MULTIRESOLUTION SPOT-5 DATA FOR BOREAL FOREST MONITORING

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ABSTRACT:

The improved spatial resolution of SPOT-5 data 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. The large scene size combined with very high resolution is an operational strength when compared to VHR satellite data, although there are operational limitations for very large area coverage. 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.
User adapted methods for change detection and analysis were developed and implemented by Metria in the ENFORMA tool, now used operationally at the 100 forestry districts of Sweden. Yearly national satellite data coverages of Sweden, from SPOT-4 and Landsat-7 ETM are acquired by NBF and operationally used in the daily work. In 2003, a national coverage with SPOT-5 10 m multispectral data was ordered with 150 SPOT-5 and 50 SPOT-4 delivered. 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.

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. SPOT data has also historically proven to have excellent geometric and radiometric quality, simplifying the use of the data.
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. The total land area of Sweden is 450.000 km^2. In 2003, a national coverage with SPOT-5 10 m multispectral data was ordered and approximately 150 SPOT-5 scenes supplemented by some 50 SPOT-4 XI scenes were delivered.
This study, selected by the French Space Agency, CNES and SpotImage to be part of the SPOT 5 Application Valorization Program (SAVP), 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. Change detection methods between 20 and 30 m resolution data are already proven and are used operationally on older datasets including Landsat-5 TM and SPOT 1-4 data. These methods can be further developed for better, combined use of the different resolutions of SPOT-5 multispectral bands.
Multiresolution, single band change detection between image pairs with pixel size differences of 2.5 – 30 m was evaluated. Methods for enhanced change detection were also examined.
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.
A method for multiresolution merging of panchromatic with all multispectral bands including SWIR applicable for boreal forestry was tested for this purpose.

2. STUDY AREA AND DATA

2.1 Study area

The study area, Figure 1, 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 SPOT and Landsat TM 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.

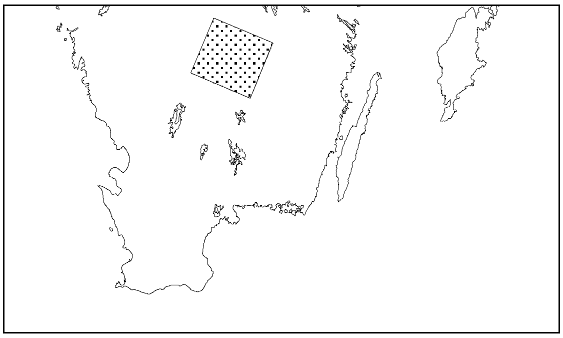

Figure 1 The localization of the study area

2.2 Satellite data

Satellite data from Landsat TM and SPOT were used. The SPOT-5 data were made available by SpotImage for this project.

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

Table 1 Satellite data used

2.3 Other input data

- Digital map data from Geographical Sweden Data, GSD – digital topographic map database (National Land Survey of Sweden.)
- DEM with 50m grid (base (National Land Survey of Sweden.)

2.4 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.

2.5 Interpretability

Figure 2, shows the same detail from different sensors and resolutions. A forest stand harvested between 1999 and 2002 with seed trees left is seen (the light area at the right side of the road in the lowest 3 images). In the upper right part, areas with a typical pattern of lines are clearly seen in the panchromatic data. These areas are thinning cuttings performed, 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. The standard band combination used in all colour images is (SWIR, NIR, red) = (rgb).

