R-02-06

Vegetation mapping with satellite data of the Forsmark and Tierp regions

Laine Boresjö Bronge and Kjell Wester
SwedPower

April 2002

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1402-3091
SKB Rapport R-02-06

Vegetation mapping with satellite data of the Forsmark and Tierp regions

Laine Boresjö Bronge and Kjell Wester
SwedPower

April 2002

Keywords: Site, biosphere, surface ecosystem, forest, vegetation mapping, satellite data.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Summary

SKB (Swedish Nuclear Fuel and Waste Management Co) performs a siting program for deep repository of spent nuclear fuel that includes survey of three potential sites. The SKB siting process has now reached the site investigation phase. There are several fields of investigations performed in this phase. One of them is description of the surface ecosystems.

The surface ecosystems are mapped both on a regional (50-100 km^2) and a local level (1 km^2). Two inventory methods are used, remote sensing (satellite data/aerial photographs) for the regional level, and field inventory for the detailed level.

As a part of the surface ecosystem characterisation on the regional level vegetation mapping using satellite data has been performed over the three potential deep depository sites, Forsmark, Tierp and Oskarshamn. The user requirements for the vegetation mapping of the potential sites are the following:

- Dominated species in the tree layer, shrub layer, field layer and ground layer shall be described both on regional and local level.
- Dominated species in all layers shall be quantified regarding share and percentage of ground cover, or absence of cover (vegetation free ground).
- The regional and the local inventory shall have identical or comparable classification systems.
- The classification system and the method used shall make it possible to scale the results from local to regional level and vice versa.
- The produced layers shall be presented in digital form and make it possible to model biomass and turnover of organic matter (carbon, nutrients, water).
- The produced information shall in a first phase be of use for planning and for making nature and environmental considerations.

Data sources used in the study include geo-referenced SPOT4 XI data (20 m ground resolution), geo-referenced Landsat TM data (30 m ground resolution), soil type data, topographic map data and colour infrared aerial photographs.

The production of vegetation layers has been carried out in two steps. In the first step the vegetation/land cover was classified by using satellite data and information from the topographic map in a stratified approach. In the second step the vegetation/land cover classification was used together with other information in a ruled GIS procedure to produce the vegetation layers. The work carried out includes:

- Control and preparation of data
- Selection of training areas/ analysis of spectral signatures
- Field check/calibration
- Stratified classification and analysis of results
- Field check of classification result
- Modification of training areas/reclassification if necessary
- Merging of results to create vegetation/land cover map
- Editing and post-classification
- Generalisation
- Production of vegetation layers
- Control and editing, production of final result.

Sammanfattning

Svensk Kärnbränslehantering AB (SKB) genomför ett lokaliseringsprogram för djupförvar av utbränt kärnbränsle vilket inkluderar kartläggning av tre potentiella områden. Ett flertal ämnesspecifika undersökningar genomförs. Ett av dessa är beskrivning av de ytnära ekosystemen.

De ytnära ekosystemen kartläggs både på regional (50-100 km^2) och lokal nivå (1 km^2). Två inventeringsmetoder används, fjärranalys (satellitdata, flygbilder) för den regionala nivån och fältinventering för den detaljerade nivån.

Som en del av karakteriseringen av de ytnära ekosystemen på regional nivå har satellitdatabaserad vegetationskartering genomförts för de tre potentiella djupförvarsplatserna Forsmark, Tierp och Oskarshamn. Användarkraven för vegetationskarteringen är följande:

- Området ska beskrivas regionalt och lokalt vad gäller vegetationens dominerande arter i träd-, busk, - ört- och markskikt.
- Dominerande arter i alla skikt skall kvantifieras med hänsyn till andel och täckningsgrad, eller frånvaron av skikt (t ex vegetationsfri mark).
- Den regionala karteringen (satellit-/flygbildsbaserad) och den lokala inventeringen (fältinventering) ska ha identiska eller likvärdiga system för att beskriva vegetationen.
- Indelningssystemet och metodiken ska möjliggöra att inventeringarna ska kunna skalas upp från lokal till regional nivå och vice versa.
- De framtagna dataskikten ska presenteras digitalt och möjliggöra modelleringar vad avser biomassa och omsättning.
- Informationen ska inledningsvis kunna användas för planering och natur- och miljöhänsyn.

