Asian devil's-club (wolfberry, *Oplopanax elatus*); Siberian Cypress communities (*Microbiota decussata*).
3. Forest communities with an unusual combination of species which are not individually rare: dark coniferous (Yezo spruce, *Picea jezoensis* and East Siberian fir, *Abies nephrolepis*) – hornbeam (*Carpinus cordata*) forests; dark coniferous (Yezo spruce, *Picea jezoensis* and East Siberian fir, *Abies nephrolepis*) – dwarf Siberian pine (*Pinus pumila*) forests; coastal larch forests, or larch (*Larix* spp.) – dwarf Siberian pine (*Pinus pumila*) forests; Mongolian oak (*Quercus mongolica*) – dwarf Siberian pine (*Pinus pumila*) forests; Mongolian oak (*Quercus mongolica*) – stone birch (*Betula ermanii*) forests; lime (*Tilia spp.*) – stone birch (*Betula ermanii*) forests.

We selected the communities from the list for which we had sufficient data. Forests with Daimio oak and Manchurian apricot forests from the first group could not be located – neither by the state forest inventory data or by remote sensing methods.

Locating communities from the second group presented similar obstacles – groundcover is poorly reflected in both forest inventory data and remote sensing materials. However, most of these forests are intact highland communities. So, they make up a part of the core areas of the Less Disturbed Forest Tracts (see the previous section). Also, we identified some of these forests while looking for rare and endangered species habitats (see the next section).

To identify other communities (group 3 and the most of group 1), we used the official forest survey data. We filtered the data by present tree species.

Some rare forest ecosystems could have been described inaccurately in the forest survey data. So, we buffered all forest stands (*vydels*) selected from the database by 200 meters to ensure that no part of a rare ecosystem is lost because of possible inaccuracies.

4 KNOWN HABITATS OF RARE AND ENDANGERED PLANT SPECIES

Since the Red Data Book of the Primorsky Kray has not been published yet, we used the Russian Federal Red Data Book as a resource for the list of rare and endangered plant species for our work. From the red-listed species we mapped only forest species. We also examined the remainder of the list and eliminated species, which do not need any special protection measures due to their abundance in the region and/or absence of threats to their typical habitats.

Data on the selected species were gathered from all possible sources, including our own field findings. Thus, we processed about 2000 herbarium samples from different research institutes in Moscow, Saint Petersburg and Vladivostok. Unfortunately, these data are not representative, showing the habitats of rare and endangered forest species, mainly in the places, where most of scientific studies were conducted. However, producing a more representative picture will require an enormous amount of planned and systematic field studies, and therefore might not be feasible.

Known locations of rare and endangered plant species were plotted on the maps. The location of herbarium species is usually described rather approximately – often just down to vicinity of a certain settlement. In such cases we tried to use our expert knowledge about species biology to find the most likely location of the species wherever it was possible.

A buffer zone of 200 meters has been added around the locations of observed rare and endangered species. The area within the buffer zone is regarded as a probable habitat for those species.

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STATE OF ART AND PERSPECTIVES IN REMOTE SENSING METHODS APPLICATIONS IN RUSSIAN FOREST INVENTORY.

R.F. Treifeld[a] and A. S. Alekseev[b]

[a] North-West State Forest Inventory and Management Enterprise, Koli Tomchaka str., 16, Sankt-Petersburg, Russia, e-mail: trf@lesproekt.sp.ru

[b] Sankt-Petersburg State Forest Technical Academy, Russia

ABSTRACT

Since 30-th years of XX century up to now aerial photographs is used in Russian forest inventory. Aerial photographs changes during this period of times from low resolution (10-15 meters) panchromatic pictures to medium resolution (2-5 meters) multi spectral (color) ones. Now multi spectral (color) aerial pictures made in the limits of 380-770 nanometers of visual specter are of main use in forest inventory. Forest area annually covered by aerial photographs depends on needed precision of forest inventory and funding. In the low populated Siberian and Far Eastern regions of Russia mainly used aerial photos of 1:40 000 – 1:70 000 scales with subsequent enlarge of positives up to scales of 1:25 000 – 1:15 000. In Western regions with high intensity of forestry used survey at scales 1:25 000 – 1:40 000 with late enlarging up to 1:10 000 – 1:15 000. Aerial pictures format is of 30x30 or 60x60 centimeters. Aerial photos after interpretation implemented for forest land classification, support of field inventory inspection, forest maps and ortho photo plans development, forest stands measurements, forest land changes detection. Implementation of GIS and computer based techniques in forest management planning, inventory data treatment and forest maps production actualized change traditional, both aerial and satellite photograph methods on digital (scanning) ones, which have obvious advantages. The most serious problem for Russian forest inventory system is selection of rational and cost effective remote sensing methods for development of a new forest inventory technology, which should be applicable, and account for specific features of Russian forests.

Keywords: Aerial photos, satellite images, forest inventory and management, GIS technology.

1 INTRODUCTION

All forests of Russian Federation are objects of functional, “management” forest inventory. No other systems of the inventory of forests (statistical, for example) are in official use yet. The only study of the possibility to set some statistical inventory or monitoring of forest resources has been done in last decades.

The state forest inventory enterprises have the authority to assess the state and leased forests. They follow the regulations set by the Federal Agency of Forestry of Russia. The common system of Russian forest inventory consists of the use of aerial photographs for separating the primary units in combination with ground ocular estimates in all units (varying from 3 to 50 ha). The forest inventory mainly provides estimates of growing stock and mean increment by species per unit. There have been no major changes in the Russian forest inventory system during the past 30-40 years. The last updated set of rules and regulations for the inventory was adopted in December 1994 (Forest inventory instruction).

Since 30-th years of XX century up to now aerial photographs is one of the main sources of information for regular Russian forest inventory. Aerial photographs used changes during this period of times from low resolution (10-15 meters) panchromatic pictures to medium resolution (2-5 meters) multi spectral (color) ones. Now multi spectral (color) aerial pictures made in the limits of 380-770 nanometers of visual specter are of main use in forest inventory. Forest area annually covered by aerial photographs depends on needed precision of forest inventory and funding.

Satellite images of KOSMOS and METEOR systems was used for forest inventory purposes since 70-th of XX century mainly for survey Siberian and Far Eastern forest.

The most serious problem for Russian forest inventory system is selection of rational and cost effective remote sensing methods for development of a new forest inventory technology, which should be applicable, and account for specific features of Russian forests.

2 AERIAL PHOTOGRAPHS IMPLEMENTATION FOR FOREST INVENTORY PURPOSES.

In the low populated Siberian and Far Eastern regions of Russia mainly used aerial photos of 1:40 000 – 1:70 000 scales with subsequent enlarge of positives up to scales of 1:25 000 – 1:15 000. In the Western regions with high intensity of forestry used survey at scales 1:25 000 – 1:40 000 with late enlarging up to 1:10 000 – 1:15 000. Aerial pictures format is usually as much as 30x30 or 60x60 centimeters.

Aerial photos after thematic interpretation implemented for (Sukhikh, *et.al*., 1977; Daniulis, *et.al*., 1989; Dmitriev, *et.al*., 1989):

- Forestland classification and delineation of the basic forest management units (figure 1). Such a units should be homogeneous as much as possible. This kind of aerial photos treatment is of great importance for precision in determination of a number of tree stands parameters such as species composition, age, mean diameter, mean height and growing stock which are basic information for forest management planning

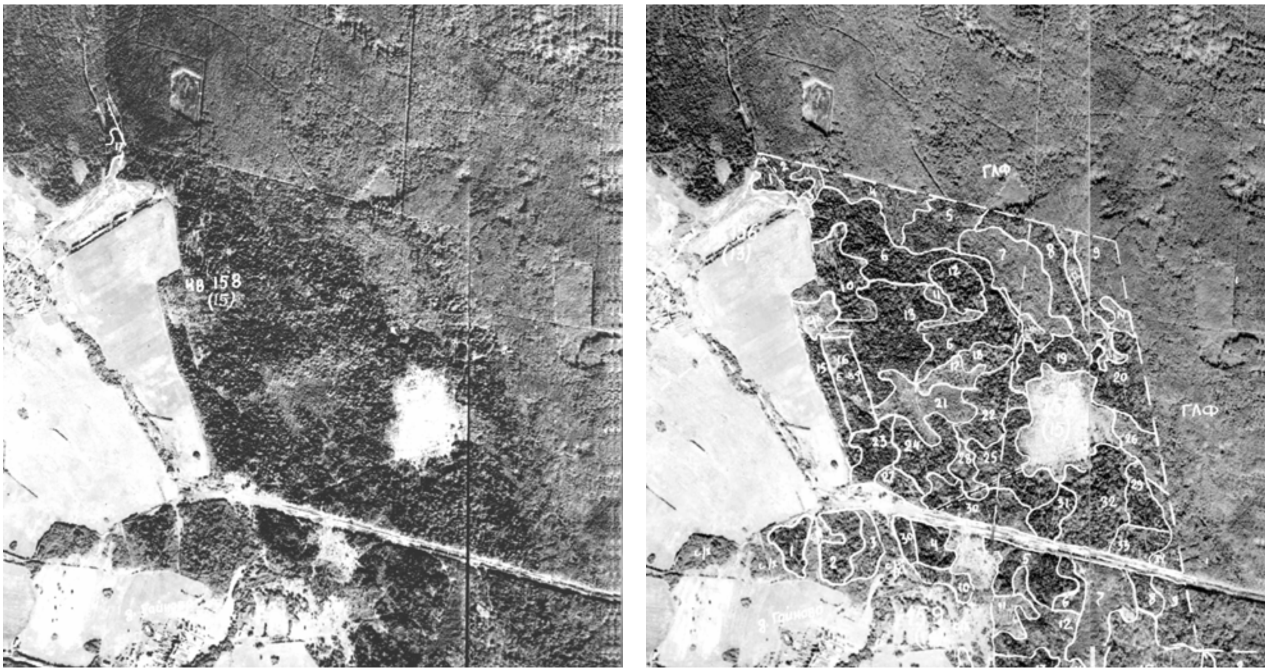

Figure 1. Aerial photos before (left) and after (right) consisting in delineation of the basic forest management units.

- Orientation during field inventory inspection and forest measurements. For this purposes aerial photos used not only by inventory inspectors, but also by forestry staff persons, leasers, harvesters, researchers etc.
- Direct forest stands measurements using stereo effect methods. First of all in such a way may be detected tree stands mean height with the precision of 0.5 m
- Forest lands changes detection on the base of comparison the aerial photos of the same area made in different time
- Ortho photo plans development using photogrammetric and GPS technologies
- Forest map of different kind development. The set of local level forestry maps includes 4 basic cartographic products. Thematic maps can be prepared on the customer's request. The following set of cartographic products is listed in the new rules and regulations for the inventory of Russian forests: basic forestry maps (Planshets, scale 1 : 10 000); forest management unit's maps (Plan lesnichestva, scale 1: 25 000) color-coded according to dominant species (figure 2) and planned forest management activity; maps of the exploitation fund distribution (all mature stands where final harvesting is allowed); thematic maps: such as berry fields and herbs distribution as requested by the customer; technician's area maps; ranger's maps. For the whole forest enterprise the following maps or schemes can be prepared:

dominant tree species distribution; forest protection (territory organization and planned management activity to prevent unmanaged forest fires); rented forest areas; black and white multi-scale and multi-purpose maps and schemes of the forest enterprise on customer's request. For the regional level of aggregation the cartographic method of presenting information is the most significant. It allows decision-making based on the carefully processed and generalized information. The levels of generalization and scales of the cartographic products depend on the problems, which have to be solved. At present no GIS technologies are available for the regional levels of cartographic data analysis and presentation. The manual production of maps is too labour consuming. This is the reason for the limited implementation of the cartographic analysis methods in the management planning and optimization. Small-scale maps are currently used only to demonstrate the planned management activities

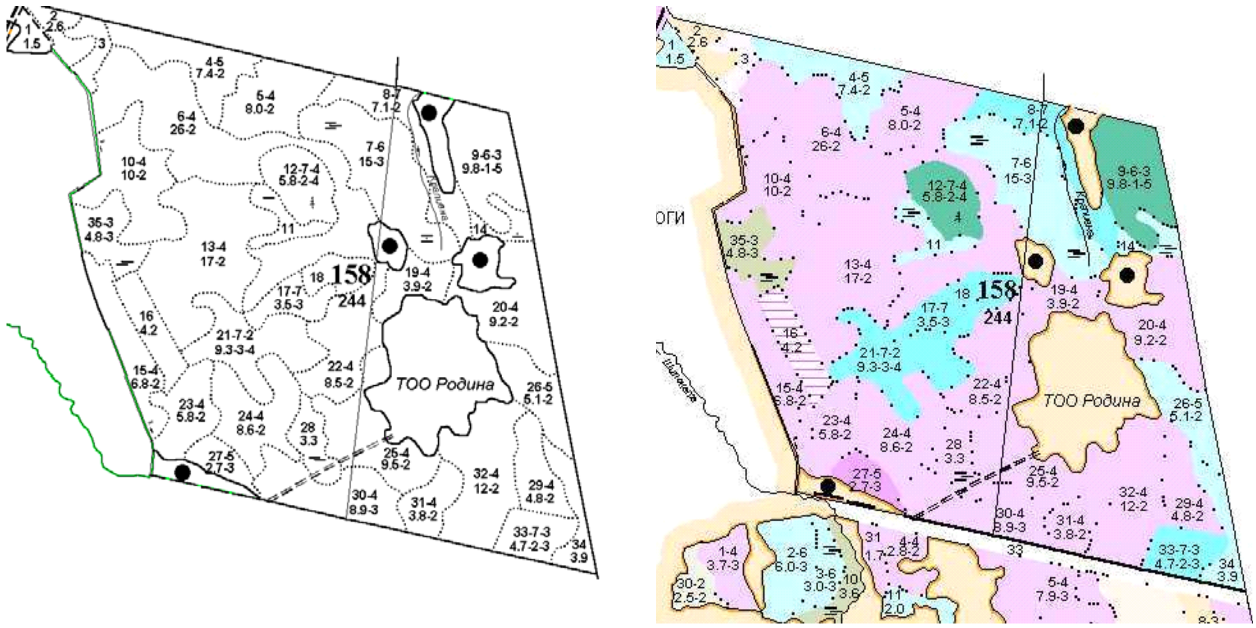

Figure 2. Two main types of forest maps – tablet (planshet) (left) and colored according tree species map of forest stands (right).

Now, after introduction in practice of forest inventory data treatment the GIS and also computer based techniques in forest management planning and forest maps production it is actual to change traditional both aerial or satellite photograph methods on digital (scanning) ones, which have obvious advantages consist in direct obtaining of digital picture leaving stages of picture scanning for raster with following digitizing.

3 SATELLITE IMAGES IMPLEMENTATION FOR FOREST INVENTORY PURPOSES.

Since 70-th of XX century satellite images of KOSMOS and METEOR satellite systems was used for forest survey in Siberia and Far East regions (Sukhikh, *et.al.*, 1979). Usual scale of survey was 1:1 000 000-1:270 000 with subsequent enlarging up to scale of 1: 250 000 – 1:50 000 respectively. Survey was multi spectral with size of the picture 30x30 centimeters.

Satellite images of low resolution (75-250 meters on the natural surface) was used for following purposes:

- Land classification on the landscape and ecological base with determination of forests and its areas
- Forest fire protection and control, pre fire phenomenological observations, revealing of forest fires, calculation of damaged areas
- Forest damage detection from pollution, insects and windstorms. Estimation of damage and control of results of repairing activities

- Reforestation control and control of illegal cuttings (figure 3). Using satellite images the places with intensive harvesting may be detected and subsequent detailed aerial survey allows determining the illegal cuttings and results of reforestation. After these fields inspection may fix detected violations and produce penalties for violators.

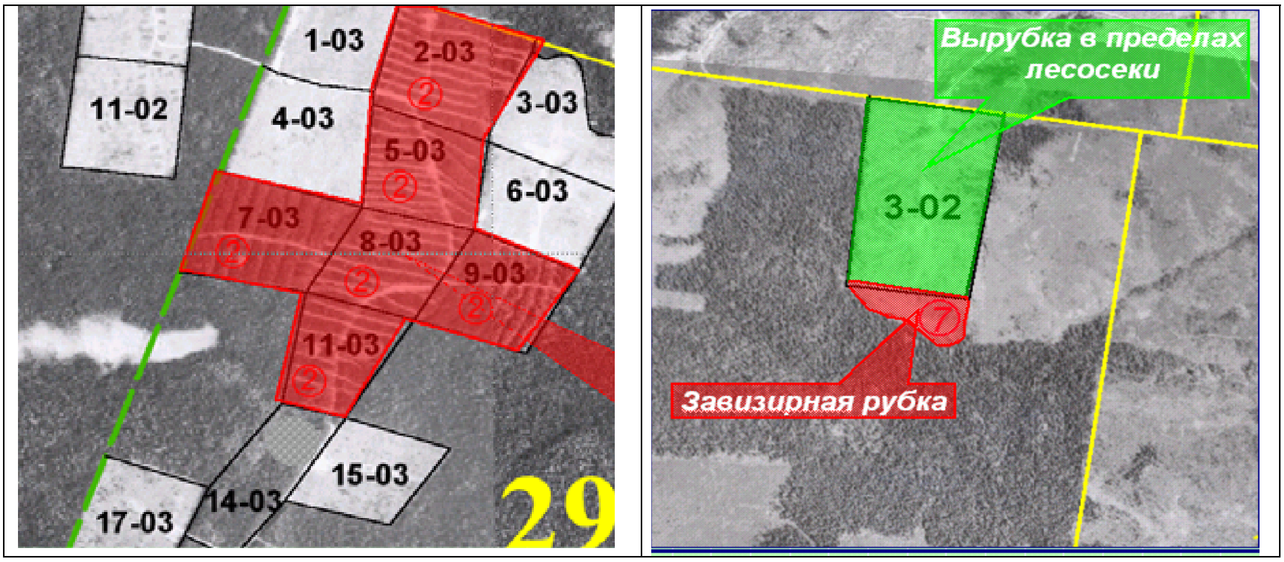

Figure 3. Usual types of illegal cuttings (red color): thinning on adjacent to legal clear cut area (left), clear cutting out of legal area (right).

Satellite images of medium resolution (10-30 meters on natural surface) of satellite systems MK-4, RESURS, LANSAT and SPOT usually used for forest inventory in Siberia, Northern and Far Eastern regions. Results of comparison of precision in determining of tree stand parameters by field inspection; aerial photos and satellite images interpretations are presented in the table 1.

Table 1. Results of comparison of precision in determining of tree stand parameters by field inspection; aerial photos and satellite images interpretations.

Tree stand parameter	Precision of tree stand parameter determination, % of mistaken occasions			
	Relative value of tree stand parameter	Field inspection*	Aerial photos interpretation, spatial resolution 1-3 meters	Satellite image interpretation, spatial resolution 10-30 meters
Group of species, coniferous or broadleaves	5	1	5	15
Species	5	5	15	30
Age	5	12	20	30
Mean height	30	10	18	25
Mean diameter	10	12	20	40
Tree stand density	25	10	15	25
Growing stock	15	17	30	40
Forest type	5	5	20	50
Precision index = parameter relative value*precision of determination	100	10.4	18.7	30.0

* Precision of field inspection according to now acting Forest inventory instruction is the lower limit for forest inventory of the areas with intensive forestry and forest industry

The data of table 1 shows that remote sensing methods of forest inventory such as aerial photos and moreover satellite images interpretations can't be used for inventory of the areas with intensive forestry and forest industry. Intensive forestry and forest industry take a place on all area of Europe – Ural part of Russia and on dense populated and industrially developed areas of Siberia and Far Eastern regions. Total area of the forest fund of these regions estimated as much as 350-500 millions of hectares.

It seems to be perspective to the future use for forest inventory purposes satellite images of high spatial resolution of such a systems as EROS, IKONOS and QUICKBIRD. Already now are accessible the satellite images with spatial resolution of 1 meter and less in panchromatic and 2-3 meters in multi spectral diapasons but they are now expensive and can't compete yet with traditional remote sensing data sources. The firm Digital Global conducting the project QUICKBIRD planned for the year 2006 to launch the commercial satellite WORLDVIEW of new generation with more advanced characteristics.

The most serious problem for Russian forest inventory system is now selection, using all accumulated experience both national and international, of rational and cost effective remote sensing methods for development of the new forest inventory technology which should be applicable and account for specific features of Russian forests. To solve this problem it is necessary to accumulate the experience in dealing with satellite images of high resolution, determine the informative effectiveness of these survey from point of view of forest inventory and determine the possibilities for replacement of aerial photos on satellite images of new generation from economics point of view and point of view of raising demand on precise forest inventory data.

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STATUS CONTROL AND MONITORING OF THE MOSCOW REGION FOREST RESERVES: APPLICATION OF HIGH RESOLUTION SPACE IMAGES

Alexander A. Maslov.[a, b]

[a] Inst. of Forest Science RAS, Uspenskoe, Moscow region, 143030 Russia; e-mail: am@pyrola.msk.ru
[b] ScanEx R&D Center, Lva Tolstogo 22/5, Moscow, 119021 Russia; http://www.scanex.ru

ABSTRACT

Application of high-resolution space images (IRS LISS/PAN) is shown to be very useful tool in status control and monitoring of strict forest reserves in the Moscow region. Having no official guards these high conservation value forests suffer from status violations and disturbance such as logging in buffer zones, illegal logging, recreation, forest fires, pest outbreaks. The most important advantages of high-resolution space images in status control of forest protected areas were found to be follows: independent control, large area coverage, non-secret data, and reasonable revisit period.

Keywords: Russia, protected areas, dynamics, logging, bark beetle outbreak.

RESULTS

The net of the federal strictly protected areas – forest reserves – was established in the centre of the Russian plain (Moscow region) in 1979–1981. Recently the net comprises 73 reserves with the total area of ca. 28,000 ha. Each forest reserve represents high conservation value natural forest with old-growth typical forest communities and (often) occurrences of Red data list species (Maslov, 2000).

Many of forest reserves are quite small (300–400 ha) and surrounded by fields and managed forests that cause problems of status control (clear-cuts in buffer zone, illegal logging, recreation, power and pipe line construction, etc.). There are no guards responsible for the area, and all types of control are provided mostly by scientific researches and environmental NGOs. It was impossible to take care carefully over so large total area during the last drastic decades in Russia having very few people for that.

Use of the high-resolution space images provides us with such essential monitoring tool and let us control all-over protected area yearly or even more often. In Russia it is a really new tool after the long years when all space images were secret and not available. (All types of aerial photographs are still secret and not available). The use of space images for status control and monitoring of forest reserves in the Moscow region started from year 2004. For retrospective analysis we used ScanEx R&D Center archive of images (mainly Landsat), for recent analysis – images from ScanEx Moscow center for remote sensing data acquisition (www.scanex.ru).

IRS-1C and IRS-1D satellite images (LISS camera with spatial resolution 23 m) were found to be the most useful for detection of status violations and monitoring of natural disturbance regimes. Fig. 1 presents typical situation in small (367 ha) strict forest reserve in the eastern part of the Moscow region. The core area of reserve is surrounded by clearcuts of different age. Many of clearcuts in buffer zone adjoin the border of strictly protected area, and logging process must be controlled during operations in order to prevent violations. Some forest stands in buffer zone were heavy damaged by forest fire during the extremal drought in 2002.

High-resolution space images were also used for monitoring of natural gap dynamics as a result of catastrophic and multiple treefalls. In order to increase spatial resolution IRS-1C and IRS-1D LISS multispectral images (spatial resolution 23 m) were merged with PAN (panchromatic) images (spatial resolution 5.8 m). All types of data management (geometric correction, creation of mosaics, image fusion) were made using Scanex Image Processor® software.

From the year 1999 foresters, scientists, and nature conservation manages of the Moscow region are faced with a new problem of drastic bark-beetle (*Ips typographus*) outbreak in old-growth Norway spruce forests. Most of damaged forests are protected areas of different status including strict forest reserves. The use of clearcut "salvage" logging in such areas is widely discussed and still is a "topic of the day". It is well known that salvage loggings against bark-beetle could be effective only if they are provided in short period when trees are infested. The problem is that most of so called “salvage” loggings in the Moscow region are designated in 1–2 years after bark beetle attack and couldn’t prevent beetle dispersion. The forest companies pretend bark beetle outbreak as a reason for loggings in protected areas. The use of high resolution space images as a matter of fact is the only way for independent dating and assessment of damaged areas for official permissions to do» extraordinary salvage logging” and control position of logging sites (*Earth images from space…* 2005). Examples of damaged protected and managed oldgrowth Norway spruce forests with some salvage clearcuts are shown on Fig. 2.

The most important advantages of high-resolution space images in status control of forest protected areas were found to be follows: independent control, large area coverage, non-secret data, and reasonable revisit period.

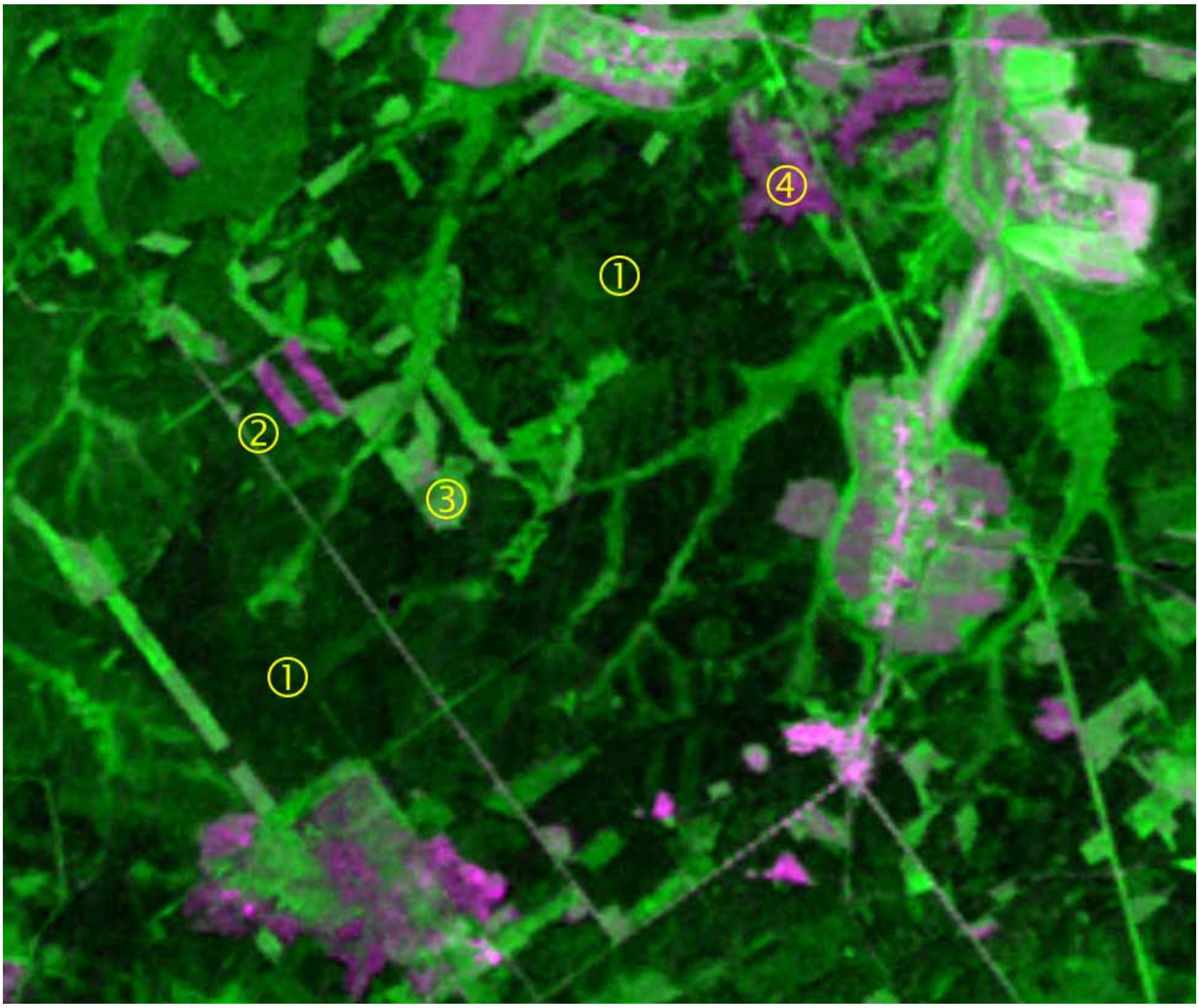

Figure 1. Monitoring of logging and burnt areas in strict forest reserves and their buffer zones: case study from Pavlovskiy Posad district, the Moscow region. ① – intact area of strict forest reserve, ② – recent cleacuts in buffer zone, ③ – old clearcuts (1990–2000) in buffer zone, ④ – burnt area after the forest fire in year 2002. IRS–1C/1D satellite, LISS-3 camera, spatial resolution 23 m. Date of acquiring: 22.07.2003. © ANTRIX, Space Imaging Inc., R&D Center ScanEx, 2002.

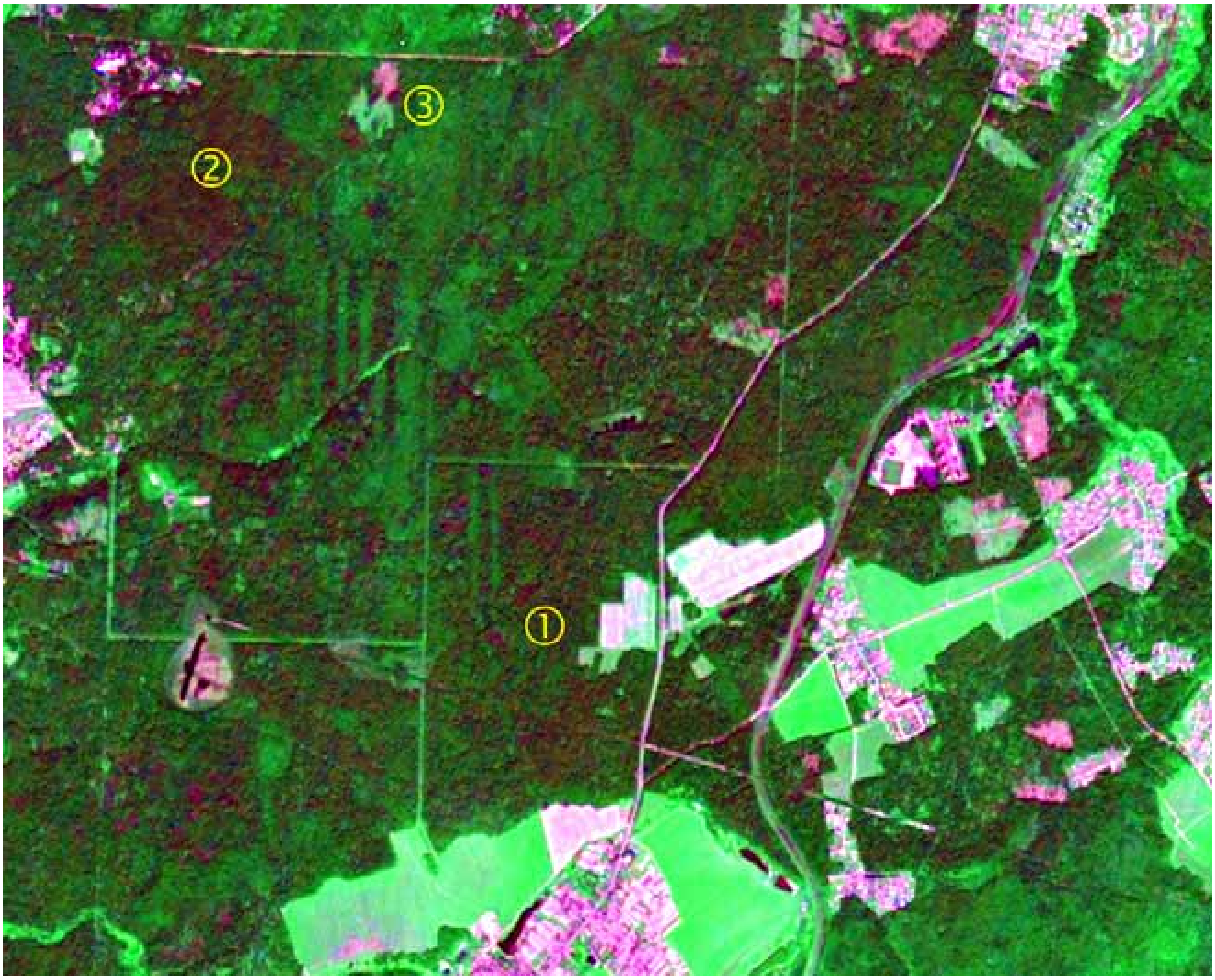

Figure 2. Assessment of bark-beetle (*Ips typographus*) damage to spruce forests in the Moscow region during 4 years outbreak (1999–2002). ① – moderately damaged forests, ② – severe damaged forest, ③ – “salvage” clearcuts. IRS–1C/1D satellite, LISS-3 camera, spatial resolution 23 m. Date of acquiring: 26.05.2002. © ANTRIX, Space Imaging Inc., R&D Center ScanEx, 2002.

ACKNOWLEDGMENTS

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A NEW FOREST COMPOSITION MAP OF RUSSIA

Dr. Alexey Yaroshenko

Greenpeace Russia and Global Forest Watch
forest@rol.ru
On behalf of the team of authors: Bartalev, S.A (1)., Ershov, D.V. (2), Isaev, A.S. (2,3), Potapov, P.V. (3,4), Turubanova, S (3,4), Yaroshenko, A.Yu. (3,4)

1. Space Research Institute of the Russian Academy of Sciences (RAN)
2. Forest Ecology and Production Center of the Russian Academy of Sciences (RAN)
3. Global Forest Watch
4. Greenpeace Russia

ABSTRACT

Greenpeace Russia, Institute of Space Research RAS, Centre for Ecological Problems and Productivity of Forests RAS and Global Forest Watch have prepared a unique map called "Forest Landscapes of Russia". This is the first post-USSR map that presents the state of forest resources in Russia. The map shows clearly that the common image of Russia as a country with immense forest resources is too exaggerated.

No country in the world is able to organize effective use and protection of their forests without detailed information about the state of forest landscapes. The previous map ("Forest landscapes of the USSR") was issued in 1990, but was based on old materials of varying age and represented the situation 25-30 years earlier.

The new analysis has combined four existing maps to provide a current and detailed picture.

Forests are defined as areas with at least 10% tree cover, according to the Global Percent Tree Cover map (Reference 2). Areas with 10% to 39% are considered open canopy forests, while closed canopy forests have greater than 40% tree cover. Dominating species and species groups are shown according to map of the forests of the USSR (Reference 3), published in 1990, except for in those places where a comparison with the land cover map of Northern Eurasia (Reference 1), published in 2003, indicates that the species composition has changed. Areas where deciduous or mixed forest has replaced coniferous forest are categorized as “birch/aspen and mixed forest”. Areas with other types of species change (rare in comparison with the previous case) are classified based on expert interpretation of the two compared maps (References 1 and 3).

Areas of potential forest growth, consisting mainly of agricultural and other non-forest managed ecosystems, are shown according to the map “Vegetation of the USSR” (Reference 4). The boundaries of this category are uncertain and determined to a large extent by expert opinion.

First of all, the new map demonstrates that most valuable in the industry coniferous forests have been preserved only in sparsely populated and difficult to access regions of the European North and Siberia. In the most fertile forest areas, spruce and pine have been replaced by second growth of birch and aspen forests, which are less attractive to the forest industry. At present the territory with deciduous second growth amounts to 31% of the total forest area in Russia.

The main reason for this mass degradation of forest capital is the extensive and poorly implemented forest management that prevailed in Russia in the last century. This includes large-scale clear cutting, low-quality reforestation work and insufficient tending of saplings.

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Closing Session

GMES SERVICE ELEMENT FOREST MONITORING: ACHIEVEMENTS AND FUTURE DEVELOPMENTS FOR FOREST MANAGEMENT AND UNFCCC/ KYOTO PROTOCOL REPORTING

T. Haeusler[a] , R. Fockelmann[b] , J. Van Brusselen[c],
[a,b] GAF AG, Arnulfstr 197, D-80364 Munich, Germany
[c] European Forest Institute, Torikatu 34, 80100 Joensuu, Finland
[a] email: haeusler@gaf.de; [b] fockelmann@gaf.de, [c] jo.vanbrusselen@efi.fi;

ABSTRACT

The Global Monitoring for Environmental and Security (GMES) initiative is a joint European Space Agency/European Union programme which has as its main aim to improve the monitoring of the European and global environment for sustainable management of resources. The first stage (2003-2004) of the GMES Service Element for Forest Monitoring (GSE FM) focused on analysing information needs of environmental policies (such as the United Nations Framework Convention on Climate Change-UNFCCC), reviewed existing infrastructural systems and data sources in order to develop forest monitoring services such as yearly carbon balance information, forest disturbance data, as well as products for practical forest and land use management. These services were well assessed in terms of utility and quality by the users; thus the main achievements of this stage were a marked improvement in forest management techniques and an improved ability for agencies to fulfil reporting obligations for UNFCCC and other national policies. Non-EU countries such as Russia and countries in the southern African region were also introduced to GSE FM and preliminary activities undertaken to develop frameworks for service delivery. The success of the first stage has led to the current consideration of the further development of GSE FM into an implementation stage which has the aim of operationalising the services over the next three years in a sustainable and viable manner with continued user engagement to include an expanded user community and geographical area.

Keywords: Forest Monitoring, Policy Relevant Services, User Involvement.

1 INTRODUCTION

The Global Monitoring for Environmental and Security (GMES) initiative is a joint initiative of the European Space Agency (ESA) and European Union (EU), providing a response to dynamic and growing global information needs. The main vision and goal of both ESA and the EU for the GMES programme is to establish a European capacity for the provision of operational information services for global monitoring of environment and security. Concurrent to this first major ESA/EU Earth Observation (EO) programme the first international EO Summit was held in Washington DC in 2003 which “affirmed the need for timely, quality, long-term, global information as a basis for sound decision making, and recognized the need to support a comprehensive, co-ordinated sustained EO system and, finally, established an ad-hoc Group on EO (GEO) to develop a 10 year Implementation Plan”. The GEO programme is comprised of both developed and developing countries and is being championed at a politically high level by Heads of States and governments (GMES, Vancouver, 2004). As the main objectives of the GMES fit in with the vision of GEO, it is ESA’s and the EU’s main contribution to GEO.

