report

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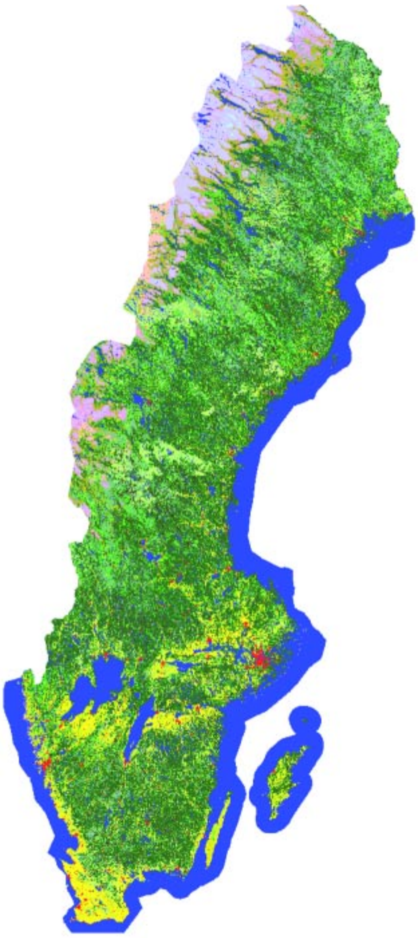
National land cover mapping for air pollution studies



Camilla Mahlander Sofi Hellsten Cecilia Akselsson Sam Ekstrand

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Organisation/Organization IVL Svenska Miljöinstitutet AB IVL Swedish Environmental Research Institute Ltd.	**RAPPORTSAMMANFATTNING** **Report Summary**
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Rapportförfattare/author

Camilla Mahlander, Sofi Hellsten, Cecilia Akselsson, Sam Ekstrand

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National land cover mapping for air pollution studies

Sammanfattning/Summary

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IRS WiFS satellite data only, without support from ancillary information, was found not to yield satisfactory accuracy given the classes required by the ASTA programme. When used integrated with county statistics on forest and agricultural areas, as well as digital maps, the results, however, reached an acceptable quality level.

Accuracy assessment could not be carried out in all counties of Sweden, and therefore the data should be used with caution if the end users are interested in regional or local scales rather than the national perspective. This does however not mean that the data cannot be used for local applications. In most areas the accuracy is good also with aggregations of 0.5 km or 1 kilometre resolutions.

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Summary

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IRS WiFS satellite data only, without support from ancillary information, was found not to yield satisfactory accuracy given the classes required by the ASTA programme. When used integrated with county statistics on forest and agricultural areas, as well as digital maps, the results, however, reached an acceptable quality level.

Accuracy assessment could not be carried out in all counties of Sweden, and therefore the data should be used with caution if the end users are interested in regional or local scales rather than the national perspective. This does however not mean that the data cannot be used for local applications. In most areas the accuracy is good also with aggregations of 0.5 km or 1 kilometre resolutions.

Introduction

The research programme ASTA (International and National Abatement Strategies for Transboundary Air Pollution), financed by MISTRA, includes a national subprogramme with focus on effects of interactions between air pollution and land use. Of particular interest for ASTA are effects on forests, especially in relation to harvest. In order to quantify harvest ASTA needs a national land use map with a class nomenclature that corresponds to the needs. This project aims at producing such a map to a reasonable cost. The report describes how the land use data were produced. The second part of the report consists of an end-user evaluation and describes how the classification is used for nutrient balance calculations.

The end user requirements at the outset of the project emanated from the following major tasks:

- Quantification of the harvest in forestry. Specific foci are the harvest loss of base cations and the increase in hydrogen ions as indicators for soil acidification. An additional target is the change in the nitrogen balance caused by harvest.

- Quantification of emissions dependant on agricultural productivity, specifically the occurrence of pasture-land. Emissions of ammonium nitrogen to air are a central issue.

The requirements regarding the land cover map were that the data should allow aggregation to a 10 x 10 km or at least 20 x 20 km grid covering the country. Data should be up to date. These requirements coincide with the research and implementation focus of RESE.

Objectives

The major objective was to deliver land use data for Sweden meeting the end user requirements of ASTAs national subprogramme.