Datakällor som använts i studien är geo-refererade SPOT4 XI-data (20 m mark-upplösning), geo-refererade Landsat TM-data (30 m markupplösning), jordartsdata, topografiska kartan samt IR-färgflygbilder.

Tillverkningen av vegetationsskikt har utförts i två steg. I det första steget genomfördes en satellitbildsbaserad klassificering av vegetation/marktäcket i de tre områdena med utnyttjande av information från den topografiska kartan. I det andra steget användes denna klassificering som bas tillsammans med annan information för att i en regelstyrd GIS-process skapa slutresultatet, vegetationsskikten. Arbetet har omfattat följande moment:

- Kontroll och preparering av indata
- Urval av träningsytor/analys av spektrala signaturer
- Fältkontroll/kalibrering
- Stratifierad klassificering och analys av resultat
- Fältkontroll av klassningsresultat
- Ev modifiering av träningsytor/omklassificering
- Sammanvägning av resultat till vegetation/landtäckekarta
- Editering och efterklassificering
- Generalisering
- Tillverkning av skikt
- Kontroll och editering, produktion av slutgiltigt resultat.

Contents

1 Introduction

1.1 Background

SKB (Swedish Nuclear Fuel and Waste Management Co) performs a siting program for deep repository of spent nuclear fuel that includes survey of three potential sites. The SKB siting process has now reached the site investigation phase.

SKB´s goal for the site investigation phase is to obtain the permits that are needed to site and build deep depository and the encapsulation plant. There are several fields of investigations performed in this phase. One of them is description of the surface ecosystems.

One important part of the surface ecosystem characterisation is to describe the biological variables and to create a base-line vegetation map. Vegetation is one of the most important features that characterise the landscape. Different vegetation types provide habitats for a variety of species contributing to the biological diversity of the landscape. Vegetation types are interesting also in a monitoring context since they are, in contrast to most species, relatively easy to identify and thus to follow in a long-term perspective.

The surface ecosystems are mapped both on a regional (50-100 km^2) and a local level (1 km^2). Two inventory methods are used, remote sensing (satellite data/aerial photographs) for the regional level, and field inventory for the detailed level.

As a part of the surface ecosystem characterisation on the regional level, vegetation mapping has been performed over the three potential deep repository sites using satellite data. This report describes the work carried out.

1.2 User requirements

The user requirements for the vegetation mapping of the potential deep depository sites are the following:

- Dominating species in the tree layer, shrub layer, field layer and ground layer shall be described both on regional and local level.
- Dominating species in all layers shall be quantified regarding share and percentage of ground cover, or absence of cover (vegetation-free ground).
- The regional and the local inventories shall have identical or comparable classification systems.
- The classification system and the method used shall make it possible to scale the results from local to regional level and vice versa.
- The produced layers shall be presented in digital form and make it possible to model biomass and turnover of organic matter (carbon, nutrients, water).
- The produced information shall in a first phase be of use for planning and for making nature and environmental considerations.

2 Study areas and Data sources

2.1 Study areas

Vegetation mapping has been carried out in three areas: Forsmark, Tierp and Oskarshamn (Figure 1), although the mapping in Oskarshamn has been delayed and will be completed later. The Forsmark area is covered by the topographic map sheets 12 I NO and 13 I SO (Figure 2), the Tierp area by the map sheets 12H NO, 12I NV, 13H SO and 13I SV (Figure 3), and the Oskarshamn area by the map sheets 6G SO and 6H SV (Figure 4).