The GMES Service Elements (GSE’s) are one element of the ESA Earthwatch Programme, which includes the next generation of ESA EO operational missions, and which will also contribute to GMES; the main aim of the GSE’s is to deliver policy-relevant, operational information services, primarily (but not exclusively) derived from EO. Stage 1 of the GSE Programme was considered the consolidation stage, which focused on consolidating, aggregating and improving existing pre-cursor services in order to make them sustainable within a reasonable timeframe.

In addition to acknowledging the need for (monitoring) services, GMES also identified thematic priorities for service development in Stage 1, one of which being GSE Forest Monitoring (GSE FM). ESA contracted an international Consortium led by GAF-AG to consolidate the GMES Service Element GSE FM for this latter stage. Through a Service Portfolio of validated products and services, GSE FM supplied users with accurate, reliable, timely and effective information on the state of global forest systems in order to support decision-making and improved policies that enable sustainable forest management; compliance with specific protocols and binding conventions; and related user and/or policy-driven activities. The information provided by the monitoring service was delivered as standardised spatially referenced, quality products e.g. maps, that are cost effective, readily accessible and transparent to users, thereby promoting key applications and good governance within the forestry sector with sustainability as a paramount consideration.

The aim of this paper is to provide an overview of GSE FM, the key achievements from Stage 1 and the future developments anticipated, which will form the main contributions towards sustainability. The next section will provide an outline of the policy sectors and related service packages that the GSE FM initially dealt with in the consolidation stage. The Second Section will then present the main achievements of this stage that led to improved future prospects. The Third Section will highlight the future developments anticipated for the further expansion of GSE FM and finally the paper will conclude with some strategic comments.

2 MAIN POLICY SECTORS AND RELATED GSE FM SERVICES

The GSE FM's main objectives during Stage 1 focused on consolidating European industrial and scientific know-how for developing global operational forest monitoring services that could deliver information. The policy processes that drove the development of the GSE FM services were:

- United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP)
- European Union Forest Focus Regulation
- United Nations Forum on Forests
- Ministerial Conference on the Protection of Forests in Europe (MCPFE)
- United Nations Convention on Biological Diversity (UNCBD)
- United Nations Convention on Combating Desertification (UNCCD)
- Forest Law Enforcement, Governance and Trade processes (FLEGT)

The service portfolio offered both information services designed to help enforce policy objectives as well as practical forest management information. At the beginning of the project, the main emphasis was put on user segments within EU-countries that included:

- Governmental bodies responsible for reporting under UNFCCC and KP
- Project developers for Clean Development Mechanisms in the forestry sector
- National and sub-national forest administrations
- Governmental bodies responsible for environmental policy and nature protection

It was however also considered important to assess the requirements of non-ESA member countries and in this context Russia, Poland and countries in the southern African region were introduced to GSE FM and a series of preliminary activities were undertaken in these countries in order to develop the institutional and technical frameworks for establishing the GSE FM programme. It should be noted that the GSE FM received endorsement and support for implementation in southern Africa from the New Partnership for Africa's Development (NEPAD), which provides the framework for development programmes on the continent. Information from these user communities and high-level political support formed an important basis from which the development of a demand-driven service portfolio and supply chains was performed in order to implement a pilot phase for South Africa and Poland.

The GSE FM Stage 1 analysed forest and environmental policies for information needs, contacted stakeholders and reviewed the current data collection infrastructure networks and sources of in-situ data, models and other necessary precursor data. Based on these policy driven user needs a Service Portfolio was constructed outlining the services and products, as well as the production, quality control and verification processes. GSE FM is thus capable of offering a range of products and user oriented services that stretch from highly accurate yearly carbon balance estimates and the compilation of forest disturbance data such as forest fires and windthrow but also for example information products for practical forest and land use management operations. In brief, GSE FM offered the following services addressing specific policy areas including:

<u>Forest Monitoring for Climatic Change</u>

- Forest Monitoring Inputs for National Greenhouse Gas (GHG) Reporting
- Forest Monitoring Inputs for CDM Projects

<u>Forest Monitoring for Sustainable Forest Management</u>

- Sub-National Forest Information Updates
- Clear Cut Mapping and Monitoring Service

<u>Forest Monitoring for Environmental Issues & Nature Protection</u>

- Land Cover & Forest Indicators

The services were based on combinations of products including: land use and land use change maps; land cover and land cover change maps; forest cover and forest cover change maps; clear cut/disturbance maps and related databases; stand-type maps that support sub-national forest Geographic Information Systems (GIS); forest fragmentation and structural diversity maps; stem volumes, biomass and carbon statistics and corresponding change data, as well as user-customised versions and/or combinations of the above.

The GSE FM Service Portfolio was designed to include quality control and verification processes. The complex issue of standards (for example for the production, quality control, verification and documentation processes) was also addressed in the service production and delivery chain and was central to the sustainability of GSE FM services. These factors assisted in obtaining viable results and the assessment of these results and achievements will be presented in the next Section.

3 MAIN ACHIEVEMENTS OF GSE FM STAGE 1

The key achievements of the first stage of the GSE FM are divided into 4 main areas, which relate to the user assessments of the Service Portfolio, the value of the services provided, a cost-benefit analysis, and the development of an effective service supply chain. The respective achievements for each of these categories is summarised as follows:

User Assessment

The services were delivered to 9 users in 7 countries with a total geographic coverage of 1.01million km^2. Additionally, there was a preparatory assistance to users in 6 countries which included countries in the southern African region. Even with quite modest promotion and incrementally growing (user) awareness, a significant number of parties including national-level users and service providers have stepped forward and expressed an interest in joining the GSE FM partnership under the implementation phase. Thus, the GSE FM identified new committed users both in Europe and in Africa and thereby also demonstrated the potential for increased geographic coverage which is a key indicator of the sustainability and viability of the GSE FM.

Value of Services

A Service Appraisal was undertaken as an independent assessment by users and was intended to cover the next few years. The users were requested to assess various criteria such as: credibility; competitive value; overall utility; availability of Earth Observation (EO) data; availability of value-added info; reliability and access conditions; competitive value; expansion of services; and financing of services. These criteria were all well evaluated for the current services and projected evaluation of these criteria was foreseen as very good into the next decade (see Figure 1).

Two issues pulled the overall evaluation downward. These were the appraisal of: ‘access conditions’ and ‘availability of EO’ data. The core-end-users’ concerns about ‘access conditions’ mainly relate to financing of the services and to technical access to services. These issues are foreseen to improve in the nearby future, influenced on the one hand by EO infrastructural developments and on the other hand by on-going processes aiming at increasing data transparency and availability of both traditional forestry data (e.g. Collaborative Partnership on Forests; Global Forest Information Service) and of geographical information including Earth Observation information (e.g. INSPIRE (Europe's infrastructure for spatial information)).

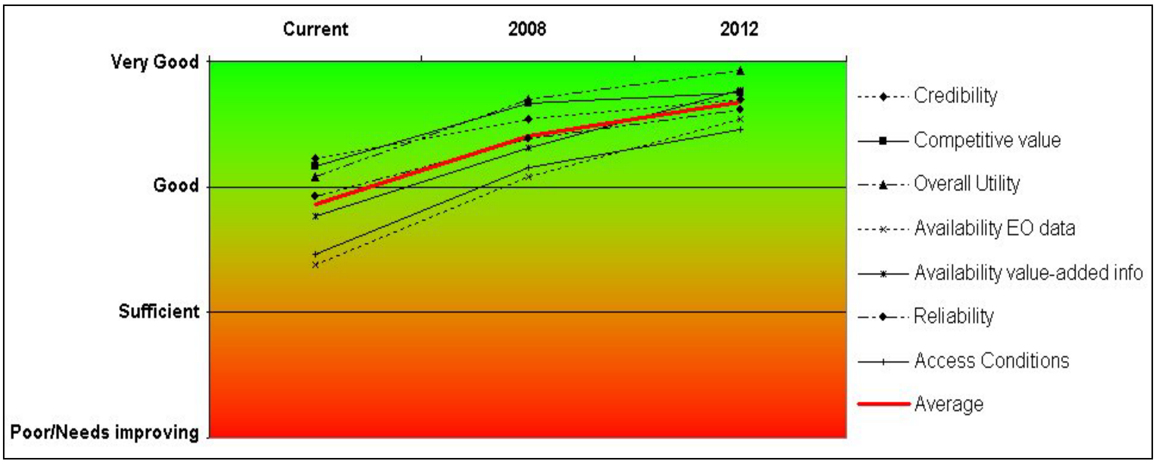

Figure 1. Summary results from Stage 1 of independent service assessment by users including the service prospectus for next 2 years, 2-5 years and 5-10 years

This user assessment demonstrated how routine reporting commitments within the forest sector can be more readily and cost effectively fulfilled at various administrative levels and geographic scales. Thus, all stakeholders including those in the non-EU countries have indicated confidence that GSE FM will fulfill its objectives for improved implementation of environmental policies and conventions (regionally and internationally) and furthermore will support the next stage of the programme.

Cost-Benefit Analysis

A Cost Benefit Analysis (CBA) for the services/products showed a net present value (NPV) of Euro 570 million in the next 20 years. For example, the average annual cost saving attained using GSE FM services as inputs for National Greenhouse Gas (GHG) reporting was noted to be an estimated Euro 13.1 per km2 and for Mapping and Monitoring Disturbances to be an estimated Euro 5.5 per km2. The additional non-quantified benefits were noted to be improved policy planning and management for various key environmental policies.

Effective Service Supply Chain

An effective Portfolio Supply Chain was developed which comprised 5 main elements: the products/service packages of known and validated quality with clear policy relevance; vertically organised value chains delivering products and services to users; pre-qualified service providers delivering services in a timely and cost effective manner; support to the supply chain by multiple service providers to complement competencies and to ensure back-up systems; and finally the use of a Global User and Open Service Partnership (OSP) network with distributed regional competences and a global presence.

These achievements highlight the main successes of the consolidation stage for GSE FM and reflect the improved information available to decision makers for forest management and environmental policy implementation; these factors also provide the basic fundamentals for a successful next stage.

4 FUTURE DEVELOPMENT FOR GSE FM

Due to the successful consolidation stage and achievements as described in Section 2, The GSE FM Service Network prepared a work plan for the implementation Stage 2 which is currently being reviewed by ESA. The main aim of Stage 2 is to operationalise the services in a sustainable and viable manner with further user engagement. The expanded user community that is committed for implementing the services in Stage 2 and the geographical scope is illustrated in Figure 2.

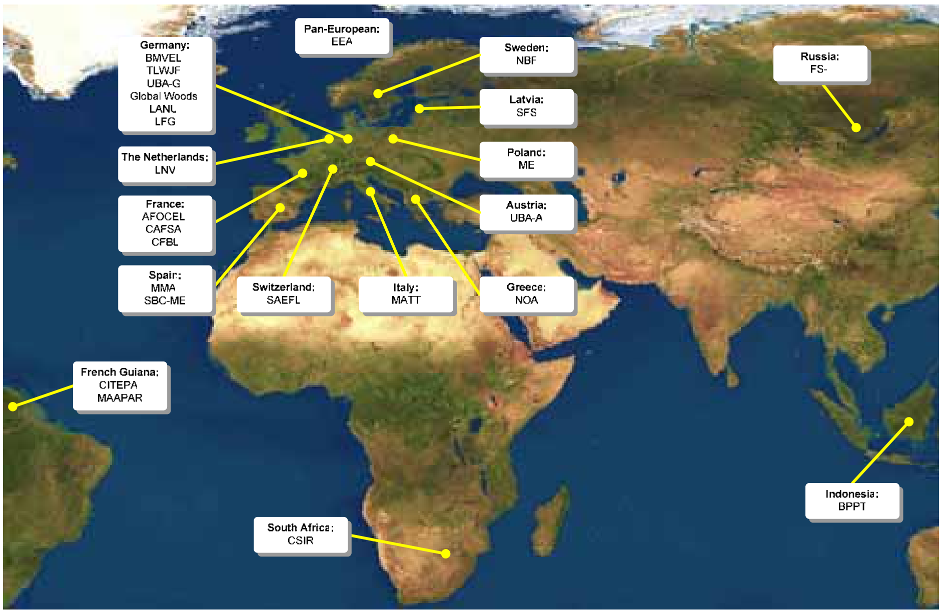

Figure 2. Expanded User Community ready to receive GSE Forest Monitoring Services in Stage2 (see list of user organisations in Appendix A

This stage would be the opportunity for GMES to fulfill its overall policy and vision. The policy sectors that the expanded phase will focus on include all those that were targeted in Stage 1; that is 'climate change, biodiversity and sustainable forest management'. It should be noted that the Kyoto Protocol has now entered into force, which means that for the signatory countries, the formalities of fulfilling the requirements are more legally binding, with punitive fines for non-compliance with the agreed emission limitations. For this reason there will be continued emphasis on services related to the Kyoto Protocol reporting in GSE FM Stage 2. Finally, there is a special effort in Stage 2 to provide a Pan European Case which will address the needs expressed by the European Environmental Agency (EEA) in terms of monitoring sustainable forest management (SFM).

The next stage will be implemented over a period from June 2005 to 2007. This stage has as its overall objectives to:

- Demonstrate progress towards long-term sustainability for a set of GMES services.
- Deliver services and benefits to users on progressively larger scales.
- Establish a durable, open, distributed GMES Service Provision Network.
- Establish standards and working practices for GMES Services.

These objectives will be achieved with an effective service network co-ordination/management of the expanded user community (to include an expanded geographical coverage) and new service providers. There will be a continuation of the Service Provision and Qualification process which will focus on services from the Service Portfolio to users in an operational and fully compliant manner so as to fulfill user requirements, thereby establishing the Service Network as a reliable, accessible and cost effective source of essential information, but also with a service qualification and validation process to ensure the delivery of services of a verifiable quality and standards together with independent validation. Finally, the evolution of the service portfolio will be based on the contribution of Research and Development (R&D) to the development of the GSE FM. This will include the identification, testing, transferring and integrating into the Service Portfolio of mature results of R&D from research partners and wider R&D domains. Therefore, R&D has an important role in improving operational efficiencies and contributing to the evolution of the Service Portfolio to better meet user requirements.

Several new and innovative approaches towards streamlining the process and improving data access to users have already been constructed for testing in Stage 2; for example a cost reduction for EO data that has already been offered by SPOT, EUROMAP and European Space Imaging for all GSE's will also assist in the feasibility of increasing the geographical coverage that is expected.

The main anticipated achievements for the implementation stage are:

- innovative and new programmes designed to improve a common access to EO and related data for policy implementation;
- improved information flow as a result of implementing operational systems which are a combining EO and in-situ data for the government agencies especially national and regional Forest Services;
- multiple applications of the product families from GSE FM (such as land use/cover maps as well as forest type maps) for both forest-related planning as well as general land use planning;
- inclusion of the user community in the design of technical programmes such that these programmes are incorporated into current working systems and practices in the public sector;
- involvement of private sector as major stakeholders in the GSE programmes which hitherto has not been an area of emphasis.

5 CONCLUSION

GSE FM has made major strides in the new ESA/EU programme with investigating the various institutional and infrastructural as well as technical needs for supplying services on a sustainable basis to users and getting the user community involved in the service provision process. The public sector agencies in the forest and environment related services of both EU and non-EU countries do not have much experience in being actively engaged in this type of programme and processes and therefore the consolidation stage uncovered new technical and processing issues for the service providers to manage effectively. These findings will have to be incorporated into the implementation stage for improved service delivery. The success of the GSE FM programme hinges on various factors such as the effective and transparent management systems, the inclusion of partners in the various stages of programme development (that is the service network), and having a quality assurance programme that involves the user or client. Close cooperation with existing in-situ data collection networks is important for cost-efficient application of existing resources. Increased transparency and establishment or further development of interface mechanisms with such precursor data providers is desirable. It is anticipated that these factors will continue to be the main strengths of the programme which will facilitate in the improved services especially for forest management and UNFCCC/KP reporting in the future.

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APPENDIX A PLANNED USER NETWORK FOR STAGE 2

Committed End-users for GSE FM Stage 2, grouped according to policy related services

PAN European Forest Monitoring Service	
Europe	European Environment Agency; EEA
Support to National UNFCCC and Kyoto Protocol Reporting on LULUCF Activities	
Germany	Ministry of Consumer Protection, Food and Agriculture (BMVEL)
Greece	National Observatory of Athens (NOA)
France, French Guiana	Centre Interprofessionel Technique d'Etudes de la Pollution Atmosphérique (CITEPA) Ministry of Agriculture, Food, Fishery and Rural Affairs (MAAPAR)
Italy	Ministry of Environment and Territory Protection (MATT)
Indonesia	BADAN PENGKAJIAN dan PENERAPAN TEKNOLOGI (BPPT)
Switzerland	Swiss Agency for Environment, Forests and Landscape (SAEFL)
Spain	Ministrio de Medio Ambiente (MMA)
The Netherlands	National Reference Centre for Agriculture, Nature and Food Quality (LNV)
Poland	Ministry of Environment of Poland (ME)
Republic of South Africa	Council for Scientific and Industrial Research; Institute for Environmental Technologies (CSIR-ENV)
Forest Information Up-date at National and Sub-national Scales	
Germany	Thuringian State Institute for Forest, Game and Fishery (TLWJF)
Germany	Landesamt für Forsten und Großschutzgebiete in Mecklenburg-Vorpommern (LFG)
Supporting to Environmental Monitoring at National and Sub-national Scales	
Austria	Federal Environmental Agency Ltd. (UBA-A)
Germany	Umwelt Bundesamt; Federal Environmental Agency (UBA-G)
Germany	Landesamt für Natur und Umwelt Schleswig Holstein (LANU)
Italy	Ministry for the Environment and Territory (MATT)
Spain	Ministry of Environment, State Biodiversity Office (SBO-ME)
Detection and Post-monitoring of Natural and Human induced Forest Disturbances	
Sweden	National Board of Forestry (NBF)
Latvia	State Forest Service (SFS)
France	Association Forêt Cellulose (AFOCEL)
France	Coopèrative Agricole et Forestière Sud Atlantique (CAFSA)
France	Coopèrative Forestière Bourgogne Limousin (CFBL)
Russia	Forest Service of Irkutsk (FS-I)
Service Supporting Management and Reporting Obligations of LULUCF CDM Projects	
Germany	Global Woods AG

Poster contributions
Large area mapping and monitoring

EUCALYPTUS HEALTH MONITORING SYSTEM BASED ON REMOTE SENSING AND GIS FOR PLANTATIONS AFFECTED BY WEEVIL OUTBREAKS IN GALICIA (NORTHWEST SPAIN)

M. F. Álvarez[a], H. Lorenzo[b], J. Picos[b] and E. Valero[b]

[a] EST. Ingeniería de Minas. Universidad de León, Avd. Astorga s/n 24400 - Ponferrada, León. (Spain), email: flor.alvarez@unileon.es

[b] EUET. Forestal. Universidade de Vigo, Campus A Xunqueira, s/n 36005 - Pontevedra (Spain)

ABSTRACT

In Spain there are more than 500,000 ha of Eucalyptus plantations. These represent 3,5% of the national forest and the 25% of the timber harvested. Galicia monocultures of *Eucalyptus globulus* Labill. plantations cover 177.679 ha, and mixed stands of eucalyptus cover 200.000 ha more. This high productivity has been powered by the absence of pests and pathogens. However, since 1991 the health and productivity of these stands has been threatened by the Eucalyptus snout beetle (*Gonipterus scutellatus* Gyll.), which causes a severe defoliation to eucalyptus stands in Galicia. The aim of this study is to propose and describe an objective, accurate, timely and efficient Eucalyptus Health Monitoring System for plantations affected by weevil outbreaks in Galicia by means of remote sensing techniques and a geographic information system.The main goal is locating the areas where pest outbreaks affect health status and productivity in *Eucalyptus globulus* in Galicia. In those areas a more intensive health assessment/monitoring survey should be considered. The interest is focused on detecting those areas where damages caused by defoliation are severe enough to not to be compensated by the high growth rates in these plantations or where the growth rates are slowed down. Thus, the areas identified by the proposed model are suggested areas to monitor by field survey, as part of a multistage or multiphase sampling. Hence, field work is led to those stands with a high likelihood of being infested, increasing sampling efficiency and decreasing sampling pressure, which results in lower costs.

Keywords: remote sensing, GIS, process-based model, defoliation, *Eucalyptus globulus*, forest health

1 INTRODUCTION

In Spain *Eucalyptus* plantations cover 500,000 ha and considering its extent and the utility of its wood, *Eucalyptus globulus* has become the most important species. *Eucalyptus globulus* location is mainly limited to the North and Northwest (Galicia, Asturias, Cantabria) and to some areas in the Southwest due to its climatic requirements (González-Río *et al*., 2004): humid climates, without frost periods, and with an uniformly distributed annual precipitation over 700 mm. These plantations comprise the 25% of the total harvested wood each year in Spain (77% if only leaf broad trees are considered (MMA, 2004)). According to the 3rd National Forest Inventory (1997-2006) in Galicia there are 429,000 ha of mixed stands where *E. globulus* is the primary species and 178,000 ha of pure *E. globulus* stands (12% of the total forest area) (MMA, 2004). Furthermore, *Eucalyptus globulus* plantations are the most productive forest stands in Spain. While the mean annual increment in the productive forests in the Iberian Peninsula is 2.5 m^3/ha·year, the mean for eucalyptus plantations is around 7.5 m^3/ha·year (Toval, 2002).

Regarding stocks (around 23 million m^3 in pure stands according to the 3rd National Forest Inventory) and extension, Galicia is the most representative area for Eucalyptus plantations in Spain. Concerning wood production, *E. globulus* reaches an annual increment of 3 million m^3/year, which means nearly the 28% of the total in Galicia. The yield is also higher for eucalyptus than for the other species, achieving average values of 13-17 m^3/ha·year, and is possible to reach 30 m^3/ha·year on the best terrain (Rois, 2004). The high growth rate, the simple silviculture (it does no need to be pruned or thinned and it coppices do not need to replant after harvesting) and the frugality of this species, combined with a highly demanded wood, have been the enticing factors for a land owner when deciding planting Eucalyptus in Galicia. Nevertheless, since 1991 the high productivity of this species has been threatened by the outbreaks of the

Eucalyptus snout beetle (*Gonipterus scutellatus,* family *Curculionidae),* found at first time in Pontevedra (Mansilla & Pérez, 1996). However, other beetles and diseases affect Eucalyptus stands in Galicia, the most harmful has been the snout beetle, concerning its proliferation and the extent of its effects over the trees.

Gonipterus scutellatus is native to south-east Australia and it had a rapid spread in Spain (around 100 km/year in some areas), being detected in the other northern regions of Spain and in Portugal, and reaching the South of Portugal in 2003 (Xunta de Galicia, 2004). The speed of spread has to do with the absence of natural enemies, and the lack of an ecological balance between the populations. In these latitudes the snout beetle can produce up to three generations per year and both larvae and adult phases are very active, causing intense defoliation by eating shoots and tender leaves, which means significant losses in forest productivity. These damages have tried to be minimized using the mymarid *Anaphes nitens* Girault, a parasitoid of Gonipterus eggs, for biological control. In Galicia the first campaigns with *Anaphes nitens* started in 1994 and the results can be considered very successful. Where the biological control is not possible because the degree of infection is too high, a pesticide is being effectively used. For one individual tree defoliation is more marked in July and August (Ruiz *et al.*, 2002), maybe because the growth rate of Eucalyptus interferes in the way defoliation is showed, and in spring high damages can be hidden by growth rates in the tree. According to the Pan European forest monitoring system defoliation increased during the period 2002-2004 in *Eucalyptus globulus* plots mostly due to an augment of damaged caused by *Gonipterus scutellatus*. In 2004, 88% of *Eucalyptus globulus* plots showed defoliation, most of them (59%) in a slight degree; besides, the moderate class increased in comparison to 2002 and 2003.

Maybe most *Gonipterus scutellatus* outbreaks cannot be prevented, but damage can be managed by forest restructuring. This will undoubtedly become a more important strategy for reducing weevil damage in the future, as costs and environmental concerns about insecticide use increase. It is presently uncertain whether our activities are creating forest landscapes that will be more resistant to pathogens, or are creating a habitat for potential future epidemics. These relationships between stand characteristics and weevil damage allow the use of silviculture and forest management to reduce the incidence of the most damaged stand types across the landscape. That is the main reason to develop a Eucalyptus Health Monitoring System (EHMS), where not only defoliation (forest health), but also silvicultural, dasometrical, dendrometrical, climate and soil data are assembled.

Although it is not generalized the use of a systematic system in place to collect or report information and incorporate it into decision making regarding monitoring insects and diseases, fuel loading, stand density, and other stress indicators to maintain forest health, several forest health monitoring systems have been developed by the governments or the local agencies in areas like Europe, Canada, the United States or Australia. The implementation of these forest health assessment programs has met with mixed success, and the main reasons have been attributed to a lack of understanding as to what is meant by forest health and/or varying definitions of forest health depending on management perspectives, budget constraints in forest management, a poor integration of health monitoring programs with other forestry management operations and to limitations associated with the qualitative, visual and subjective assessment of forest health (Stone *et al.,* 2000).

The aim of this study is to propose and describe an objective, accurate, timely and efficient Eucalyptus Forest Monitoring System for the eucalyptus stands affected by weevil outbreaks in Galicia using remote sensing and Geographic Information Systems (GIS).

2 STUDY AREA

Galicia is in the North West of Spain and covers an area of nearly three millions hectares. Of this area the 69.67% is forest land, and 48.18% is forestry-wooded land[6]. The most frequent species in Galician forest are *Pinus pinaster* Ait. (390,000 ha), *Quercus robur* L. (195,000 ha), *Eucalyptus globulus* (177,000 ha), mixed-forest of *P. pinaster* and *E. globulus* (159,000 ha), and *Quercus pyrenaica* Willd. (101,000 ha). The total growing stocks in Galicia are 135 253 945 m^3, being mainly of *Pinus pinaster* and *Eucalyptus* spp. These afforestations cover more than the 70% of the forestry wooded-land (MMA, 2004). In Galicia, in the coastal area, the mean annual precipitation is about 1,000 mm, depending on the considered area. A target area of about 300 km^2 in Pontevedra in the Morrazo's peninsula has been selected for this study. Its location has been selected because the weevil outbreaks have been important since the beginning, and it is where it was first detected.

3 PROPOSED EUCALYPTUS HEALTH MONITORING SYSTEM

A forest management and monitoring system for eucalyptus plantations which integrates remote sensing and GIS is proposed. There is a critical need to consistently map and monitor the spatial location and dynamics of insect defoliation to provide information for prescribing pest management practices and to assess their impacts on eucalypts health and productivity. The workflow is shown at Fig. 1. This system provides decision support to forest managers by identifying areas of concern, recommending areas to monitor and recommending areas to treat using biological control, silvicultural treatments, chemical treatments.

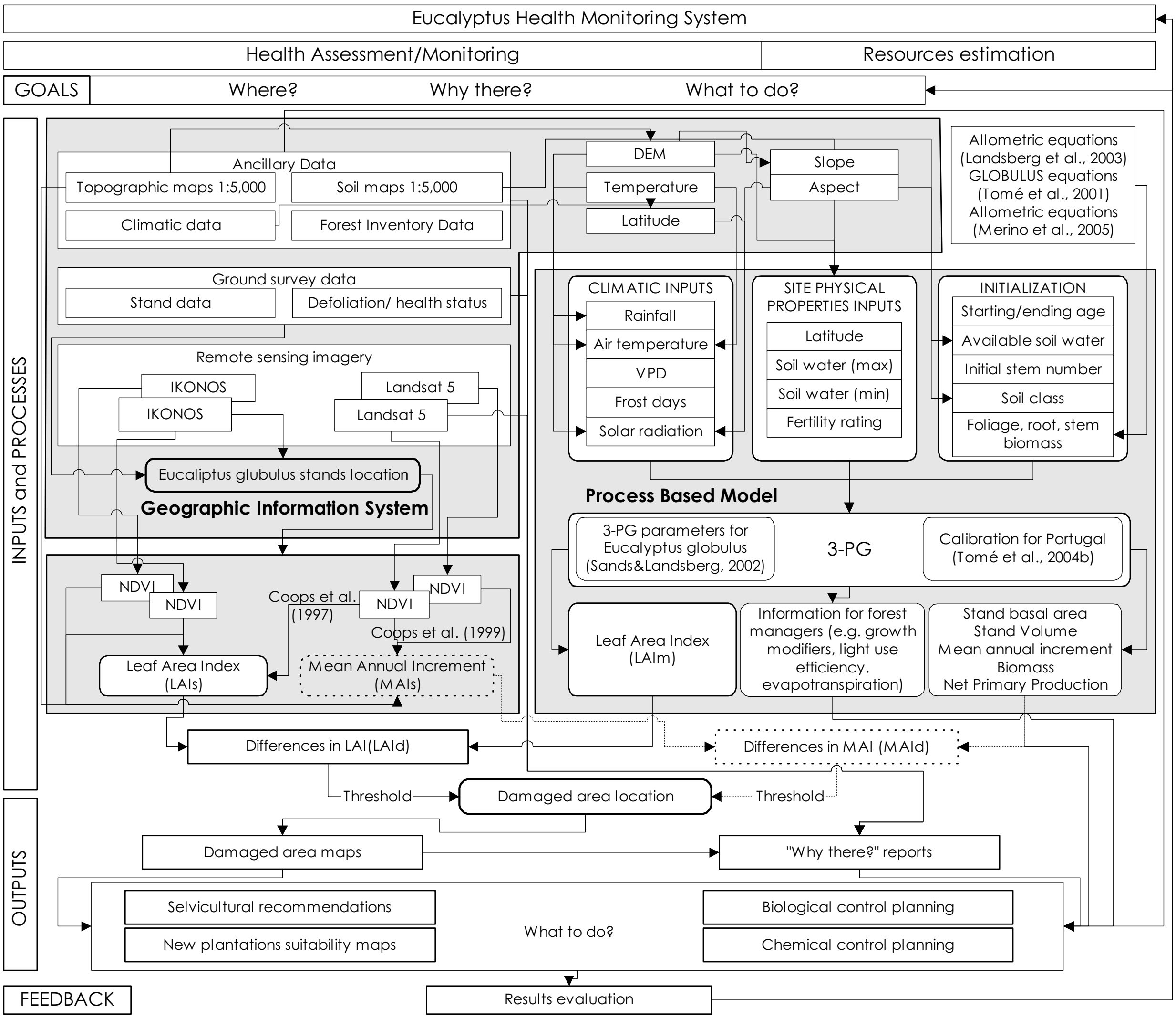

Figure 1. Proposed Eucalyptus Health Monitoring System

The main goal is, as described before, locating the areas where pest outbreaks affect health status and productivity in *Eucalyptus globulus* in Galicia. In those areas a more intensive health assessment/ monitoring survey should be considered. The proposed monitoring system is designed for *Gonipterus scutellatus* outbreaks, but it is possible to detect other disturbances which disturb eucalyptus growth (e.g. abiotic damages, diseases). The interest is focused on detecting those areas where damages caused by defoliation are severe enough to not to be compensated by the high growth rates in these plantations or where the growth rates are slowed down. The areas of concern where disturbances are identified are not straightforward identified as defoliated areas by the weevil, because is not reliable assessing causal agents merely from remote sensing imagery (Ciesla, 2000). Thus, the areas identified by the proposed model are suggested areas to monitor by field survey, as part of a multistage or multiphase sampling (Wulder & Dymond, 2004). Hence, field work is led to those stands with a high likelihood of being infested, increasing sampling efficiency and decreasing sampling pressure, which results in lower costs.

3.1 INPUTS AND PROCESSES

The proposed Eucalyptus Health Monitoring System is developed for *Eucalyptus globulus* stands, so that their locations have to be known and stored in a Geographic Information System (GIS). If updated and reliable maps from forest inventory are available, they can be used and straightforward integrated in the GIS. Otherwise, *Eucalyptus globulus* stands are identified and mapped using remote sensing imagery.

One of the most important factors governing the use of remote sensing for assessing insect damage, including defoliation, is timing (Ciesla, 2000). Damages in eucalyptus stands canopy due to snout weevil are not permanent, because often the high *E. globulus* growth rate and postdefoliation compensatory growth make the likelihood of insect defoliation exceeding foliar production decrease, ensuring rapid recovery after defoliation (Loch & Floyd, 2001). Only severely and repeatedly attacked areas look permanently defoliated. Thus, attacked areas can be masked by posterior refoliation and sometimes the effect of defoliation is only showed as a slow down in growth or growth rate lower than the expected. It makes difficult to define a suitable bio-window to monitor defoliation using remote sensing, and suggest the low suitability of using change detection techniques, because changes in biomass are often too slight to be detected. Although refoliation would not have been expected to produce very high Leaf Area Index (LAI) values, its occurrence raises issues that the timing and magnitude of the second flush are very important from the perspectives of defining the bio-window when remote sensing can be applied for detection of defoliation, and assessing the impact of defoliation on C uptake and productivity (Hall *et al,* 2003). Thus, another approach is proposed to monitor healthy status in eucalypt stands, by comparing LAI estimated by remote sensing (LAIs) and LAI estimated by means of a process based model (LAIm). Thus, in defoliated stands actual LAI (LAIs) will be smaller than LAI predicted by a process based model (LAIm). Considering this approach, not only likely currently defoliated areas are detected, but also areas where there is or there has been disturbances (e.g. weevil outbreaks, frost) which have modified LAI evolution.

A timely and cost affordable assessment of LAI in a large area is not possible by ground-based measurements, so that remote sensing techniques are proposed for its estimation. Coops *et al.* (1997) compared field LAI to the Normalized Difference Vegetation Index (NDVI) and the Simple Ratio (SR) derived from Landsat MSS data in Eucalyptus mixed hardwood forest in south-eastern Australia. Linear relationships were shown to be appropriate to relate both transformations to the LAI data with r^2 values of 0.71 and 0.53 respectively. Therefore, the predictive regression relationship of the form $LAI = a + b(NDVI)$ (r=0.84) developed by Coops *et al.* (1997) is integrated in the proposed model to estimate LAI from NDVI derived from Landsat 5 imagery (LAIs). In order to achieve more accurate results, the equation parameters should be calibrated for Galicia using field data. If higher spatial accuracy determining actual LAI is required, high spatial resolution satellite data (IKONOS) is proposed to be used.

Process based models can determine stand parameters such as stand basal area, stand volume, Mean Annual Increment (MAI), biomass or Leaf Area Index (LAI) taking into account variations in soil or weather conditions (Landsberg *et al.,* 2003). Regarding its simplicity the process-based forest growth model called 3-PG, developed by Landsberg and Waring (1997) is included in the Eucalyptus Health Monitoring System to estimate LAI. The parameters necessary to drive the 3-PG model in *Eucalyptus globulus* stands in Galicia are already available (Sands and Landsberg, 2002), and the results are likely to improve by using the calibration developed for Portuguese stands (Tomé *et al.,* 2004b). Basic climatic data in the GIS are monthly temperature (maximum and minimum) and rainfall records from nearby weather stations. Vapor Pressure Deficit (VPD) is estimated straightforward by the 3-PG model using the maximum and minimum monthly temperature values. A Digital Elevation Model is used to calculate soil variables and to topographically correct radiation and temperature data, as proposed by Coops and Waring (2001) and Tickle *et al.* (2001). Soil water holding capacity is primarily a function of texture, permeability, and soil depth (Almeida *et al.,* 2004), and estimates are based on soil physical properties and soil depth (from available soil maps) and chemical analysis when available, as done by Landsberg *et al.* (2003). Soil fertility is inferred from mineralogy classes available from soil maps, which provide broad indications of the fertility of the major soil types (Coops & Waring, 2001). Slope and topographic parameters are used in the modeling of soils properties at landscape scale, as proposed by Tickle *et al.* (2001). Initial values of available soil water can be estimated by using the Willians *et al.* (1992; in: Tickle *et al.,* 2001) pedotransfer functions. Initial values of foliage, stem and root mass, appropriate to the age of the stand at the beginning of a run are also required; specific biomass equations depending on diameter at breast height, height and basal area are available for *Eucalyptus globulus* in Galicia to predict these biomass fractions (Merino *et al.*, 2005). If height data are not available, allometric equations for *Eucalyptus globulus* developed by Landsberg *et al.* (2003) can be used. Foliage, root and stem biomass can be also estimated from the equations of the GLOBULUS stand model for *Eucalyptus globulus* plantations in Portugal (Tomé *et al.,* 2004a).

The main outputs of 3-PG model (leaf area index, mean annual increment, stand basal area, stand volume, foliage biomass) are showed as layers in the GIS, achieving values for all areas with Eucalyptus stands. Therefore LAI values are predicted through the model (LAIm) can be compared with actual LAI values derived from satellite imagery. When the difference (LAId) is negative, LAI predicted by the model is larger than the estimated using satellite imagery; thus, the first output of the system is achieved after selecting a threshold to differentiate areas where the differences are so large that they can be due to defoliation. The differences are ranked and showed in a map, so that areas where differences in LAI are larger are more likely to be damaged areas. Some spatial context will be needed in to separate differences in LAI due to insect infestation versus changes due to other factors such as harvesting. Mean Annual Increment (MAI) is proposed as additional criterion in order to achieve consistent results because severe health issues are reflected in growth and changes in growth rate can be an effect of pest/diseases pressure (De Jong, 1995). Mean Annual Increment can be predicted using 3-PG model (MAIm), using the same data as for predicting LAI (see above). Differences in MAI predicted by the 3-PG model (MAIm) and from satellite (MAIs) will highlight those areas where the growth patterns are/have been disturbed.