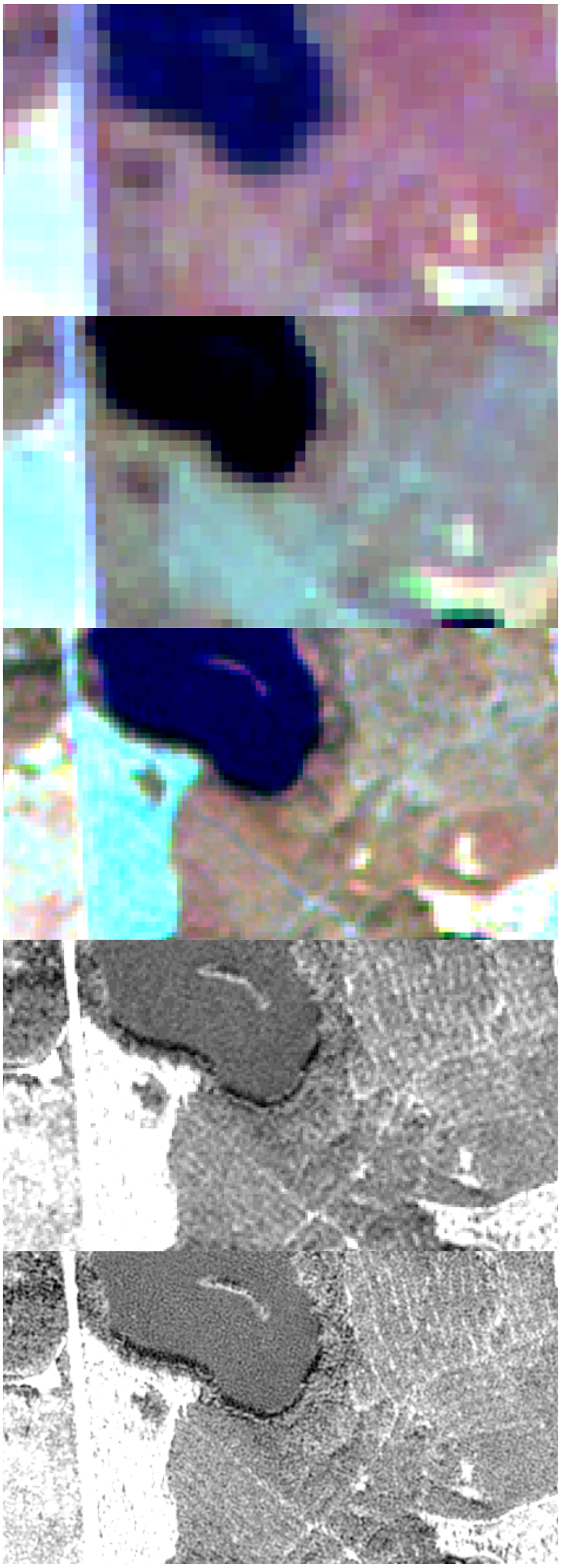

Figure 2 Detail from the satellite datasets analysed. From top: Landsat-7, 1999-09-04, 25 m; SPOT-4, 1999-06-02, 20 m; SPOT-5, 2002-08-19, 10 m; SPOT-5, 2002-08-19, 5 m pan; SPOT-5, 2002-08-19, 2.5 m pan.

3. METHODS

3.1 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, Netzband, 1998) 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) given by:

$$XS_i^H = XS_i^L \cdot \left[\frac{P^H - P^L}{P^H + P^L} \cdot \alpha + 1 \right] \qquad (1)$$

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.

3.2 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.

By using cubic convolution resampling when the difference image is calculated, satellite scenes with different resolutions are easily handled. This would not be the case if nearest neighbour resampling was used, as this would have introduced false pixel border effects from the lowest resolution image used. The resulting single band difference image will have the smallest pixel size of the input images.

3.3 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 fulfil 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.

4. RESULTS AND DISCUSSION

4.1 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 Figure 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 3 and Figure 4, 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.

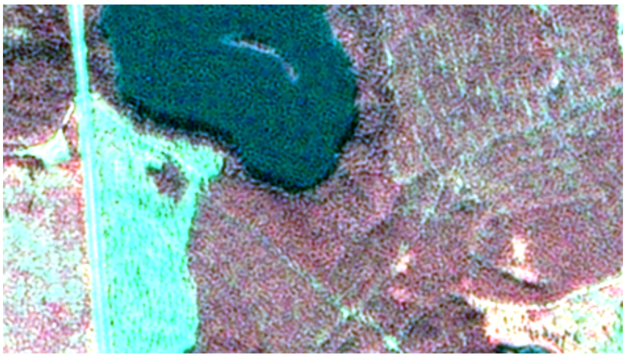

Figure 3 Resolution merge of SPOT-5 10m multispectral and 2.5m panchromatic data. Standard merged product from SpotImage. (Band 3=r, 2=g, 1=b)

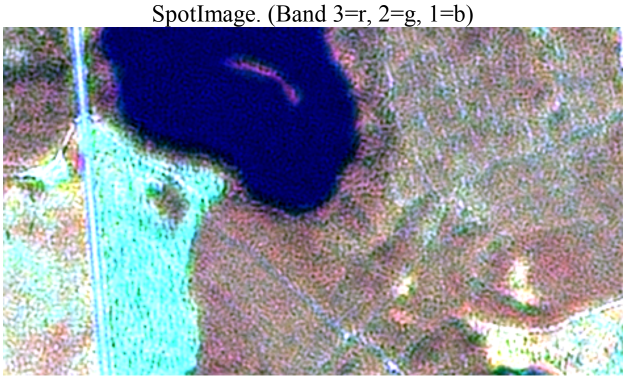

Figure 4 Resolution merge of SPOT-5 10m multispectral and 2.5m panchromatic data using the normalised difference modified HFM technique including the SWIR band. (Band 3=r, 4=g, 2=b)

4.2 Clear cut mapping

An example of the single SWIR band difference image is shown in Figure 5. 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. Another clear benefit, according to user requirements, is the better area contours mapped with the SPOT-5 data.