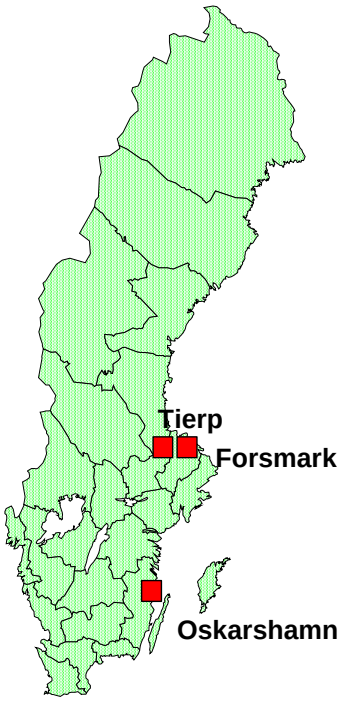


Figure 1. *Location of the study areas*

The Forsmark and Tierp areas are situated in the northern part of the province of Uppland and cover rather flat country with arable land and pastures mixed with coniferous forests. Due to influence from the Cambrian-Ordovician bedrock in the Baltic Sea north of the Uppland coast (Figure 5), the forests of these areas are comparatively rich in species and can be characterised as forests of herb or herb-shrub types (Hägglund and Lundmark, 1982). The Oskarshamn area is situated in eastern Småland on bedrock mainly built up of granites and is dominated by meagre coniferous forests of heath type.

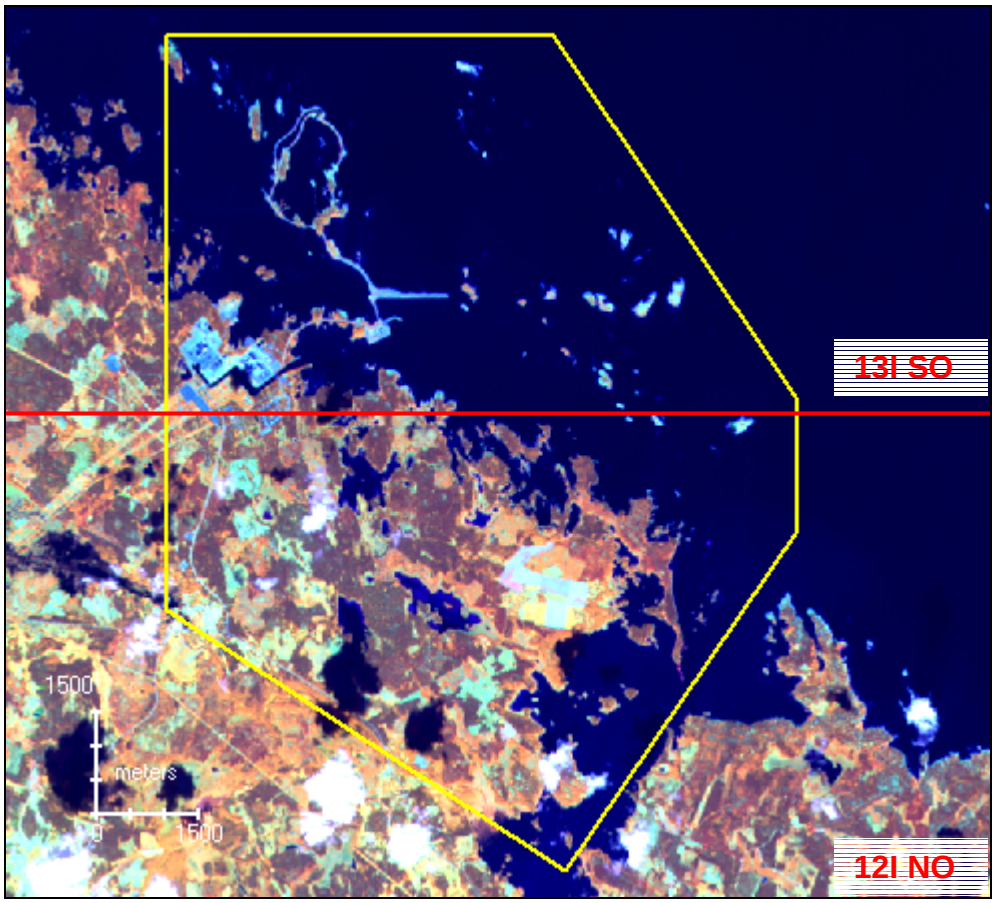


Figure 2. *SPOT4 image from 1999-08-01 over the Forsmark study area (yellow line). Red line shows the topographic map sheets division.*