One of the outputs of the Eucalyptus Health Monitoring System is reporting if defoliation is related to stands parameters, spatial data (topographic variables, climatic data) and/or spectral response, so that "Why there" reports are generated. The method is calibrated and validated with ground survey data, topographic data and medium spatial resolution imagery stored in GIS layers. Due to the lack of current defoliation data registered enough geometric accuracy, a network was designed to gather suitable data. More than 200 plots are measured following a 1x1 km grid, coincident with one used during the III IFN, and in each plot dasometric, dendrometric variables were collected, in order to stratify data depending on age, canopy or stand structure, GPS position and physiographic variables are also recorded, as well as understory data.

3.2 OUTPUT

Once the damaged areas are located using remotely sensed imagery, the system's first output is achieved: the damaged area maps. These can be directly used by the administration for inventory purposes and to quantify how large are the areas likely to be affected by the outbreaks. However, the EHMS does not attempt to identify causal agents by the solely use of remote sensing imagery, an component of the operational system will be a supportive ground-based program. Hence, when necessary, more intensive surveys will use as reference these damaged area maps.

The second output is obtained after combining the damaged area maps and information about physiographic variables, dasometric variables, site index and ancillary information regarding soils, climate, etc. This data fusion is the first step in investigating "Why there?" and explaining the detected patterns.

The third output is actually a set of outputs, gathering practical recommendations that take into account the damaged area maps and the "Why there?" reports, as well as information from the growth model regarding resource estimations. Depending on the economical value, the suitability for forest production, the site index, the degree of infection, the outbreaks' frequency, the efficiency, and the environmental impact of the treatment in the area, then new plantations suitability maps are developed, silvicultural recommendations for current/new plantations are reported, and a calendar and a map to apply biological or chemical control are built up. Chemical treatments will be suggested after considering the degree of damage, stand location, expectable effectiveness, and likely environmental impact.

3.3 FEEDBACK

At the end of the year the results are evaluated, with consideration of their applicability. Feedback from the administration and from the plantation owners is requested, in order to modify the goals, methods and/or outputs. Questions as: user friendly format, understandable reports, and specific and useful recommend-dations are critical to achieve a successful forest management system.

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A PRODUCTION SYSTEM FOR MAPPING HISTORICAL FOREST CHANGES FROM SATELLITE REMOTE SENSING

Steve Joyce and Håkan Olsson

Department of Forest Resource Management and Geomatics,
Swedish University of Agricultural Sciences. Umeå, Sweden.
email: Steve.Joyce@resgeom.slu.se

ABSTRACT

Historical archives of satellite imagery make it possible to make retrospective analysis of forest landscape change over large areas and long periods of time. Besides providing a historical record of the size and distribution of forest harvesting activities, a detailed map of historical changes can be used to improve estimates of the current forest state and can be an important basis for studying changing wildlife habitats and landscape patterns. While the methods for satellite remote sensing change detection are fairly well developed, there are few software tools available that can map changes from multiple scenes over large areas in an automatic way. One major challenge is how to make a coherent change product from a large set of images with different acquisition dates and different areas of overlap. In this paper we describe an ongoing project that aims at developing algorithms and a software system for mapping major forest changes from historical image archives. The approach is to find the intersection of all image pairs after applying necessary geometric and radiometric pre-processing and map major forest changes as objects with polygon topology. Each change object can then have associated metadata describing the relevant time interval and be used for further analysis and modeling in a GIS. System development is done with ESRI ArcGIS components and C#.net

Keywords: Forest change detection, change mapping.

1 INTRODUCTION

Forest landscapes are in a constant state of change due to harvesting and regeneration, forest land development, forest damage, and natural forest succession. These changes have implications for future wood supply, for wildlife habitat and biodiversity, for recreational opportunities and well as for carbon accounting. Forest inventory and mapping activities are often directed at estimating the current state of the forest resource, and not well suited to monitoring the change in the forest landscape over time. Summary statistics from a repeated forest inventories may give the change in total amounts of various forest parameters, but often it is the spatial distribution and sizes of contiguous patches that are important for analyzing landscape change from an ecological perspective.

Satellite remote sensing can play an important role in monitoring changes in the forest landscape over time. Satellite images acquired in the past and stored in archives provide a permanent record of the historical state of the landscape. When compared with more recent image acquisitions, much information can be extracted about the nature and spatial extent of changes. Satellite remote sensing has the advantage of covering large areas at relatively low cost. Compared to historical maps which have already been interpreted and generalized, historical satellite images give an objective view of past landscapes which can always be re-analyzed for a specific purpose in the present. A number of civilian remote sensing satellite systems have been acquiring and archiving data since the start of the Landsat program in 1972. These historical archives, especially of Landsat Thematic Mapper imagery, are an enormous resource for answering current questions about landscape change that have yet to be fully explored. Even more interesting is the fact that much of this historical data is now available from archives at low cost or even free of charge. It wasn't too long ago that processing a single Landsat scene was a significant burden for computer processing speed, memory and storage space. Now, it is completely within the capabilities of modern desktop computers to store and analyze multiple scenes covering large areas. Even transferring full scenes over regular networks from central servers is not unreasonable. Commercial software for remote sensing image analysis usually includes some functionality for change detection, but it can be complicated and time consuming to go beyond a simple raster map of change pixels within the intersection of two scenes. For most subsequent analysis in a geographic information system, it is desirable to identify contiguous regions of change pixels as a single change object (such as a recently clearfelled forest stand).

In this project we are building a software system for forest change mapping from satellite imagery intended for exploring these historical archives of satellite images. Besides being a production system for change mapping, the system will serve as an in-house test platform for developing change detection algorithms. The system applies the necessary geometric coregistration and radiometric matching before detecting changes between pairs of overlapping images. The detected changes on pixel level are then merged to form change objects that can be further analyzed in a GIS. The system is intended to be fully automatic: after the user selects an area of interest the raster image database is searched for available images and their intersection regions are calculated for change detection. We use ESRI's ArcObject components for software development to take advantage of its facilities for database handling and spatial analysis. The results are a set of change polygons with attributes identifying the change interval and change magnitude.

2 DESIGN REQUIREMENTS

2.1 USERS AND APPLICATIONS

The majority of Swedish forest land is intensively managed for wood production by a mix of industrial and private forest owners. Typically stands are managed in small patches of 1 to 10ha with a nominal rotation period of 80 to 100 years. Up to 3 thinnings are applied during a stand's life cycle before final felling. This creates a landscape that is dominated by relatively uniform forest patches of different ages. Forest damage agents and wild forest fires are rare, but there are events such as the recent windstorm of January 2005 which resulted in large areas of windthrown forest. Change detection from satellite remote sensing can at least detect the majority of new clearfellings and major damages, thereby creating a map of the spatial distribution and age of different forest patches.

There are several applications where maps of historical and forest landscape change would be useful. Overview maps of the spatial distribution and size of clearfellings during different time periods would provide important input into the current debate the influence of forest activities on the landscape. Forest age and statistics about historical cutting patterns could also be used for modeling and visualizing future landscapes which is being explored in the HEUREKA forest management planning system (Lämås and Eriksson, 2002). "k-NN Sweden" is a nationwide raster database of forest variables derived from Landsat ETM + satellite data and national forest inventory sample plots (Reese et al, 2003) which could be improved by incorporating stand age information derived from historical change. The National Forest Inventory in Sweden could provide better estimates of change from its annual sample plot data by using changes detected from satellite imagery in a post-stratification design (Stehman et al 2003). The Swedish Forest Administration has been delineating all new clearfelled areas since January 2003, but the database could be complemented with historical information. By including historical clearfellings, there is a technical possibility to delineate and put a time stamp on approximately 1/3 of the forest stands in Sweden if the age of the stands can be estimated (Wulder et al, 2004). Beyond the applications in Sweden, there are many regions of the world where there is a lack of information about the extent of forest activities, and since satellite imagery is widely available, it will be possible to construct large area historical change maps in these areas as well.

2.2 INPUTS AND OUTPUTS

The primary input to this change mapping system will of course be a database of historical satellite imagery. If other map data is available, such as a mask covering forest land or a coverage identifying roads, these data can be used to restrict the processing extent. In the simplest case, the operator need only specify the geographical region of interest, and the system will automatically retreive available imagery and present a list to the user. The user can then select a subset of the images or choose to process all available.

Change detection is then done for the overlap of all image pairs using one of the available algorithms with automatic or user-specified parameters. The intention is that the change detection can be fine-tuned by experienced users, but a sensible set of defaults is always calculated from image statistics. The detected changes are segmented to form change regions (polygons) and their attribute data is stored in an associated database. It will be quite common that the same change area is identified from different image pairs independently. In this case it will be possible to prune the polygon database to keep only those with the shortest change interval.

2.3 INTERACTIVE AND BATCH PROCESSING

Processing large areas with multiple images can take some time, so it will be possible to first process a subset (spatially or temporally) to fine-tune the change detection parameters, and then process the entire area selected in batch.

3 DATA SOURCES

3.1 HISTORICAL DATA OVER SWEDEN

A primary source of high quality satellite data is the Image 2000 data set (fig. 1d), which is an almost nationwide data set of Landsat-7 ETM+. This data set was compiled for the CORINE landcover mapping project and is freely available for use by Swedish authorities. The so-called EPOK data sets with a national coverage from 3 time points: Landsat MSS data from the mid 1970s (fig. 1a); Landsat TM data from 1986-1990 (fig. 1b), and 1994-1999 (fig. 1c) were processed by the former Environmental Satellite Data Centre (MDC) in Kiruna, and are now archived by METRIA in Kiruna; Processed scenes from Landsat, SPOT and IRS, which have been used in various projects in Sweden, including national coverage's ordered by the Swedish forest administration the last five years; Raw, still unprocessed, high density tapes.

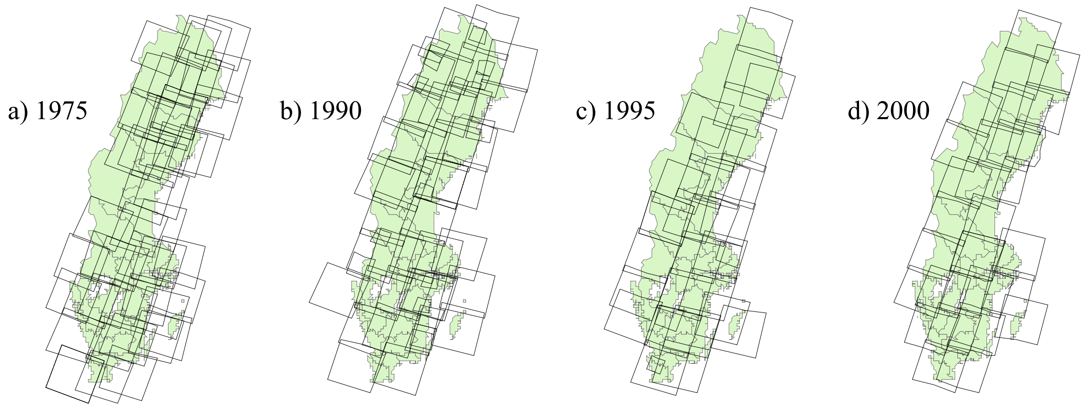

Figure 1. Scene extents of several historical Satellite datasets over Sweden. a) Landsat MSS 1975, b) Landsat-5 TM and SPOT 1990, c) Landsat-5 TM 1995, d) Landsat-7 ETM+ 2000.

The Swedish National Space board has also acquired a nationwide data set of SPOT 5 data from 2004, which could be used for their projects.

3.2 GLOBAL LANDSAT EPOCH DATASETS

Historical data from Landsat MSS from the 1970s and Landsat-5 TM with nominal acquisition year 1990 is available free of charge from University of Maryland and USGS. This dataset was compiled as part of a NASA sponsored global mapping project (Tucker et al, 2004) and individual orthocorrected scenes are available online at the University of Maryland's Global Landcover Facility (http://www.glcf.umiacs.umd.edu). Worldwide more than 27000 such scenes from 1972 and onwards are presently available of which about 270 are covering Sweden. Although most of these scenes already exist in the Swedish archives, it is of interest to develop automatic processing capability for these scenes, both for their availability but also since there is global coverage and a validated production line for processing of data over Sweden could also be used for other regions in the boreal zone, such as Russia.

3.3 FUTURE DATA SOURCES

During at least the coming five years, we can expect that the medium resolution satellite data available for change mapping will come from various satellite series, such as for example SPOT, IRS, CBERS and Raid Eye. The need to use data from more sensors in the future (due to the ending of the present versions of the Landsat and SPOT systems) is a further motivation for the development of a versatile system that can handle various types of data in an automatic way.

4 METHODS

4.1 RADIOMETRIC NORMALIZATION

Images acquired at different times of the year under different solar illumination geometry and different atmospheric conditions are not directly comparable without some type of radiometric correction. The classical approach of converting to physical units of reflectance is often difficult or impossible if the sensor calibration and atmospheric conditions are unknown, especially for historical datasets. For the purposes of change detection, it is often desirable to take a simpler approach to radiometric normalization based on image statistics or pseudoinvariant features instead. Our experience is that a normalization strategy based on the distribution of pixel values under a forest mask works reliably for Scandinavian forest types and images taken during the vegetation season. Several approaches are possible including regression and histogram matching and we intend to implement several options in our system.

4.2 GEOMETRIC PRE-PROCESSING

Accurate geometric co-registration of images is critical for change detection success. The Swedish datasets available for this project will already be precision corrected to the Swedish National Grid, but it may be necessary and advantageous to apply an additional automatic co-registration procedure (Zitova and Flusser, 2003) to reduce residual misalignments, especially those caused by scan-swath shift. In addition, there is a need to develop routines for geometric correction of the TM scenes which are freely available from USA. The final production system will also be required to handle image data from different sensors at different source resolutions (such as SPOT or MSS). We intend to implement an automatic image co-registration procedure in our production line that is based on hierarchical image correlation matching.

4.3 CHANGE DETECTION

Change detection was recognized early as one of the important applications for satellite remote sensing and much research effort has been directed towards development of algorithms for detecting and mapping various types of changes (Coppin and Bauer, 1996). Most effective change detection algorithms involve the taking differences of spectral bands or band combinations that result in a distribution of residuals that represent "normal variation" and a number of outliers in the tails of the distribution that can be classified as "change". Change detection is then a matter of setting an appropriate threshold to identify the outliers. There is no immediate indication of the type of change, only that the difference is larger than what is considered normal variation. For this approach to work well, the expected proportion of change pixels should be significantly less than the total (a criteria that is satisfied in the case of identifying forest harvest activities within a large forest landscape). Thresholds can rarely be considered as absolute or objective, but can be set with some consistency from image statistics. Furthermore, what is considered a statistical change in a spectral feature does not always correspond to what we would consider a significant change on the ground, and some significant changes may not at all show up spectrally. Nevertheless, automatic change detection can give some useful results, and it is comparatively easy to detect new clearfellings because the corresponding spectral change is very large.

4.4 CHANGE MAPPING

Thresholded differences give an spatially explicit indication of change/no-change in an image but are only a first step in producing a change map that can be used in further analysis. For most applications, it is desirable to group change pixels together into contiguouis objects that can be related to some feature on the ground such as a single forest stand. Simple raster-to-vector conversion usually doesn't achieve the desired result since if the threshold is set too conservatively, the change objects will have missing pixels in the interior and eroded edges. Reducing the threshold may fix this problem at the expense of introducing extraneous pixels and falsely identified changes elsewhere in the image. We intend to address this problem by introducing a change detection between two thresholds with hysteresis: A conservative threshold identifies at least some part of all change areas of interest (seed points) and a second threshold sets a limit for region growing segmentation from these points.

5 SYSTEM IMPLEMENTATION

In order to ease the tasks of input data storage and output data delivery, we plan to make use of ESRI tools for managing image and spatial databases, as well as handle most of the spatial operations. The tools for application development in ESRIs ArcGIS offer excellent access to built-in components for spatial data analysis, but unfortunately are somewhat weak on functionality for serious raster image processing. Nevertheless, we have chosen to build this application within a GIS environment because much of the complexity will be in handling the input and output data rather than the actual change detection. The final application will appear as an extension that runs under ArcGIS, and we intend to use the DataSourcesRaster object model available in ArcObjects as much as possible for raster change detection.

6 SYSTEM VALIDATION

There are no immediate plans for a large scale change mapping effort within the scope of this project, rather the focus is on developing the tools to process such datasets. When the functional system components are in place, we plan to test its performance in a number of regions in Sweden.

6.1 TEST AREAS

We have chosen three main study ares for testing. The first is in the near-mountain area covering part of the Vilhelmina Model forest. This will give some experience with the particular difficulties with slope, vegetation phenology, and sparse forest types when operating near the Swedish mountains. The second study area is in Coastal Västerbotten near Umeå, where we have assembled a long time series of annual Landsat TM imagery stretching back to 1984. The third area is in southern Sweden, where new SPOT imagery will be acquired to test the possibility to map stormfellings after the recent wind storm of January 2005.

6.2 EVALUATION OF RESULTS

The main aspects of system performance that we are interested in initially are 1) the minimum size of new clearfellings that can be reliable detected for a given data resolution, 2) the maximum elapsed time after harvest where a clearfelling can still be detected for normally regenerating stands, and 3) the detectability of partial cuts and wind damages, and their confusion with older clearfellings. The long time series of images in coastal västerbotten presents a good opportunity to test the detectability of clearfellings for images with many different time intervals. For evaluation data, we intend to use forest company cutting records where available plus specific field inventories to identify the age of detected changes.

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DETECTION OF CHANGES IN EURASIAN BOREAL FOREST

Aksenov. D.[a], Kostikova A.[b], Karpachevsky M.[c], Egorov A.[d], Esipova L.[e], Dubinin M[f]
[a,] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: picea@online.ru
[b] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: geoeco@rambler.ru
[c] Biodiversity Conservation Center, Vavilova 41, 117312 Moscow Russia, e-mail: forest@biodiversity.ru
[d] Biodiversity Conservation Center, Vavilova 41, 117312 Moscow Russia, e-mail: egorov@psn.ru
[e] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: Efedra@GisCraft.ru
[f] International Social Ecological Union, P.O. Box 211 119019 Moscow Russia, e-mail: m_a_x_d@mail.ru

ABSTRACT

Boreal ecosystems present critical importance in global ecological processes. They are complicated system with great numbers of inner connections and dynamic pattern. The role, which boreal ecosystems play in sustainability of the environment as well as their significant value within forest cover of the Earth, is beyond question.

The influence of anthropogenic activities on the condition of the boreal forests is growing up every year. That is why the determination of zones of current changes and definition of criteria which could be considered as key in the processes of identification such areas, are in a great interest. Besides, it is very important to predict areas where these changes are most likely could happen in next years. The results of such estimation could help to prevent negative impacts upon forest cover. Main goals of current work were to detect areas with significant changes in vegetation cover within forest landscapes in the Russian boreal zone and to determine zones of potential changes during next 5 years. On the one hand, detection of changes was carried out on the border with intact forest landscapes (IFL) with the assumption that expected changes could expand deep into intact forest landscapes. Thus, there was a possibility to identify both areas of the current changes and areas of changes expected in the next 5 years. On the other hand, a detailed estimation of the changes for all the Russian territory requires lots of time and information, including a huge scope of remote sensing data. That is why we decided to estimate the changes only on the border with IFL and extensively use the moderate spatial resolution satellite imagery.

Keywords: Forest cover changes, Boreal forest, Eurasia, Intact Forest Landscapes, biodiversity, conservation, anthropogenic activities.

1 INTRODUCTION

The Joint Research Centre (JRC) past initiatives include projects on identifying “hotspots” in the tropical forest. Experts on tropical forests convened in workshops to map change in tropical rainforest, covering the evergreen rainforest and the monsoon forest of South East Asia, including Northeast India, Bangladesh and Papua New Guinea.

In this project, we aimed to detect areas with significant change in vegetation cover, or “hotspots,” within forest landscapes in the Russian boreal zone and estimate zones of potential changes in next 5 years. To reach this aim we advanced the following objectives:

1. to define the main types of change in forest cover in Russia
2. to map current “hotspots” of change in forest cover that occurred over the last 15 years
3. to estimate and map “hotspots” of change in forest cover in the next 5 years
4. to map density of potential “hotspots”

Because estimating changes for all of the forest of the Russian Federation require an enormous amout of resources and remote sensing data, we identified only those “hotspots” that were on the border of intact forest landscapes (IFL), as determined by Greenpeace Russia and Global Forest Watch (Yaroshenko, A., Potapov, P., Turubanova, S., 2001). Moreover, we assumed that future disturbances would possibly expand into IFL.

2 DATA DESCRIPTION

For this project we used the following data:

1. Landsat-7/ETM+ images – high spatial resolution images with 6 spectral bands.

2. Landsat-7/ETM+ image previews – moderate-resolution browse images sub-sampled from the actual scene data. The image is displayed as a 5,4,3 (RGB) band composite with a standardized 2% linear stretch applied.

Spectral resolution of the both data types described in the Table 1.

Table 1. Spectral resolution of the data

Band*	Preview Landsat-7/ETM+ (250 meters resolution)	Landsat 7/ETM+ images (30 meters resolution)
Band 1	0,63-0,69	0,45-0,515
Band 2	0,75-0,90	0,525-0,605
Band 3	1,55-1,75	0,63-0,69
Band 4	-	0,75-0,90
Band 5	-	1,55-1,75
Band 6	-	2,09-2,35

* - band numbers shows order but not the actual number of the band

Our Landsat data covered the time periods between January 1999 and December 2001. The number of images from different season used in the analysis is described in the Table 2. Most of the data was acquired during summer and autumn.

Table 2. Number of processed images

Numbers	1999 summer	1999 autumn	2000 summer	2000 autumn	2001 summer	2001 autumn
Landsat scenes	36	49	69	22	49	36
Preview of Landsat scenes	79	28	253	38	82	20

In total, we processed 261 scenes of Landsat and about 500 previews of Landsat data. All images and previews were geometrically transformed into the Albers conical equal area projection. Depending on the zone different parameters of the projection were used, Russia's territory was divided into three zones: European Russia, Siberia, and the Far East. Detailed parameters for each zone are in Table 3

Table 3. Projection paraments

Projection parameters (Albers Equal-area Conic)	European zone	Siberia zone	Far East zone
Spheroid	Krasovsky	Krasovsky	Krasovsky
Central meridian	45	105	135
Reference latitude	0	0	0
Standard parallel 1	64	64	64
Standard parallel 2	52	52	52
False easting	8500000	18500000	23500000
False northing	0	0	0

3 DEFINITIONS

We defined "hotspots" as areas with significant change in vegetation cover as a result of intensive anthropogenic influence. The following types of "hotspots" of change in forest cover were determined:

- burned areas (at least 15 years old)
- intensive forest exploitation (clear-cuts)
- fossil fuel mining (oil and gas extraction, open cast mining, gold mining)
- agricultural development
- other evidence of intensive anthropogenic activities

4 METHODS IN IDENTIFYING CURRENT "HOTSPOTS"

Using Landsat images and image previews, we visually detected the above-listed types of disturbances. To delineate burnt areas we used image previews, while for other types of "hotspots" image previews were not sufficient and we used high spatial resolution images. Working on 1:100,000 scale, minimum size for a change area to be considered was 50,000 sq. m.

5. METHODS IN IDENTIFYING FUTURE "HOTSPOTS"

Changes occurring on the border of IFL are highly likely to expand into the IFL area, mainly because of the being built infrastructure and, consequently, better accessibility compare to those area where infrastructure is absent.. Thus, we aimed to identify those areas of IFL that might be threatened:

1. We calculated the average speed with which "hotspots" expanded into the IFL by selecting several representative areas that significantly changed over the last two or three years and calculating the average speed of "hotspots" growth per year. For clear-cuts this speed was on average from 2 to 5 kilometers per year for model areas. In most cases, "hotspots" grew between two and three kilometers per year and sometimes 5 or more kilometers. Thus, we chose a buffer that was most likely to cover areas of potential change, which we determined to be 5 kilometers. For the mining and agricultural development the buffer size was determined to be 2 and 0,5 kilometers accordingly.
2. Territories of protected areas (zapovedniks and national park) were excluded from the buffer zones.
3. Non-forest areas were excluded from the buffers.
4. Density of the remained polygons was calculated (using moving window of 7,500 meter radius). The resulting map showed density of predicted "hotspots" of change in forest cover.

6 RESULTS AND DISCUSSION

The following results were achieved:

1. We defined the main types of the "hotspots" of disturbances
2. We mapped "hotspots" of current change in forest cover in Russia.
3. We mapped potential changes in forest cover for the next 5 years.
4. We mapped the density of potential "hotspots.

In most cases, "hotspots" on the border with IFL were specific to each region. For example:

- Far East – fresh burned areas (catastrophic fires of the 90s and 70s), logging in mixed conifers and deciduous forests and conifers forests
- East Siberia – burned area in larch forests (burned many times, difficulties in age determination), clear cutting/logging in conifers forests (Angara river area, basin of Baikal, Chitinskaya oblast)
- Northern European Russia (Karelia, Arkhangelskaya oblast) – clear-cutting in coniferous forest
- West Siberia (Tumen region) – mining (oil and gas extraction).

Our methodology presented several advantages and disadvantages. One of the difficulties of working with satellite images is that it is almost impossible to determine the age of disturbances, especially burnt areas as they are susceptible to future fires. For example, it was not clear how to interpret massive areas of larch-forest within the East Siberia territory (Evenkia, Yakutia). On the one hand, fire dynamics of this territory could be treated as natural, however, we also could guess that number of fires on this area increased due to intensification of anthropogenic influence. Additionally, our study area included only changes in forests bordering with or located in IFL. But also, our method was rather time-consuming, because delineation was done manually.

However, to our advantage high resolution images covered all of the study area, and the data for this area was more precise and current, giving us an opportunity to make an accurate estimation.

After analyzing several methodologies (Lillesand T.M., Kiefer RW. "Remote sensing and image interpretation"; Jensen J.R. "Introductory digital image processing") we concluded that three bands, that are included to Landsat image previews, are most sufficient to detect change. The 5, 4, 3 combination, used in preview imagery composite, provides a great amount of information and color contrast. Healthy vegetation is bright green and soils are mauve. The 5, 4, 3 combination has the most agricultural information. This combination is useful for vegetation studies, and is widely used in the areas of timber management and pest infestation. In addition, this combination is useful in the fire management applications for post-fire analysis of burned and non burned forested areas interpretation.

To our convenience, several previews of Landsat images were available for each footprint of Landsat in the territory of investigation. On average, at least than 2-3 previews obtained in different seasons were used instead of only one full Landsat scene typically available for each footprint. Thus, if using only one seasonal image did not allow detecting changes, there was a possibility to use previews of different seasonal previews. During the analysis, summer and autumn (rarely – spring) seasonal previews were used. In work we did not conduct an additional geometric correction through ground reference points. On average, RMS error with automatic geometric correction was no more than 400 meters for previews and no more than 250 for Landsat images. Taking into account the big scale of the project this accuracy could be recognized satisfactory.

7. OPPORTUNITIES FOR FUTURE WORK

In the future we see several possible streams for this work

- increasing the accuracy of the results - making more precise definition of the changes using only high resolution data
- increasing the study area - delineation of the changes not only on the border with IFL, but for all of the Russian territory
- conducting a change analysis – detection of the changes for different time points (using Landsat mss, tm data) and obtaining the dynamic of changes and possibly, determination the key factors of changes

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SIMPLE PRACTICAL APPLICATION OF CHANGE DETECTION FROM SATELLITE IMAGES, NATIONAL FOREST INVENTORY DATA AND FIELDWORK TO ASSESS THE VOLUME OF ILLEGALLY FELLED TIMBER IN ESTONIA

Mait Lang[ab], Margarete Jürjo[ac], Veiko Adermann[ac]

[a] Estonian Agricultural University, Kreutzwaldi 5, 51014 Tartu, Estonia
[a] Tartu Observatory, 61602 Tõravere, Estonia
[c] Centre of Forest Protection and Silviculture, Rõõmu tee 2, 51013 Tartu, Estonia

ABSTRACT

Careful planning of forest management activities and continuous monitoring are very important factors to maintain forest sustainability. The aim of our rather practical pilot study was to assess the share of the timber in Estonia that is felled by violating the obligation to declare forest felling and by braking the rules of the forest stand thinning and renewal felling. Large discrepancy between the estimates based on National Forest Inventory (NFI) and forest declarations based statistics has caused an opinion that about 50 % of the Estonian forestry is illegal. While the construction of sustainable forest management infosystem is at the beginning stage and digital maps and databases are not yet available for queries, the satellite remote sensing and change detection combined with volume prediction functions based on NFI results and field checking of changed areas was proposed.

Change detection using images from sensors like Landsat Thematic Mapper (TM) has been proved to be a working remote sensing application in the practice. We calibrated Landsat TM and Landsat ETM+ scenes from WRS paths 186...188 and row 19 to detect clear-cut like changes and to create digital maps for the period from 1999 to 2002. From the map of felling locations 667 areas, that were located closer than 100 m to the apexes triangular network of sampling points, were chosen for detailed study. Fieldwork and documentation checking was done by forest specialists of County Environmental Departments while they are responsible of archiving forest declarations and possess paper copies of forest management plans. Cutting areas were delineated using GPS or digital ortophotos. Detected law violations were mapped and the results were compiled into the digital map for analysis. NFI plot data were used to develop a simple function to simulate NFI volume estimate for comparison to the declared volume for each felling area.

The declared area agreed rather well with the measured area. The declared volume, on the other hand, tended to be smaller than it was estimated by the NFI volume function. This tendency was more pronounced on the checked thinning cuttings. While analysed sample consisted of areas that expressed reflectance change similar to clearcuts, the results are biased towards worse, because problematic thinning cuttings are prevailing in our sample. One cause behind the volume difference is that stem volume function, developed on NFI data, predicts systematically about 20% bigger volumes compared to the regular forest inventory estimates.

Felled problematic wood was finally divided into five groups that do not overlap. Following are the 95% confidence limits for the estimates. The share of wood that was not declared was 5.6%-9.7%. The wood that was not declared and felled by violating the forest felling rules was 3.0%-6.2%. The share of declared wood, felled by violating the forest felling rules, was 1.8%-4.5%. The amount of wood that had forest theft as one of the problem was 2.3%-5.3%. Countershaft person usage was related to the 0.5%-2.4% of felled wood. Overall estimate of the wood, cut by violating forest felling rules, was 8.1%-12.8%. For 9.4% of felling areas the declaration was not submitted at all. Most of the problems were found in the private forests.

Keywords: change detection, forest felling, satellite images, illegal wood

AN NDVI AND FAPAR DATABASE FOR SCANDINAVIA 2000-2004

P. Olofsson[a], L. Eklundh[a] and P. Jönsson[b]

[a] Department of Physical Geography and Ecosystems Analysis, Lund University, Sölvegatan 12, 223 62 Lund, Sweden, email: pontus.olofsson@nateko.lu.se

[b] Department of Physics, Box 118, SE-221 00 Lund, Sweden

ABSTRACT

We are setting up a database of seasonally adjusted NDVI (Normalized Difference Vegetation Index) and FAPAR (Fraction of Absorbed Photosynthetically Active Radiation). FAPAR gives the percentage of the total amount of radiation that is absorbed and used for growth by e.g. a forested area. The data is based on the Terra/MODIS Vegetation Indices product (MOD13Q1) and covers the whole of Scandinavia for 2000-2004, with a temporal resolution of 16 days and a spatial resolution of 250 m. The database will be made public through the department homepage.

FAPAR is obtained by linear scaling of the NDVI. Scalings are calculated for five different land cover classes: (1) different needleleaf tree cover, (2) broadleaf tree cover, (3) mixed tree cover, (4) open fields (pasture, etc.), (5) lichens and mosses (urban areas and water are masked out). Land cover data is obtained from GLC2000, which is based on data from SPOT Vegetation.

In order to validate the FAPAR dataset, measurements of PAR interception and absorption were carried out in Norunda and Skyttorp, (needleleaf forest, 100 km northwest of Stockholm) Aug-Oct, 2001; Skarhult (broadleaf forest, southernmost Sweden), summer 2003; Asa research station (needleleaf forest, southern Sweden), summer 2004; Norunda, summer-autumn, 2004.

Keywords: FAPAR, NDVI, Terra/MODIS

1 INTRODUCTION

Green vegetation has a reflectance maximum in the near infrared wavelength area and a minimum in the red. Since this reflectance is absent in non-photosynthetic tissue, the near infrared to red quotient is sensitive to the amount of vegetation and its condition. The NDVI is obtained by normalizing the expression. A major problem with NDVI time series, especially at northern latitudes, is the cloud interference resulting in disturbed and noisy signals throughout the year. To overcome this problem a new method for extracting seasonally information is employed. The method is based on nonlinear least squares fits of asymmetric Gaussian model functions to the time series (see Figure 1).

The NDVI has a number of properties, including its relation to absorbed radiation, and there is evidence of linear relationship between NDVI and FAPAR (Asrar *et al.*, 1984). FAPAR is an important parameter commonly used for estimating the increase in biomass of a plant community.

The database has been successfully employed for estimation of net primary production (NPP) in Olofsson *et al.* (ACCEPTED) and Olofsson and Eklundh (2005). NPP was modeled as a product of absorbed PAR and light use factor, describing how efficiently the plant community utilizes the absorbed PAR. The amount of absorbed PAR was derived from the fractional absorption, FAPAR, and the amount of incident PAR.

2 SITE DESCRIPTIONS

Norunda. The Norunda area (60° 50' N, 17° 29' E), located in central Sweden about 100 km northwest of Stockholm, mainly consists of old and middle aged (50-100 y) Scots pine and Norway spruce with a LAI of 3-7. More information about the Norunda area can be found in Lundin *et al.* (1999).

Skyttorp. Skyttorp is located approximately 20 km east of Norunda. The two plots where the measurements were carried out consist of a 30 year old Scots pine stand and 60 year old mixed Scots pine and Norway spruce stand. The latter is located approximately 4 km south of the former.

Skarhult. Located in central in the southernmost part of Sweden (55.8° N, 13.4° E). Measurements were carried out in a dense beech stand with no understory vegetation, and in a fertilized oak stand with an

LAI of about 3 and massive understory vegetation (Olofsson and Stenström, 2000). Both with a tree height of approximately 20 m.

Asa. Asa research station in southern Sweden (57.2° N, 14.8° E) is, just as Skyttorp and Norunda, a NECC flux site. Measurements were carried out in two Norway spruce stands: one rather heterogeneous located right next to the Asa flux tower, and one younger more homogenous with a tree height of slightly less than 20 m.

3 NDVI

The raw NDVI data was acquired from the MODIS VI product, MOD13Q1. The spatial resolution of the NDVI dataset is 250 m and data is composed over periods of 16 days, with the final version available from 24 Feb 2000 (Huete *et al.*, 1999). In order to cover Scandinavia, two MODIS tiles are required.

Prior to scaling NDVI to FAPAR, the data was seasonally adjusted by nonlinear least square fitting of local asymmetric Gaussian model functions to the time-series, using the computer program TIMESAT (Jönsson and Eklundh, 2002; Jönsson and Eklundh, 2004). An example of the adjustment for the mixed coniferous stand in Skyttorp is seen Figure 1.

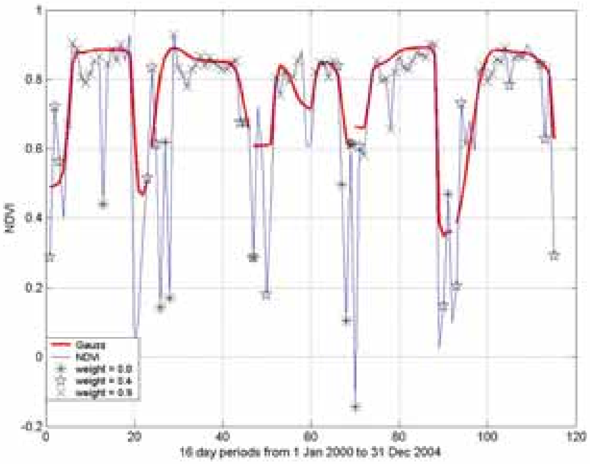

Figure 1. Seasonal adjustment (red line) of NDVI for the mixed coniferous stand in Skyttorp.The data points in the time-series were classified into six different quality levels, assigning each point a weight between 1 and 0. The quality levels were based on the "VI Usefulness Index" quality assessment data set included in the MODIS VI product.

4 FAPAR

FAPAR for both years was derived by linear transformation of NDVI data (described in the previous paragraph). Accordingly, the FAPAR data has the same resolution as the NDVI data (16 day temporal resolution and 250 m spatial resolution). Generating the FAPAR data set was done in three steps:

i) Seasonal adjustment. As described in the paragraph above, the NDVI data was first processed using TIMESAT.

ii) Median filter. The function adaptation described above sometimes fails in individual pixels, and therefore, a 3 × 3 pixel median filter was used to filter the adjusted data.

iii) Linear transformation of NDVI. Using the land cover classification from the GLOBAL LAND COVER 2000 Project (Bartholomé *et al.*, 2002) the 98th and 5th percentile was calculated for six different land cover classes, and for each year. By assuming that the 98th percentile represents a FAPAR of 95% and the 5th percentile a FAPAR of 0% (Sellers *et al.*, 1994), linear relationships between NDVI and FAPAR were obtained for each land cover class. Deriving the FAPAR time series presented in the Results section percentiles calculated for 2001 were used for both the coniferous and deciduous stands: 0.0165 and 0.8871 for the former; and -0.0729 and 0.8729 for the latter.

5 FAPAR AND FIPAR MEASUREMENTS

By measuring incident PAR below and above the canopy it is possible to calculate the fraction of intercepted PAR (FIPAR). In order to obtain the fractional absorption, the PAR reflected from ground and canopy also have to be measured. At the four sites where PAR was measured, PAR reflectivities were measured in Skarhult and at one plot in Asa. Accordingly, FAPAR was obtained at Asa (2004) and Skarhult (2003), and FIPAR at Norunda (2001, 2004) and Skyttorp (2001).

At all plots, incident PAR below the canopy was measured by randomly placing 8 to12 PAR sensors on the ground, each connected to the same logger. For Norunda and Skyttorp, incident PAR above canopy was measured with a sensor placed on the Norunda tower at a height of approximately 100 m. In Asa and Skarhult, a 20 m telescope mast was used for PAR measurements above ground.