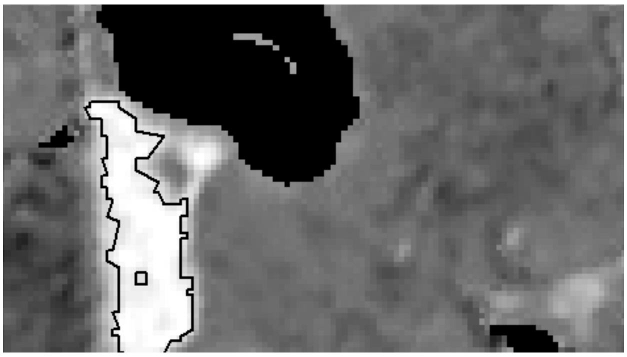

Figure 5 SWIR single band difference image between SPOT-5 2002 and Landsat-7 ETM+ 1999 scenes. Contour from threshold with 10m pixels.

Buy 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 6. The black contour is mapped from 2.5 m data and is compared to the area mapped with 10 m pixels in purple..

Figure 6 SWIR single band difference image between 2.5 m resolution merged SPOT-5 2002 and Landsat-7 ETM+ 1999 scenes.

4.3 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. Figure 7 shows the result of the classification and the arrow is showing the look direction of the ground photo in Figure 8.

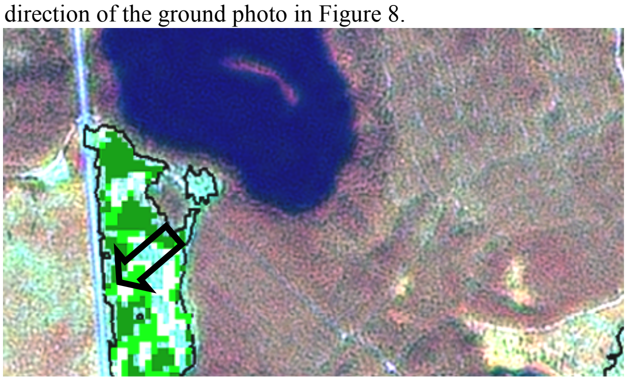

Figure 7 Density of seed trees left mapped in 3 classes.

Figure 8 Seed trees, 90-100 stems per ha

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

4.4 National coverage of Sweden with SPOT-5 data

For the summer of 2003, a complete coverage of the forested parts of Sweden by SPOT-5 multispectral data was ordered, Because the colour information and especially the SWIR band was considered to be of higher importance than the higher resolution of the panchromatic data. Panchromatic data in addition to the multispectral data were not considered due to the cost and the doubled demand for satellite capacity needed. For this reason, the methods developed should be based on the 10 m multispectral data only.

Approximately 200 multispectral SPOT-5 and SPOT-4 scenes were delivered. The addition of SPOT-4 data was needed in order to get a reasonably cloud free coverage. More than 2000 SPOT-5 scenes were acquired, but this was not enough for a complete coverage. More than 10 scenes had to be acquired for each scene delivered. It is difficult to get a complete coverage with SPOT-5 of such a large area as Sweden, with the size of 450 000 $km^{2,}$ in only one vegetation season. This is due to the cloud coverage in combination with the short vegetation season, especially in the northern part of the country above 65 degrees latitude. A satellite system adapted for yearly complete large area coverage at high latitudes every year must have a higher repetition rate and a systematic acquisition plan in order to guarantee this. Technically, this could only be met by sensors having larger scenes or with several satellites. It is also mandatory to receive all data possible because of the cloud coverage.

5. 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.

The need for yearly nationwide cloud-free coverage cannot be met by SPOT-5 alone. Future systems combining the 10 m multispectral data, including the very important SWIR band, with higher repetition rates through larger scenes or several satellites may meet these needs.

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