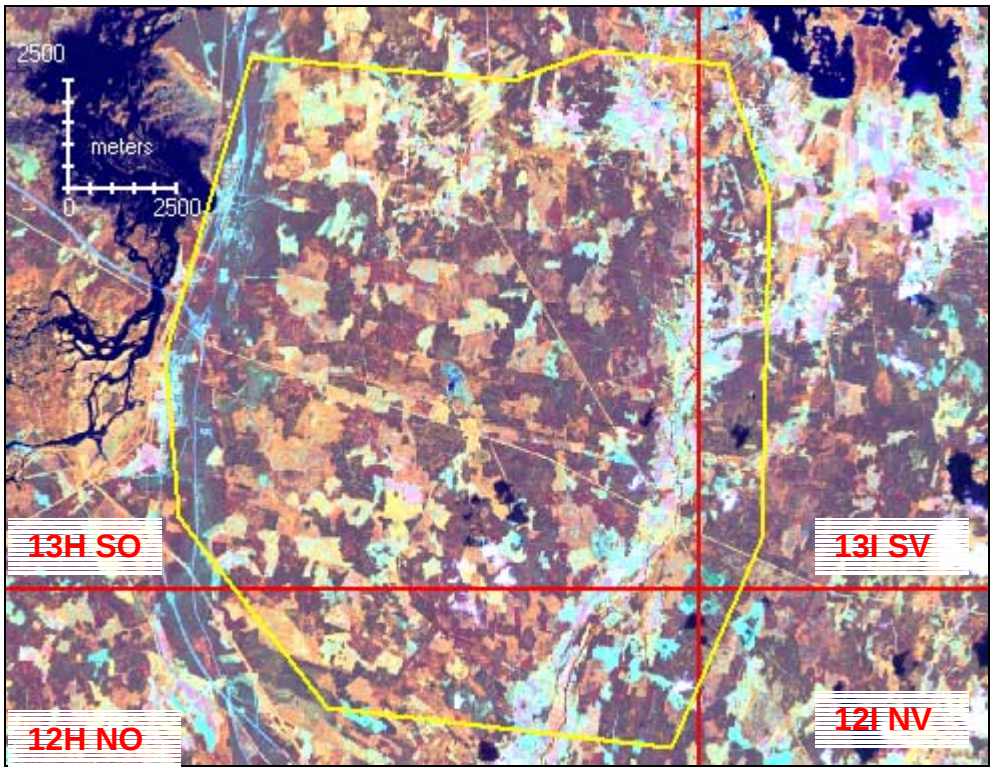


Figure 3. *SPOT4 image from 1999-08-01 over the Tierp study area (yellow line). Red line shows the topographic map sheest division.*