In the initial project description additional objectives were to deliver also productivity data, to calculate emission factors and impact factors for land cover and productivity classes, and to compare emissions from area sources (e.g. agriculture) to point and infrastructure sources. Due to somewhat reduced funding from RESE, and to requests for extended accuracy assessment of the land use data towards the end of the project, these additional objectives have not been addressed.

Material

Satellite data

The land cover classification was based on IRS WiFS data with an original spatial resolution of 180 m, here resampled to150 m. Each image consists of two bands, in the red and the near infrared part of the spectrum respectively. Five images were used in order to cover the whole country. Due to problems with haze in one of the images Landsat TM data were used for the area of Bohuslän on the West Coast.

For identification of training data and for evaluation purposes Landsat TM data were available for some areas. The satellite data used for classification and evaluation are listed in Table 1. In one area also IKONOS data with 4 m resolution were available.

Table 1. Satellite data used in the classification and evaluation process.

Data used for classification			
Geographic area	**Data**	**Spatial resolution**	**Acquisition date**
Central Sweden	WiFS	150 m	August 2, 1999
Central-southern Sweden	WiFS	150 m	July 30, 1999
Northern Sweden	WiFS	150 m	June 26, 1999
Southern Sweden	WiFS	150 m	May 18, 1999
Central-eastern Sweden	WiFS	150 m	July 11, 1999
Bohuslän	Landsat TM	30 m	May 15, 2000
Data used for evaluation			
Skåne	IKONOS	4 m	July 4, 2001
Skåne	Landsat TM	30 m	
Halland	Landsat TM	30 m	
Medelpad	Landsat TM	30 m	
Västerbotten	Landsat TM	30 m	

Aerial photography

Digital Colour Infrared (CIR) aerial photos at a scale of 1:30.000 or 1:60.000 were available for some areas as listed in Table 2. They were used to define training areas as well as for evaluation of the classification accuracy.

Table 2. Aerial photographies used in the classification and evaluation process.

Data used for definition of training areas	
Geographic area	**Acquisition date**
Skåne	July 1999
Uppland	July 1999
Västerbotten	July 1999

Map data

In order to support the classification digital general maps[1] were used. The following classes were available from these maps:

- Forest
- Open land
- Wetland
- Bare mountain
- Glacier

[1] The general map database with the original scale 1:250 000 is part of GSD (Geographical Sweden Data) managed by the Swedish National Land Survey.

Topographic paper maps[2] as well as county borders in digital form were also used to support the classification.

Elevation data

Grid elevation data from the Swedish National Land Survey with a spatial resolution of 200 metres were used in order to define areas above a certain height above sea level. This was particularly useful for classification of vegetation classes in the mountain areas in the northern part of Sweden, e.g. mountain forest and bare mountain areas.

Statistics

Statistics concerning farming and forestry, including coverage of varying species, were available from Statistics Sweden (Statistiska Centralbyrån) and used for comparison of classification results.

Methods

Image pre-processing

Each IRS WiFS image included a pixel-level error that had to be corrected before the images could be used for classification. The methodology for this correction was described in material delivered together with the images from the Swedish National Land Survey.

The images were geometrically corrected and resampled from WGS 84 to the Swedish co-ordinate system RT90.

Land cover classes

The images were classified into the following classes:

- Water
- Wetland
- Bedrock
- Agriculture
- Pasture-land
- Clearcut
- Broadleaved forest
- Mixed forest
- Coniferous forest
- Urban areas
- Mountain forest
- Bare mountain
- Glacier
- Roads

Due to problems with clouds the following classes were also required:

- Open land covered by clouds (Open land taken from the digital general maps)
- Bare mountain covered by clouds (Open land in the digital general maps above a specified elevation in the grid elevation data)

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[2] The topographic map series with the scale 1:50000 is part of GSD (Geographical Sweden Data) managed by the Swedish National Land Survey.

Selection of training areas

Training areas for the different land use classes were defined in each of the IRS images. To support this the aerial photos, Landsat images and paper maps were used. The topographic maps were primarily used for orientation in the images.

The aerial photos were mainly used to define training areas for agriculture and pasture-land. Aerial photos for three areas were used: southeastern Skåne in the southernmost area of Sweden, an area around the city of Uppsala in the central part of the country, and an area south of the city Skellefteå in the northern part of Sweden. At least one of these three areas was present in each IRS image. The aerial photos were also used in order to define training areas for broadleaved forest and clearcuts.

