Species Identification and Stress Detection of Heavy-Metal Contaminated Trees

I. Reusen, L. Bertels, W. Debruyn, B. Deronde, D. Fransaer, S. Sterckx

VITO - Flemish Institute for Technological Research, Mol, Belgium

INTRODUCTION

'Maatheide' in the north-eastern part of Belgium is contaminated with heavy metals like zinc, lead, cupper and cadmium due to several decades of zinc-melting activities. In August 2000 an airborne CASI campaign was organized in this region. CASI images were acquired with a spatial resolution of 1 m by 1 m in 18 'vegetation bands', mainly concentrated in the red edge curve (680 nm- 780 nm). The most dominant tree types in this region are pine, oak and birch. After the definition of pine, oak, birch, … regions of interest, SAM classification and subsequently multi-band segmentation and 'highest frequency smoothing', a pine mask, oak mask and birch mask were created. For the pine mask several vegetation stress indices (Peñuelas J., *et al.,*1994, Zarco P.J., 1999) were calculated. The 'EGFN' (Edge-Green First derivative Normalized difference) clearly indicates vegetation stress in pine trees in the region near the former zinc-melting factory and no vegetation stress in pine trees for the reference track where no heavy-metal contamination is expected.

OBJECTIVE OF THE STUDY AND LOCATION OF THE STUDY AREA

The aim of the study was to detect heavy-metal soil contamination by means of stress detection in vegetation which has its roots in the historical contamination. The study area is located in the north-eastern part of Belgium. At the end of the 70s the zinc factory was dismantled, crushed into small pieces and spread over the terrain. Therefore high concentrations of Zn (10000 mg/kg), Pb (1700 mg/kg), Cu (1000 mg/kg) and Cd (10-70 mg/kg) can be found at the site (J.Vangronsveld *et al*., 1995).

Data collection and processing

CASI images were collected in August 2000 over the contaminated region of 'Maatheide', and were accompanied with simultaneous dGPS, reflectance and irradiance measurements at the ground. The flights lines were oriented in SW-NE direction according the main wind direction and therefore the expected heavy-metal concentration gradient. The images were acquired with a spatial resolution of 1 m by 1 m in 18 'vegetation bands', mainly concentrated in the red edge curve (680 nm- 780 nm).

Location	Maatheide (north-eastern part of Belgium)
Sensor	CASI (Compact Airborne Spectrographic Imager)
Airplane	Piper Navajo Chieftain
Field of view	37.8°
Altitude	2600 ft
Ground speed	120 knots
Spatial resolution	1 m x 1 m
Swath width	511 m
Track length	30 km
Number of bands	18
Flight orientation	SW – NE

Table 1: Details of the CASI campaign 2000.

The geometrically corrected CASI images were atmospherically corrected with ATCOR4, developed by DLR. ATCOR4 allows to deduce radiometric calibration correction factors based on the ground reflectance measurements of natural and artificial targets.

DATA PROCESSING CHAIN

Figure 1 gives an overview of the used processing chain starting from 18 bands radiometric, geometric and atmospheric corrected CASI images. Due to a spectral calibration shift of the CASI sensor of a few nm, ATCOR4 was not able to correct properly at bands near the O_2 and H_2O absorption features. Therefore four spectral bands were removed. A vegetation mask is built using a NDVI threshold eliminating non-vegetation pixels in order to decrease the further processing time.

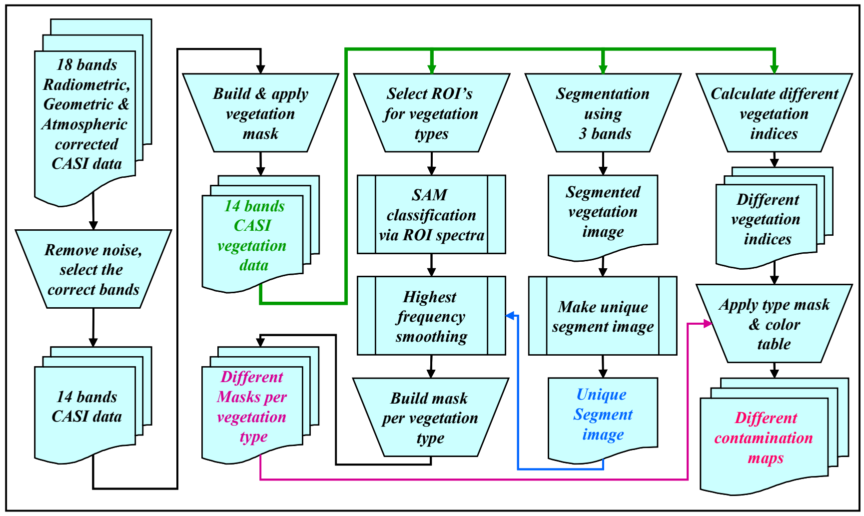

Figure 1. Processing chain: from 18 bands CAS Iimages to contamination maps.