At Norunda, Skytttorp and at one plot in Asa the PAR reflectivity used for obtaining the fractional absorption from the interception was set to 3% (Russell *et al.*, 1989). This is supported by the reflectivity measured at Asa, which varied between 2 and 3%. For the deciduous stands the reflectivity is about 1%.

6 RESULTS

As can be seen in Figure 2 below, there is a good agreement between FAPAR calculated from NDVI and measured FAPAR. FAPAR obtained from MODIS LAI/FAPAR product (MOD15A2, generated every 8th day with 1 km spatial resolution) performs less well and contains unrealistic values during most of the measurement period (at the spruce stand in Asa, however, the agreement between MOD15A2 and the measurements is almost perfect, even though the former displays unrealistic values just before and after). When using the MOD15A2 product for needleleaf forest in Sweden it is recommended to consult the belonging quality controls.

For the deciduous stands in Skarhult the situation is different: the MOD15A2 is obviously able to map FAPAR more accurate compared with the coniferous stands. For the oak stand both MOD15A2 and the NDVI transformation are both able to estimate FAPAR, however, a slight under- and overestimation, respectively, can be seen. For the beech stand, the NDVI transformation accurately traces the measurements while MOD15A2 slightly underestimates FAPAR with about 4-8 percentage points during the measurement period.

Since the plots where the measurements took place are not as large as the satellite pixels of 1 km for the MOD15A2 (or even for the 250 m NDVI data) a scaling error is introduced biasing the comparison of in-situ measurements and satellite sensor-derived FAPAR. This could be the case for the deciduous stands where neighboring areas may lower the FAPAR values of MOD15A2. Further research is needed in order to investigate this bias.

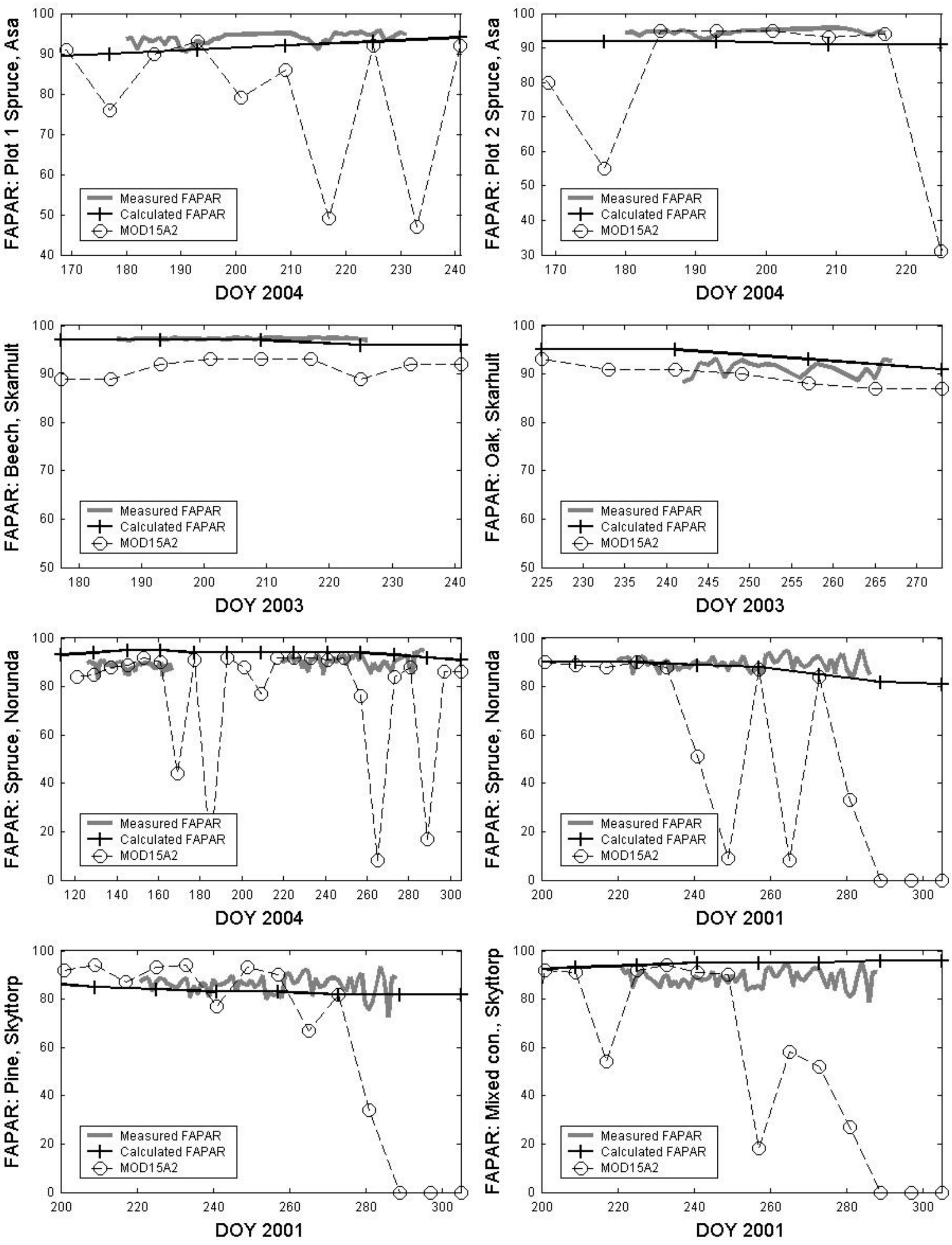

Figure 2. Measured FAPAR plotted with FAPAR from MOD15A2 and FAPAR derived from NDVI transformation.

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MAPPING FOREST COVER CHANGES CAUSED BY MINING ACTIVITIES USING SPECTRAL MIXTURE ANALYSIS AND OBJECT-ORIENTED CLASSIFICATION

O. Fernández-Manso[a], A. Fernández-Manso[a], C. Quintano-Pastor[b] and M.F. Álvarez[a]

[a] Grupo de investigación IPR-Ingeniería y Planificación Rural. University of León. EST. Ingeniería Agraria, Av. Astorga sn, 24400 Ponferrada (Spain), email: oscar.manso@gmail.com
[b] Departamento de Tecnología Electrónica. University of Valladolid

ABSTRACT

Information about mining activities location is essential for environmental applications and sustainable forest management. Advancements in satellite imagery analysis provide possibilities to investigate new approaches for forest cover changes detection caused by mining activities (coal contour surface, slate and limestone mining). Classification based purely on spectral values of pixels has its limitations and has reported to create confusion between mining affectation areas and other like urban areas or those with water bodies. These confusions are related to the problem of the mixed pixel. To provide a solution the synergy between a subpixel technique (linear spectral mixture analysis) and objected-oriented image classification was tested in El Bierzo County (Spain) with the aim to locate sites for restoration and to monitor future mines (special interest at illegal exploitations). A model was developed for this study involving the segmentation of shade fraction image into objects at once level and classification based in membership functions as classifier. The combination of both techniques showed very promising results.

Keywords: segmentation, object-oriented classification, unmixing, mining activities

1 INTRODUCTION

Remote sensing plays an important role in identifying forest areas associated with mines or older operating mine sites. Improvements in the spatial and spectral resolution of remote sensing data and new image analysis techniques have provided a wider scope for studying environmental attributes affected by mining, which include forest cover change, land and water. Mining brings about significant geomorphological changes in the mine site as well as in the surroundings. To monitor the changes in these attributes, remote sensing acts as an essential tool. Remote sensing provides the basic data to undertake inventory of land use, water resources as well as the temporal information required to monitor sustainable land management practices.

The traditional satellite image classification has been performed by pixel-based classification (unsupervised and supervised). Alternatives to this are being currently developed for instance the spectral mixture analysis (SMA) approach that takes subpixel classification techniques (i.e. SMA) on remotely sensed data and the object-oriented (OOIC) approach which is based fuzzy logic, allows the integration of a broad spectrum of different object features, such spectral, form, shape and texture.

Although SMA have been extensively used in different applications during the last decade (Cross *et al*., 1991; Ustin *et al*., 1993; Caetano *et al*., 1994; Novo and Shimabukuro, 1994), it was first proposed in the early seventies (Horwitz *et al*., 1971; Marsh *et al*., 1980; Adams *et al*., 1986). The SMA intends to derive the proportions of different basic land cover types that compose a mixed pixel. As a result, this technique is very appropriate to monitor cover change processes, since the mixture of vegetation and soil is very common in forest areas.

The objectives of this paper were: (a) to evaluate the potential of SMA and OOIC techniques using Landsat ETM+ images in the discriminating of mining activities in a forestry context; (b) to determinate the exploitation size that is capable to discriminate the model keeping in mind the complexity of the territory (El Bierzo); and (c) to map the areas affected by mining exploitations.

2 MATERIAL AND METHODS

2.1 SITE DESCRIPTION

The study was carried out in El Bierzo County (Figure 1). It is in a sheltered mountain valley on the north-western boundary of the province of León, in the autonomous region of Castilla y León (Spain) and defined by: 7º5’23”-6º6’6”W longitude and 42º54’23”-42º24’10”N latitude. The area is sandwiched between the Cordillera Cantábrica and the Montes de León, its natural limits being the Sierras de Caurel and Ancares, the Aquilanos mountains and the Sierra de Gistredo, and is irrigated by the rivers Sil, Ancares and Burdia. The mountain ranges shelter it from the excesses of both continental and temperate climate and produce some of the most exciting landscapes (i.e. Las Médulas) in Continental Spain. The altitudes are between 359 to 2,110 m a.s.l, and the mean slope is 17%. Annual rainfall is among 670 to 720 mm and temperatures range from a summer high of 32º C to a winter low of 1º C with a year- round average of 13º C. The proximity to Asturias and Galicia make it an area with its own characteristic vegetation, different to the rest of Castilla y León. It contains a microclimate where vineyards coexist with fruit trees, pastures and immense oak and chestnut forests.

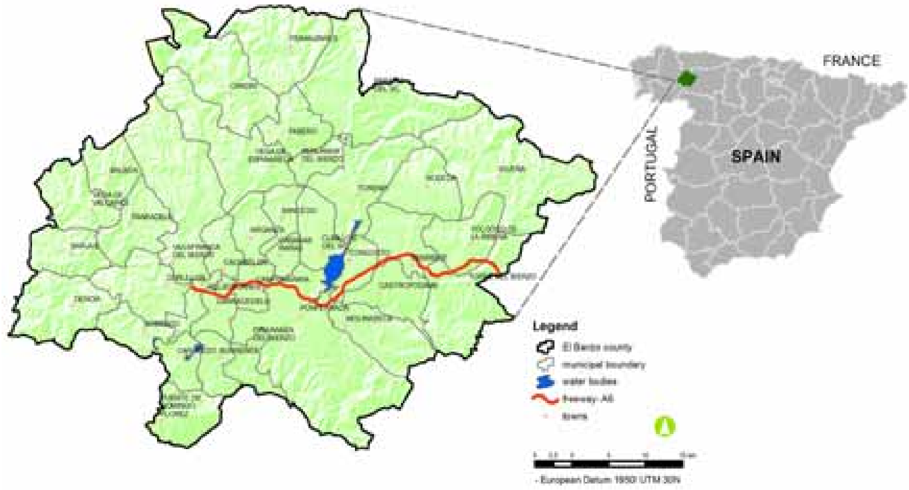

Figure 1. Location of the study area

2.2 MATERIAL

Two Landsat-7 ETM+ satellite images acquired on 20 June 2001 and 17 June 2000 were used for this research. The other datasets used in this study were: orthophoto mosaic of the area (Sept-Oct. 2000) and cadastral map.

2.3 METHODOLOGY

Prior to the SMA and OOC image analysis the Landsat image was pre-processed. Pre-processing of the remotely sensed data included his radiometric and geometric correction. Reflectivity conversion was un-necessary because linear SMA can be applied directly to the original digital numbers (DN). A mosaic of the two satellite imagery was performed as well.

Subsequently, spectral mixture analysis was applied to the image. It is generally defined as the calculation of area land cover fractions within a pixel (Roberts et al., 1998). The process involves the selection of representative pure land cover spectra (endmembers) and the unmixing of the spectral information of a pixel. The unmixing considers that each pixel can be represented as a weighted linear combination of the selected endmembers, with the weight being the endmember fractions, and a residual that all sum to one. A MNF (Minimum noise fraction) transformation was applied to the data to reduce the noise in the data and to focus the spectral unmixing on the image information with most thematic content. The final end-members used for the spectral unmixing were determined by a pixel purity analysis (PPI) that identifies the purest pixels on the edges of the multi-dimensional point cloud of pixel vectors. The PPI selected candidate pixels were evaluated and the four final endmembers (dark soil, light soil, shade and vegetation) were selected to subsequently perform the spectral mixture analysis. The next two steps: endmembers spectra definition and unmixing of bands number 3, 4, 5, and 7, were remade till de RMS error was inferior to 1. After the purest pixels were identified in the n-dimensional scatter plot, an inverse MNF transform was applied to obtain the endmembers spectra and their spectral response was visually verified. The fractions derived from these endmembers (Figure 2) then will be used as inputs in the OOIC model.

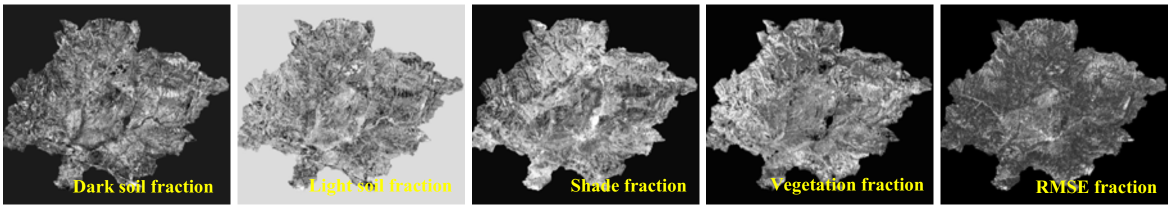

Figure 2. Fraction imagery

In contrast to classic image processing methods, the basic processing units of object-oriented image analysis (OOIC) are image objects or segments and not single pixels, moreover, classification acts on image objects. One motivation for the object-oriented approach is the fact that, in many cases, the expected result of most image analysis tasks is the extraction of real world objects, proper in shape and proper in classification. This expectation cannot be fulfilled by traditional, pixel-based approaches (Baatz, 1999).

Analysis of an image in the object-oriented approach involved classifying the image objects according to class descriptions organized in an appropriate knowledge base. The knowledge base itself was created by means of inheritance mechanisms, concepts and methods of fuzzy logic and semantic modeling. The development of the object-oriented model involved two steps, namely segmentation and classification (Mitri and Gitas, 2002).

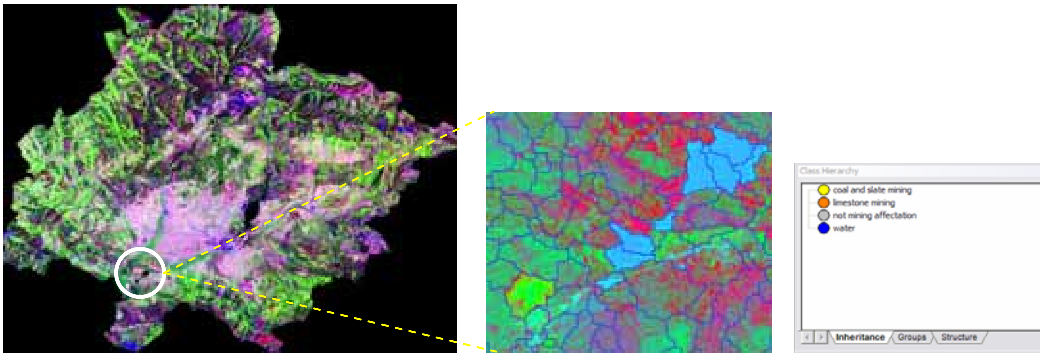

Figure 3. A section of the study area showing the segmentation and the classes

The shade fraction image was segmented into objects on once scale level (Figure 3). After segmentation, all image objects were automatically linked to a network in which each image object knows its neighbors, thus affording important context information for later analysis. Subsequently, repetition of segmentation with different scale parameter creates a hierarchical network of image objects. The better segmentation results were given out with a scale parameter of 4 and composition of homogeneity criterion (color=0.9 and compactness=0.23).

It was enough once segmentation level in discriminating between mining affectation and the other classes of confusion. We tried a multiresolution segmentation approach with two segmentation levels but were not possible to distinguish among kinds of mining activities. Anyway, our first goal was to detect these impacts and not to discriminate the type.

The objects were classified as coal and slate mining, limestone mining, not mining affectation and water without related classes. This level provided a context to detect the places with mining affectation. In the classification membership functions (fuzzy rules) was used as classifier.

3 RESULTS AND DISCUSSIONS

The map resulting from the object-oriented classification is shown in Figure 4. According to the classification the mining class occupying the largest area is coal and slate mining (1,128.62 ha) with the number of objects identified as belonging in that class being 66. The total area affected by mining detected was 1,174.84 (SD= 14.15 ha).

Figure 4. Mining activities detected by the model **Figure 5.** Site of Community Importance affected by mining

By crossing the map of classification result with the Site of Community Importance (included in the network of protected areas “Natura 2000” of the European Union-according to the Habitats Directive 92/43/EEC) was possible to observe that some of the mines detected are into or very close to cited sites (Figure 5).

Regarding to the land use affected by mining activity it was possible to determine that the largest areas influenced were shrubs and broadleaved forests (Table 1).

Table 1. Types of land use affected by mining activities

Land use	Mining type	Area (ha)	Area (%)
Broadleaved forests	coal surface; limestone; slate	288.39	24.55
Coniferous forests	coal surface; slate	59.75	5.09
Mixed forest	coal surface; slate	11.71	1.00
Shrubs	coal surface; slate	672.42	57.23
Natural grassland	coal surface; slate	129.76	11.05
Crops	coal surface; slate	7.47	0.64
Others	coal surface; slate	5.34	0.45
	Total	**1,174.84**	**100.00**

It was necessary to obtain information about the classification stability (Figure 6) and about how capable the classes were of extracting the desired image information. Besides the classical methods of accuracy assessment, special methods, based upon fuzzy concepts, were used. The accuracy of the classified image was the assessed using test areas collected in the orthophotos (pixel size of 0.7 m) and imported into the project by means of a TTA mask to compare the classification with ground truth based on pixels. Producer, user and overall accuracies were calculated along with the Kappa statistic (Congalton and Green, 1999).

The biggest error source in the classification comes mainly from the confusion with the class urban area. This problem can be solved with simplicity using a mask (cadastral map) that includes these surfaces. As for the type of extracted mineral the pattern allows to differentiate groups between two: exploitations of limestone and those of coal-slate, although it can be discriminated against later on by means of the use of the geologic map.

User \ Reference Class	water	coal and slate mining	limestone mining	not mining affectation	Sum
Confusion Matrix					
water	1081	0	0	0	1081
coal and slate mining	0	9508	0	0	9508
limestone mining	0	0	397	0	397
not mining affectation	0	4639	18	15226	19883
unclassified	0	0	0	0	0
Sum	1081	14147	415	15226	
Accuracy					
Producer	1	0.672	0.9566	1	
User	1	1	1	0.7658	
Hellden	1	0.8039	0.9778	0.8674	
Short	1	0.672	0.9566	0.7658	
KIA Per Class	1	0.5261	0.956	1	
Totals					
Overall Accuracy	**0.8491**				
KIA	**0.7205**				

Class	Objects	Mean	StdDev	Minimum	Maximum
water	42	0.04761...	0.2130	0	1
coal and slate mining	66	0.9755	0.139	0.1091	1
limestone mining	2	1	0	1	1
not mining affectation	15520	0.9999	0.007405...	0.0777595...	1

Figure 6. Accuracy assessment for the final classification/Classification stability (fuzzy accuracy assessment)

The result of the classification confusion matrix is showed in Figure 6. The overall classification accuracy was estimated to be 84.91 %. Kappa statistic was 72.05 %.

4 CONCLUSIONS

The proposed methodology allows the elaboration of forest cover change maps in the current moment in one of the main mining regions of the European Union in the obtaining of non metallic minerals.

The model works optimally for mining impacts largest than 5 ha. The tessellation and complexity of the land uses make that the smallest impacts are of difficult segregation. This apparent problem, in the practice, is resolved since the type of exploitation of more impact, surface mining, generally occupies large surfaces.

The obtained maps have a great utility for the analysis of the regressive changes in the forest since these activities correspond to the main genesis of changes.

The synergies of SMA and OOIC to map forest cover changes caused by mining activity have been demonstrated. Although this work is only in its preliminary stages the results indicate a great potential for extracting information from multispectral satellite imagery.

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CONTINUOUS COVER FORESTRY IN THE UK? QUANTIFYING FOREST STRUCTURE USING REMOTE SENSING.

R.Gaulton [a*], G. Olaya [a], E.D. Wallington [a], T.J. Malthus [a], I.H. Woodhouse [a] and J.C. Suarez [b]

[a]Edinburgh Earth Observatory, School of Geosciences, The University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, UK, *email: R.Gaulton@sms.ed.ac.uk

[b] Forest Research, Northern Research Station, Roslin, Midlothian, EH25 9SY, UK.

ABSTRACT

Forest management in the UK now has multiple objectives. While sustaining an economically viable timber yield is still important, forests must also meet recreational, aesthetic and ecological needs. In recent years there has been a national and international move towards more sustainable forestry practices which attempt to create heterogeneous stands which emulate 'natural' structures. The conversion of British even-aged conifer plantations to Continuous Cover Forestry (CCF) will pose many challenges for forest managers in terms of operational and silvicultural systems and inventory and monitoring methods, which will put added pressure and expense on traditional management systems. New approaches will therefore be needed. These may include an amalgamation of traditional field methods with current and emerging remote sensing and GIS techniques.

The transformation to CCF and continued management cannot rely on traditional inventory protocols. The interpretation of forest structure for CCF needs to be redefined to include the evaluation of the spatial distribution of parameters, such as species, height, DBH, density and age. This study aims to quantify both horizontal and vertical forest structure, initially assessing the individual tree and stand level, before extrapolating to the landscape scale.

A combination of remote sensing techniques can provide more detailed parameter measurements over a wider area at a more frequent time scale, thus providing the forest manager with better information to assist management decisions. Current research at the University of Edinburgh, in collaboration with Forest Research, uses LiDAR, SAR, Hyperspectral and other optical instruments to quantify forest structure over 4 test sites in the UK. These sites include semi-natural woodland, commercial plantations and sites in the process of transformation to CCF. This paper presents the preliminary key results of this study in terms of quantifying both vertical (with commercial airborne Lidar and X-band SAR) and horizontal forest structure.

Keywords: Forest inventory, adaptive management, heterogeneity, monitoring, SAR interferometry.

1 INTRODUCTION

In recent years, there has been a national and international move towards more sustainable forestry practices. An international commitment to more sustainable management and conservation of forests was made at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro and at the Helsinki Ministerial Conference in 1993. In the UK, this led to policy changes to encourage lower impact silvicultural systems (for example the United Kingdom Woodland Assurance Scheme of 2000), especially in conifer plantations (Malcolm *et al.*, 2001). Forest management in the UK now has multiple objectives. While sustaining an economically viable timber yield is still important, forests must also meet recreational, aesthetic and ecological needs (including maintaining biodiversity and protecting riparian zones, soils and sensitive sites) (Mason *et al.*, 1999). Clear-cutting is usually unable to meet these objectives due to the resulting lack of continuity of forest cover and major impacts on the landscape and there is growing interest in alternative silvicultural systems that more closely emulate natural forest structures and conditions. The UK Forestry Commission is therefore aiming to transform 10% of Scottish plantations and 50% of Welsh plantations to Continuous Cover Forestry.

Continuous Cover Forestry (CCF) is a new term that incorporates a wide range of well established silvicultural techniques. Mason *et al.* (1999) define CCF as 'the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clear felling'. CCF therefore aims to ensure continuity of forest conditions over time, by avoiding clear-cutting large areas of forest and making increased use of natural regeneration instead of planting. It is also usually desirable to introduce more irregularity into the stand structure and to move away from even-aged monocultures. Whatever the chosen silvicultural system, the transformation of an even-aged plantation to CCF can be a long and unpredictable process. The stand must be old enough for the trees to have reliable production of seed and can then be opened up in gaps or progressively thinned, to allow regeneration beneath the canopy (Malcolm *et al*., 2001). However, a wide range of other factors will also affect the success of transformation including windthrow risk (Mason and Kerr 2004), site conditions (Pyatt *et al*. 2001), levels of herbivory (Mason and Kerr 2004) and seed bed availability (Nixon and Worrel 1999). Forests will therefore need to be managed as they exist in situ. The silvicultural system needs to be flexible enough to adapt to the response of the forest to treatment (for example unexpected failures of natural regeneration) and the management plan should incorporate ongoing studies, research and monitoring (Wilson *et al*., 1999). This highlights the need for an adaptive management approach in both the planning and implementation stages.

1.1 IMPLICATIONS FOR INVENTORY AND MONITORING

For an adaptive management approach to be successful, inventories and monitoring before, during and after transformation will be essential. It is important to set quantitative aims for transformation and to be able to verify whether these aims have been or are being achieved. Relatively little consideration has been given to the increased and variable information and data requirements of transformation from even-aged silvicultural systems to CCF. Traditionally, UK forestry has relied on stand level measurements of factors such as species composition, height, D.B.H. and basal area, and this monitoring approach has adequately characterised the homogeneous plantation forest stands (Kerr *et al*. 2005). The uneven-aged, heterogeneous stands resulting from CCF can not be adequately monitored by such methods and within stand variations in structural parameters, natural regeneration and environmental conditions will need to be quantified. Detailed information will be needed on a more regular basis than is required for more traditional silvicultural systems. As one of the main aims of CCF is to increase the heterogeneity of forest structure it is particularly crucial to develop a method by which the spatial components of forest structure can be monitored. Forest structure can be defined as “the spatial arrangement of tree positions, the distribution pattern of species and the size differentiation between trees” (Kint *et al.*, 2004) and can therefore be characterised by the vertical and horizontal arrangement in space of different plant species and age or size class (Zenner & Hibbs, 2000). There are therefore two major components of forest structure; the horizontal and the vertical. These components cannot be separated completely but are often treated independently. Horizontal structure is usually based on tree positions and aims to describe the spatial arrangement of tree stems or attributes (such as species or size), in terms of a random, aggregated or regular distribution (Pommerening, 2002). However, spatial structure can also be described based on the position and size distribution of canopy gaps, and this may provide a simpler, more useful measure of horizontal spatial structure (Sun and Ranson, 1998). Vertical structure reflects the stratification of tree crowns and variation in tree heights within the stand (Latham *et al.*, 1998) and can also have a horizontal spatial component in terms of the distribution of canopy height and canopy gaps (and therefore light availability for regeneration) across space.

1.2 QUANTIFYING FOREST STRUCTURE

While spatial forest structure can be quantified from data collected in the field using a variety of indices and parameters (Pommerening 2002), this requires intensive sampling and the recording of tree positional information (or at least inter-tree distances) over large areas. Such indices also have limitations. Sampling errors and bias seem to be quite large in estimates of structure based on indices calculated from field data; large sample sizes are therefore often required. To give adequate accuracy levels, sample sizes may sometimes need to be in excess of 20% of tree density, which may often not be feasible in forestry applications due to time constraints and inventory costs (Kint *et al.*, 2004). Field work will also have to be followed by extensive data analysis, calculation of indices and interpretation. Alternative strategies, such as quantifying spatial forest structure from remotely sensed data, therefore need to be investigated with some urgency to allow sufficient monitoring of the transformation of stands to CCF. Remote sensing (including optical, radar and LiDAR techniques) has the potential to provide vertical and horizontal structural information with increased spatial and temporal resolution over larger areas, which may ultimately allow for cheaper monitoring of forest structure. Remotely sensed data opens up new possibilities and techniques for the retrieval of quantified estimates of structure that can be directly integrated into GIS systems and databases and could reduce the need for approaches involving sampling and extrapolation to different scales or interpolation to derive measurements between samples. Research at the Edinburgh Earth Observatory in collaboration with the UK Forestry Commission is aiming to investigate the potential applications of remote sensing to meet the increased information needs of CCF and in particular to contribute to quantifying forest structure through the use of a variety of approaches and sensors. This ongoing research will be summarized and some preliminary results presented.

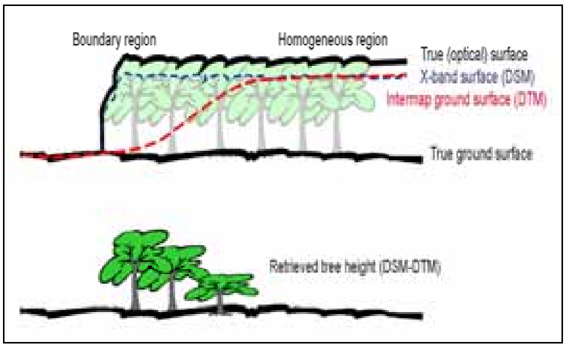
2 STUDY SITES AND DATA SETS

Four UK test sites are being used to develop remote sensing techniques to quantify the vertical and horizontal aspects of forest structure: Coed Y Brenin Forest District in North Wales (N52:49:12 W:3:53:27 lat/long); Kielder Forest District in Northumberland, Northern England (N55:11:44 W2:32:11 lat/long); Glen Affric in the Scottish Highlands (N57:17:00 W4:54:49 lat/long) and the Queen Elizabeth Forest Park, Aberfoyle in South West Scotland (N56:11:05 W4:22:00 lat/long). These sites include semi-natural woodland, conifer plantations and plantations in the process of transformation to CCF and a range of different coniferous and deciduous tree species. Data sets available for these sites include an InSAR Digital Surface Model (supplied by Intermap Technologies), Ordnance Survey DEM, Landsat TM (Thematic Mapper), Airborne Thematic Mapper (ATM), CASI hyperspectral data, Optech ALTM Light Detection and Ranging (LiDAR) and aerial photography.

3 PRELIMINARY RESULTS AND DISCUSSION

3.1 VERTICAL FOREST STRUCTURE

The retrieval of forest stand height using commercial airborne X-band SAR (provided by the Intermap Star-3i system) has been attempted at two test sites (Coed Y Brenin in North Wales and Kielder Forest in Northern England) composed of a variety of conifer species. SAR data was used in combination with ground elevation data (Ordnance Survey DEM and Intermap DTM) to estimate canopy height, an important indicator of standing biomass (Wallington *et al*., 2004). This research showed that SAR interferometry has the potential to retrieve height information at the stand level but that considerable underestimations can occur. The Intermap DTM was found to show large errors under forest canopies as the retrieved heights tend towards the top of the vegetation canopy. This results in underestimates of tree height when the DTM is subtracted from the Intermap DSM, as depicted in Figure 1 (left). Better results are obtained using an Ordnance Survey DEM to give the ground elevation data (Figure 1 (right)). Underestimations still occur but overall accuracy was increased to a RMSE of 7.4m (an error of 28.4%). This can be improved further by the removal of residual values to give a RMSE of 2.5m for inversion of the height retrieval for a 20m high tree, giving a prediction error of 12.5%. Errors in height retrieval increase in low density stands and stands on steep slopes.



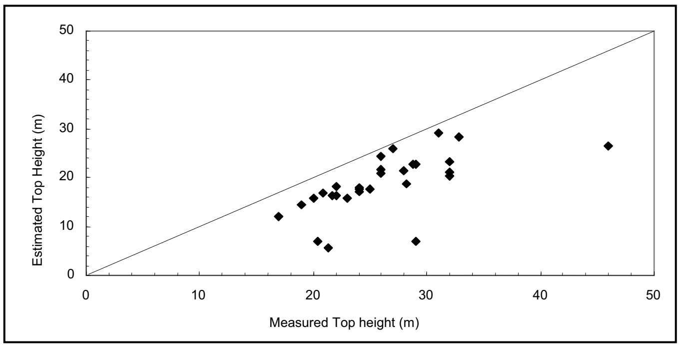


Figure 1. Left: DTM interpolation limitation (top) and corresponding (underestimated) retrieved tree height (bottom). **Right:** Measured top height against retrieved top height. From Wallington *et al*., 2004.

A newly developed Polarimetric Radar Interferometry Simulator (PRIS) was used to further examine relationships between height retrieval and forest and radar dependent parameters. Severe height underestimation near the edges of stands was found to be due to an increasing contribution of ground surface to scattering, suggesting improved height estimates may be obtained from areas further from the stand edges where the main contribution to scattering will be from the top of the canopy. More details of this research can be found in Wallington *et al*. (2005) in this volume and this research highlights the potential for using remotely sensed data to estimate the vertical component of forest stand structure in an economically viable way, allowing the creation of forest height maps with a sub-stand level resolution that can be used in CCF management.

3.2 HORIZONTAL FOREST STRUCTURE

The horizontal component of forest structure (in terms of the spatial distribution of trees and canopy gaps) can have a major effect on the light environment of a forest stand and therefore on the potential for natural regeneration to occur (which is important to the success of CCF). Currently, these factors are determined by field measurements and by hemispherical photography. This research therefore aims to examine forest structural variables determined from remote sensing as indicators of light availability for regenerating seedlings and also to evaluate the synergistic benefits of LiDAR, aerial photography and ATM imagery for crown delineation purposes.

Six plots (50m x 50 m size) were established within the Queen Elizabeth Forest Park with the purpose of measuring forest variables by using a forest inventory approach and hemispherical photography. The plots lie within stands covered by species with differing light requirements; European larch (Larix decidua), Sessile oak (Quercus petraea) and Norway spruce (Picea abies). Plots were precisely located using a Global Positioning System (GPS) unit. Within each plot, a relatively broad level of inventory was carried out including: tree-counting, DBH (diameter at breast height), identification of dead or alive trees, identification and marking of forked trees and dominance, height, and crown diameter measurement of the 25 biggest trees. These field sites were also over-flown in August 2003 by the NERC Airborne Research and Survey Facility, to collect LiDAR, ATM, and aerial photographs. LiDAR data were processed using a program written in Fortran for the purposes of classification of points as belonging to the ground or trees and to allow interpolation in areas with low ground points registration. The program works on the assumption that the lowest points in a point cloud must belong to the terrain. The program uses the raw point cloud and operates locally, performing a point by point classification using a slope-based algorithm that classifies points in a single step. After filtering, an approximate digital terrain model (DTM) and Digital Surface Model were produced. Tree heights were calculated as the difference between the interpolated ground and the DSM (Figure 2). The following metrics were derived: the quantiles corresponding to the 0, 10,…, 90 percentiles of the distributions, the maximum values and the mean values. The differences between predicted and ground truth mean heights of 0.82-1.35 m seems to correspond to findings in previous research (Means *et al.* 2000; Næsset 2002). The next stage in the research is to develop a methodology to perform crown delineation on height information from the Lidar dataset and carry out comparisons against results obtained from aerial photographs and ATM imagery. Light incidence calculated from hemispherical pictures will also be compared with the estimates from Lidar and ATM datasets with a view to quantifying the light environment of forest stands.

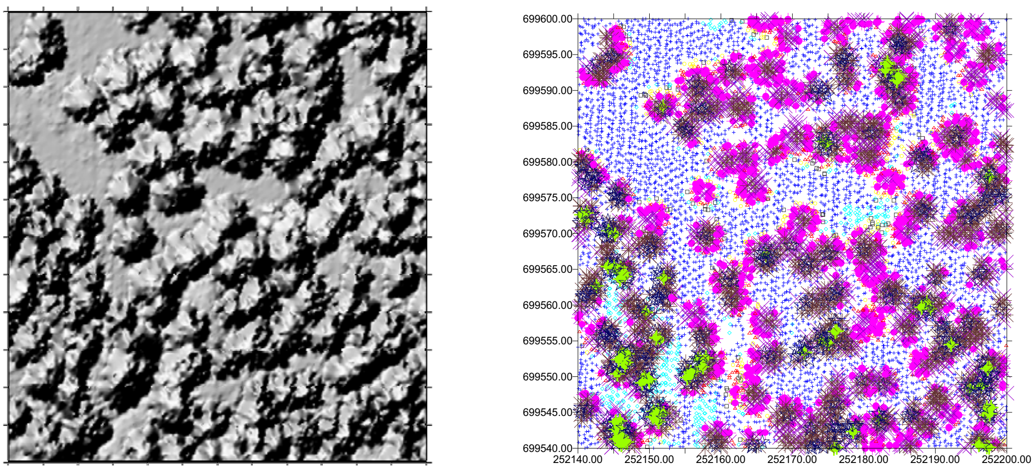


Figure 2. Left: Visualisation of the calculated lidar heights. **Right:** Image of vegetation heights derived from LiDAR data. The individual tree crowns are oak. The blue patches are clear cuts. Image brightness scales from blue for zero vegetation height to green for trees 22 to 24 m tall, in 2-meter classes.

4 CONCLUSION

Significant progress has been made in retrieving tree height at the landscape, stand and individual tree scales and the first steps have been taken to begin examining within stand variability in height and in delineating tree crowns using a synergistic approach with a view to quantifying horizontal forest structure. Quantifying within-stand variability of plantation forests in the process of conversion to CCF will allow improvements in adaptive management approaches to meet the aims of CCF (increased structural heterogeneity and the use of natural regeneration) and in monitoring and assessment of success. Further research is needed using both a modelling approach to determine how the horizontal and vertical components of spatial structure effect reflectance and texture of images and the optimum spatial resolution at which these effects can be detected and in the use of real images to retrieve these parameters for use in CCF management. Future work at the Edinburgh Earth Observatory and the Forestry Commission will aim to develop techniques by which the horizontal spatial distribution of canopy gaps and canopy height variation at the within-stand scale can be quantified from remotely sensed data (especially by the synergistic use of hyperspectral optical and LiDAR data) and used in the forestry industry as an indicator of stand heterogeneity and theoretically, in predicting the likely distribution of natural regeneration.