Training areas for bedrock, mixed forest, coniferous forest and clearcuts were in most cases identified using Landsat images covering the areas of Skåne, Halland and Bohuslän in southern Sweden, Medelpad in the central part of the country, as well as an area in Västerbotten in north-western Sweden.

Water was easily detectable in the IRS images. Also urban areas could easily be identified with support from the topographic maps.

No training areas were used for mountain forest and glaciers. Mountain forest was classified using a mask from the digital map, and glaciers were extracted directly from the map. Training areas for bare mountain and bedrock were identified using the mask for bare mountain.

Classification

The classification was performed separately for each of the 21 Swedish counties in order to enable comparison with statistics concerning forestry and agriculture acreage within each county.

Initially the digital general maps were overlaid on the IRS images. Some discrepancies in geometry had to be corrected for in order to use the data together. The satellite images were thus adjusted to the map.

The used method for classification was Bayesian maximum likelihood classification, meaning that the different classes could be given different weights during the classification. The digital general maps included five land cover classes. These classes were used as masks, defining the areas to be classified. During the classification the mapped land cover type was assigned a higher weight than other classes. Table 3 illustrates how the masks were used. For instance, the forest mask was used for classification of water, agriculture, pasture-land, clearcut, coniferous forest, mixed forest, and broadleaved forest. Among these classes clearcuts and the different types of forest were assigned higher weights than the other classes. The result was a classification of areas previously mapped as forest in the county. The new information derived was the division of forest into the four forest classes (five in the mountain areas). Only a few areas were classified as water, agriculture and pasture, since these classes were assigned weaker weights than the other classes. These areas were primarily found at the boundaries of the masks, which is explained by the combination of satellite data with rather coarse resolution and the masks represented by vector polygons.

The open land mask was used in a similar manner, where water, agriculture, pasture-land, bedrock and the different forest classes were classified and agriculture and pasture-land were assigned higher weights than the other classes.

Under the wetland mask, wetland, water, agriculture, pasture-land, and the different types of forest were classified. Also bare mountain was classified in this manner. Glacier however, was directly set according to the mask.

Table 3. Usage of masks during the classification process.

Mask Weight	Forest	Open land	Wetland	Bare mountain	Glacier
Dominating classes (high weight)	Clearcut Broadleaved forest Mixed forest Coniferous forest	Agriculture Pasture-land	Wetland	Bare mountain	Glacier
Other classes (low weight)	Water Agriculture Pasture-land	Water Bedrock Broadleaved forest Mixed forest Coniferous forest	Water Agriculture Pasture-land Broadleaved forest Mixed forest Coniferous forest	Bedrock	

For the two classes urban areas and water there were no masks that could be used, meaning that when the classifications performed using the masks described above were merged there were unclassified areas that either consisted of water or urban areas.

To solve this problem each county was also classified in only the two classes urban areas and water. The rest of the classifications were then overlaid on this classification, resulting in a classification of the county where all land use classes were represented.

The result of the classification from each county was compared to the statistics from Statistics Sweden concerning forestry and agriculture. This was done in order to indicate the accuracy of the classification. The comparison was primarily used for the classes agriculture and pasture-land and for the different forest classes. The statistics showed the amounts of these land use types in each county and could thus be used to indicate approximately how many pixels there should be of each class in the county.

As a final step all classifications for the counties were merged together, creating a complete land cover map for Sweden. Obvious misclassifications were edited by hand. Problems occurred for instance along the coasts, where water had been classified as urban area, and vice versa. Paper maps were used to support the editing of the classifications. Another type of misclassification was that major highways were classified as clearcuts, which was also corrected by editing.

Mountain forest

Mountain forest was identified by using a mask created by combining the elevation data and the lower elevation boundary for mountain forest, e.g 800 metres. Since this lower elevation boundary varies from south to north (and to some extent also in the east-west direction) the mountains were divided into four different areas with varying lower boundaries for mountain forest. All areas that had been classified as forest and were located at elevations higher than the boundary were classified as mountain forest.