ENVI's Spectral Angle Mapper (SAM) classification based on reference spectra determined from Regions Of Interest selected within the image (and verified in the field) results in a first rough classification, as shown in figure 2. The insert shows that a single tree is classified as consisting of different vegetation types. Multi-band segmentation with eCognition and 'highest frequency smoothing' is used to determine the final class for each tree (figure 3).

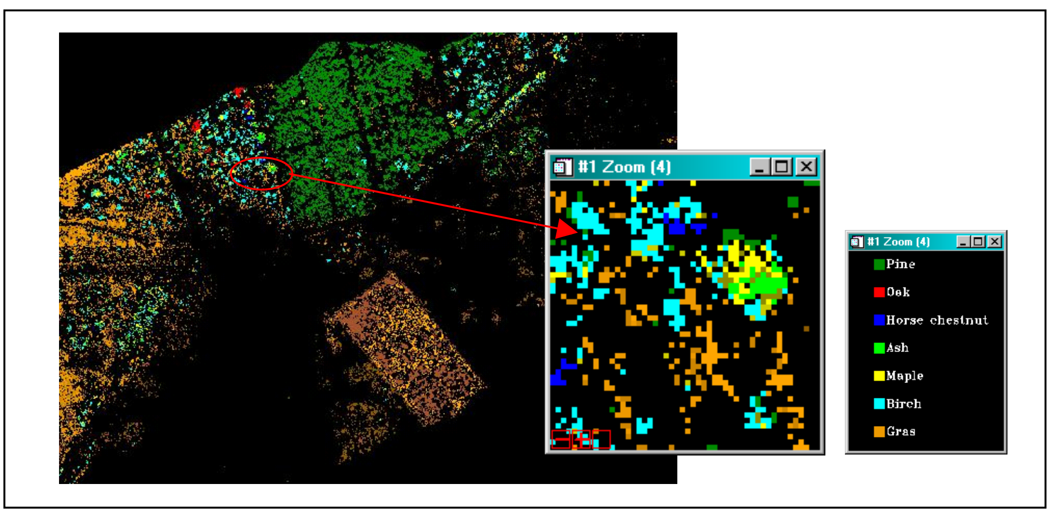

Figure 2: Result of SAM classification with image reference spectra. Insert: a single tree is classified as consisting of different vegetation types.

Three spectral bands were used to segment the image using color, shape and scale parameters with eCognition. The result is that corresponding pixels of a tree are clustered. Each segment is labeled with a unique number to allow identification of each segment (figure 3 middle). 'Highest Frequency Smoothing' finally determines the class attributed to each segment. To avoid misclassifications only segments consisting of at least 40% meaningful pixels are considered as shown in figure 3 (right).

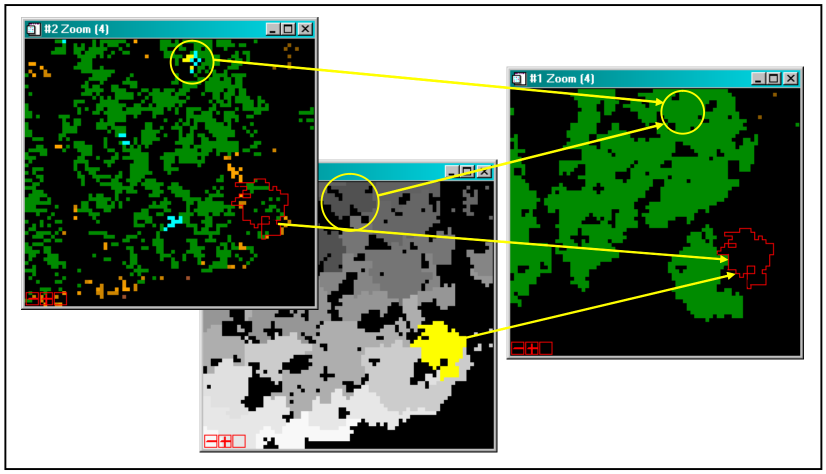

Figure 3: Left: Result of SAM classification with image reference spectra. A single tree is classified as consisting of different vegetation types. Middle: Result of multi-band segmentation with eCognition clustering pixels of a single tree (segment) together. Right: 'Highest Frequency Smoothing' determines the class attributed to each segment containing at least 40% meaningful pixels.