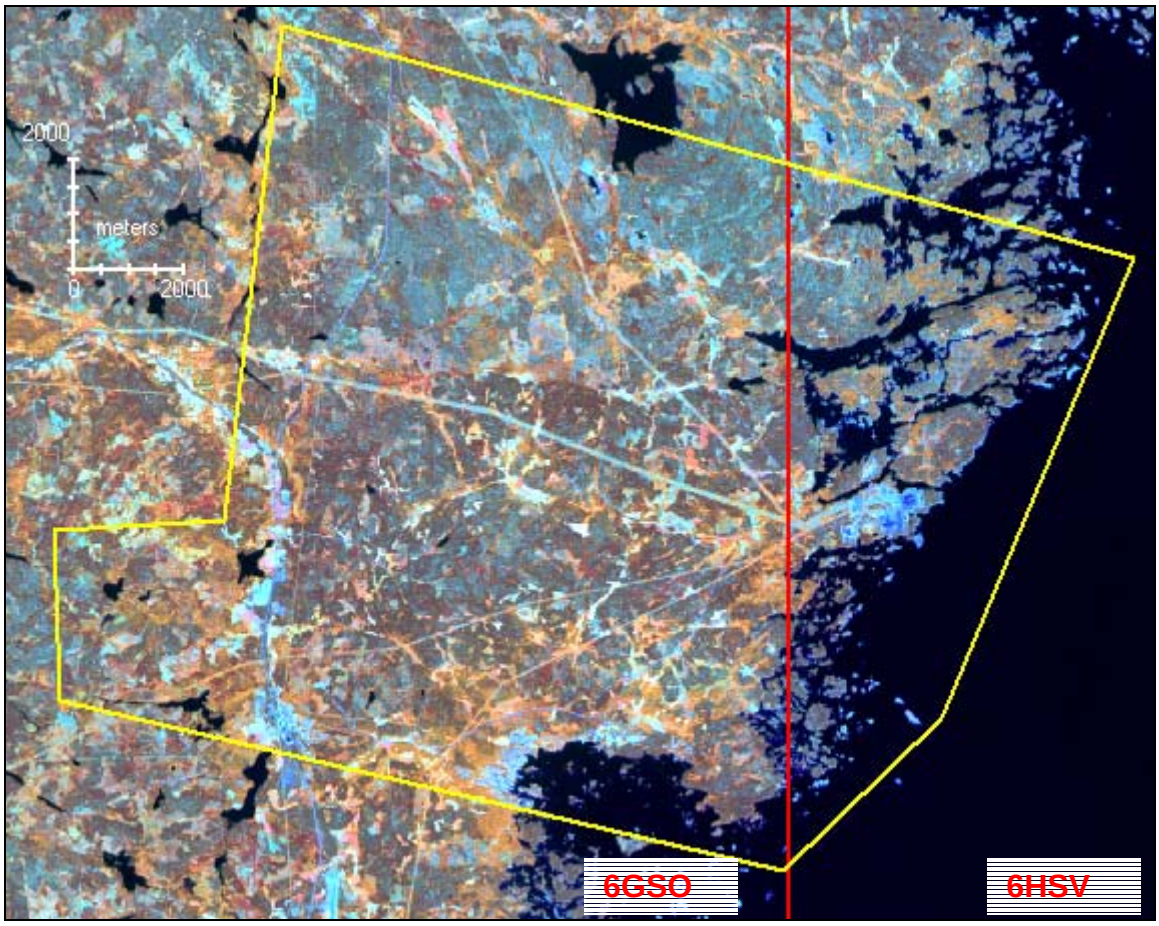


Figure 4. *SPOT4 image from 1999-07-11 over the Oskarshamn study area (yellow line). Red line shows the topographic map sheets division*.