No specific training areas were used for mountain forest, since it was impossible to separate this class from the other forest classes, also in the Landsat TM data and in the CIR photographies. Instead, areas close to the masks for mountain forest that had been classified as broadleaved forest were assigned to the class mountain forest. This was based on the assumption that these areas consisted of mountain birch.

Clouds

In some cases parts of the IRS images were covered by clouds. The clouds as well as their shadows make it impossible to classify the land cover. Also haze causes problems and misclassifications. Areas covered by snow is another problem that obstruct classification of land cover.

To avoid some of these problems cloud-covered areas were masked in the images by manual digitising. For some of the areas there was an overlap with another image, which could be used. When this was impossible the digital general maps were used in order to define areas like “cloud-covered forest” (i.e. clearcut, broadleaved-, coniferous- or mixed forest), “cloud-covered open land” (i.e. pasture-land or agriculture), and “cloud-covered bare mountain” (i.e bare mountain or bedrock). Cloud-covered areas falling within the wetland mask were classified as wetland, and cloud-covered areas within the glacier mask were classified as glacier. Water and urban areas that were affected by clouds could also be classified using map data.

The IRS image covering the area of Bohuslän was to a large extent covered by haze. A Landsat image was therefore used for classification of this area. The image was classified in the same manner as the IRS image, and resampled to 150 m resolution.

Results

The merged result from the classifications is shown in Figure 1. The new land cover map represents an improvement to existing satellite land cover classifications based on medium resolution satellites such IRS WiFS by the separation of pasture-land and agriculture, as well as in the number of forest classes, and by the comparatively ambitious assessment of the classification accuracy.

Accuracy Assessment

The classifications were compared to different types of reference data as presented in Tables 4-9. In Table 4 a summary of the classification result for the whole country is expressed as overall classification accuracies for different reference areas. The accuracy varies between 60% and 87%. Tables 5-9 consist of confusion matrices for each of the evaluated reference areas.