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UTILIZING FUZZY CLASSIFICATION IN DELINEATION OF TREELESS PEATLANDS

R. Haapanen

University of Helsinki, Dept. of Forest Resource Management
Address (home): Kärjenkoskentie 38, 64810 Vanhakylä, Finland
Tel: +358 40 5021571, email: haapanen@kauhajoki.fi

ABSTRACT

Treeless peatlands support almost no trees, but in Finnish satellite image aided forest inventory applications they are an important class to be separated from forested land-cover classes. In this study the ability of fuzzy classification to delineate treeless peatlands from Landsat satellite images was tested. Two mutually different test areas were selected: one rich in peatlands and other with very few peatlands in Finnish conditions. The results of the region with more peatlands were promising, while those from the region with minor peatland coverage were poor. In the well classified area, the differences in tree stocking and moisture content were reflected in the membership values, despite the coarse information content of the training data. If the membership values were combined with auxiliary data, reasonable results could be obtained from the poorly classified test area as well.

Keywords: Forest inventory, stratification, classification, Landsat imagery

1 INTRODUCTION

Stratification aims at improving the accuracy and efficiency of statistical inference. In forestry related satellite image applications, stratification may be used for efficient selection or post-stratification of the field sample. In Finland, a peatland mask based on aerial photography made by National Land Survey is commonly utilized in satellite image aided estimation and classification of forest variables. The field data is stratified and mineral soil forests are processed separately from peatlands. This has been shown to reduce the biases of both strata (Katila and Tomppo, 2001). However, the mask is not perfect for forestry applications. It is based on the geological peatland definition, and does not contain all peatlands by the silvicultural definition. There are also errors: some treeless peatlands are missing and some have been converted to forested peatlands by draining. The classification is not based on site types, but on tree cover and accessibility. Furthermore, it is 'hard', while the changes in tree cover and vegetation are seldom strict and sudden. More typically, the tree size and stocking change along a continuum from mineral soil forest to treeless peatland. Employing remote sensing data in the interpretation of forest variables brings in the problem of mixels, which adds artificial continuums on top of the natural ones.

In those forestry applications, where collecting of field data is minimized in such a way that more resources are allocated into the valuable strata, it is important to remove all non-productive peatlands from the calculation process, including also the sparsely forested ones. In some applications, the end-user may need a more restricted delineation. For these reasons, it would be advantageous to try to update the applied peatland mask with the same satellite imagery that is to be used for forest variable estimation. In regions, where no mask is available, one should be created from scratch. Classifications of Landsat satellite images aiming at peatland detection and habitat classification within peatlands have been carried out to some extent (e.g. Lahti and Häme, 1992; Poulin *et al.*, 2002, Boresjö Bronge and Näslund-Landenmark, 2002). More experiences have been gained as a bi-product of other classifications (e.g. Saukkola 1982; Horler and Ahern, 1985; Tomppo *et al.*, 1998). There are difficulties: peatlands vary in nutrient and moisture content more than mineral soils and many vegetation groups can form the visible surface layer of a treeless peatland. Open pools cause complex textures. The reflectances of wet peatlands mix with fully stocked mineral soil forests, while peatlands and mineral soil forests with similar stockings may differ in estimation results. This confusion of reflectances can in turn be handled with help of stratification in regions where auxiliary data sources exist, and it is another important reason for processing peatlands and mineral soils in separate strata in forest variable estimation.Fuzzy classification belongs to the group of soft classifiers. Like in traditional supervised classification procedures, ground truth information is used for training. The output is a set of images (one per class) that express the fuzzy set membership of each pixel in each class.

Foody (1996) softened the vegetation classification results of three techniques and found that this way the class composition of image pixels could be reflected in the output. Townsend (2000) studied the fuzziness in tree-cover classes as a reason for the inaccuracies of satellite image based vegetation maps. There were vegetation classes that were so similar to each other that cross-classification between them should not be labelled erroneous. However, there were also classes which were very similar to each other in the ecological sense, but the reflectances differed greatly. Townsend and Walsh (2001) successfully used fuzzy set theory for accuracy assessment after classifying forested wetlands with satellite imagery. Laba *et al.* (2002) compared conventional and fuzzy classification methods in the accuracy assessment of a land-cover map. They stated that conventional methods should be used when possible, but there are situations, when fuzzy accuracy assessment should be considered.

The aim of the present study was to test the capability of fuzzy classification for flexible delineation of treeless peatlands in Finnish landscape.

2 MATERIAL AND METHODS

Two mutually differing study areas were used in the analyses. Study area I was located in Southern Finland. It was covered by Landsat 7 ETM+ satellite image: path 189, row 17, dated 20 May 2002. Due to cloudiness only the Southwestern quarter of the image was utilized and for this remaining quarter a cloud mask was digitized on screen. According to the peatland mask (described later), treeless peatlands covered 0.6% of the area, and forested peatlands 6.4%. The peatlands were scattered, forming small compartments. There was, however, a cluster of some relatively large treeless peatlands in the area. Ditching had been common, creating new landscape types between forested and treeless peatlands. The study area II had a more northern location, most of it belonging to Kainuu region. It was covered by Landsat 7 ETM+ satellite image: path 188, row 15, dated 29 May 2002. This region has a high percentage of peatlands: 3.6% of peatland mask pixels were treeless and 27.9% forested peatlands. Both Landsat ETM+ images were rectified to the Finnish Uniform Coordinate System with an error of 0.3 pixels or less. The final pixel size was 25 m. Cubic convolution resampling was applied. In Study area II bands 1-7 were utilized, but in Study area I only bands 1-5 and 7.

A digital peatland mask of National Land Survey was available. The peatland mask comprised of the following classes: background, paludified forest, open peatland with easy access, forested peatland with easy access, open peatland difficult to enter and forested peatland difficult to enter. The ones with easy access have dry surface, and those difficult to enter are wet. This mask was used for creating simulated training data: values were picked from the digital peatland mask for a 3 x 3 window of pixels located every 2.5th kilometer in Study area I and every 5th kilometer in Study area II. Training data pixels occurring in water bodies were visually separated to own class. In all, six classes were present in the training data (Table 1), since none of the wet forested peatlands were captured.

Table 1. Pixels in different classes of training data in Study areas I and II.

	Backgr.	Paludified forest	Treeless peatland, dry	Forested peatland, dry	Treeless peatland, wet	Forested peatland, wet	Water	All
Study area I	8224	255	40	642	16	0	918	10095
	81.4%	2.5%	0.4%	6.4%	0.2%	0.0%	9.1%	100.0%
Study area II	6103	533	328	3105	77	0	1248	11394
	53.6%	4.7%	2.9%	27.3%	0.7%	0.0%	11.0%	100.0%

For evaluation, field data and digital orthophotos were available. Two separate field datasets were measured from study area I. Dataset F_Ia consisted of 369 mineral soil forest and forested peatland plots, while dataset F_Ib (153 plots) concentrated on peatlands with minor coverage on mineral soils. Two separate sets were measured also from study area II. Dataset F_IIa (220 plots) was in the Southeastern corner of the Landsat image and dataset F_IIb (312 plots) close to the centre of the image. Neither of the field datasets on Study area II contained treeless peatland plots. Attributes in field data sets contained e.g. volumes by tree species and land-cover class. Four digital orthophotos with 0.5 m field resolution from study area I and five from study area II were purchased. They covered approximately 25 km^2 each. A quarter of each photo was selected for detailed photointerpretation: photoplots corresponding to Landsat

ETM+ pixels were visually classified in 14 land-cover classes, resulting in ca. 10 000 interpreted plots per orthophoto.

The Landsat images were classified with IDRISI's (Clark labs, Clark University 2004) FUZCLASS procedure. In FUZCLASS, the fuzzy set membership is based on the standardized Euclidean distance of each pixel to the mean reflectance on each band for a signature. At the mean of a signature the fuzzy set membership is 1. Furthermore, the user inputs standard deviation limit at which fuzzy set membership decreases to zero. Here, it was set to 2. A sigmoidal membership function was used. A normalized procedure was applied, where it is assumed that full information of classes is achieved and signatures do not overlap. This was not entirely true, but in preliminary trials the results were in line with an unnormalized procedure. The degree of classification uncertainty is expressed in a separate output image. It shows the degree of uncertainty the classifier would experience if a hard answer would be required.

3 RESULTS

The fuzzy classification results differed between the study areas. First, the created membership images were compared with the existing peatland mask. In Study area I, the average membership of dry treeless peatland pixels in the corresponding class was 0.10 while in Study area II it was 0.35. The highest membership value in dry treeless peatland class in Study area I was 0.25 and in Study area II 1.0. Within the datasets measured in the field, the average memberships of field plots on mineral soil forests, spruce mires and pine bogs in separate result classes were very close to each other (Table 2). The pine bogs showed the greatest treeless peatland class membership values in dataset F_Ib, where comparison between all field classes was possible. The same was true in the photo interpretation results of Study area I. Sparsely forested and near-treeless peatlands showed highest membership values in dry and moist treeless peatland classes. Entirely treeless dry peatlands were rare, and they got low values in their own class, but somewhat higher in wet treeless peatland class. With wet treeless peatlands the situation was conversed.

Table 2. Average fuzzy memberships in classes from background to water by true land-cover group.

		Backgr.	Paludified forest	Treeless peatl., dry	Forested peatl., dry	Treeless peatl., wet	Water
F_Ia:	Mineral soil forest	0.38	0.31	0.05	0.25	0.02	0.00
	Spruce mires	0.40	0.30	0.04	0.26	0.00	0.00
	Pine bogs	0.32	0.28	0.10	0.26	0.04	0.00
F_Ib:	Mineral soil forest	0.41	0.28	0.05	0.25	0.00	0.00
	Spruce mires	0.33	0.33	0.05	0.25	0.04	0.00
	Pine bogs	0.31	0.25	0.14	0.21	0.08	0.00
	Treeless peatlands	0.43	0.22	0.06	0.14	0.06	0.09
F_IIa:	Mineral soil forest	0.48	0.22	0.03	0.17	0.10	0.00
	Spruce mires	0.49	0.24	0.00	0.17	0.10	0.00
	Pine bogs	0.34	0.26	0.02	0.23	0.15	0.00
F_IIb:	Mineral soil forest	0.37	0.21	0.06	0.19	0.17	0.00
	Spruce mires	0.37	0.23	0.01	0.20	0.19	0.00
	Pine bogs	0.31	0.23	0.05	0.23	0.18	0.00

The aerial photograph interpretation results of Study area II were more comprehensible. There the membership in dry treeless peatland class followed mostly the stand stocking. The membership in wet treeless peatland class was generally relatively high in forests growing on mineral soil and forested peatlands, but they were revealed by their low membership in dry treeless peatland class. Wet treeless peatlands got high memberships in the corresponding class, but adding some trees confused the situation. Results for photo interpretation classes from dry treeless peatland to mature forest growing on mineral soil are presented in Fig. 1. Wet treeless peatland class is also shown. The figure concerns one photograph quarter only, but the results from all five photograph quarters from Study area II were similar.

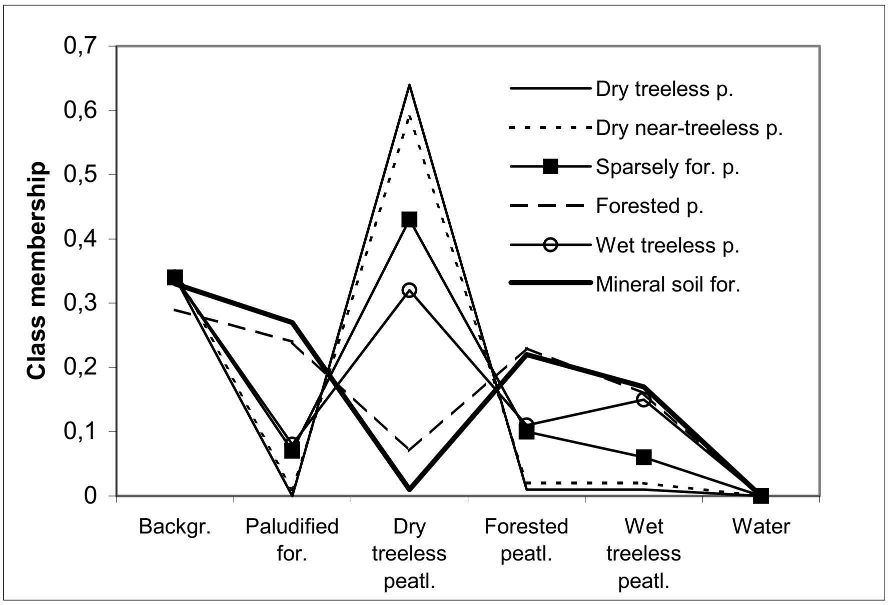

Figure 1. Average class memberships in a selection of photo interpretation classes in Study area II, one aerial photograph quarter.

The results in Study area I seem somewhat better if the volume of the field plots is examined. The treeless peatland class membership (dry and wet combined) showed negative correlation with the volume of the field plots (Fig. 2). Correspondingly, there was also an increase in the membership value when moving from better site types to poorer.

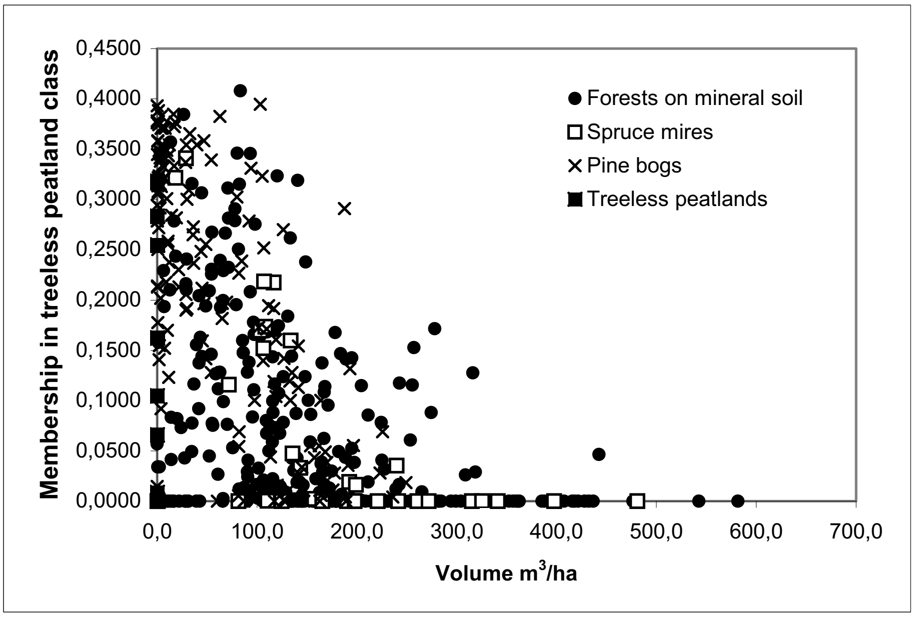

Figure 2. Treeless peatland class membership value plotted against volumes of field plots in Study area I.

4 DISCUSSION

Fuzzy classification gives means to flexible treeless peatland definition. Here the differing landscapes in separate study areas affected the results. The coarse classes in the training data could be transformed into tree stocking and moisture content degrees in Study area II, while Study area I characterized by few small and heterogeneous peatlands was classified poorly. In this test the training data was picked from existing peatland mask, but visual interpretation of satellite image or field data from National Forest Inventory could have been used as well. The regular problems in treeless peatland detection were present, but they could be alleviated with the fuzzy approach. For instance in Study area II mature forest stands got high membership values in wet treeless peatland class. However, the differences in other class memberships revealed the true land-cover. The obtained information could further be refined by combining the membership values with the information of the existing peatland mask. Even in Study area I very sparsely forested pine bogs with volumes close to 0 could be found and added to the treeless peatlands, based on high membership in treeless peatland class and location on the masks forested peatland class. A stratified approach would be the only feasible solution in cases like that of a large esker-region covered by pine forests in Study area I, where spectral differences from dry treeless peatlands were very subtle.

ACKNOWLEDGMENTS

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A LEARNING SYSTEM APPROACH FOR SINGLE TREE DETECTION IN HIGH RESOLUTION SATELLITE IMAGES

O. Hagner [a], K. Olofsson and H. Olsson.

Remote Sensing Laboratory,
Department of Forest Resource Management and Geomatics,
Swedish University of Agricultural Sciences (SLU)
[a] email: olle.hagner@resgeom.slu.se

ABSTRACT

The presentation reports on the work and preliminary results of an on-going 3-year project (2003-2005) aimed at the development of advanced methods for detection and measurement of single trees in high-resolution satellite imagery e.g. IKONOS, Quick Bird and airborne optical sensors.

The apparent radiance pattern of single tree canopies and corresponding cast shadows depends on the viewing and illumination directions, tree species, topography and atmospheric conditions. There is also a large variation among trees of the same species, due to age, size, branch structure etc. The patterns are also affected by the spatial arrangement of neighbouring trees due to cast shadows and occlusion effects. If the forest is dense and regularly spaced the contrast between the sunlit part of tree crowns and shaded background allows for the use of simple "blob segmentation" algorithms or template matching techniques. However, sparse or open forest conditions motivate more advanced methods that explicitly accounts for the spatial arrangement of neighbouring trees.

The detection algorithms under development in this project are based on a learning system approach using artificial neural networks with a feedback loop that incorporates an iteratively refined hypothesis of tree positions into the detection process. The networks are trained on datasets generated by a new geometric-optical model developed specifically for this application. The model is driven by detailed field plot information from the National Forest Inventory database. The paper focus on the specific image processing and detection algorithms to be used in the analysis.

Keywords: Single tree detection, geometric-optical model, high-resolution satellite images, neural networks, National forest inventory.

1 INTRODUCTION

The spectral signature alone for groups of trees (many trees per pixel, as obtained with for example Landsat TM or SPOT HRV) does not contain sufficient information to effectively resolve tree size and structural parameters. The reason for this ambiguity is that canopy closure; leaf area index, species composition and the ground cover type are the main driving factors for the spectral reflectance (Syrén, 1990, Hagner, 1997, Nilsson et al., 2003). The specific effects of tree size and vertical canopy structure are quite marginal. It has however been shown that the structural properties of the forest canopy has a significant influence on bi-directional reflectance (Li and Strahler, 1986) thus indicating that repeated imaging from multiple viewing angles might resolve some of the ambiguity. As a consequence, the spectral response to increased stem volume saturates as the forest canopy approaches full closure. Another problem is that the response from the forest canopy cannot easily be separated from that of the ground vegetation. The inability to separate density from size and ground vegetation severely limits the utility of medium resolution satellite imagery for operational forestry management at the stand level (Holmgren and Thuresson, 1998).

The new generation of high-resolution satellite imagery with a resolution of 2 meters or better allows for individual tree canopies to be resolved and separated from the background which provides the means for truly effective characterisation of tree size, stand structure, and ground vegetation.

Single tree detection in high-resolution optical imagery has been demonstrated in several studies. It has been shown that relatively simple algorithms are quite sufficient in the case of well-stocked homogenous coniferous stands viewed in nadir (Pinz, 1989, Dralle and Rudemo, 1996). Broadleaf trees with irregular crown shapes can be delineated with contour-following methods (Gougeon, 1995, Brantberg, 1999).

Medium-stocked or open uneven-aged forests are much more challenging, since the pattern and contrast of cast shadows tend to dominate over the tree crown pattern. These cases require more advanced methods based on a geometric-optical model of tree canopies that accounts for the specific illumination- and viewing geometry (Pollock, 1996, Korpela 2004). One of the more problematic forest types are dense stands of broadleaf trees with irregular shaped crowns that blend into each other and form a more or less continuous forest canopy. Although it is almost impossible to identify individual trees in this case, the pattern still contains valuable information on species, age- and size distribution etc. that can be extracted with texture-based methods (Pollock, 1996, Hagner, 1997, Franklin, 2001). If the spatial resolution is sufficient to derive textural characteristics from within individual tree crowns the classification of species can be improved (Pollock, 1996, Brandtberg, 1999).

A common feature of the detection algorithms mentioned above is that they do require some form of parameter tuning in order to produce useful results. Unless there is reliable ground truth available, the tuning has to be done subjectively with ad-hoc methods, which is not satisfactory if the method is required to produce consistent or repeatable results. To address these problems an improved detection algorithm should also utilise the cast shadow from the tree itself and account for the occlusion and shadowing effects from adjacent trees. It should also be more flexible in terms of crown shapes and branch structure in order to account for the natural variability.

Due to the very complex nature of the underlying model, the inversions problem cannot be solved with analytical methods without too much simplification. Hence empirical methods have to be used instead. Neural networks have been shown to be an excellent tool for model inversion (Pinz et al 1993, Pierce et al 1994, Hagner, 1997, Kimes et al 1998, Jensen et al 1999, Atzberger, 2001, Udelhoven et al 2001). The problem is that the higher degree of model complexity, the larger training set is required. This means that in practice huge training sets (in the order of hundreds of thousands sample plots) are needed to derive the kind of inversion model mentioned above. For obvious reasons the effort and costs required to derive such a dataset by field measurements is prohibitive.

Fortunately there is a solution to the problem. By development of a geometric-optical model capable of realistically simulating the response of high-resolution optical sensors for groups of trees in representative viewing and illumination conditions, such datasets could be derived. By integrating the model with the National Forest Inventory (NFI) database for individual tree positions on permanent plots, training sets can be derived by simulation techniques that represent the full spectrum of forest types.

As part of an ongoing three year project financed by the Swedish National Space Board, such a geometric-optical model is being implemented at the Remote Sensing Laboratory, SLU, Sweden. The current implementation is working and is a simplified version of the final model. A complete implementation of the geometric-optical model is intended to be finished at the end of 2005.

2 GEOMETRIC OPTICAL MODEL

A detailed description of the geometric optical model is found in (Hagner and Olofsson 2005). It is modular and consists of:

- A scene model including a detailed representation of the vegetation and soil layers. The vegetation optical properties based on the structural of the scene are represented in a 3-dimensional grid of volume elements (voxels)
- An illumination model that specifies direct and diffuse illumination
- A radiative transfer model that calculates the radiation flux in each voxel
- A sensor model that calculates the response of a specific sensor.

3 TREE DETECTION ALGORITHMS

The detection algorithm is based on a learning system approach where the detection algorithm "learns " to recognise the significant features by training on a very large training data set consisting of synthetic imagery produced with the geometric-optical model (figure 1). The model will be driven by national forest inventory plot data to ensure that the spatial arrangement and size distribution of trees is representative for Swedish forests.

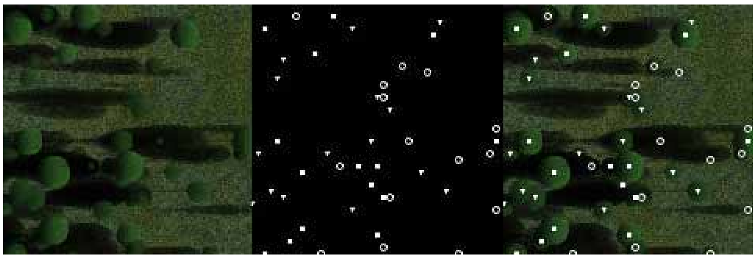

Figure 1. A virtual forest and the corresponding tree positions (reference tree map). This type of data will be used in the training of the detection algorithms. The circles, the squares and the triangles mark the positions of spruce, birch and pine trees.

The detector is recursive and incorporates a feedback loop where the tree map with confidence levels derived from previous loops is used as input features. To start with, the tree map consists of randomised tree positions with zero confidence but gradually converges towards a final hypothesis of tree positions as the detector is reiterated. A simplified representation of the network structure is shown in figure 2. Each node is fully connected to all nodes in the next layers.

4 IMAGE PROCESSING AND FEATURE DESCRIPTORS

Initial image processing consists of radiometric calibration, orthorectification, scaling and rotation to a standardised illumination direction and pixel size. The radiometric processing transforms the image data into standardised panchromatic intensity, hue and saturation components. The spatial pattern of the input imagery is encoded by directional scale-space filters (Freeman and Adelson 1991). The spectral features will be represented by ratios between spectral bands at different resolutions after radiometric calibration.

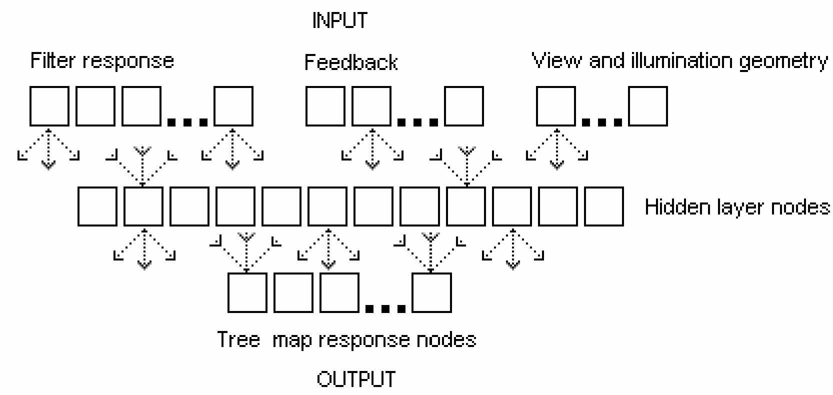

Figure 2. Outline of the detector neural network. Each node in the hidden layer is connected to all nodes in both the input and output layers. The input nodes represent scale-space filter responses, spectral features, tree map with associated confidence levels, view and illumination geometry and geographic information. The output layer represents detection confidence levels for trees (by species and size class) at different locations relative to the anchor point of the processing window.

5 DISCUSSION

Due to the parallel nature of the neural network, the trained detector should be able to detect trees both by the aid of the cast shadow and the crown itself. Since the detection output refers to the actual tree position in 2D is also straight forward to include multiple viewing directions, dates and sensors in the detection process. The method is well suited for computationally efficient implementation due to the parallel nature of neural network and scale space filtering. The detector will be implemented and tested on Swedish coniferous and mixed forests during 2005. It is our belief that there is a need to start using adaptive systems, AI-systems and more input data such as several viewing angles to increase the accuracy of single tree detection systems.

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AN EMPIRIC FOREST REFLECTANCE MODEL FOR AUTOMATED CALIBRATION OF LANDSAT DATA

O. Hagner and H. Olsson

Remote Sensing Laboratory
Department of Forest Resource Management and Geomatics
Swedish University of Agricultural Sciences
SE-901 83 Umeå, Sweden
email: Olle.Hagner@resgeom.slu.se

ABSTRACT

Empirical functions for calibrating different Landsat TM or ETM+ images into a common reflectance scale have been developed for Swedish forest conditions. The functions for converting the six reflective TM bands to reflectance are based on the forest parameters measured on more than 18000 national forest inventory (NFI) plots. Corresponding reflectance signatures for the NFI plots were derived from calibrated Landsat imagery. The Landsat scenes used for developing the functions were first calibrated to reflectance by relative calibration against simultaneously acquired Terra MODIS reflectance products. The functions are aimed to be used for automated reflectance calibration without the requirement for specific information on atmospheric conditions at the time of image acquisition. Calibrated satellite imagery will enable the use of standardised functions for forest type classification, estimation of forest parameters, change detection etc. An extension of the model to also incorporate the spectral bands of the SPOT satellites is currently in progress.

Keywords: Reflectance calibration, Landsat, regression analysis.

1 INTRODUCTION

The Swedish Forest Administration is yearly acquiring a nation wide data set with satellite data of Landsat / SPOT type. The images are used for change detection of new fellings but also for other tasks, such as surveillance of areas with young forests, where it is a likely need for pre commercial-thinning. Due to the fact that the scaling between Digital levels (DN) and surface reflectance is unique for each satellite scene, each image must be analyzed with image unique thresholds. A more homogenous scaling between DN and surface reflectance would allow for more automated image analysis methods. This would be welcomed since the digital image analysis of these data is carried out at local level, at about 100 district offices.

Also the Swedish University of Agricultural Sciences has a need for developing methods that calibrates satellite data to a common radiometry. We are producing nation wide forest data bases, which are trained with National Forest Inventory sample plots. With current methods, we are limited to selecting field plots within the area covered by a satellite scene.

There are several reasons for the image unique scaling between digital values that is recorded by a satellite sensor and the actual surface reflectance. The radiance sensed by a satellite sensor is dependent on the sun elevation and the atmospheric optical thickness, which are factors that vary between acquisition dates. There is also a risk for variations in the sensor calibration and the pre-processing of the data. Furthermore, there are natural reasons also for variation of the surface reflectance in the boreal landscape, including penology differences and decreased reflectance at low sun angels because of increased shadows.

There are two main approaches to radiometric calibration of satellite data. In the *physical approach*, the surface reflectance is computed from the radiance recorded by the satellite sensor, by modeling the atmospheric influence on both the incoming sun irradiance and reflected radiance with computer software's such as 6S. This requires good knowledge about the atmosphere, as well as all other factors influencing the reflectance. When reflectance calibrated Landsat TM data from different dates are compared, the absolute difference in reflectance is often in the order of 0.01 reflectance. Since this is the same order of magnitude as the reflectance differences to be studied in the boreal forest, absolute calibration used alone is generally not a good solution. The *relative calibration* approach is based on normalizing grey values towards a reference scene, using statistical methods. This method generally works well for forestry applications, but there is a requirement for scenes with overlapping areas and the method will not directly provide results scaled to reflectance.

In this paper, we present a third method for reflectance calibration. It is based on scene wise prediction of reflectance with regression functions using forest variables from a large number of forest inventory plots. This allows reflectance calibrated scenes to be produced over any area where the forest plots are available. In the paper three steps of the method are briefly described: *i)* relative calibration of Landsat ETM+ reference scenes against MODIS reflectance calibrated data; *ii)* development of a regression model for reflectance calibration, based on National Forest Inventory plots; *iii)* and application of the reflectance model on uncalibrated TM scenes.

2 METHODS

2.1 REFLECTANCE DATASET

A large dataset containing NFI field plot data matched with Landsat surface reflectance data was compiled by selecting Landsat scenes from the Image-2000 dataset that had corresponding MODIS BRDF-corrected reflectance data available (Vermote and Vermeulen, 1999). A total of 7 Landsat scenes from 2000, 2001 and 2002 were selected. Only summer scenes between July 5 and August 11 were used. The scenes represented boreal forests in northern and central Sweden. Unfortunately no scenes from southern Sweden with matching MODIS-data were available. The NFI field data and the Landsat images were processed in the MUNIN production line (Reese *et al.*, 2003) to identify and eliminate abnormal observations and also to eliminate illumination effects due to sloping terrain and effects of within-scene differences in atmospheric optical thickness (Hagner and Olsson, 2004).

The Landsat scenes were calibrated to surface reflectance by relative calibration against the reflectance calibrated MODIS scenes, using regression analysis. Due to the different spatial resolution the Landsat data was averaged. Corrections of the regression functions for geometric matching errors were applied based on a technique suggested by Bondesson (1985). The final dataset consisted of 18350 NFI-plots on forest land with corresponding surface reflectance factors for the six reflective Landsat bands.

2.2 REFLECTANCE MODEL

Based on previous modeling efforts, a set of regression models that estimates the nadir reflectance factor obtained from the TM data based on forest properties obtained from the NFI plots, were derived. The final reflectance model included 33 parameters that account for the effects of stem volume, species composition, stand age, basal area, field vegetation type, soil moisture, site quality, and the rapid vegetation succession after clear felling. The estimation model also included indicator variables to account for residual scene-specific effects that were unrelated to forest conditions.

2.3 CALIBRATION PROCEDURE

For applying the regression models on new, uncalibrated Landsat images, a simple calibration procedure was developed where the reflectance factors predicted for each NFI plots are regressed on the corresponding pixel values sampled from the satellite image. The derived gain parameter is then adjusted by a band-specific scale factor to correct for the bias induced by the prediction errors of the reflectance model. Finally the offset term is calculated so that output and modeled means become identical.

3 RESULTS

3.1 RELATIVE CALIBRATION AGAINST MODIS DATA

The calibration results for the seven Landsat scenes were inspected visually by overlaying them on of the corresponding MODIS datasets. The boundaries between adjacent Landsat scenes was also checked in both visible and infrared bands. The results were very satisfactory provided that local atmospheric and slope nduced illumination effects had been removed from the TM scenes. An example of the calibration result is shown in figure 1. After calibration and haze removal, the only visible difference are the clouds in the right scene.

Figure 1. Results of relative calibration of Landsat imagery against the MODIS BRDF-corrected surface reflectance product. The left image shows the uncorrected scenes (top of atmosphere radiance) and the result after correction is shown in the right image. Local variations in atmospheric optical thickness and illumination effects due to sloping terrain in the Landsat data has been removed by processing in the MUNIN production line.

3.2 REFLECTANCE MODEL

The model parameters were estimated separately for each Landsat band with the natural logarithm of the nadir surface reflectance as the response variable and 33 field plot variables as predictive variables. Scatter plots of observed DN values versus modeled reflectance's showed near linear correspondence (figure 2). Also the general interband relationships were checked visually with band-to-band scatterplots of both the relative calibrated and modeled reflectances. The results indicate that the functions produce realistic results (figure 3).

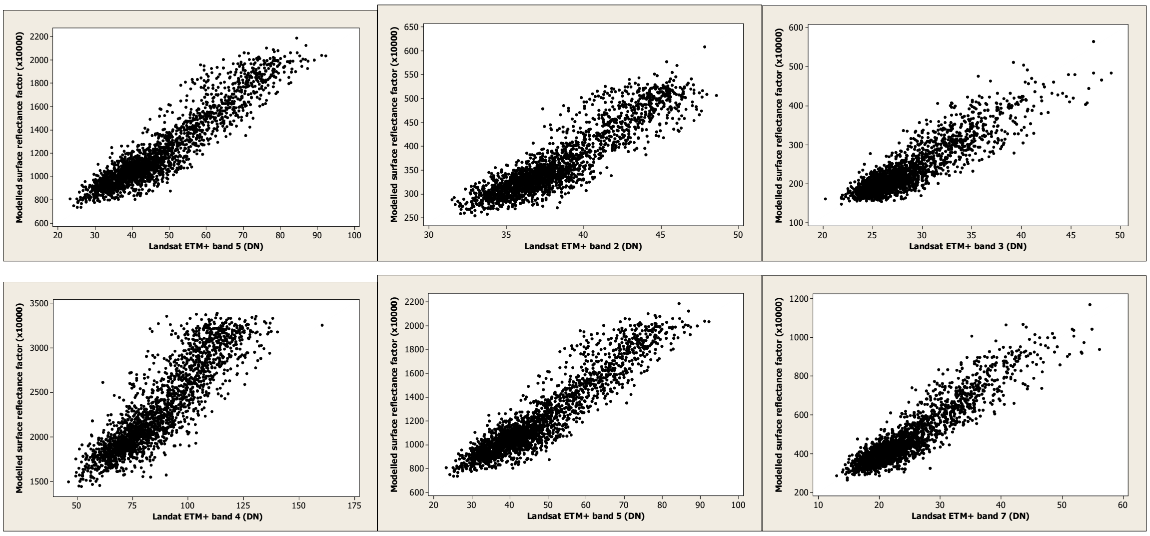

Figure 2. Scatter plot for modeled reflectance versus observed DN values for all bands, scene 193/15 2000-07-29.

3.3 CALIBRATION

The calibration coefficients for each ETM+ scene and band derived using the NFI-data based reflectance model corresponded very well to the coefficients derived by relative calibration against MODIS data (figure 4). The visible inspection of the calibration results (figure 5) confirmed that the NFI-plot based regression model is able to produce uniform mosaics, provided that local atmospheric effects are corrected. Correction factors to account for logarithmic bias and regression fallacy were derived from the training set.

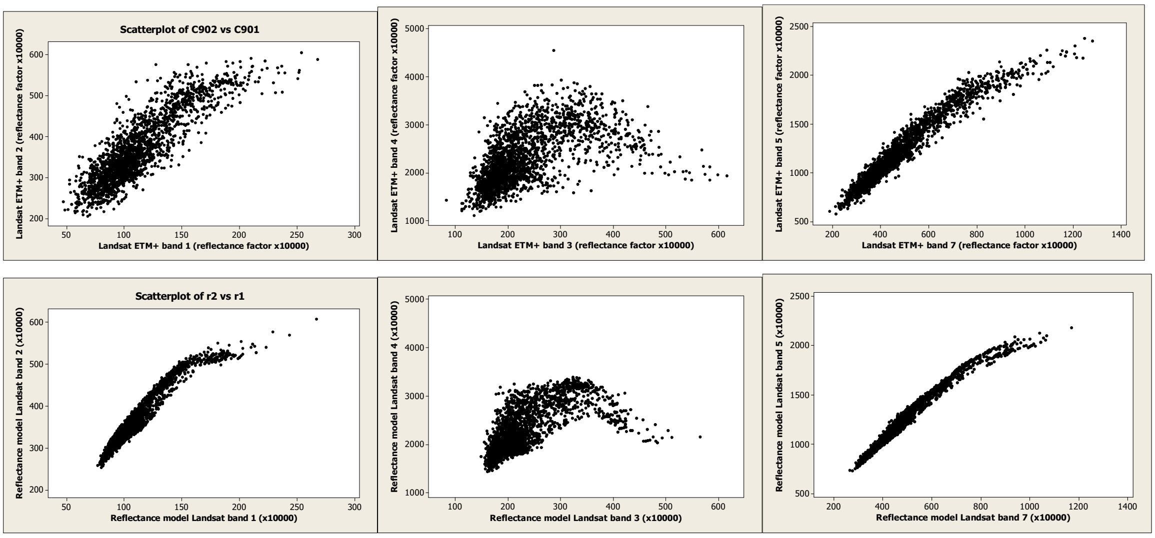

Figure 3. Scatter plots of surface reflectances for pair wise Landsat TM bands. Upper row: actual reflectance's for pixels corresponding to NFI plots, obtained by relative calibration against MODIS data. Lower row: reflectance's for the same NFI plots, obtained by applying the developed regression functions based on the NFI data.

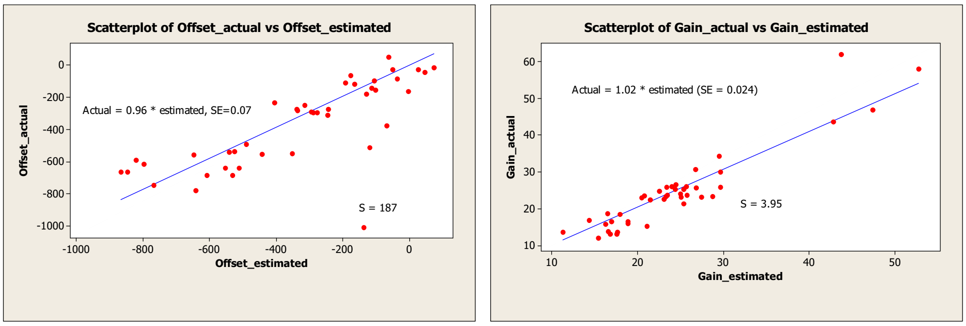

Figure 4. Plots showing the correspondence between actual (obtained from relative calibration against MODIS data) and model-based (obtained from NFO plots) calibration parameters for all the reflective Landsat bands and all scenes.