The final classification result after SAM classification, multi-band segmentation and 'Highest Frequency Smoothing' is shown in figure 4 (left). Subsequently a pine mask could be deduced from the Pine class of the final classification result (figure 4 right). Pine (*Pinus Sylvestris L.*) is the dominant tree type in this region.

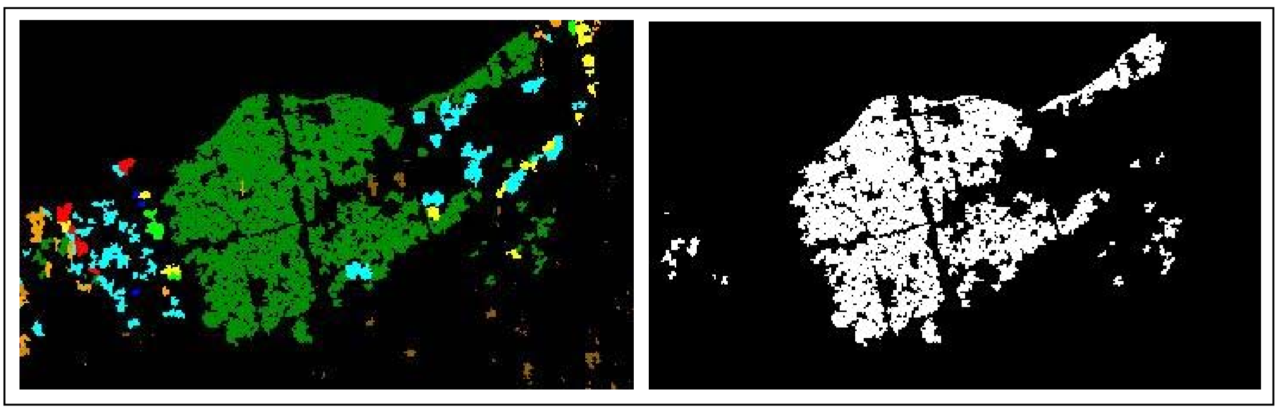

Figure 4: Left: Result of SAM classification, multi-band segmentation and 'Highest Frequency Smoothing'. Right: Pine mask deduced from the Pine class after SAM classification, multi-band segmentation and 'Highest Frequency Smoothing'.

For each pixel in the pine mask several vegetation stress indices (Peñuelas J., *et al.,*1994, Zarco P.J., 1999) were calculated and averaged per segment. The EGFN (Edge-Green First derivative Normalized difference) values are represented by a 10 percentile color code. The EGFN vegetation stress index clearly indicates high vegetation stress levels (low EGFN values) near the former zinc-melting factory (figure 5) and lower vegetation stress levels at more distant locations.