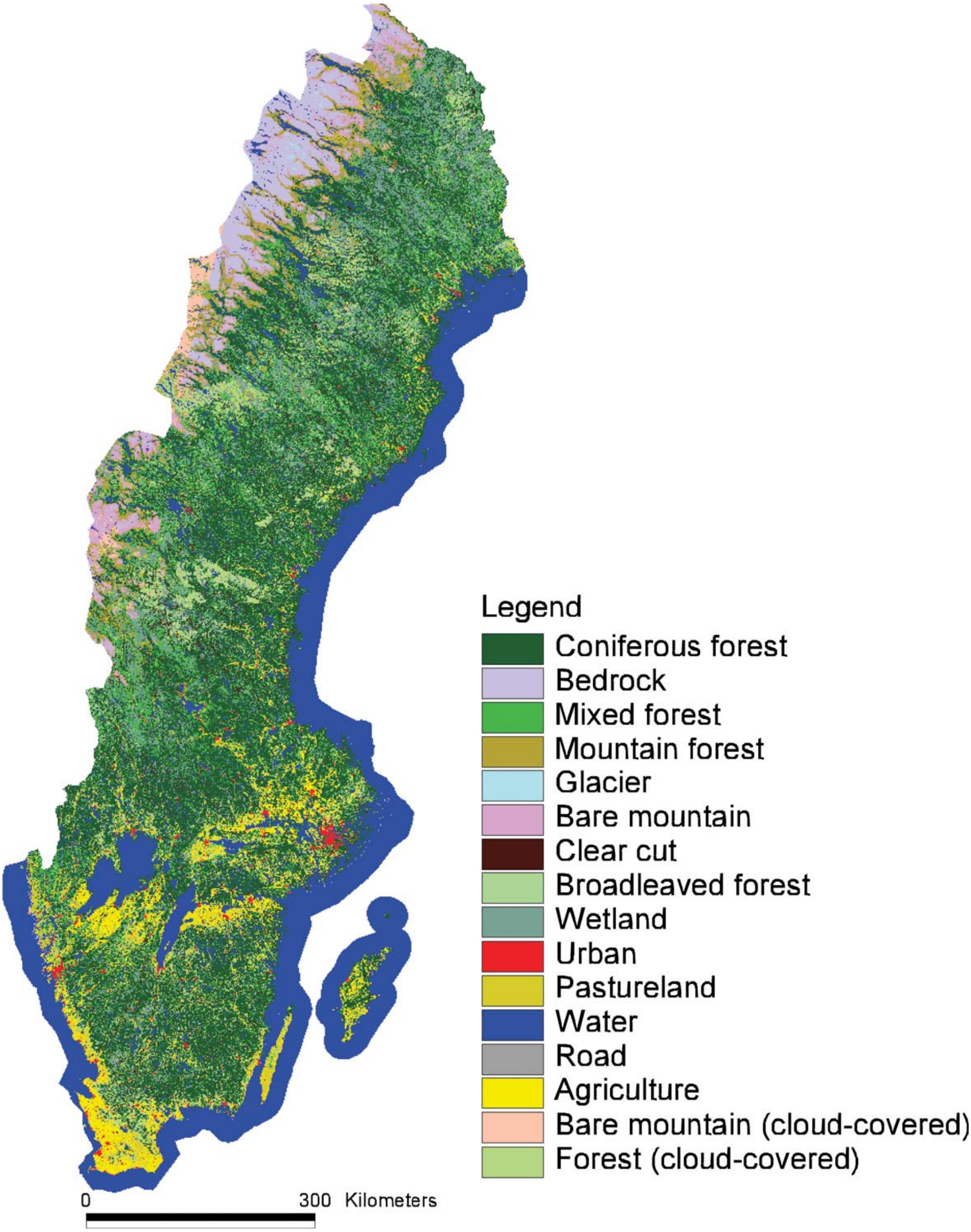

Figure 1. The resulting land use classification.

Table 4. Results of classification presented as overall classification accuracy.

	Area	**Reference data**	**Overall classification accuracy**
Southern Sweden	South-East Skåne	Aerial images	
	Central Skåne - Höör	Ikonos image	
	Blekinge, Halland, Bohuslän	Landsat TM data	73 %
Central Sweden	Sundsvall	Landsat TM data	60 %
	Östersund	Landsat TM data	65 %
	Åkersjön/Kall	Map, scale 1:100 000	87 %
Northern Sweden	Kiruna	Landsat TM data	85 %

Table 5. Classification accuracy in southern Sweden.

		Reference data									
		Water	Wet-land	Agri-culture	Pasture-land	Clear cut	Broad-leaved forest	Mixed forest	Conif-erous forest	Urban	**Total**
Classification	Water	13					1				**14**
	Wetland		9					2			**11**
	Bedrock										**0**
	Agriculture			27	7		1	2		4	**41**
	Pasture-land			12	23						**35**
	Clearcut		1			5	2				**8**
	Deciduous forest				1	1	11	3	1		**17**
	Mixed forest					1	1	3			**5**
	Coniferous forest		1		2	1	2	8	19		**33**
	Urban									33	**33**
	Total	**13**	**11**	**39**	**33**	**8**	**18**	**18**	**20**	**37**	**197**

Table 6. Classification accuracy in the Sundsvall area

		Reference data								
		Water	Wet-land	Open land	Clear cut	Broad-leaved forest	Mixed forest	Conif-erous forest	Urban	**Total**
Classification	Water	13		1		1				**15**
	Wetland		10		1			1		**12**
	Open land			13					1	**14**
	Clearcut				6			1		**7**
	Deciduous forest			1		1				**2**
	Mixed forest		3		3	3	3			**12**
	Coniferous forest	2	6		6	7	8	12		**41**
	Urban								9	**9**
	Total	**15**	**19**	**15**	**16**	**12**	**11**	**14**	**10**	**112**

Table 7. Classification accuracy in the Östersund area.

Classification	**Reference data**									
		Water	Wet-land	Open land	Clear cut	Broad-leaved-forest	Mixed forest	Conif-erous forest	Urban	**Total**
	Water	9							1	**10**
	Wetland	2	14				1			**17**
	Open land		2	12				1		**15**
	Clearcut				12				2	**14**
	Deciduous forest			1						**1**
	Mixed forest		3	1	4		2	1		**11**
	Coniferous forest	4	1	1	2		11	13		**32**
	Urban								8	**8**
	Total	**15**	**20**	**15**	**18**	**0**	**14**	**15**	**11**	**108**

Table 8. Classification accuracy in the Åkersjön-Kall area.