4 DISCUSSION

As shown above, the reflectance model and calibration procedure works well for boreal forests in northern and central Sweden. Further testing is on the way to reveal if it can also be applied in other parts of the country such as alpine forests close to the mountain range or more broadleaf dominated forests in southern Sweden. The calibration procedure will be integrated into the MUNIN production line by the end of 2005. An extension of the model to also incorporate the spectral bands of the SPOT satellites is currently in progress.

Since image unique dummy variables is used in the parameter estimation of the reflectance model, the model will calibrate the TM images to the reflectance of the reference date where bo dummy variables are used, in this case July 27, 2000. Thus, the reflectances obtained at the calibration of a new scene is not true reflectances for that date, but instead estimated reflectances as they wewe at the reference date. This is however an advantage if the the reflectances should be used for enabling standardised processing routines.

Relative calibration of Landsat scenes with MODIS reflectance product as reference can only be applied for relatively recent dates. Of the 58 scenes in the Image 2000 dataset used for production of the CORINE land cover map, only 10 have corresponding MODIS data available. A major benefit of using NFI plots as spectral reference is that archived Landsat data can be processed since NFI-plot data is available for entire period of Landsat operations.

Figure 5. Mosaic of the visible bands in three Landsat scenes before (upper image) and after calibration (lower image) The left scene was registered July 27, 2000, the middle scene in August 11, 2002 and the right scene in July 27, 2000.

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EVALUATION OF AERIAL PHOTO-INTERPRETATION FOR ESTIMATION OF FOREST STEM VOLUME AT STAND LEVEL

M. Magnusson and J.E.S. Fransson

Swedish University of Agricultural Sciences
Department of Forest Resource Management and Geomatics
Remote Sensing Laboratory
SE-901 83 Umeå, Sweden
Tel: +46-90-7868579, Fax: +46-90-778116
Email: Mattias.Magnusson@resgeom.slu.se

ABSTRACT

In this paper the accuracy of forest stem volume estimation at stand level has been investigated using aerial photo-interpretation in an analytical stereo instrument. The test site is located in the south of Sweden and consists mainly of coniferous forest. The stem volume for the selected stands was in the range of 15-585 m^3 ha^{-1} with an average stem volume of 266 m^3 ha^{-1} and an average size of 3.5 ha. Panchromatic aerial photos were collected by the National Land Survey of Sweden with a wide angle WILD RC30 15/4 Uag-S camera at a flight altitude of 4 600 m above ground level, corresponding to a scale of about 1:30 000. Contact dia-positives were used in the aerial photo-interpretation conducted by three professional interpreters, individually. The accuracy in terms of root mean square error (RMSE) was found to be 21% of the average stem volume. In particular, the obtained result was compared with previous studies using multi-spectral optical satellite data over the same forest stands. In these studies, SPOT-4 and Landsat ETM+ showed an RMSE of 24% and 25%, respectively. In conclusion, the aerial photo-interpretation provided more accurate stem volume estimates than the multi-spectral optical satellite images.

Keywords: Aerial photo, forest inventory, photo-interpretation, stand level, stem volume.

1 INTRODUCTION

Aerial photos have been used for decades to estimate forest parameters in support of forestry management planning (e.g., Åge, 1985). Through manual interpretation in aerial photos using a stereo instrument, stand delineation, tree species composition, and stand density can be performed. The stereoscopic view also allows accurate tree height measurements in forest stands provided that the ground is visible in the photos. Using tree height and stand density, standwise stem volume can then be estimated through established tree species specific empirical functions (e.g., Tomter, 1988; Jonson, 1914). A forest stand is considered as homogenous forest in terms of tree cover and site conditions, typically 0.5-20 ha in size. Stem volume represents the trunk volume per unit area (m^3 ha^{-1}) excluding branches and stumps. According to the major Swedish forest companies stem volume is one of the most important parameters in forestry planning (Walter, 1998). To improve forest parameter estimation using aerial photo-interpretation a subsequent subjective field inventory can be performed. The interpretation and the subsequent field inventory are based on manual work and rely on the expertise of the personnel involved.

Aerial photo-interpretation for stem volume estimation in panchromatic photos (e.g., Ericson, 1984; Ståhl, 1992) and IR-color photos (e.g., Ståhl, 1988) in the scale of 1:30 000 have been carried out at different test sites in Sweden. Ericson (1984) reported a standard error of 19% of the average stem volume in the range of 60-425 m^3 ha^{-1} (average 189 m^3 ha^{-1}) for a test site located in the central part of Sweden. On two other test sites, located in southern and in northern Sweden, with stem volumes ranging from 80-500 m^3 ha^{-1} and 70-350 m^3 ha^{-1}, the standard errors were 26% and 13.5%, respectively (Ståhl, 1988; Ståhl, 1992). Norwegian studies using either panchromatic or IR-color aerial photos in the scale of 1:15 000 show a standard error in the range of 13-33% for stem volume estimation (Eid, 1996; Næsset, 1996; Eid and Næsset, 1998). In the Swedish studies, stand density was represented by volume density, i.e., actual standing stem volume in relation to a fully stocked stand according to Jonson (1914), and in the Norwegian studies by crown closure. All studies were performed in coniferous dominated forest at stand level using analog stereo instruments.

The objective of this paper is to evaluate the accuracy of forest stem volume estimation at stand level using aerial photo-interpretation in an analytical stereo instrument. In particular, the obtained result is compared with previous studies using multi-spectral optical satellite data over the same forest stands investigated.

2 TEST SITE AND FIELD DATA

The test site, Remningstorp, is located in the south of Sweden (58°30'N, 13°40'E) and covers about 1 200 ha of productive forestland. The prevailing tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and birch (*Betula* spp.). The dominant soil type is till and where present the field layer consists of blueberry (*Vaccinium myrtillus*) or narrow thinned grass (*Deschampsia flexuosa*). The topography is fairly flat with a ground elevation varying between 120 and 145 m above sea level.

Altogether, 106 stands were randomly selected and objectively field inventoried using the forest management planning package (Jonsson *et al.*, 1993). The standwise estimated stem volumes and tree heights from field measurements collected between 1997 and 2002 were adjusted to 2001 to match aerial photo acquisition. In this study, stands were selected using the criteria of coniferous stem volume >70%, soil type till, and ground slope <4°. These criteria were set up to limit the variation of variables that could influence the estimation of stem volume. In total, 61 stands were chosen in the stem volume range of 15-585 m^3 ha^{-1} (average 266 m^3 ha^{-1}) corresponding to basal area weighted mean tree heights in the range of 5-27 m (mean 18 m). The stands varied between 0.6-19.2 ha in size, with an average of 3.5 ha. On average, nine sample plots (radius 10 m) were measured in each stand. The estimated accuracy, in terms of standard error, was about 9% of the average stem volume and 2% of the average tree height, at stand level. Additional, 12 objectively inventoried sample plots located outside the 61 stands were selected as reference plots for the aerial photo-interpretation. The plots were chosen to match the stem volume range and the above set up stand criteria.

3 AERIAL PHOTO-INTERPRETATION

The panchromatic aerial photos were registered April 22, 2001, with a wide angle Wild RC30 15/4 Uag-S camera mounted on an airplane looking in nadir mode. The film type was Kodak Double-X and a 505 nm filter was used to exclude the blue light. The photos were registered by the National Land Survey (NLS) of Sweden at a flight altitude of 4 600 m above ground level with a scale of about 1:30 000 in the photos. The overlap between the photo pairs was 63%. The weather condition was good and the relation between the height of an object and the length of the corresponding shadow was 1.4. The photo quality was graded 5 by the NLS on a scale from 1 to 7 where 1 is very poor and 7 very good regarding weather condition, photo exposure, and photo processing. Contact dia-positives were used in the aerial photo-interpretation. The aerial photo-interpretation was performed in a Zeiss Topocart instrument upgraded by QASCO QA (Analytical Conversion) to an analytical stereo plotter, i.e., an instrument used for measuring photo coordinates that is transformed to ground coordinates (Kraus, 1993). The viewing magnification of the instrument had a power of 6 times. The standard error in height measurements using an analytical stereo plotter, including photo quality, instrument error, and errors produced by a professional aerial photo-interpreter, is expected to be better than 0.015% of the flight altitude for a well defined object (Boberg, 2001).

Three professional aerial photo-interpreters conducted the interpretation, individually. Measurements of basal area weighted mean tree height, interpretation of tree species composition, and volume density according to Jonson (1914) were performed for the 61 stands. In the interpretation procedure, the objectively inventoried sample plots located outside the selected stands were used as reference plots. Finally, with access to the subjectively inventoried forest management plan each of the interpreters adjusted their results in order to improve the stem volume estimation.

4 STATISTICAL ANALYSIS

Standwise stem volume derived from aerial photo-interpretation was estimated through established empirical functions according to Jonson (1914). The stem volume accuracy assessment was performed both in absolute (m^3 ha^{-1}) and relative terms (%) of standard error, systematic error, and RMSE. The difference between subjectively estimated stem volume from the aerial photo-interpretation ($\hat{v}_i$) and objectively inventoried stem volume (v_i), denoted Δ_i, for stand i was used to calculate the standard deviation (i.e., standard error), Std_Δ, and bias (i.e., systematic error), $\overline{\Delta}$:

$$Std_\Delta = \sqrt{\frac{\sum_{i=1}^{n}(\Delta_i - \overline{\Delta})^2}{n-1}}, \tag{1}$$

$$\overline{\Delta} = \frac{\sum_{i=1}^{n}\Delta_i}{n}, \tag{2}$$

where $\Delta_i = (\hat{v}_i - v_i)$ in absolute and $\Delta_i = (\hat{v}_i - v_i)/v_i$ in relative terms, respectively, n is the number of stands. The RMSE was calculated as:

$$RMSE = \sqrt{Std_\Delta^2 + \overline{\Delta}^2} \quad . \tag{3}$$

The statistical significance of the mean differences was assessed by means of a two-sided t-test, i.e., to test whether systematical differences are present. To correct for systematic error, a ratio estimator and a regression estimator, respectively, were applied. The ratio estimator was calculated as the average stem volume from field data divided by the average stem volume from aerial photo-interpretation and used as correction factor. The regression estimator was derived using a linear regression function describing the relationship between stem volume from field data and stem volume from aerial photo-interpretation, and used for correction. For the accuracy assessment calculated in relative terms, weighted linear regression was used with a weight $w_i = 1/\hat{v}_i^2$ for the ith stand. The intercept and slope regression coefficients were estimated by means of ordinary least squares. The RMSE of stem volume was corrected for sampling error as described in Fransson et al. (2001). In addition, accuracy assessment of tree height measurement in the aerial photos (both in absolute and relative terms) was calculated and expressed in RMSE, at stand level. The results were presented in relative terms of the average stem volume and average tree height from field data for the three interpreters, denoted A, B, and C. Finally, the average of the relative standard error, systematic error, and RMSE for the three interpreters was calculated.

5 RESULTS

The results from the aerial photo-interpretation are presented in Figure 1 and Tables 1 and 2. In Figure 1, stem volume is plotted against estimated stem volume from aerial photo-interpretation, at stand level.

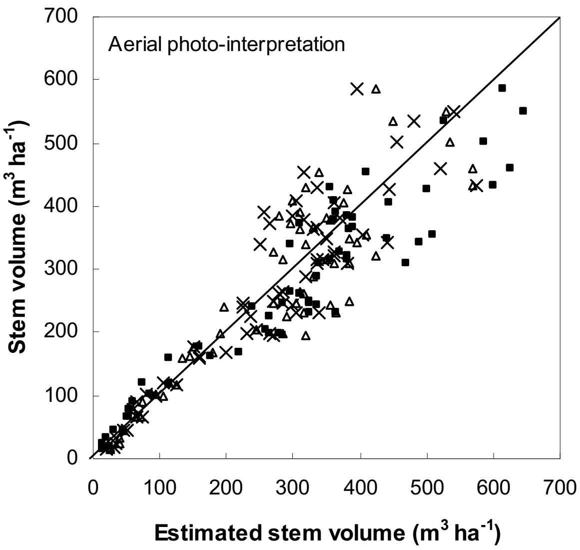

Figure 1. Stem volume plotted against estimated stem volume from aerial photo-interpretation for three professional interpreters A (■), B (×), and C (Δ) based on 61 objectively inventoried stands.

For the accuracy assessment calculated in absolute terms, the standard deviation of the difference between subjectively estimated stem volume from the aerial photo-interpretation and objectively inventoried stem volume was on average 23.5% with an average bias of 4.6%. The *t*-test showed that the stem volume estimates from one of the three photo-interpreters systematically differed from the objectively inventoried stem volumes. The RMSE of stem volume estimate was on average 24.5% and corrected for sampling error 23.7%. Applying the ratio estimator an average RMSE of 22.3% was obtained, corresponding to 21.4% after correction for sampling error. The RMSE using the regression estimator was on average 22.0% and 21.1% after correction for sampling error. For the accuracy assessment of tree height measurement in aerial photos the RMSE was found to be 8.4% on average (Table 1).

Table 1. Stem volume accuracy calculated in absolute terms and expressed in relative standard deviation (Std_Δ), bias ($\overline{\Delta}$), root mean square error (RMSE) for uncalibrated, ratio and regression calibrated stem volume, and tree height measurement for three professional aerial photo-interpreters based on 61 objectively inventoried stands.

	Std_Δ (%)	$\overline{\Delta}$ (%)	Uncalibrated RMSE (%)	Ratio cal. RMSE (%)	Regression cal. RMSE (%)	Tree height RMSE (%)
Interpreter A	22.5	12.0***	25.5 (24.8)	19.3 (18.3)	18.5 (17.4)	7.1
Interpreter B	22.9	-0.8ns	22.9 (22.0)	22.9 (22.1)	22.9 (22.1)	9.9
Interpreter C	25.0	2.5ns	25.1 (24.4)	24.8 (24.0)	24.7 (23.9)	8.2
Average	23.5	4.6	24.5 (23.7)	22.3 (21.4)	22.0 (21.1)	8.4

Note: Values in parentheses are adjusted for sampling error.
Significance levels: ns = not significant ($p > 0.05$); ***$p < 0.001$.

For the accuracy assessment calculated in relative terms the standard deviation of the difference between subjectively estimated stem volume from the aerial photo-interpretation and objectively inventoried stem volume was on average 23.8% with an average bias of 6.1%. The *t*-test showed that the stem volume estimates from two photo-interpreters systematically differed from the objectively inventoried stem volumes. The RMSE of stem volume estimate was on average 24.6% and corrected for sampling error 23.8%. Applying the ratio estimator an average RMSE of 22.8% was obtained, corresponding to 21.9% after correction for sampling error. The RMSE using the weighted regression estimator was on average 22.5% and 21.6% after correction for sampling error. For the accuracy assessment of tree height measurement in aerial photos the RMSE was found to be 9.3% on average (Table 2).

Table 2. Stem volume accuracy calculated in relative terms and expressed in relative standard deviation (Std_Δ), bias ($\overline{\Delta}$), root mean square error (RMSE) for uncalibrated, ratio and weighted regression calibrated stem volume, and tree height measurement for three professional aerial photo-interpreters based on 61 objectively inventoried stands.

	Std_Δ (%)	$\overline{\Delta}$ (%)	Uncalibrated RMSE (%)	Ratio cal. RMSE (%)	Weighted regression cal. RMSE (%)	Tree height RMSE (%)
Interpreter A	24.4	7.6*	25.6 (24.9)	21.8 (20.8)	21.4 (20.4)	7.9
Interpreter B	21.4	3.4ns	21.7 (20.7)	21.6 (20.6)	21.3 (20.2)	11.8
Interpreter C	25.5	7.2*	26.5 (25.9)	24.9 (24.2)	24.9 (24.2)	8.1
Average	23.8	6.1	24.6 (23.8)	22.8 (21.9)	22.5 (21.6)	9.3

Note: Values in parentheses are adjusted for sampling error.
Significance levels: ns = not significant ($p > 0.05$); *$p < 0.05$.

6 DICUSSION

The results from the accuracy assessment showed on average small differences between calculations in absolute terms in comparison to relative terms (Tables 1 and 2). In absolute terms, the difference between subjectively estimated stem volume from the aerial photo-interpretation and objectively inventoried stem volume showed on average a standard error of 23.5% and a systematic error of 4.6%. The RMSE corrected for the sampling error was reduced from 23.7% to about 21% after applying either the ratio estimator or regression estimator to remove systematic errors. In Figure 1 it is illustrated that the variance increases with increasing stem volume for all three aerial photo-interpreters, in particular for stands with stem volume >250 m^3 ha^{-1}. Interpreter A has the smallest standard error and the largest systematic error in comparison to interpreter B and C. Furthermore, interpreter A underestimated stands with low stem volume and overestimated stands with high stem volume. Hence, applying the regression estimator for correction of systematic error, interpreter A obtained the largest improvement of stem volume accuracy.

Stem volume estimation from aerial photo-interpretation are in good agreement with several previously presented studies (e.g., Eid, 1996; Ståhl, 1988), however not as good as in Ståhl (1992) with a standard error of 13.5%. Using similar instrument for interpretation, photo, scale, and professional personal it is likely that the range of the investigated stem volume can explain the differences in stem volume accuracy between Ståhl (1992) and the present study, i.e., stem volume range of 70-350 m^3 ha^{-1} in comparison to 15-585 m^3 ha^{-1}. For stands with high stem volume it is harder for the operator to estimate stem volume (Figure 1). The tree height accuracy expressed in RMSE was on average 8.4% in comparison to about 9% in Ståhl (1992), demonstrating that the differences in stem volume accuracy is related to difficulties for the interpreters to determine volume density in dense stands. In Magnusson and Fransson (2004a; 2004b) stem volume estimation was performed using multi-spectral optical satellite data for the stands included in this paper. The results showed an RMSE of 24% and 25% for SPOT-4 and Landsat ETM+ data, respectively, compared with the present study with an RMSE of 21% for aerial photo-interpretation. In conclusion, the aerial photo-interpretation provided more accurate stem volume estimates than the multi-spectral optical satellite images.

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ASSESSMENT OF LANDSAT TM FOREST-NON FOREST CLASSIFICATION: HOW THE SELECTION OF THE TEST SET AFFECTS THE CLASSIFICATION ACCURACY EVALUATION

F.De Natale[a], V.Puzzolo[b], F.Giannetti[c], A.Canavesio[c]

a I.S.A.F.A-C.R.A., P.za Nicolini n.6 – 38050, Trento, Italy, e-mail: denatale@isafa.it
b J.R.C., Via E. Fermi n.1 – 21020, Ispra (VA), Italy, e-mail: virginia.puzzolo@jrc.it
c I.P.L.A., C.so Casale n.476 -10032, Torino, Italy, e-mail: giannetti@ipla.org

ABSTRACT

The accuracy assessment of a land cover map as well as a forest cover map obtained from satellite data is a crucial issue because of the many uncertainties associated with the meaning and interpretation of the map quality. The main object of this paper is to assess how the selection of the test set affects the accuracy of the classifications obtained from middle resolution images. Moreover, the usefulness of a multi-temporal set of Landsat TM images of the same year for local scale forest/non-forest classification was evaluated comparing the results obtained applying the Maximum likelihood classifier to each single image and to a multi-temporal image created co-registering and adding all the image bands together.

The accuracy of the obtained forest/non-forest classification was evaluated using independent ground sample points, randomly distributed on the study area and classified through photo-interpretation of digital ortho-photos at 1 m of spatial resolution. Each test point was firstly classified according to its exact location on the ground and later reclassified in mixed, pure forest and pure non-forest according to the pixel in which the point was located. This approach allowed us to estimate how much the sample points located close to the edges of different land cover units can affect the result of the accuracy statement and how much, deselecting those test points, the resulted accuracy can increase for the Producer's and User's accuracies of each cover class as well as for the Overall classification accuracy. The results showed a remarkable increase in the accuracy values when the test points located in mixed pixels were excluded.

Keywords: Accuracy assessment, Test set selection, Forest-non forest classification, Landsat TM images.

1 INTRODUCTION

The availability of update information about composition, extension and evolution of forest cover is a crucial issue in the perspective of a correct management of forest resources. In this framework, remote sensing is one of the most important sources of forest cover data at different scales. For this reason, the accuracy assessment of the land cover maps is very important, particularly when the maps are derived from automatic digital classification of remotely sensed images (Congalton, 1991). In fact, the high risk to produce unreliable accuracy estimates due to the use of invalid methods is already well known (Czaplewski, 2003; Foody, 1999)

The main aim of the accuracy assessment is to evaluate the classification errors as well as describing the spatial pattern of classification errors, assessing effects of environmental conditions on map accuracy, comparing different classification techniques or selecting the best land-cover map for a particular region (Stehman, 2000). It is also to underline the role that accuracy plays in monitoring land cover changes studies (Foody, 2002) where is particularly important the discrimination between real changes and classification errors.

In general, the map accuracy depends on two different sources of errors: (i) mislocation errors and (ii) thematic errors (Perdigao and Annoni 1997). Thematic accuracy is not spatially uniform and depends on the relief condition, land cover complexity, radiometric effects on the images, etc… It is also time dependent (e.g. recent forest cut at the satellite image date) and it is related to a certain extent to the spatial accuracy. Spatial accuracy itself depends on the geometric quality of the source data (resolution of both satellite images and topographic maps used to correct them) and on the procedure selected to correct geometric errors and to geo-reference the satellite images. This accuracy can also change within a map, especially in complex rugged territories.

Accuracy statements are obtained comparing the map land-cover label to the reference (truth) one at the same spatial location. They are generally based on statistical sampling, which allows to apply sampling inference of the accuracy values assessed on the sample units to the whole map (Stehman, 2000). The sampling design adopted for this purpose can change in relation to the sample size, the distribution of the sampling units, the type of the sampling units and the criteria followed to classify the reference units – i. e. the so-called "labeling protocol" (Stehman and Czaplewski, 1998).

This paper focuses on the last two topics: the definition of the type of the sampling units and the labeling protocol. Indeed it compares the accuracy statements based on applying different sampling units (points or pixels) to four different forest-non forest classifications obtained from single Landsat TM images and a derived multi-temporal one. Moreover, this work aims at assessing the effect on the accuracy values due to the mislocation of the land cover features in the map, by also considering the mixed pixels and the closeness of the sampling units (points or pixels) to the class edges.

2 MATERIAL AND METHODS

2.1 STUDY AREA AND DATA

The work was carried out in a test area of about 72,000 ha located in the Central Italian Apennines. This area is characterized by a fragmented landscape and by a complex rugged terrain. At the lower altitudes the landscape is dominated by intensive agricultural practices while, at the higher altitudes, by broadleaved deciduous forests. In particular, many different forest formations can be found in the study area due to the high geologic and geomorphologic environmental variability and to the wide altitudinal range.

Three Landsat TM images taken in 1999 in late spring (03/06), middle summer (06/08) and early autumn (23/09) have been selected in order to use the different phenological information for the forest/non forest classification of the study area. These images were firstly ortho-rectified using a DEM of 10 m spatial resolution obtained from the already digitised elevation curves at 10 m elevation interval. The ortho-rectification was carried out applying a geometric correction model based on collinearity equations implemented in Erdas 8.7. In order to guarantee the overlapping of the images taken in different dates, an image co-registration was carried out in the mean time of the rectification process selecting the same set of 35 Ground Control Points for all the three images. An RMSE of less than 1 pixel was obtained and the geometric accuracy of the results was also visually checked comparing the pixels of the rectified images with the black & white digital ortho-photos of 1999 at 1 m of spatial resolution.

A test set of 500 points randomly distributed on the study area have been used for carrying on the accuracy assessment of the obtained forest/non forest classification. The black & white digital ortho-photos were used for collecting the reference data values in Arc/View 3.3.

2.2 METHODOLOGY

2.2.1 Forest/non forest classification

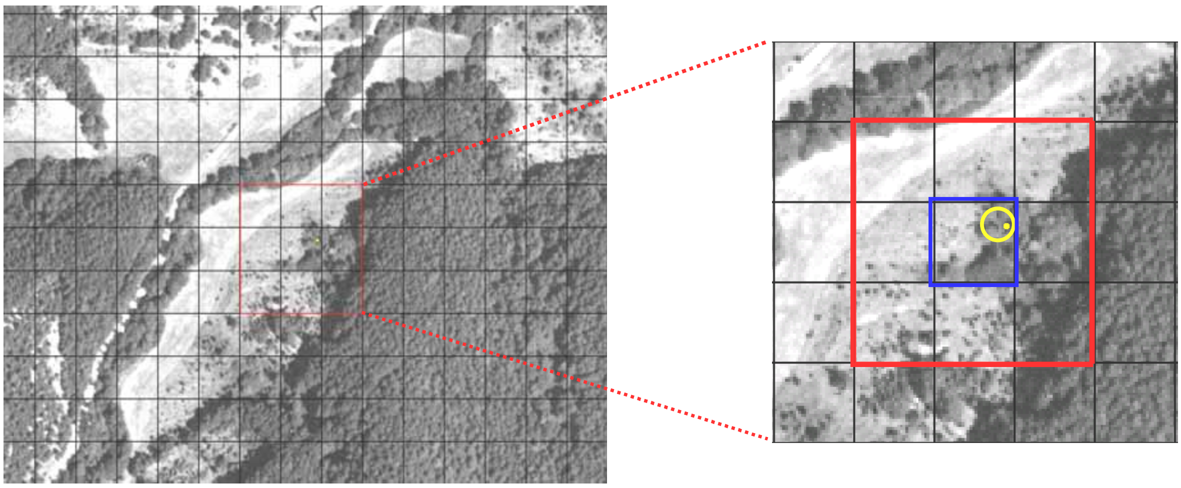
The Maximum likelihood classifier was selected for carrying on the image classification of each TM image and of the derived multi-temporal one using ENVI 4.0. Six land cover classes were specified in the training selection and in particular: 3 non-forest classes (agricultural fields, pastures and urban areas) and 3 forest classes (mixed broadleaved forests, beech forests and coniferous plantations). From each maximum likelihood classifications, a forest/non forest classification was later extracted in order to ensure a reliable photo-interpretation of the test reference data. In this way, the source of uncertainty due to their photo-interpretation was minimised.

2.2.2 The accuracy assessment procedure

The reference data used for the accuracy assessment were collected using a statistical sampling design based on 500 points randomly distributed on the whole study area through the Arc/View extension Random Point Generator (Jeness, 2001).

Firstly, it was necessary to adopt a definition of the detected classes in order to standardize the procedure of reference data labeling. By photo-interpretation, these points were assigned to the forest or non forest class according to the FAO-FRA2000 forest definition. The threshold of 5000 m^2 as minimum area, 20 m as minimum width and 10% of minimum crown cover stated by this definition were applied, while the height threshold of 5 m was not taken into account considering the difficulty to assess it on digital ortho-photos. At the same time, a grid of 30x30 m corresponding to the image pixel location was created in Arc/View in order to ensure the exact location of each image pixel on the digital ortho-photos and to allow the measurement of the forest cover percentage of each image pixel including each test point (Fig.1). Following this procedure, two different sampling units were considered: (i) the sample points and (ii) the pixels which contain the sample points. Finally, a block of 3x3 pixel around each sample pixel was considered in order to detect the effects of edge presence between the two considered classes: forest and non-forest. This information allows considering the effect on the classification results due to a mislocation of about 1 pixel.

Figure 1. Two reference units considered for this study: the accuracy statements were based on the sampling poins (in yellow) and the connected pixels (in blue). The presence of edges was detected in a 3x3 pixels blocks (in red) around each sampling point



The accuracy assessment was conducted for every forest/non-forest maps basing on the confusion matrix (Congalton, 1991) by using the two types of selected reference data: (i) the sampling points and (ii) the sampling pixels. Moreover, in relation to the pixel units, different statements of the accuracy were derived considering: all the pixel units, only the pure pixels and only the central pixels of 3x3 blocks without edges. All the accuracy statements were based on the Producer's and User's accuracy as well as the Overall accuracy calculated on the confusion matrices.

3 RESULTS AND DISCUSSION

3.1 IMAGE AND REFERENCE DATA CLASSIFICATION

In figure 2, the forest/non-forest classification obtained from the TM image of 23/09/99 is shown. This map, as well as the classifications derived from the other TM images and from the multi-temporal image, highlights the high fragmentation of the forest landscape within the study area. This is particularly evident in the eastern part, where the elevations are lower and the agricultural practices are dominant,while in the western part the forests are more compact along the Apennine dorsal.

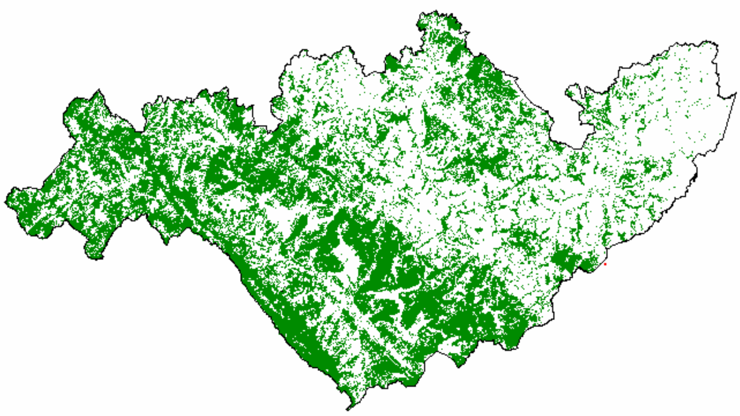


Figure 2. Forest-non forest classification of the study area obtained from the image of the 23/09/99.

Considering the 500 sampling points of reference data, 278 points were assigned by photo-interpretation to forest while 222 were labeled as non-forest. The figure 3 shows the distribution of the sampling points in relation to their pixel composition. According to this figure, the 78 % of the pixels related to the sampling points were pure, therefore they were assigned to the same class of their points. On the other hand, the mixed pixels were more than 20% of the whole test set.

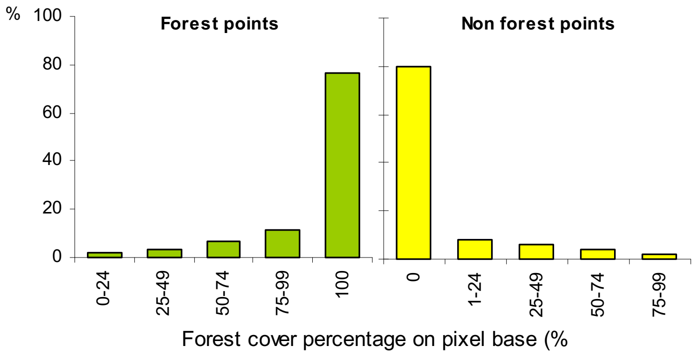


Figure 3. Distribution of the sampling points in relation to the composition of their pixels.

The labelling of the mixed pixels was based on the prevalent class within the pixel. The mixed pixels with a forest cover of more than 50% were classified as forest while the ones with less than 50% were assigned to the non-forest class. The results showed that more than 25% of the mixed pixels were assigned to the opposite class of their sample points. This means that the accuracy statement based on reference points can be very different from that one obtained with the reference pixels related to the same points, especially when there is a high proportion of mixed pixels.

The distribution of the pixels containing the test points in relation to their homogeneity is presented in figure 4. In this figure, the pixel sample is subdivided into three categories according to the increased homogeneity: the mixed pixels, the pure pixels located near an edge occurring within a 3x3 pixel block, and the pure pixels belonging to a pure 3x3 block, i.e. without edges between the two classes. The majority of the pixel samplings was pure (about 80%) but only one third of the whole test set was located in a pure 3x3 pixel block, therefore more than 70% of pixels intercepted or were close to class edges.

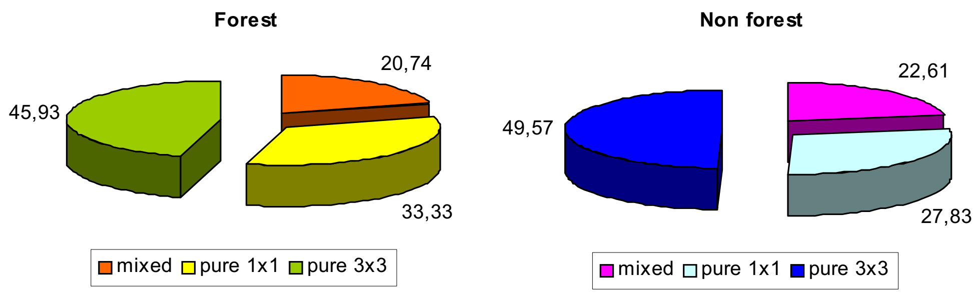


Figure 4. Distribution of the pixels connected to the sampling points in relation to their homogeneity.

3.2 THE ACCURACY ASSESSMENT

The accuracy statements obtained for the four forest/non forest classifications changed in relation to the sampling units how it is shown in table 1. The results of the accuracy assessment based on the point units were very similar to those based on the prevailing class at the pixel level, but the presence of the mixed pixels have noticeably affected the resulted accuracy values at both Producer's and User's accuracies as well as the Overall accuracy. These values raised considerably from 11% up to more than 15% when the mixed pixels were excluded from the test set, especially when the analysis was limited to the pure pixels located in the middle of pure 3x3 blocks. The same trend is observed for all the considered classifications.

The correspondence between the reference data and the classification data was also analyzed for the sub-sample of the mixed pixels. As showed in table 1, the accuracy values based only on the mixed pixels were obviously very lower than the values calculated with the full sample. It is interesting to remark that the Producer accuracies of the non-forest class were particularly affected by the presence of mixed pixels in the test set. It seems therefore more likely that the lower accuracy obtained is mainly due to a thematic error than to a spatial error. Spatial accuracy indeed would have affected both classes in the same way. These results confirm what Smith *et al.* (2003) suggested about the different sensitivity to landscape heterogeneity and to the patch-size of the thematic accuracy of each class.

Table 1. Producer's, User's and Overall accuracies obtained in relation to the considered sampling unit type: sample points, sample pixels, pure pixels (1x1), pure 3x3 blocks, mixed pixels.

		Points		Pixels (>50%)		Pure pixels (1x1)		Pure blocks (3x3)		Mixed pixels	
		PA	*UA*	*PA*	*UA*	*PA*	*UA*	*PA*	*UA*	*PA*	*UA*
03/06/99	Forest	88.74	60.43	88.26	62.27	90.45	66.8	93.86	79.26	80.77	49.41
	non forest	53.60	85.63	54.44	84.48	62.62	88.74	77.42	93.20	23.21	56.52
	OA	**69.20%**		**70.00%**		**75.26%**		**85.29%**		**50.93%**	
06/08/99	Forest	85.59	70.9	86.52	74.25	89.89	78.82	92.11	88.24	75.00	60.00
	non forest	71.94	86.21	74.44	86.64	79.91	90.48	88.71	92.44	53.57	69.77
	OA	**78.00%**		**80.00%**		**84.44%**		**90.34%**		**63.89%**	
23/09/99	Forest	93.69	71.72	93.48	74.14	96.07	80.66	97.50	81.25	84.62	56.41
	non forest	70.50	93.33	72.22	92.86	80.84	96.11	89.02	98.65	39.29	73.33
	OA	**80.80%**		**82.00%**		**87.76%**		**91.80%**		**61.11%**	
multitemp	Forest	91.89	69.15	91.30	71.19	93.82	77.67	96.49	87.3	82.69	53.75
	non forest	67.27	91.22	68.52	90.24	77.57	93.79	87.10	96.43	33.93	67.86
	OA	**78.20%**		**79.00%**		**84.95%**		**91.60%**		**57.41%**	

4 CONCLUSION

Different accuracy assessment approaches can lead to different statements, therefore it is important that the quality of thematic maps derived from remotely sensed data be assessed and expressed in a meaningful way (Foody, 2002). The results of this study highlight that the criteria of sampling unit selection affect considerably the accuracy values. The option of excluding the pixels located in the more heterogeneous part of the territory has led to overestimate the accuracy with increases up to 15%. Other studies reported that removing the boundary regions raises the estimated accuracy of the map from 46% to 71% (Fuller *et al.* as cited in Foody, 2002). Actually, to be applicable to the entire map, the sample of the reference data would have to be fully representative of the conditions found in the region (Congalton *et al*. as cited in Foody, 2002). Edge conditions can be very prevalent in detailed thematic maps and the effect of the registration error can be greatest near the edges (Czaplewski, 2003). However, in this study case both thematic and spatial errors were mainly located in the more heterogeneous zones and the values of the obtained overall accuracy applying the full test sample seem to be inadequate to describe the actual map quality. As already suggested by Foody (2002), it may be preferable to derive more than one measure of accuracy. Providing different accuracy statements in relation to different homogeneity levels, as this study has done, could be useful for improving the reliability description of the considered maps. Such a multiple accuracy assessment could be mainly meaningful if information about the spatial distribution of the homogeneity are also taken into account.

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DETECTION OF ERRORS IN FOREST STAND DATABASES WITH REMOTE SENSING

Erik Willén and Mats Rosengren[a]

[a] Metria Miljöanalys, P.O. Box 24154, SE-104 51 Stockholm, Sweden - (erik.willen, mats.rosengren)@lm.se

ABSTRACT

The aim of this study is to test the use of satellite data and neural nets to find errors in large forest stand databases at forest companies. The correlation between satellite data and forest parameters is used to point out forest stands with errors in the forest parameter description in the stand database. This is then used as stratification and planning of field inventory efforts for more efficient updating of stand databases.