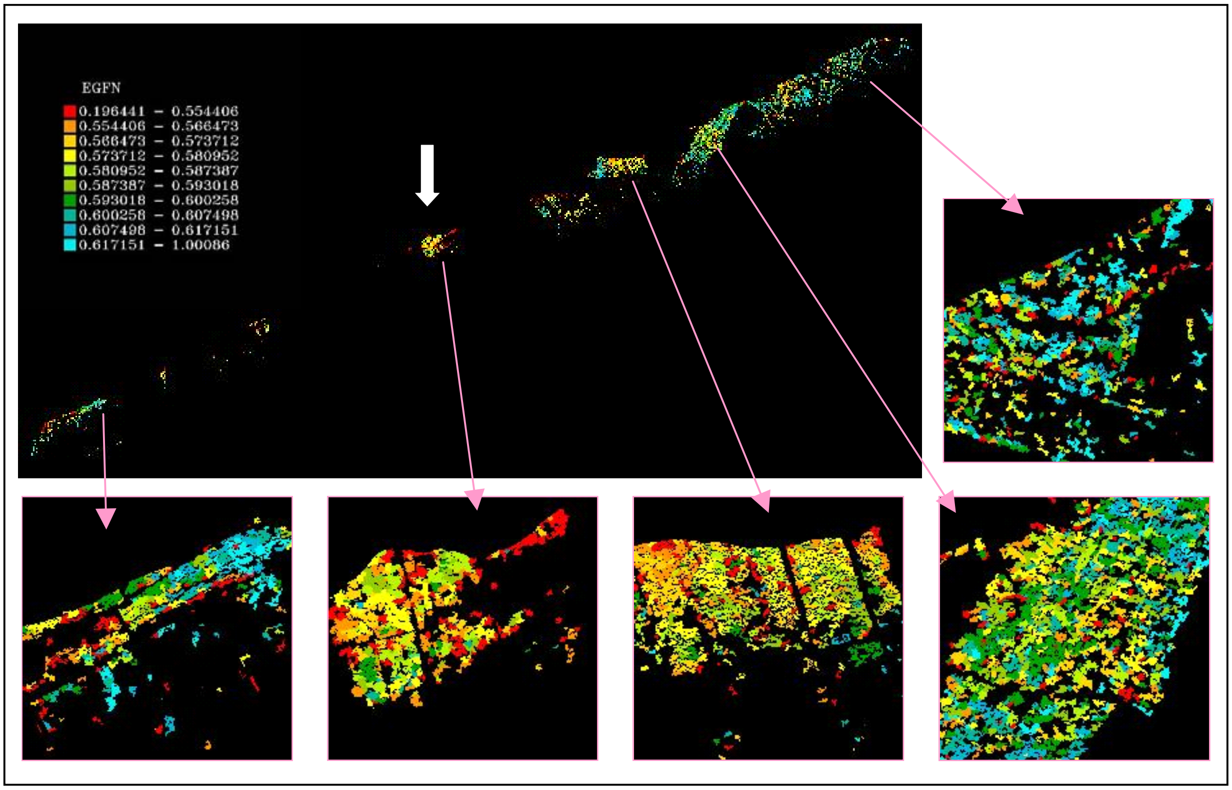

Figure 5: EGFN vegetation stress index map for pine in the 'Maatheide' track. The location of the former zinc melting factory is indicated by the white arrow.

The described vegetation stress detection technique was verified at a reference track where no heavy-metal contamination is expected. Figure 6 shows the location of the 'Maatheide' track with the former zinc melting factory indicated and the reference track.

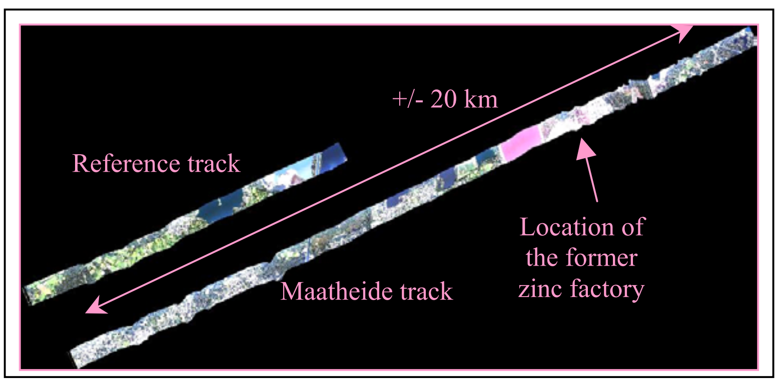

Figure 6: Location of the 'Maatheide' track with the former zinc melting factory indicated and reference track, where no heavy metal contamination is expected.

Subsequently both tracks are 25° rotated clockwise and divided into 100 m slices. If at least 2% meaningful pixels are present within the slice, the 20 percentile EGFN contribution bars are calculated. The location of the former zinc-melting factory is indicated. Figure 7 clearly shows low vegetation stress levels (high EGFN values) for the reference track as expected and high vegetation stress levels (low EGFN values) near the former zinc-melting factory. For comparison Cd concentrations, determined from soil and vegetable samples collected in gardens about 1000 m south of 'Maatheide' by LISEC, are displayed for the same 100 m slices. Clearly a correlation is present between the vegetation stress index EGFN for pine and the Cd concentrations 1000 m south of ‘Maatheide’: high Cd concentrations (which are correlated with Zn concentrations) correspond to a low (red) EGFN value.