Classification	**Reference data**			
		Forest	Mountain forest	**Total**
	Forest	10	1	**11**
	Mountain forest	2	10	**12**
	Total	**12**	**11**	**23**

Table 9. Classification accuracy in the Kiruna area.

Classification	**Reference data**								
		Water	Wetland	Bare Mountain	Open land	Forest	Urban	Mountain forest	**Total**
	Water	10							**10**
	Wetland		8						**8**
	Bare mountain			12				1	**13**
	Open land		1				1		**2**
	Forest		1			11	1	5	**18**
	Urban						3		**3**
	Mountain forest	1	1			1		30	**33**
	Total	**11**	**11**	**12**	**0**	**12**	**5**	**36**	**87**

Discussion

Classifications involving a large number of land use classes tend to be difficult to perform, since there is a high risk that the classes are mixed. In this classification 13 classes were used and it has sometimes been very difficult to separate the classes. Another factor making the classification difficult is the fact that the IRS images only include two wavelength bands (red and near infrared). The spectral signatures of different classes were thus in many cases difficult to separate. Also the coarse resolution of the data must be taken into account, when studying the accuracy tables. Many pixels are “mixels” representing several different types of land cover. This problem was most obvious for classes that typically cover small areas, such as bedrock.

Training areas have only been available from certain parts of the country. It would have been an obvious advantage if training data for all classes had been available for each county. The images cover very large areas, and the variation concerning the amount of green vegetation, etc. could be of high importance, depending on the acquisition date of the image.

The image used for the southern part of Sweden was acquired on May 18, and the training areas for agriculture and pasture are from the area of Skåne since aerial photos were available for this area. When classifying the northern part of the image almost all open land was classified as pasture-land, probably due to differences in growing season. The problem would probably have been avoided if training areas had been identified more locally. In order to reduce such problems different weight settings for the classes was used. For classification of open land the county statistics concerning agriculture was useful, making it possible to identify approximately how large areas that should be assigned to each class. This information proved very useful and was together with the masks from the digital map used to iteratively classify the images in order to achieve as good results as possible for each county. Thus, the problems with overestimation of pasture-land in the north part of the southern IRS image were strongly reduced. The class areas given by the digital maps were not considered to be the definite truth, but was subject to improvement based on the satellite data. This method was also applied for forest areas, even though the statistics for the forest classes was not as accurate as for agriculture.

The masks from the digital maps were also used to limit the problem with separation between many classes. Since a maximum of seven classes were used under the same mask the mix between classes could be minimised. It was also possible to separate classes with very similar spectral characteristics, such as clearcut and wetland. Wetland was not classified under the forest mask and clearcuts were not classified under the wetland mask.

The land use map - end user evaluation

Land use information is crucial for nutrient balance calculations. Forest types are important for estimating nutrient inputs (deposition) as well as nutrient outputs (harvest). Geographical information about agricultural land is important for estimations of nitrogen emissions, which also is an issue for the national subprogram of ASTA.

The RESE land use map, based on satellite images (IRS WIFS) with a resolution of 180*180 m, means an improvement of the resolution compared to the statistical data from the National Forest Inventory that were used before. The land use map was delivered in two versions, one with the original classification and one with area fractions for the different classes for 5*5 km grids (Figure 2). The later version is the one that will be used for the national mapping. The high resolution is needed to meet the demand of mappings on a regional level. The classes used are chosen to correspond to the needs of ASTA.