Keywords: Neural network, satellite data, forest stand databases, GIS

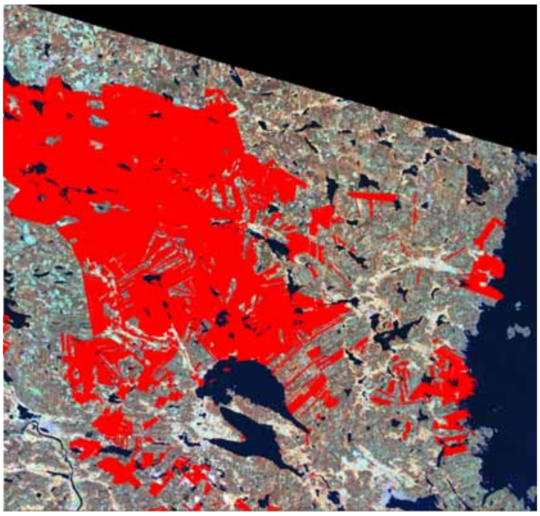
1 INTRODUCTION

One of the most important businesses for any forest company is to manage their own forests. Most forest companies have their forests described in forestry plans in GIS stand databases. These databases can be very large and up to 250 000 different stands is not unusual in Sweden. One of the most important prerequisites for efficient management of the forest is a well-kept and up to date forest stand database. Almost all forestry planning of operative activities such as pre-commercial thinning, thinnings and final fellings are based on the information in the stand database. The forest stand databases are based on extensive field data collection performed over a large number of years. Forest parameters are updated yearly with growth functions. However, sometimes the parameters were collected 25-30 years ago and the difference of the actual stand condition and the stand database may increase over time. When the errors in the stand database seem to be large, field inventories are made to update the forest parameters. These field inventories are very costly and any possibility to find methods in how to reduce field efforts will save a lot of money. By introducing methods for advanced modelling of the relationships between forest stand parameters and satellite data, errors in the stand database can be identified. The task is to sort out and rank the few percentages of stands with large deviations among thousands of forest stands with an accurate description. One method using neural networks was developed by Metria. Other studies imply the possible use of neural nets to predict and evaluate forest parameters (Simon A. Corne; Stephen J. Carver; William E. Kunin; Jack J. Lennon; Willem W. S. van Hees. 2004) or for delineation of intact forest landscapes (D. Aksenov. et. al. 2002).

2 STUDY AREA AND DATA

2.1 STUDY AREA

The study area is located in the middle of Sweden, about 300 km north of Stockholm along the coast. The area covers most of all stands in the Dellen and Bergsjö forestry district. In figure 1 the forest stand are marked in red together with satellite data from 2002.



Figur 1: Study area.

2.2 INPUT DATA

2.2.1 Forest data

As forest data the stand database of Holmen SKOG was utilised. All stand information is stored in MS Access format and stand delineations as ESRI shape files. In the stand database detailed information on the forest are stored as for example timber volume and tree species composition. The number of stand in the satellite scene was about 18 000. The forest information is updated yearly by growth functions or after forest operations.

2.2.2 Map data

As map data the topographic maps produced by the National Land Survey were used in digital format. The information used from the maps was roads and the forest land delineation.

2.2.3 Satellite data

Satellite data from two years (table 1) were used in order to detect stands with recent forest operations taken place.

Table 1. Satellite data used

Satellite/sensor	Scen id	Date of registratrion
SPOT-4 Xi	053/222	1999-09-03
Landsat-7 ETM+	194/017	2002-05-23

3 METHODS

3.1. DATA PREPARATION

The analysis was performed on forest older than 25 years due to the fact that the stand data on young forest are often insecure. Young stands may develop rapidly and are not well described in the stand database.

Some modelling were performed on the forest data only and revealed some errors like old forest with no timber volume or stands with zero tree height, but high basal area. These kinds of errors will cause errors when modelling and need to be removed.

Stands smaller than 0,5 hectare was also removed from the modelling. About 11000 stands were still to be modelled. From the stand vector database roads were removed with a width of 25 meters by buffering vector road data. Image statistics (median, max, min-values) were collected for each stand from the satellite data

3.2 NEURAL NETWORK

A neural network is easiest described graphically (figure 2). The network consist of "nodes" in several layers bound together so all nodes in one layer are connected to all nodes in the next layer. The number of layers can be varied, but normally one input layer, one output layer and a hidden layer are used. The signals are weighted in the input layer and are summed in each node in the hidden layer where they also pass a sigmoid (non-linear function). Then the signals are weighted again and summed in the output layer. The network may have several signals in or out. By varying the weight in the network can the output be adjusted to the requested one.

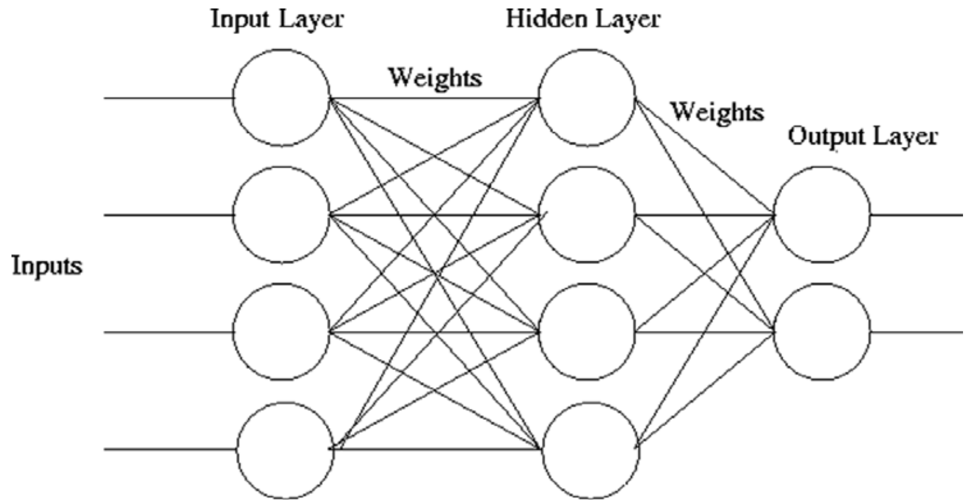


Figure 2. A model of a neural network

The qualities of the trained neural network depend on the deviation from the output signal and the requested one. In ”regression-like” estimations one normally use a least square method to calculate the total error.

In this study we used NeuroSolutions software from NeuroDimension for Neural network modeling (Neurodimension, 2005).

Input parameters for the network:

- Stand age
- Basal area
- Stand height
- Tree species composition (from basal area)
- Timber volume
- Site index

Parameters to be modeled were:

- Green, red, near infrared (NIR) and short-wave infrared (SWIR) spectral channels (Landsat ETM+ band 2,3,4,5)

Different kinds of network were tested. Among those tested were:

- Multi Layer Perceptron (MLP)
- Radial Basis Functions (RBF)
- Kohonen Self-Organizing Map (SOM)

Best results were achieved from the SOM-type of network. A SOM-network have a first step where a clustering is performed where sample with same qualities are grouped before the training of a MLP-network with a hidden layer.

Stands with a residual of more than 2 sigma in NIR or SWIR channel were considered as outliers and selected as a candidate for field validation. Also stands with very low residuals were selected as reference stands. NIR and SWIR channels were selected due to high dynamics in forest areas compared to red and green spectral channels. About 50 stands were visited in field by personnel from the forest company in order to register forest stand data to be compared with the data in the stand database.

4 RESULTS AND DISCUSSION

Timber volume errors with more than +/- 20 % were considered as large and also when the tree species composition varied more than 30 %-units from the database (for example when the stand database pine percentage is 30 % and field measurements show a pine percentage of 60%). Figure 3 show the results concerning timber volume for the field visited stands. The different colouring depends on in which direction the residual took place (in NIR or SWIR channel or in both). Reference stands are in group 10 with very low residuals from the measured to the modeled signal. It is also clear that the reference stands have a low deviation from the stand database to the field inventory.

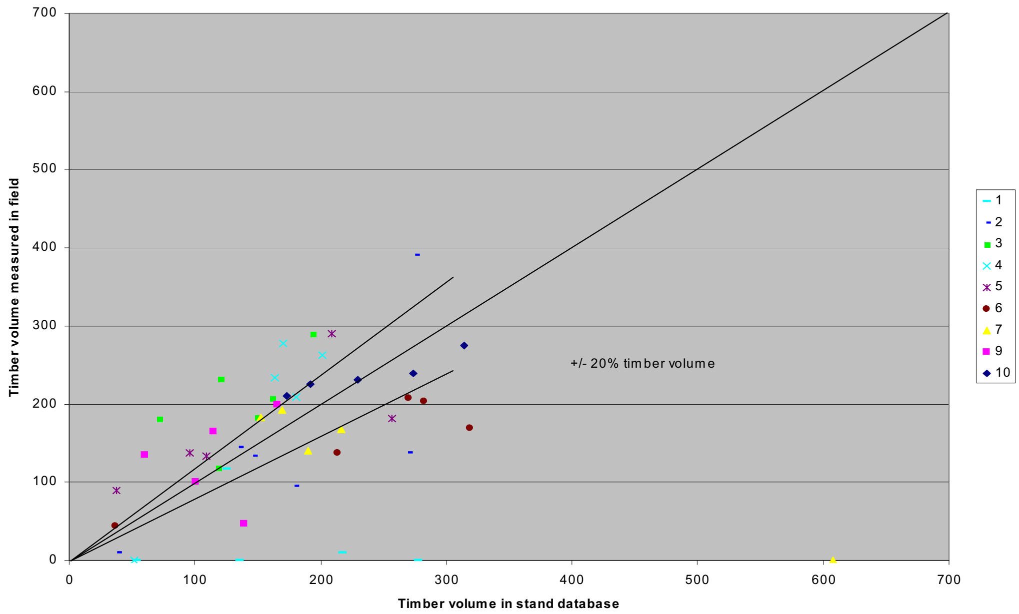


Figure 3. Timber volume comparison (m^3sk)

When tree species compositions are compared (figure 4) there are in some cases large errors, but many stands are within the +/- 30 % limit (the black ring). It is more often with timber volume errors than errors in tree species composition. However they often are linked. If the tree species composition is wrong one almost always have an error in timber volume due to that the growth functions are based on wrong assumptions. A conifer forest will have another growth than a mixed forest.

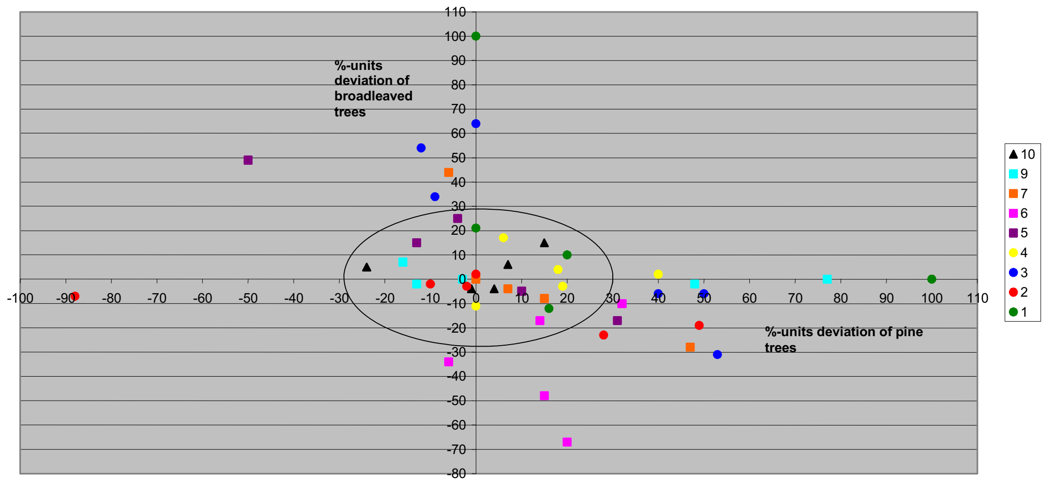


Figure 4. Tree species composition comparison (stand database minus field inventory)

When stands with acceptable timber volume deviations but large residuals in NIR or SWIR are checked concerning tree species composition they all have large errors. This implies that all stands with high residuals have rather large errors in the stand database description. Reference stands (with very low residuals) are more correct described.

5 CONCLUSIONS

The methods developed were validated in the field and the results showed that forest stands identified as having large errors also were wrongly described in the forest stand database. Forest stands that were identified to be correctly described in the stand database (reference areas) also turned out to be well described when compared to field data. Errors in large forest stand databases are possible to detect with satellite data. Of about 11 000 forest stands, 1000 were identified with errors. These estimated errors were graded to rank priorities for field efforts. The methods for ranking and the routines for updating the stand database need to be further developed in coming studies.

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BEYOND DEFORESTATION: USE OF LANDSCAPE METRICS AND SATELLITE IMAGERY TO ANALYSE TROPICAL FOREST FRAGMENTATION

F. Colson[a], Y.E. Shimabukuro[b], J. Bogaert[c] and R. Ceulemans[a]

[a] UA, University of Antwerp, Department of Biology, Research Group of Plant and Vegetation Ecology, Campus Drie Eiken, Universiteitsplein 1, B-2610 Wilrijk, Belgium, email: filip.colson@ua.ac.be
[b] INPA, Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research), INPE, C.P. 515, São José dos Campos, SP, 12201-970, Brazil
[c] ULB, Université Libre de Bruxelles, École Interfacultaire de Bioingénieurs, Laboratoire d'Ecologie de Paysage, 50 Avenue F.D. Roosevelt, C.P. 169, B-1050 Brussels, Belgium

ABSTRACT

Landscape ecological concepts, together with the availability of remote sensing data and geographic information systems software, provide a unique basis for monitoring large-scale ecological systems. Landscape ecology emphasizes the interaction between spatial pattern and ecological process, i.e. the causes and consequences of spatial heterogeneity across a range of scales. These two complementary aspects distinguish landscape ecology from other subdisciplines within ecology: the importance of spatial configuration for ecological processes, and the focus on large spatial extents.

Habitat fragmentation is the process of breaking up continuous vegetations into dispersed remnants, thus having spatial and ecological effects; it generates habitat loss, habitat isolation and edge effects. Many landscapes today have become dynamic mosaics of natural and human-induced patches. The spatial distribution of resources --including changes in light, temperature, wind, and humidity regimes-- in such heterogeneous landscapes can have important effects on the growth, reproduction, and dispersal of organisms, and is thus a critical issue for population biology and conservation ecology, as well as for management design and scenario analysis.

Numerous indices have been developed in landscape ecology for describing and quantifying both composition and spatial configuration, at the patch, cover type and landscape level. These metrics are necessary for understanding the effects of pattern on ecological processes and for documenting either temporal changes in a landscape or differences between two or more landscapes.

The presented study focuses on the patterns of fragmentation and regrowth in four areas throughout the Brazilian Amazon basin, selected for their variation in intensity, extent and strategy of deforestation, as well as the geographic distribution and availability of data on vegetation structure and land use. Maps of land use/cover based on 30 m resolution Landsat TM and ETM+ images have been produced and validated by researchers of the Brazilian National Institutes for Space Research (INPE) and for Amazonian Research (INPA). Primary proximate causes of deforestation are the extraction of wood (commercially or for domestic usage) and the expansion of agriculture (permanent or shifting cultivation, and cattle ranching). Using a landscape ecological approach, metrics are used that quantify patch size, shape, density, edge, interior area and variability, as well as proximity, contagion and diversity at the class and landscape levels.

Keywords: applied landscape ecology, spatial pattern indices, forest fragmentation, satellite remote sensing

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HABITAT MAPPING AND LAND COVER CHANGE DETECTION

D.N.M. Donoghue [a], K.B. McManus [b], R.W. Dunford [a] & P.J. Watt [a]

[a] Geography Department, Durham University, South Road Durham, DH1 3LE, UK
[a] email: danny.donoghue@durham.ac.uk
[b] CEH, Natural Environment Research Council, Monks Wood, Huntington, Cambridgeshire, UK

ABSTRACT

The Forestry Commission and private forest companies own large areas of the British uplands. However, significant parts of this land are either unsuitable for commercial forestry or include non-forest habitats protected by national and international nature conservation laws. Amongst these important habitats are areas of acid grassland, heather moorland and heathland, each of which requires careful management to ensure the preservation of their many animal and plant species. The Cairnsmore of Fleet, in Dumfries and Galloway district of S.W. West Scotland is a good example of such an area. The site is owned by the Forestry Commission but managed jointly with Scottish Natural Heritage because the area is designated as a Natura2000 site and a National Nature Reserve. The designation affords the site the highest level of environmental protection under both the EU Habitats Directive and UK legislation. The site occupies 1922 ha of remote upland that is difficult to survey and manage. The key management objectives include maintaining a habitat for black grouse, minimising bracken encroachment and preventing natural conifer regeneration encroaching on moorland. Using the Cairnsmore of Fleet as a case study, this paper describes a methodology for mapping moorland vegetation and monitoring habitat status using commercially available optical satellite imagery. The result is a series of thematic maps indicating the dominance of particular upland moorland species.

Keywords: Moorland vegetation, habitat mapping, optical remote sensing, classification.

1 INTRODUCTION TO UPLAND MOORLAND HABITAT

As well as being important for plant communities, upland moorland areas support many animal and plant species that are recognised both nationally and internationally as being of nature conservation importance. Upland moorland is typically a complex mosaic of acid grassland mixed with blanket bog and patches of heath. The acid grasslands in upland Galloway are dominated by sheep's fescue (*festuca ovina*), common bent (*agrostis capillaris*), mat-grass (*nardus stricta*) or by heath rush with more acidic grassland dominated by purple-moor grass (*molinia caerulea*). Heather moorland is dominated by dwarf-shrubs, such as bell heather (*erica cinerea*), bilberry (*vaccinium myrtilus*) forming a dry heathland assemblage, or cross-leaved heather (*erica tetralix*) and mosses including *sphagnum* species forming a wet heathland assemblage where purple-moor grass, heath rush (*juncus squarrosus*) and deer grass (*scirpus cespitosus*) may also be present. Heathland provides an important feeding and nesting habitat for black grouse, as well as other birds and wildlife and is of great importance for nature conservation. Bracken (*pteridium aquilinum*) is also found on upland moorland, but this is an aggressive and vigorous plant that invades heathland and upland grazing areas providing a habitat for the sheep tick and can cause poisoning in grazing animals if eaten. The control of bracken and the regeneration of heathland are therefore objectives for upland estate managers.

Until recently satellite imagery was too crude to allow the complexity of upland vegetation mosaics to be characterized effectively. Even with large scale colour aerial photography, interpreting vegetation patterns to any degree of accuracy requires considerable skill and experience; a task that is time consuming and so expensive. However, in recent years the spatial resolution of satellite image data has improved greatly and is now close to the size used by ecologists for surveying the species and ground cover proportion in the field. This paper explores the use of SPOT 5 optical satellite imagery for mapping large areas of inaccessible upland habitat to assist with moorland management.

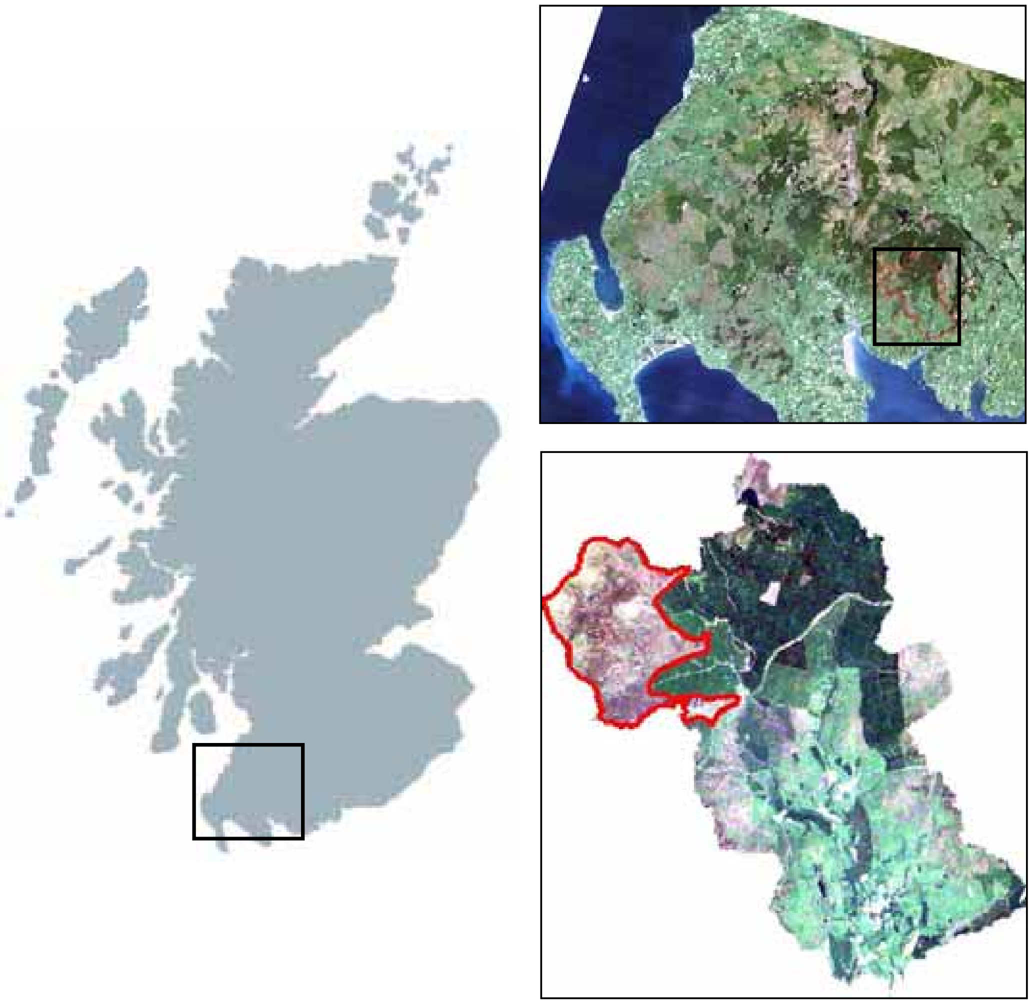

Figure 1: Location of the Fleet river basin (top right) and the Cairnsmore of Fleet, highlighted in red (lower right)

1.1 THE CAIRNSMORE OF FLEET

The Cairnsmore of Fleet National Nature Reserve and Natura2000 site is located in the Fleet river basin in south west Scotland (Figure 1) The site is managed by Scottish Natural Heritage for the rich diversity of acid grassland, heathland and for associated fauna such as Black Grouse. The main management issue in the Cairnsmore is in the conservation of habitats and species of national and international significance. Previous attempts to map the area have been carried out by field survey and air photo interpretation; this is the first systematic study of the application of high spatial resolution satellite image data. The maps generated by the Macaulay Land Use Research Institute separated the land cover into different vegetation classes and mosaics as part of a nationwide land cover mapping exercise in 1988 (LCS88), a more up-to-date map was generated from field-work 2003 (MLURI03). These maps suggest that the moorland is dominated by grassland interspersed with patches of dwarf-shrub heathland, blanket bog and bracken), see figure 2.

It is particularly important to be able to separate heath from other moorland vegetation types and also to provide an indication of the dominance of heather (*calluna vulgaris*) on the moor based. If successful, satellite imagery would be an excellent tool for monitoring temporal changes in status of the heather cover. Initial field reconnaissance of the area indicated that the abundance of heather decreased from pure heather on higher steeper slopes to areas where heather was completely absent. By far the most common occurrence is in mixed assemblages with other species such as short green grass, purple-moor grass (*molinia caerulea*), matgrass (*nardus stricta*), heath rush (*juncus squarrosus*), sheep's fescue (*festuca ovina*), bilberry (*vaccinium myrtillus*) or sphagnum moss.

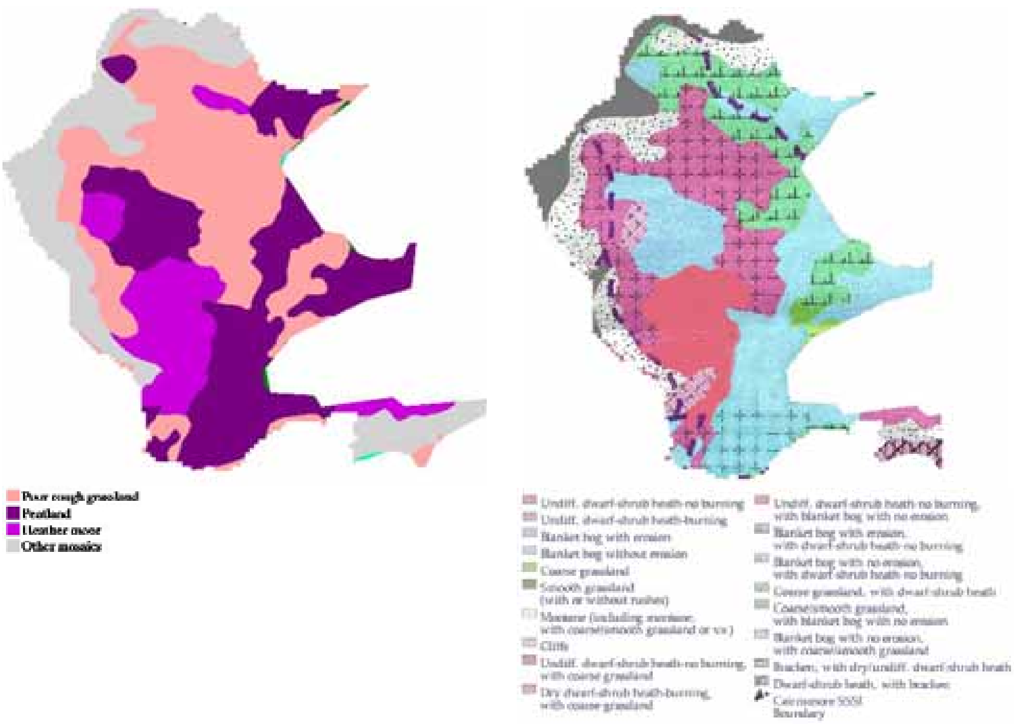

Figure 2: Cairnsmore of Fleet habitat maps LCS88 (left) and MLURI03 (right)

2 METHODOLOGY AND RESULTS

Cloud free digital multispectral SPOT 5 satellite data are available from May 2003. The image was geometrically registered to the UK WGS-84 geographical projection system and radiometrically normalized to allow direct comparison of changes in habitat with future image data.

Two approaches to land cover classification were considered. The first used the LCS88 map to help analyse the spectral characteristics of the SPOT 2003 image data. This method classified the SPOT 2003 spectral data into LCS88 land cover classes. An alternative approach used field observations of vegetation type and abundance to derive a set of new cover classes specifically to describe moorland habitat. The satellite data was then classified according to training areas identified from field observation. The field survey involved recording the GPS location, species assemblage and abundance at 200 one meter square sample points. Sample points were located within patches of vegetation that appeared homogenous within a 10m x 10m area (representing a SPOT pixel). Particular attention was given to sampling areas of different heather abundance. The detailed field data was converted to a vector layer in ArcGIS® and displayed over the SPOT image and LCS88 map using ENVI software. In this way the spectral characteristics for different heather assemblages were extracted to provide training sites for image classification. Results of the classification of the SPOT data based on the LCS88 classes showed a poor agreement with the LCS88 map and poor separation of the land cover into the field derived heather classes. Initially this was thought to be a result of the similarity in vegetation spectral response across the limited spectral resolution of the SPOT image. However, it is obvious from figure 3 that vegetation mosaics that contain similar proportions of heather cover will appear spectrally different because of the reflectivity of the other dominant species. When the spectral information in the SPOT data was enhanced using a Principal Component transformation[1], the enhanced image showed patterns of moorland vegetation similar

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[1] Principal component analysis is a statistical enhancement technique that removes the correlation between multispectral bands where data redundancy is common. The technique separates the information from the noise component and identifies the principal axes of variability within the data thus enhancing the image for visual interpretation.

to those observed in the field. The next step was to assess the maps generated from vegetation classes defined from the field sample.

Heather (70%) and Molinia (20%)

Heather (60%) and Grass (40%)

Heather (40%), Molinia (40%) and Nardus (15%)

Heather (40%) and Nardus (40%) with Molinia (15%)

Figure 3: Heather abundance on the Cairnsmore of Fleet

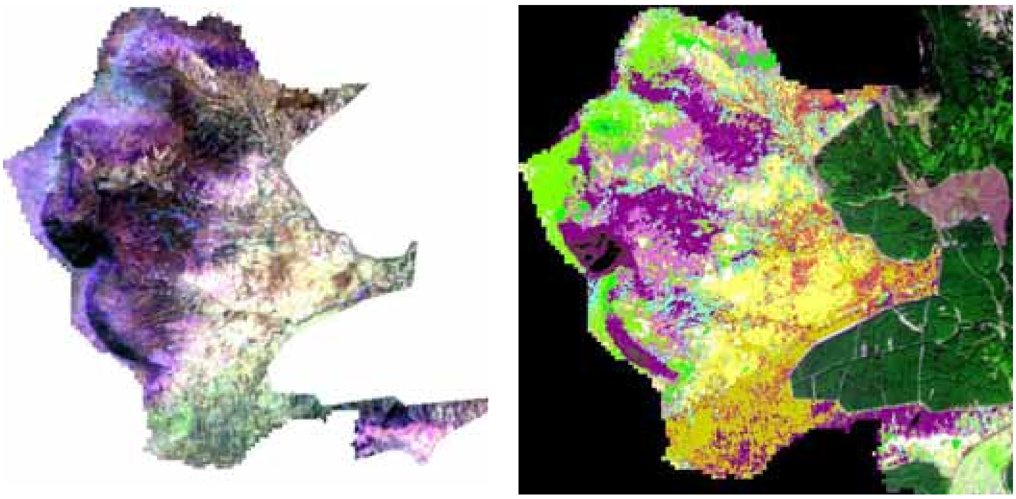

Figure 4: SPOT 5 image false colour composite (left) and Classified image (right)

The field data were grouped into moorland categories using a non-hierarchical k-means clustering algorithm using Stata software. This produced ten groupings separated according to the vegetation type and abundance that was recorded in the field. The next step was to investigate the SPOT image spectral characteristics to see if the classes would be separable from each other. This analysis is summarized in figure 2.

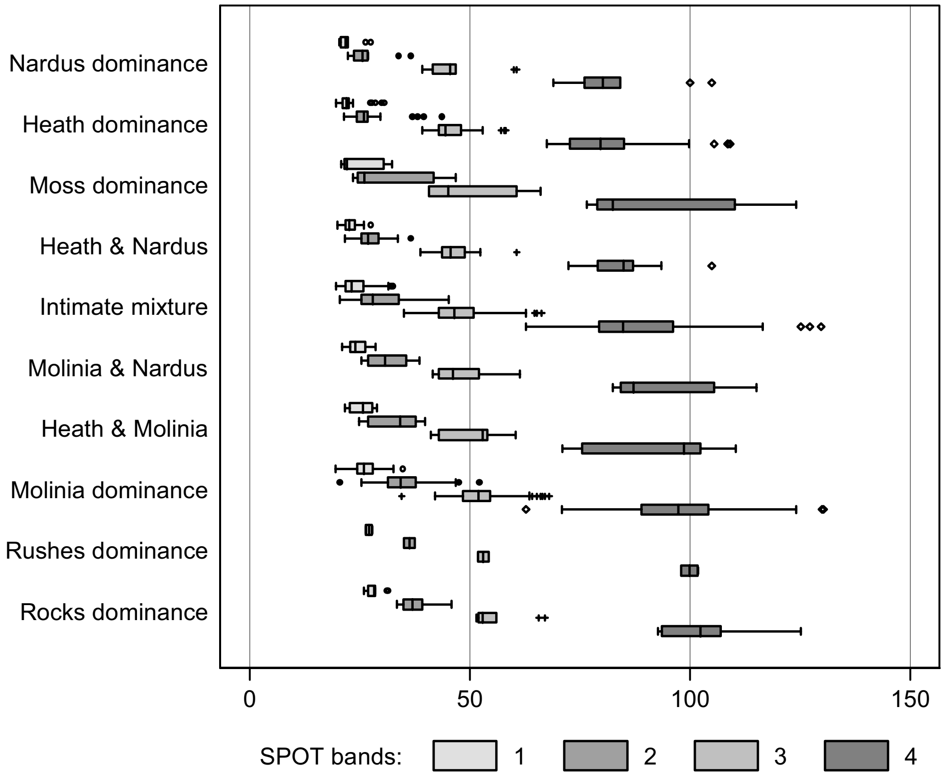

Figure 5 Spectral separability of field data derived land cover classes for Cairnsmore NNR

Figure 5 shows the new classes, listed on the y-axis of the plot, ordered by the median of reflectance in SPOT band 2. It shows that the field classes are spectrally separable and that classes dominated by Heather or wet ground show the lowest reflectivity, as would be expected. The four spectral bands of SPOT allow the mapping to be performed automatically when appropriate training data are identified. Figure 4 also shows which classes are likely to be poorly classified since these contain a large amount of variability in spectral response. Training areas were identified from sites close to the class median and the Spectral Angle Mapper routine in ENVI was used to produce a land cover classification, see figures 4 and 6.

3 DISCUSSION AND CONCLUSION

The vegetation maps shown in figures 4 and 6 show good agreement with field observations although it is difficult to provide a quantitative assessment of accuracy because many of the classes overlap both spectrally and in terms of the vegetation types they contain. Nevertheless, field data not used in the "training" phase of the classification can be used to give an indication of accuracy. For example, the field observations for the "Heath Dominance" class all show that heath species are dominant in the sample plots. The most problematic sites are areas of wet ground where reflectivity is generally low but the range of vegetation species present can lead to a wide range of reflectivity. A series of thematic maps were produced by interrogating the enhanced image data that provide an estimate of the dominance of heather and other vegetation types. The product demonstrates an appropriate methodology for mapping variations in areas of high ecological status using commercial remote sensing satellite systems in an area of Galloway Forest District. The technique focuses on an example of upland moorland management but can be adapted to a broad range of land cover mapping requirements for estate management by Forest Enterprise and other relevant public bodies such as Scottish Natural Heritage.

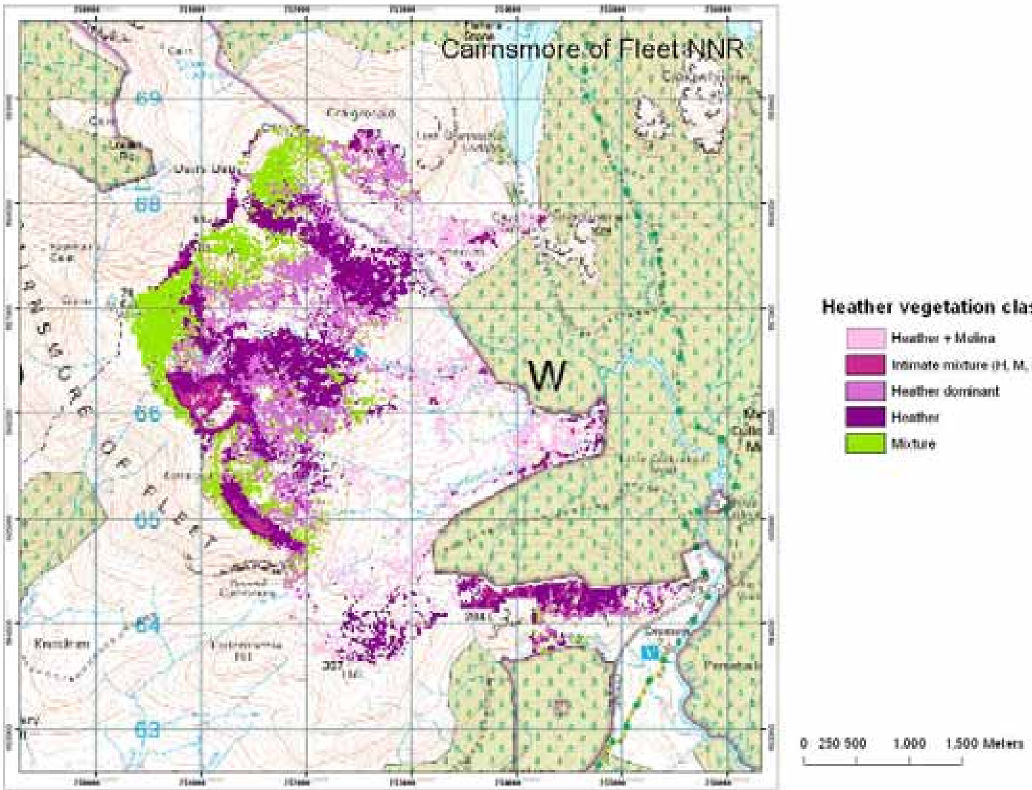

Figure 6 Map of locations with greater that 20% heather vegetation cover

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A HIERARCHICAL APPROACH TO PROTECT FOREST BIODIVERSITY AND TO ASSESS HABITAT SUITABILITY IN THE FINNISH FOREST

N. Rautjärvi[a] and S. Luque[b]

[a] Finnish Forest Research Institute, Unioninkatu 40 A, FI-00170 Helsinki, Finland, nina.rautjarvi@metla.fi
[b] Cemagref, Groupement de Grenoble, St-Martin-d'Hères, cedex., France

ABSTRACT

This study aims both at assessing forest conditions inside versus outside protected areas using habitat and forest indicators at the landscape level and at developing tools to be used in conservation area planning and management. The study focuses on forest habitats in Southern and Central Finland where the emphasis regarding nature conservation issues has recently been. This constitutes the first attempt, focusing on end users' needs, to use the Finnish National Forest Inventory database at a large regional scale for biodiversity monitoring and management. Within the project we have developed a habitat model that is an additive spatial model depicting a theoretical habitat. The input data includes multi-source thematic maps and kriging interpolation maps and a kernel density map from plot level National Forest Inventory data. All input variables were classified before adding them to the model. The approach to compare inside versus outside conservation areas used here was to look at how the habitat model behaves inside conservation areas, at certain distances from conservation areas and outside conservation areas. Landscape metrics were calculated for one version of the habitat model and age and volume maps derived from Multi-source National Forest Inventory using Fragstats and Apack software. Metrics were calculated for six rectangular windows of 125 km by 125 km placed to cover the study area completely on the north-south axis. Fragstats was used for calculating the metrics for the habitat index and Apack for calculating the metrics for age and volume maps.

Keywords: Habitat modelling, forest inventory, thematic maps, biodiversity indicators, landscape ecology, landscape metrics.