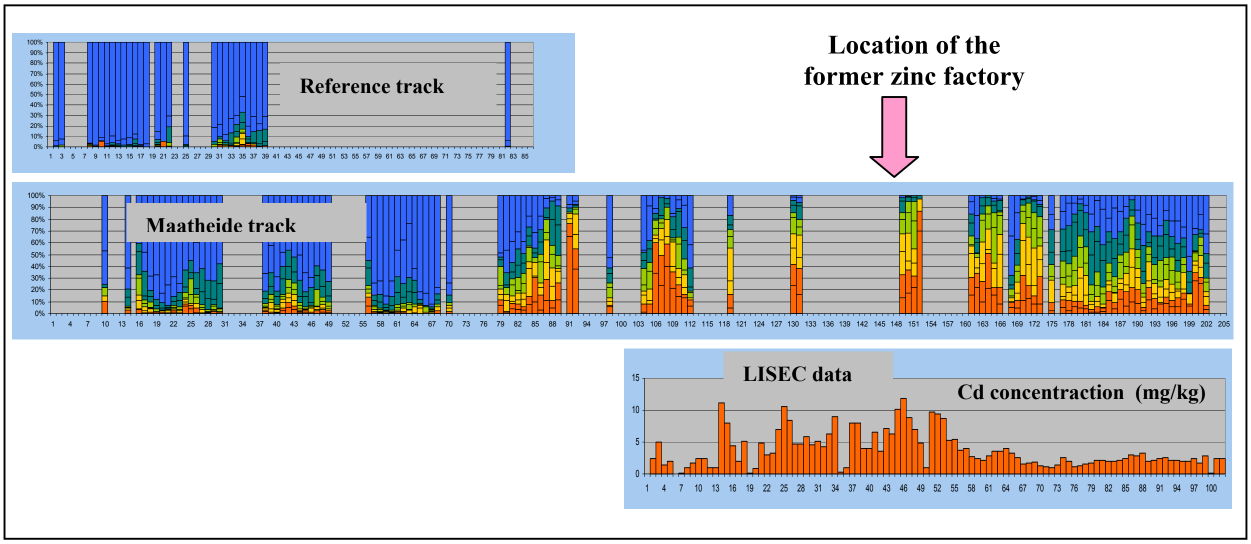

Figure 7: EGFN 20 percentile contribution bars for 100 m slices of the reference track and the ‘Maatheide’ track. For comparison the Cd concentration, determined from soil and vegetable samples collected 1000 m south of ‘Maatheide’, are displayed.

CONCLUSIONS

SAM classification of 14 bands CASI images with reference spectra from image ROI’s, combined with multi-band segmentation and ‘Highest Frequency Smoothing’ gives good vegetation type classification results. A pine mask is deduced from the classification result and vegetation stress indices like EGFN are calculated for the pine mask. The vegetation stress index EGFN shows high stress levels (low EGFN values) in the vicinity of the former zinc-melting factory at ‘Maatheide’ and decreasing stress levels at more distant locations. The EGFN map was validated against Cd and Zn concentrations determined from soil and vegetable samples collected about 1000 m south of ‘Maatheide’. High EGFN values for the reference track, where no heavy-metal contamination is present, indicate the absence of stress as expected. This technique to detect vegetation stress was applied successfully for pine, but can probably be used to map vegetation stress in other tree types, crops, …

ACKNOWLEDGEMENTS

This work was supported by the Flemish Waste Management Agency OVAM.

REFERENCES

1. *Peñuelas J., et al., Reflectance Indices Assocoiated with Physiological Changes in Nitrogen- and Water-limited Sunflower Leaves, Remote Sensing of Environment 48, p. 135-146 (1994)*

2. *Vangronsveld J. et al., Reclamation of a Bare Industrial Area Contaminated by Non-Ferrous Metals: In-Situ Metal Immobilization and Revegetation, Environmental Pollution Vol. 87, p. 51-59 (1995)*

3. *Zarco P.J., Optical Indices as Bioindicators of Forest Condition from Hyperspectral CASI data, Proceedings 19th Symposium of the European Association of Remote Sensing Laboratories (EARSeL), Valladolid, Spain, (1999)*