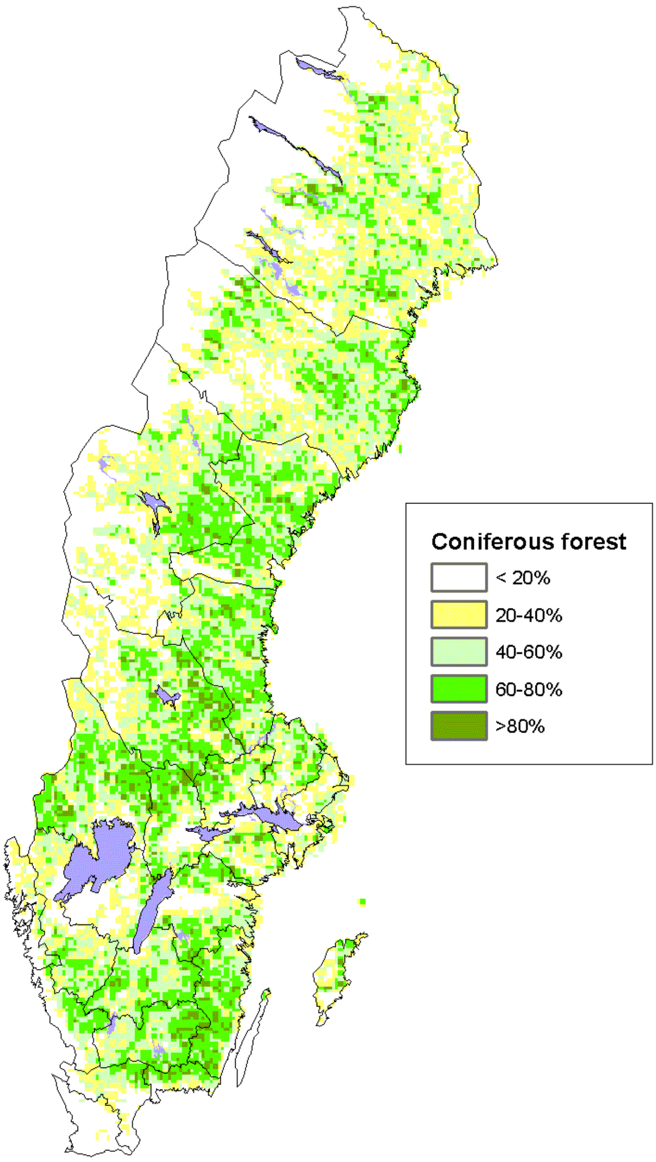

*Figure 2. Percentage of coniferous forest presented in a 5*5 km grid.*

Site productivity, biomass and growth rate will be added as layers to the land use map and it will be combined with many different types of geographical information, e.g. deposition, runoff, a national soil map, and a digital elevation model, for different applications.

Calculation of nutrient budget in forest ecosystems

The national subprogramme in the MISTRA financed programme ASTA (International and National Strategies for Transboundary Air Pollution), deals with interactions between air pollution and land use. An important task for this subprogram is to map the nutrient budget (nitrogen and base cations) on a regional level in Sweden for the present, the past and the future. This information is needed for the next generation of critical load calculations, as well as for estimations of sustainable harvesting of biofuels.

The work is done in three different steps. The first step, which is already performed, includes development of a method for mass balance calculations of nitrogen. Low geographical resolution was used in order to have a data set that is easy to handle. The focus was on the method and not on the input data. The method can be developed further when new information about for example leaching is available. The second step, which is on-going, is applying the method to 5*5 km grids, with focus on the accumulation of nitrogen in forest ecosystem in relation to the gradient of atmospheric deposition. In the third step the method, with minor changes e.g. adding weathering, will be applied for base cations.

Development of a method for mass balance calculations of nitrogen on a county level

A method has been developed to make calculations of nutrient budget of nitrogen in forest soils, by a simple mass balance method. The parameters used for the calculations are deposition, harvest, growth and leaching. Deposition is the input to the system for nitrogen, and for base cations deposition and weathering are the inputs. Outputs are harvest and leaching.

The method has been developed on a county level, which implies that mean values for each county have been calculated. Nitrogen deposition data were derived from SMHIs MATCH model[3], harvest and growth data were collected from the National Forest Inventory and leaching was estimated from runoff and soil water data. Leaching from clearcuts was estimated separately, based on an empirical function between deposition level and nitrogen content in soil water. Figure 3 shows the result for calculations on a county level in southern Sweden.

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[3] Langner, J., Persson, C., Robertson, L. & Ullerstig, A., 1996. Air Pollution Assessment Study Using the MATCH Modelling System. Application to sulphur and nitrogen compounds over Sweden 1994. Swedish Meteorological and Hydrolological Institute, Reports Meteorology and Climatology No. 69, April 1996.