1 INTRODUCTION

According to the resolutions of the Rio de Janeiro biodiversity convention and subsequent ministerial conferences biological diversity must be monitored and taken into account in forestry. The Finnish National Forest Inventory (NFI) is a part of Finland's national biodiversity monitoring system. Our research project constitutes the first attempt, focusing on end users' needs, to use the Finnish National Forest Inventory database at a large regional level for biodiversity monitoring and management.

Within this project we aim at assessing forest conditions inside versus outside protected areas using habitat and forest indicators at a landscape level. The tools and indicators developed will allow us to gain understanding on forest structure and composition as well as edge interactions between and within habitats of high biodiversity value. The focus of the work is on assessing the status of nature protection in Finland and locating regions that have potential for protection in Southern and Central Finland. We also consider implications of conservation on the environment and the economic associated value. The project relies and builds upon data from the Finnish National Forest Inventory. Different spatial scales are applied in different stages of the project.

Approximately 95% of forest land is managed in Finland (Ministry of Environment, 1999). Local forest properties have substantially changed mostly in terms of tree species composition and the amount of coarse woody debris due to management applied to forest stands (Kouki, 1994; Esseen *et al*., 1997; Kouki and Niemelä, 1997; Löfman & Kouki, 2001). Also, regional characteristics, such as the spatial structure of forest landscapes, have changed (Kouki & Löfman, 1998; Luque *et al*., 2004). Consequently, almost 700 forest-dwelling species are considered as threatened in Finland, mostly due to forestry practices during the twentieth century (Rassi et al., 2001).

As a surrogate for biodiversity value we use a spatial forest habitat quality model depicting forest structure (Rautjärvi *et al*., 2004). The model has been constructed using NFI data to cover all of Southern and Central Finland. Multi-source NFI maps are the basis of the model, which has been refined by adding data on dead wood and naturalness to it and at a later stage by adding different key biotope layers to it. Using these habitat specific versions of the model it is possible to pinpoint particular regions with different biodiversity related attributes.

Locating habitats that have particular attributes and biodiversity value and analyzing their distribution has been the starting point for building the model. Several conceptual approaches were developed in order to evaluate different habitat quality models that are used as a surrogate for biodiversity value. Variables examined include stand age, stand volume and site fertility from MS-NFI, dead wood volume, key biotope area contribution of different key biotopes, and data on damages and management history from plot-level NFI database, and vegetation data from permanent plots separate from the regular NFI. The habitat model can be used to locate potential areas that have biodiversity value to be protected. Variables can be altered in order to focus on different habitat types.

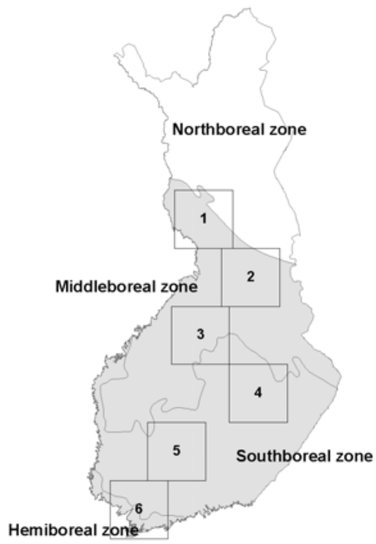
The patterns of the habitat quality model have been studied and six regions (rectangular windows) of particular interest have been chosen for further studies of the landscape ecological indicators. For these regions landscape metrics depicting forest connectivity, fragmentation and edge interactions have been calculated from multi-source NFI map estimates for volume and age of the growing stock. Landscape metrics have also been calculated for the habitat index resulting from the habitat model (version that focuses on herb rich forests).

2 STUDY AREA AND DATA SOURCES

2.1 SOUTHERN AND CENTRAL FINLAND

This study focused on Southern and Central Finland defined to include hemi-, south-, and middle boreal forest vegetation zones (Fig. 1). Recent discussion and efforts on nature conservation in Finland have focused on Southern and Central Finland, given the lack of conservation areas, in particular representative ones, especially in the area (e.g. Virkkala *et al.*, 2000) and new conservation efforts concentrate mainly on the southern part of the country including the Forest Biodiversity Programme for Southern Finland (METSO) that seeks new innovative ways to conserve forests on a voluntary basis (METSO Leaflet 1/2003).

Figure 1. Forest vegetation zones within Finland and windows 1-6 for landscape metric calculations. Shaded region shows the study area. Vegetation zone boundaries defined by Ahti *et al.*, 1968 and Kalela, 1961, produced by SYKE.



2.2 THEMATIC MAPS FINNISH MULTI-SOURCE NATIONAL FOREST INVENTORY (MS-NFI)

Finnish multi-source national forest inventory (MS-NFI) thematic maps were used both as input layers for the habitat model and for computing landscape metrics. Multi-source Finnish National Inventory produces wall-to-wall predictions on pixel level for forest characteristics based on k-nearest-neighbour (k-nn) estimation and its improved version (Tomppo 1991, Tomppo & Halme 2004). MS-NFI procedure assigns forest inventory field data to all pixels in a satellite image covering Finland using a multi-source approach (Tomppo 1991, Tomppo & Halme 2004). Before using the thematic maps in the habitat model or landscape metric calculations, the resolution of the thematic maps was shifted to 50 m and the data were classified. Landscape metrics were calculated for multi-source thematic maps that represent the volume of growing stock (m^3/ha) and stand age.

2.3 HABITAT MODEL BASED ON FINNISH NATIONAL FOREST INVENTORY DATA

The habitat model is an additive spatial model depicting a theoretical habitat (Rautjärvi *et al.,* 2004). The input data includes i) multi-source thematic maps that represent the volume of growing stock (m^3/ha), stand age and potential productivity of the site (m^3/ha/a), and ii) a kriging interpolation of the volume (m^3/ha) of dead and decaying wood data, a kernel density map representing silvicultural history of forest habitats (no operations within past 30 years), and a kriging interpolation representing the proportion of herb-rich forests and precipices of forestry land derived from plot level NFI data (figure 2). All input variables were classified before adding them to the model. The final habitat index consists of three "suitability" classes – poor, average and good. See figure 2 for the flowchart of the model version focusing on forests with high amount of dead and decaying wood and on herb rich sites. Forest habitats with dead and decaying wood and herb rich sites are deemed important regarding forest biodiversity (e.g. Kouki, 1994).

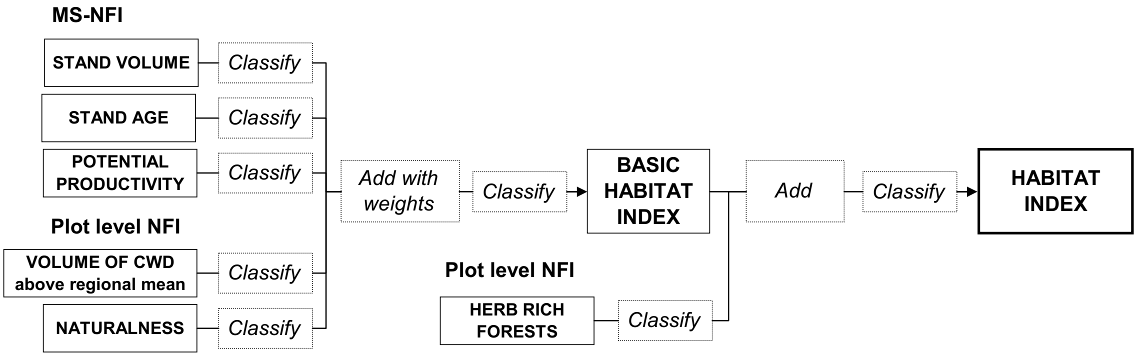


Figure 2. Flowchart of the spatial habitat model resulting to a habitat index showing also the origin of the input layer (MS-NFI or plot level NFI). All input variables were classified before adding them to the model. Weights were used in the first phase of the model.

3 METHODS

One of our approaches to compare inside versus outside conservation areas is to look at how the habitat model behaves inside conservation areas, at certain distances from conservation areas and outside conservation areas. These analyses were conducted using ArcGIS software.

Landscape metrics were calculated using two pieces of software, Fragstats (McGarigal *et al.*, 2002) and Apack (Mladenoff & DeZonia, 2001). Metrics were calculated for six rectangular windows of 125 km by 125 km placed to cover the study area completely on the north-south axis (Fig. 1). Fragstats was used for calculating the metrics for the habitat index and Apack for calculating the metrics for age and volume maps. Fragstats is a more versatile and flexible software but it was not able to process age and volume maps in all windows due to the high number of separate patches.

Quantitative landscape analyses are based on categorical maps, usually classified using aerial or satellite images (e.g. Sanderson & Harris, 2000). We conducted our analyses at this point for three maps: the habitat index map (see Fig. 2), and age and volume maps originating from MS-NFI. Age map was classified into four classes and volume map into five classes, the habitat index map had three classes. Only forested land was taken into account, other land uses were assigned as background.

4 RESULTS

4.1 COMPARISON INSIDE VERSUS OUTSIDE CONSERVATION AREAS

The (herb rich) habitat index classified in three classes has the following distribution: "poor" 41 %, "average" 34 % and "good" 25 % of forested land (table 1). Class "good" is large for a purpous: in order to find new areas that are spatially (and functionally) connected to the present conservation area network the pool of candidate areas is useful to be vast. When compairing the model's behaviour inside versus outside protected areas we can see that the contribution of "good" is the largest inside protected areas, 35 % of forested land. When looking at buffers surrounding the present conservation area network we can see that within 2 km outside conservation areas 35 % of forested land can be classified as "good" but a larger buffer of 5 km only has a 26 % contribution of class "good". According to our calculations 2.4 % of forested land is protected in the study area but 3.5 % of habitat index class "good" can be found on protected areas.

Table 1. Contribution of (herb rich) habitat index classes to forested land in different areas.

Habitat index	Conservation areas	Buffer 2 km	Buffer 5 km	Outside cons. areas	Whole study area
"Poor"	43 %	34 %	42 %	41 %	41 %
"Average"	22 %	31 %	32 %	35 %	34 %
"Good"	35 %	35 %	26 %	24 %	25 %

4.2 BASIC LANDSCAPE METRICS

Variables included the habitat index, stand age and stand volume. The classes these categorical maps had represent patch types. One of the most important landscape metrics is patch area (e.g. McGarigal *et al.*, 2002). The patch type classes observed in this study were defined based on statistics of the map for the habitat index and on using particular intervals for the age and volume maps (age and volume classes can be seen on tables 3 and 4). Looking at the average patch areas of patch type classes proceeding from north to south (from window 1 to window 6) patch sizes for most variables decrease for most patch type classes (tables 2, 3 and 4). Apparent, however, is that the habitat index class "good" has patches of same order in size in all the windows except in window 3, which has the lowest proportion of the class. Age and volume classes behave as expected - Southern Finland is more densely populated than the northern part of the study area and the overall proportion of forested land is smaller in the south.

Table 2. Average patch sizes (ha) of habitat index classes in different analysis windows.

	Average patch size (ha) of model classes		
Window	"Poor"	"Average"	"Good"
1	236,2	33,3	20,2
2	137,1	31,8	37,1
3	61,0	19,7	11,4
4	17,1	18,1	22,9
5	8,8	11,5	33,0
6	5,0	9,2	28,1

Table 3. Average patch sizes (ha) of age classes in the classified age map in different analysis windows.

	Average patch size (ha) of age classes			
Window	0 - 40 a	41 - 80 a	81 - 120 a	> 120a
1	5,6	8,7	1,7	0,6
2	3,1	16,6	1,1	1,9
3	2,8	27,5	1,1	0,4
4	4,0	9,5	1,0	0,5
5	2,3	13,9	0,9	0,3
6	1,5	10,9	1,2	0,4

Table 4. Average patch sizes (ha) of volume classes in the classified volume map in different analysis windows.

	Average patch size (ha) of volume classes				
Window	0 - 40 m^3/ha	41 - 80 m^3/ha	81 - 160 m^3/ha	161 - 240 m^3/ha	>240 m^3/ha
1	10,5	3,2	3,3	0,7	0,3
2	8,5	2,9	4,3	1,4	0,9
3	3,1	1,9	9,5	1,3	0,5
4	1,4	1,0	4,2	2,3	0,8
5	1,0	0,8	3,1	3,3	0,8
6	0,9	0,9	3,5	2,4	0,9

5 CONCLUDING REMARKS

Here were presented only general results and preliminary summaries of landscape ecological analyses conducted within our study. Please find more refined results in the poster presented at ForestSAT 2005 .

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DECISION-TREE BASED MAPPING OF FOREST PARAMETERS FROM LANDSAT DATA FOR WILDLIFE HABITAT MODELLING

Dagrun Vikhamar Schuler [a], Jan Paul Bolstad [b], Gunnar Fjone [c], Leif Kastdalen [d] and Mats Finne [e]

[a] Department of Geosciences, University of Oslo,
P.O. Box 1047, Blindern, 0316 Oslo, Norway, email: dagrunv@geo.uio.no
[b] Directorate for Nature Management, 7485 Trondheim, Norway, email: jan-paul.bolstad@dirnat.no
[c] Fjone, 3854 Nissedal, Norway, email: gunnar.fjone@forest.no
[d] Norwegian Space Centre, 0212 Oslo, Norway, email: lkastdal@online.no
[e] Utmarksavdelingen for Akershus og Østfold, P.O. Box 174, 1870 Ørje, Norway,
email: mats.finne@havass.skog.no

ABSTRACT

Tree species, age groups, wood volume per hectare and productivity classes are mapped using decision trees and Landsat ETM+ data. Reference data consist of forest stand registrations. Accuracy assessment is carried out using national forest inventory data. Furthermore, the mapped parameters are used as input to habitat models, which are based on expert knowledge of associations between habitat variables and vertebrate species.

Keywords: Decision trees, Landsat, forest mapping, habitat modelling, nature management.

1 INTRODUCTION

Forests cover approximately 37% of the area in Norway, and within these areas the diversity of wildlife and plants depends on the coverage and the composition of the forest. According to the Norwegian Red List (Directorate for Nature Management, 1999) the main threat to biodiversity in Norway is loss of habitats due to forestry, agriculture, road construction, watercourse regulation to produce hydroelectricity and general urbanisation. Productive coniferous forests, wetlands, mires, swamp woodland and certain coastal habitats are all examples of habitats whose acreage has been reduced. The Directorate for Nature Management and the Norwegian Space Centre formed the SatNat-programme in 2001 as an important element of the National Programme for Mapping and Monitoring. The programme aims to produce decision support systems for use in the management of biodiversity.

There are two aims of this work. Firstly, to map forest parameters for large regions using multitemporal Landsat ETM+ images. Secondly, to use the forest maps as input to wildlife habitat models. The habitat models are developed based on expert knowledge of associations between habitat variables and vertebrate species.

2 STUDY AREA

Østfold County (4183 km^2) is located in southeast Norway, bordering Sweden (Fig.1). The western areas is characterized by a fragmented landscape, alternating between farming, forests and cities with up to 83 000 habitants each. The eastern parts is dominated by more continous boreal forests. The topography is quite flat, ranging from sea level to 336 m. a.s.l. About 2/3 of the County is located below the marine limit. Typically, the farming landscape is located below the marine limit in clay, silt and sandy soils, while hilly forests on subglacial till soils dominate the areas above the marine limit.

3 MAPPING FOREST PARAMETERS

3.1 DECISION TREE ANALYSIS

The classification scheme is based on decision tree methods, since these techniques can handle large and heterogeneous datasets. The dataset consists of three Landsat ETM+ images acquired within a two years period (spring 2001, summer 2001, autumn 1999), terrain parameters derived from a digital elevation model, map of vegetation zones (Moen, 1999) and a heat index map. For more information about this work, see Vikhamar et al. (2004) and Vikhamar and Fjone (2004).

Decision tree methods strongly depend on large amounts of reference data representing the classes and their spectral variability. Therefore, all available digital maps of forest stands within the test area were used to build and test the decision trees. Reference data for non-forested areas were derived from a database called 3Q. This database includes detailed maps in 1 km² quadrants in a 18 x 18 grid within the farming landscape (crop fields, pastures and impervious areas).

The mapped forest parameters are tree species, age groups, wood volume per hectare and productivity classes (Figs. 2a-d). An accuracy assessment was carried out using data from the national forest inventory (Tables I-IV). Mapped forest parameters were compared to the values registered at sample locations of 250 m^2. The accuracy was tested both by using the pixel center value and the 8 neighborhood pixels. Generally, the results show that the accuracy is higher on an area level rather than on pixel level. Software used for the decision tree analysis was See5.

3.2 RESULTS

3.2.1 Tree species

Four classes were mapped: 1) Spruce; 2) Pine; 3) Deciduous forest; and 4) Mixed forests (Fig. 2a and Table I). Classes were determined based on registered wood volume per hectare per tree species. A threshold of 95% was used to distinguish the classes. This means that other tree species may constitute up to 5%.

3.2.2 Age groups

The stage of forest development was mapped using cutting classes, registered in the forest reference data (Fig. 2b and Table II). Three age groups were mapped: 1) Clear cuts and regenerated forests; 2) Young forests; and 3) Old forest.

3.2.3 Wood volume per hectare (forest density)

The parameter total wood volume per hectare was used as an indicator for forest density. The wood volume represents the volume of stems of the trees. The stem volume is not necessarily correlated to the crown coverage, which is the actual observation of the satellite sensor. Three classes were distinguished: 1) Low density (1-10 m^3/ha); 2) Medium density (10-25 m^3/ha); and 3) High density (more than 25 m^3/ha) (Fig. 2c and Table III).

3.2.4 Productivity class

Productivity class is a classification system for the fertility of the soil. It describes the potential height of trees at the age of 40 years. Productivity class is usually measured from soil samples. The project carried out an experiment to test the possibility to map productivity class using Landsat images. Three classes were mapped: 1) Low productivity (0-11 meter); 2) Medium productivity (12-19 meter); 3) High productivity (over 20 meter) (Fig. 2d and Table IV).

Best results are obtained for low and medium productivity classes. Despite that satellite observations do not provide a direct measure of the productivity, we believe that satellite measurements are a good proxy. This is probably related to the vigorousness of the vegetation.

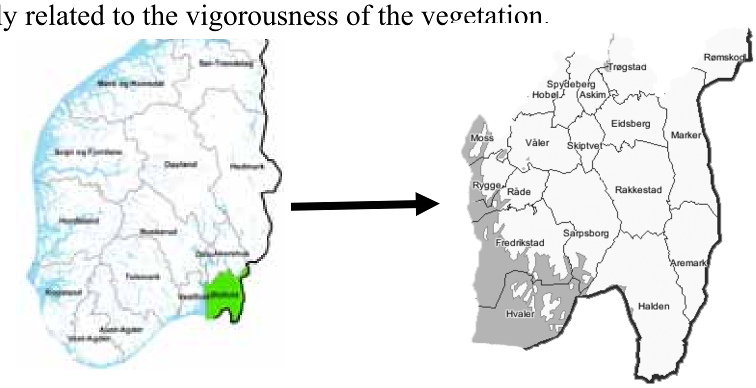

Figure 1. Østfold County in southeast Norway is the test area for the forest mapping and the habitat modelling.

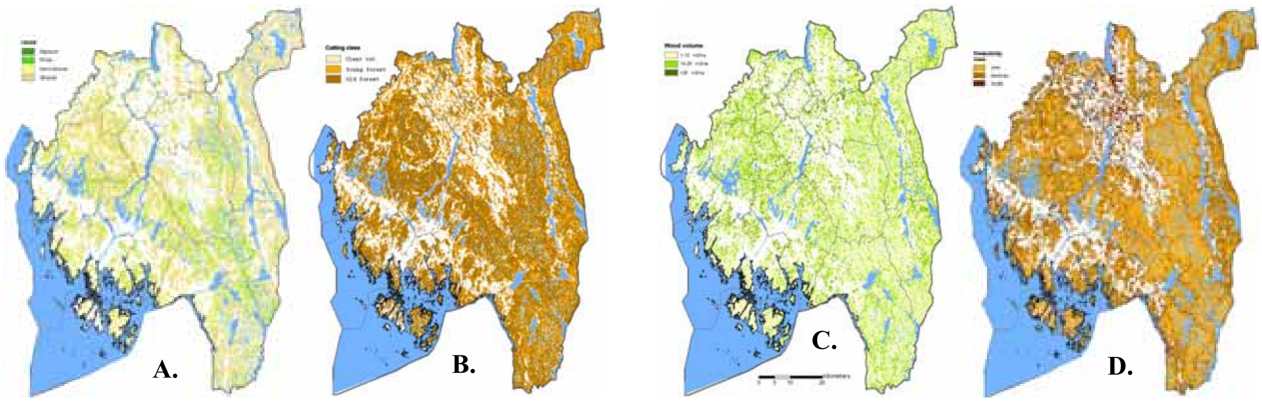

Figure 2. Resulting maps from decision tree analysis: A. Tree species; B. Age groups; C. Wood volume per hectar and D. Productivity class. White represents non-forested areas.

TABLE 1. CONTROL POINT ACCURACY FOR TREE SPECIES

Class	Center Pixel (%)	8 Neighboring Pixels (%)
Spruce[a]	17	56
Pine	42	86
Deciduous[a]	0	4
Mixed forest	51	92
Total	44 (n=745)	85 (n=745)

a. Less than 100 control points

TABLE 2. CONTROL POINT ACCURACY FOR AGE GROUPS

Class	Center Pixel (%)	8 Neighboring Pixels (%)
Clear cuts[a]	6	25
Young forests	54	90
Old forest	73	98
Total	63 (n=731)	93 (n=731)

a. Less than 100 control points

TABLE 3. CONTROL POINT ACCURACY FOR WOOD VOLUME PER HECTAR (FOREST DENSITY)

Class	Center Pixel (%)	8 Neighboring Pixels (%)
Low density	76	99
Medium density	37	84
High density[a]	21	61
Total	57 (n=745)	89 (n=745)

a. Less than 100 control points

TABLE 4. CONTROL POINT ACCURACY FOR PRODUCTIVITY CLASS

Class	Center Pixel (%)	8 Neighboring Pixels (%)
Low productivity	76	94
Medium prod.	37	93
High prod.	24	69
Total	58 (n=735)	90 (n=735)

4 PREDICTING BIRD HABITATS

4.1 HABITAT MODELLING

To map potential habitats we used in total 21 different land cover variables, among which the mapped forest parameters were included. For non-forest areas we used crop fields, pastures and impervious areas (e.g. roads, parking lots, buildings) with more or less than 50% green areas, provided from another study (Moen, 1999).

Different qualities of the environment tend to attract, or repel, a given wildlife species. We used thematic maps (scale 1:50 000), vegetation zones (Finne, 2005) and a 25 m DEM to discriminate environmental qualities that are used or not used by a given species (e.g. roads, water, built-up areas). Distribution data from the Norwegian Ornithological Association, the Norwegian Zoological Association, and species distribution data from the County Governor of Østfold were used to delimit the species range extent in 10 × 10 km quadrants. The species range extent was used to delimit the habitat maps for each species. Continuous habitats that intersect with the quadrants were included.

The analyses were performed employing a GIS extension in ArcView 3.2, using data from the habitat model and the species range extent. All map layers were transformed to a raster format equivalent to 30m Landsat TM pixels. Habitat variables of land cover, topographic maps, elevation and vegetation zones were related to each species in different map layers. The map layers were reduced to one map layer with the use of overlay and merge operations in the extension. The range extent and majority filter were used to reduce the distribution and to eliminate single pixels.

4.2 RESULTS

Predicted habitats for four avian birds are presented (Fig. 3). An accuracy assessment was performed using observational data (Table V). Counts of Black Grouse (Tetrao tetrix) and Capercaillie (Tetrao urogallus) were done by hunters with free running pointing dogs and GPS. Counts and tracks were sampled and used to analyze percent of estimated habitat and percent of counts inside a 60-meter buffer around the tracks. Data from Nightjar (Caprimulgus europaeus) and Woodlark (Lullula arborea) were sampled by drawing circles with a radius of 100 meter on topographic maps in areas were the species had been observed.

We suggested that if there were a low percent of estimated habitats inside the transect area, and the observational points covered a high percent of estimated habitats, we could conclude that the habitat model had a high degree of usability for predicting a distribution. Nightjar and Woodlark (Fig. 3) had a high percent of observational points in the estimated habitat (Tab. V). We conclude that there is a good match between the habitat model and the habitat variables described in section 2. Capercaillie (Fig. 3) had a high percent of observational points in estimated habitat and a high percent of estimated habitat inside the buffer (Tab. V). The result is not unexpected due to the high percent of estimated habitat inside the controlled area (buffer). Black Grouse (Fig. 3) had a low percent of estimated habitats in controlled areas and the observational points covered a low percent of the estimated habitat (Tab. V). The conclusion from the assessment of Capercaillie and Black Grouse is that either the habitat variables from the land cover map are insufficient due to the habitat requirements for these two species or our specification of habitat associations are to coarse. Biased sampling of observational points seems also to be a problem in this assessment.

5 CONCLUDING DISCUSSION

Recommendations from the accuracy assessment on four species indicate that the habitat maps are useful as a supplement to wildlife mapping based on field surveys to delimit areas of interest. Especially for species that have a good match between habitat model and land cover variables. Field-tests in some areas with nesting sites and observational points show that the estimated land cover variables forest age (cutting classes) and tree density (wood volume per hectare) are different than the real vegetation. This indicates that it will be essential to classify land cover variables more exactly for use in detailed wildlife mapping. Generally, results from land cover mapping show that the accuracy is higher on a regional level than on a pixel level. This suggests the main potential for this type of wildlife mapping is on a regional level, and as a supplement for wildlife mapping based on field surveys.

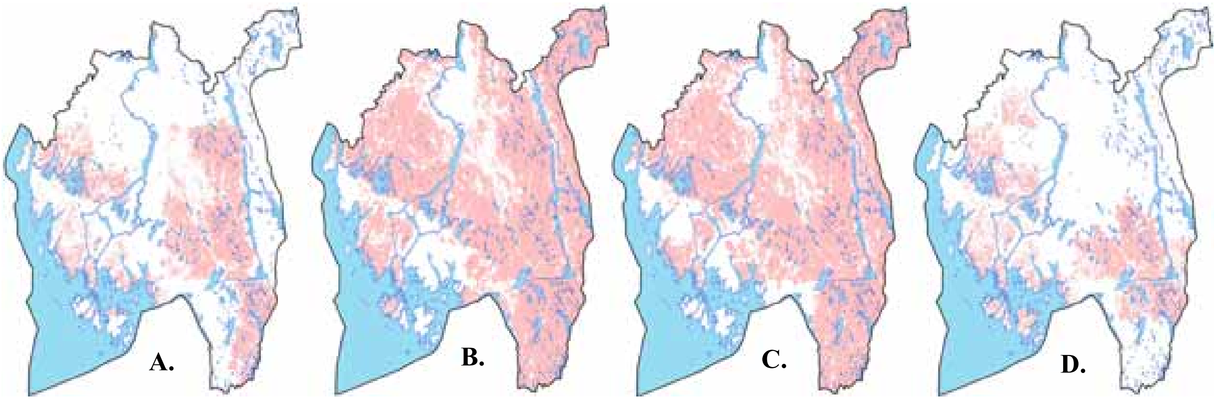

Figure 3 Predicted distributions of: A. Nightjar; B. Woodlark; C. Black Grouse and D. Capercaillie.

TABLE 5. ACCURACY ASSESSMENT BASED ON OBSERVATIONAL DATA AND ESTIMATED HABITATS FOR FOUR WOOD LIVING SPECIES

Species	A (%)	B (%)
Nightjar	39	85
Woodlark	37	76
Black Grouse	43	45
Capercaillie	84	92

A – Percent cover of estimated habitats in controlled areas
B – Percent cover of observational points in estimated habitats

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ABOUT THE MAP OF RUSSIA’S FORESTS

M. Dubinin[a], P. Potapov[b], S. Turubanova[b], A. Yaroshenko[b], L. Laestadius[c]

[a] International socio-ecological union, Moscow, Zhuravleva square, 1, sim@biodiversity.ru

[b] Greenpeace Russia, Moscow, Novaya Bashilovka, 6, alexy@diala.greenpeace.org

[c] Global Forest Watch, 10 G St. N.E., Washington, DC, 20002. USA, larsl@wri.org

ABSTRACT

In 2003, a land cover map of northern Eurasia was published (Bartalev et al., 2003). The map was based on SPOT Vegetation satellite imagery of 2000, covered the entire forest zone of Russia, and showed the distribution of different species composition classes including coniferous and broadleaved, deciduous and evergreens, and mixed forests. However, certain biologically and industrially important classes were not separated in this map. Pine and spruce forests appeared in the same class, as did temperate hardwoods and secondary birch-aspen forests. To make a more detailed classification, an older map produced from official forest inventory data was used (*The Forests of USSR,* 1990). Landsat 7/ETM+ satellite imagery and ground observation data were also used to verify the Land Cover Map of Northern Eurasia and minor revisions were made in several regions. To distinguish between closed and open canopy forests, the Global Percent Tree Cover Dataset by the Global Land Cover Facility was used. In addition, areas converted in historic times from forest to other land cover were shown, i.e. landscapes were forests may reappear naturally but is not present today, due to deforestation.

Keywords: Russia's forests, SPOT Vegetation, tree cover, tree species composition map.

1 INTRODUCTION

During the entire history of the Soviet and Russian forest service, only one relatively detailed national forest map was made (in the scale of 1: 2,500,000). This forest map of the USSR was published in the end of 1980s, but used data of very diverse age. For more densely populated and developed regions, such as European Russia, southern Siberia and the Far East, where the forests were inventoried approximately every ten years, data from the late 1970s and from the 1980s were used. For remote areas of Siberia and Far East very old data were used, sometimes as old as 1953 (as in Northern Yakutia). The map, although the only one of its kind ever made, was therefore out of date already at the moment of publication for some areas.

The Land Cover Map of Northern Eurasia (Bartalev, 2003), based on SPOT/Vegetation imagery, had also certain limitations which were closely related to the underlying data and the method used. In particular, the map did not distinguish between different dominating species (spruce, fir, regular pine, Siberian and Korean pine, dwarf pine) within the class of evergreen coniferous forests. Nor did the map distinguish between primary temperate deciduous forests (dominated by oak, lime, elm, maple, ash, or black alder depending on the conditions), and secondary deciduous forests growing back spontaneously after logging, forest fires and on abandoned agricultural land (dominated by pioneer species such as birch, poplar, and gray alder). Finally, the map did not distinguish open canopy forests from closed forests, which gives the impression of “boundless forests” in Northern Siberia and Far East.

Due to these limitations, it was decided to create a “hybrid” map, using results of satellite data interpretation and different already existing forest maps. The plan from the outset was to use this map for educational purposes.

2 MATERIALS AND METHODS

The map called *Forests of Russia* (Bartalev et al., 2004) is a synthesis of existing maps.

The boundaries of forested areas as well as boundaries between open canopy and closed forests are taken from the Global Percent Tree Cover Dataset. Forests are defined as areas with at least 10% tree cover, areas with 10% to 39% tree cover are considered open canopy forests, while closed canopy forests have greater than 40% tree cover.

Dominating species and species groups are generally shown according to the map of the forests of the USSR, published in 1990, with the exception of places where a comparison with the land cover map of Northern Eurasia, published in 2003, indicates that the species composition has changed. Areas where deciduous or mixed forest has replaced coniferous forest are categorized as "birch-aspen and mixed forest." Areas with other types of species change (rare in comparison with the previous case) are classified based on expert interpretation of the two compared maps

Potential forest areas, consisting mainly of agricultural and other non-forest managed ecosystems, are shown according to the map "Vegetation of the USSR" (Vegetation of the USSR, 1990). Boundaries of this category are uncertain and determined based on expert opinion.

For some small territories additional processing of SPOT/Vegetation data was carried out in places where it was detected that inappropriate images had been used for the and Cover Map of Northern Eurasia (mainly inappropriately early summer images for areas in the far north, where in cold years the leaves do not come out until the second half of June).

For some areas Landsat 7/ETM+ and Landsat 5/TM satellite imagery was used as well as ground observation data.

3 RESULTS AND DISCUSSION

The new forest map of Russia (the “synthesis map”) differs significantly from the Forests of the USSR map, which was prepared on the basis of official forest inventory data. The main difference is the existence in the new map of so called “birch belt” – a belt of forests dominated by birch-aspen communities of mainly secondary origin, which occupies the central parts of European Russia and the south of Siberia. The Forests of the USSR map shows most of this area as coniferous forest. The difference may have several reasons:

- The Forests of the USSR map shows these areas 20-25 years earlier than the “synthesis map”, at which time coniferous forests occupied significantly greater areas than they do today;

- The official forest inventory instruction mandates that mixed forests be classified with regard to their intended species composition at the time of final felling. The Russian forest inventory instruction does not allow mixed forests to be defined as a separate category;

- Many areas, which were treated with artificial forest restoration after clearcuts and forest fires, are still presented as coniferous in inventory materials, while in the absence of silviculture (which is the usual practice) they soon become overwhelmed by rapidly growing deciduous forests.

The new Forest map of Russia has been heavily criticized by the leaders of Russian forestry agency (the new name for the Forest Service). The official opinion was that satellite data are not adequate for mapping forests at all, because it is not possible to detect most of the important industrial indices of forest stands. At the present time, the Federal forestry agency (Rosleskhoz) is undertaking the creation of a new forest map, based on actual materials of state forest inventory.

The Forest map of Russia has been distributed widely in print format to more than 1500 state forestry enterprises (leskhozes) and to the regional forestry administration all across Russia. About one hundred responses were received from people of forest industry. Based on these responses, and after subsequent verification of the map by the authors, several limitations were detected that were dependent on particular features of source materials. Among this drawbacks are the following:

- Some regions of Southern European Russia and Siberia occupied by pine forests (mainly open canopy in transition zone from forests to grasslands) have been classified as mixed or even deciduous, which can be explained by the big portion of dominant grasslands in such forests and relative change in the spectral characteristics;

- Areas of Kuril bamboo stands on the southern part of the Island of Sakhalin were erroneously classified as temperate deciduous forests (due similarities the spectral pattern of Kuril bamboo and your birch stands);

- Some areas that were originally unsuitable for forests were shown as historically deforested (this mainly concerns some small areas of salty lands of southern Siberia).

More limitations and weaknesses are likely to be discovered in the Forest Map of Russia. At the same time, the discussion clearly shows that the map is highly appreciated by forest managers and other practitioners from all over Russia and that the map does not contain any serious mistakes for big territories.

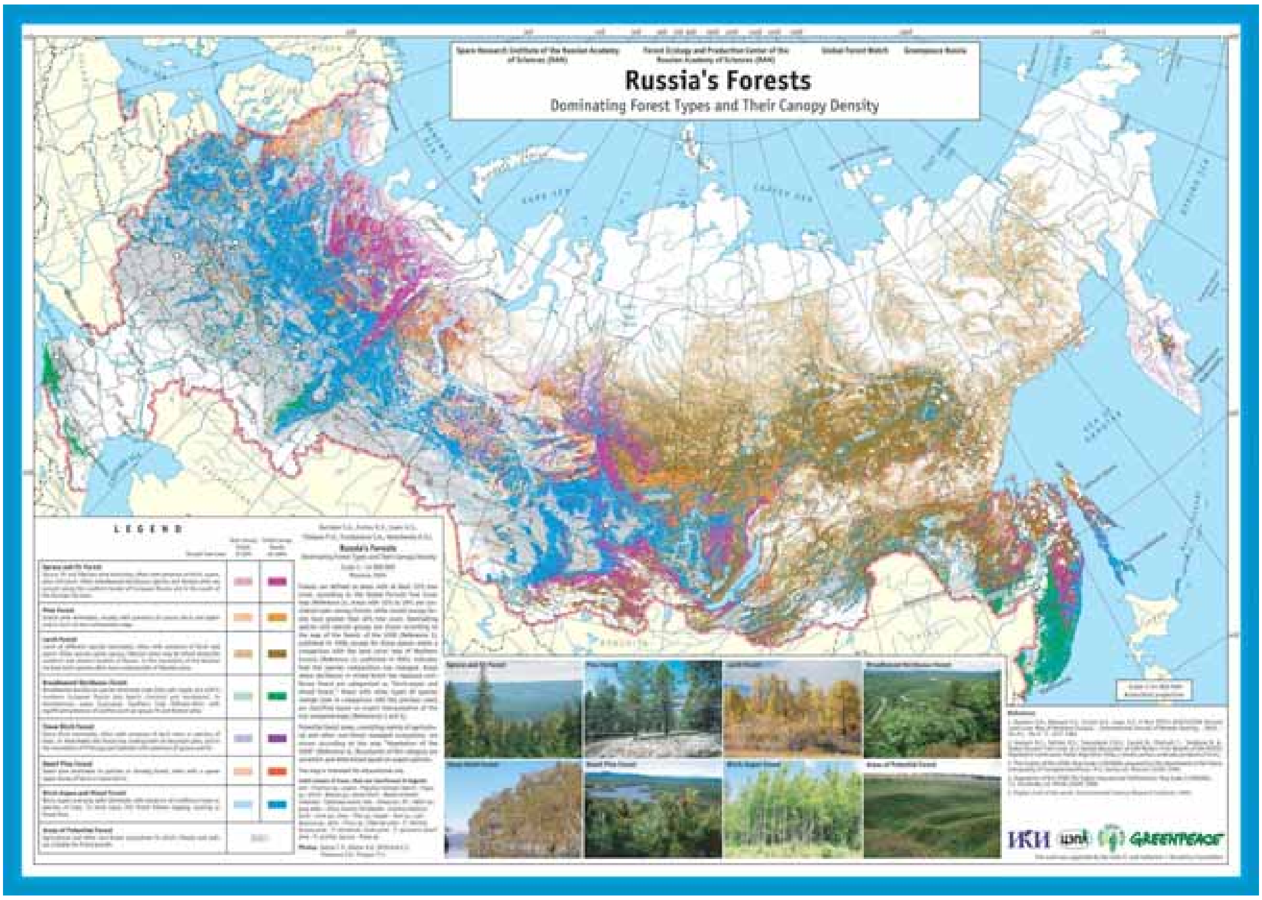

Figure 1. Overview of Russia's Forests map.

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