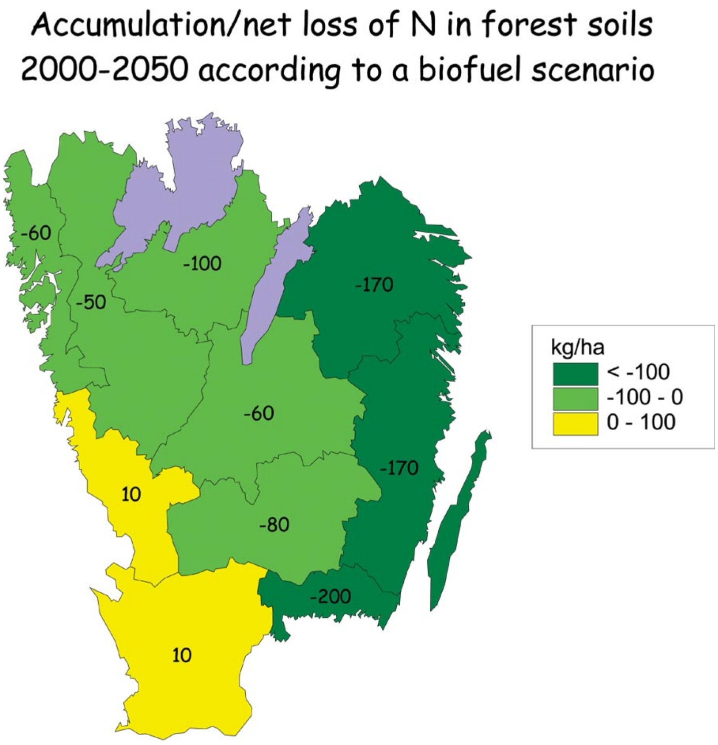

Figure 3. Result for mass balance calculations of nitrogen on a county level in southern Sweden.

Applying the method for nitrogen on a grid level

To be able to use the nutrient balance calculations on a regional level, they have to be made on a higher resolution than counties. Therefore the mass balance calculations will be applied on a grid level, with grids of 5*5 km.

Deposition will be derived from SMHIs MATCH model with the resolution of 5*5 km. For every grid, different deposition is given for different forest types and for open field, which means that the information has to be combined with land use information, which is derived from the RESE land use map with fraction of different land use classes in each 5*5 km grid.

For calculations of nutrient fluxes caused by harvest and growth statistical data for the past from the National Forest Inventory as well as future scenarios on harvest and growth is needed. The present distribution of different forest types is calculated from the RESE land use map and the data is combined with nutrient content in different forest types and in different parts of the trees. The GIS-layer describing land use and the distribution of different forest types in grids, collected from the RESE land use map, will be combined with data from different national inventories to form new GIS-layers. These layers will show the forest productivity and standing volume, soil weathering etc. For leaching of nutrients, runoff will be used together with data on nutrient contents in the soil water and surface water. For clearcuts an empirical function will be used, where the leaching depends on the deposition level. Also here, the RESE land use map is needed, since the deposition level is different in different forest types.

Applying the method for base cations on a grid level

For base cations the same method as described above will be used, with the addition of weathering rate. Weathering will be modelled by PROFILE on 25000 sites all over Sweden. The total chemistry of the till, texture and climatic and hydrologic data are input data to the model.

Conclusions

The national land use map produced in this project using IRS WiFS satellite data as well as supporting ancillary data were of adequate accuracy for the ASTA applications addressed.

IRS WiFS satellite data only, without support from ancillary information, was found not to yield satisfactory accuracy given the classes required by ASTA. When used integrated with county statistics on forest and agricultural areas as well as the digital general maps from the Swedish National Land Survey the results, however, reached an acceptable quality level.

Accuracy assessment could not be carried out in all counties of Sweden, and therefore the data should be used with caution if the end users are interested in regional or local scales rather than the national perspective. This does, however, not mean that the data cannot be used for local applications. In most areas the accuracy is good also with aggregations of 0.5 km or 1 kilometre resolutions.

IVL Svenska Miljöinstitutet AB

IVL Swedish Environmental Research Institute Ltd

P.O.Box 210 60, SE-100 31 Stockholm
Hälsingegatan 43, Stockholm
Tel: +46 8 598 563 00
Fax: +46 8 598 563 90

P.O.Box 470 86, SE-402 58 Göteborg
Dagjämningsgatan 1, Göteborg
Tel: +46 31 725 62 00
Fax: +46 31 725 62 90

Aneboda, SE-360 30 Lammhult
Aneboda, Lammhult
Tel: +46 472 26 77 80
Fax: +46 472 26 77 90

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