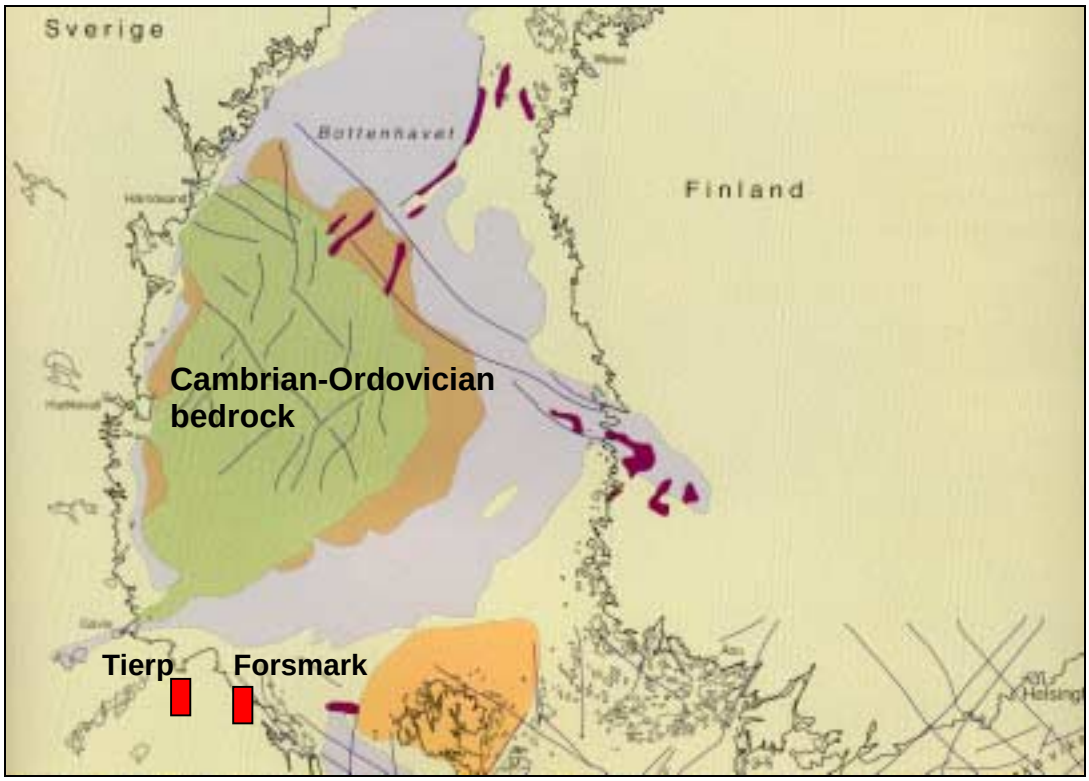


Figure 5. *Bedrock composition of the Baltic Sea (modified from Sveriges Nationalatlas (1994)).*

2.2 Data sources

Data sources used in the study include:

- geo-referenced SPOT4 XI data (20 m ground resolution),
- geo-referenced Landsat TM data (30 m ground resolution),
- soil type data,
- topographic map data,
- colour infrared aerial photographs.

Specification of the data used for the three study areas is given in Table 1. Table 2 shows the spectral bands of the satellite data used. Figure 6 gives an example of the data sources in the Forsmark area.

Table 1. *Data sources used for the three study areas.*

	Study area		
Data	***Forsmark***	***Tierp***	***Oskarshamn***
SPOT XI (scene id)	1999-08-01 (058-226)	1999-08-01 (057-226)	1999-07-11 (6gso, 6hsv)
Landsat TM (scene id)	1989-07-07 (193-018)	1989-07-07 (193-018)	1988-06-11 (193-020)
Soil data (1:50 000)	raster data, 5 m resolution	raster data, map sheet 13H SO less detailed	no data available
Topographic map (1:50 000)	edition 5,6 1998 raster data, 5 m resolution	edition 5,6 1998-2001, raster data, 5 m resolution	edition 4 1999 raster data, 5 m resolution
CIR aerial photo-graphs (1:30 000)	1992-06-10	1983-06-19	1986-06-26 1988-06-12

Table 2. *Band specification and ground resolution of Landsat TM and SPOT.*

Landsat5 TM		**SPOT4 XI**	
Band	**Band Width (μm)**	**Band**	**Band Width (μm)**
TM1	0.45 – 0.52 (blue)	**XI1**	0.50 – 0.59 (green)
TM2	0.52 – 0.60 (green)	**XI2**	0.61 – 0.68 (red)
TM3	0.63 – 0.69 (red)	**XI3**	0.79 – 0.89 (near IR)
TM4	0.76 –0.90 (near IR)	**XI4**	1.58 – 1.73 (middle IR)
TM5	1.55 – 1.75 (middle IR)	**Resolution**	20 m
TM6	10.40 – 12.50 (thermal)		
TM7	2.08 – 2.35 (middle IR)		
Ground resolution	**30 m (TM1-5, TM7)** **120 m (TM6)**		

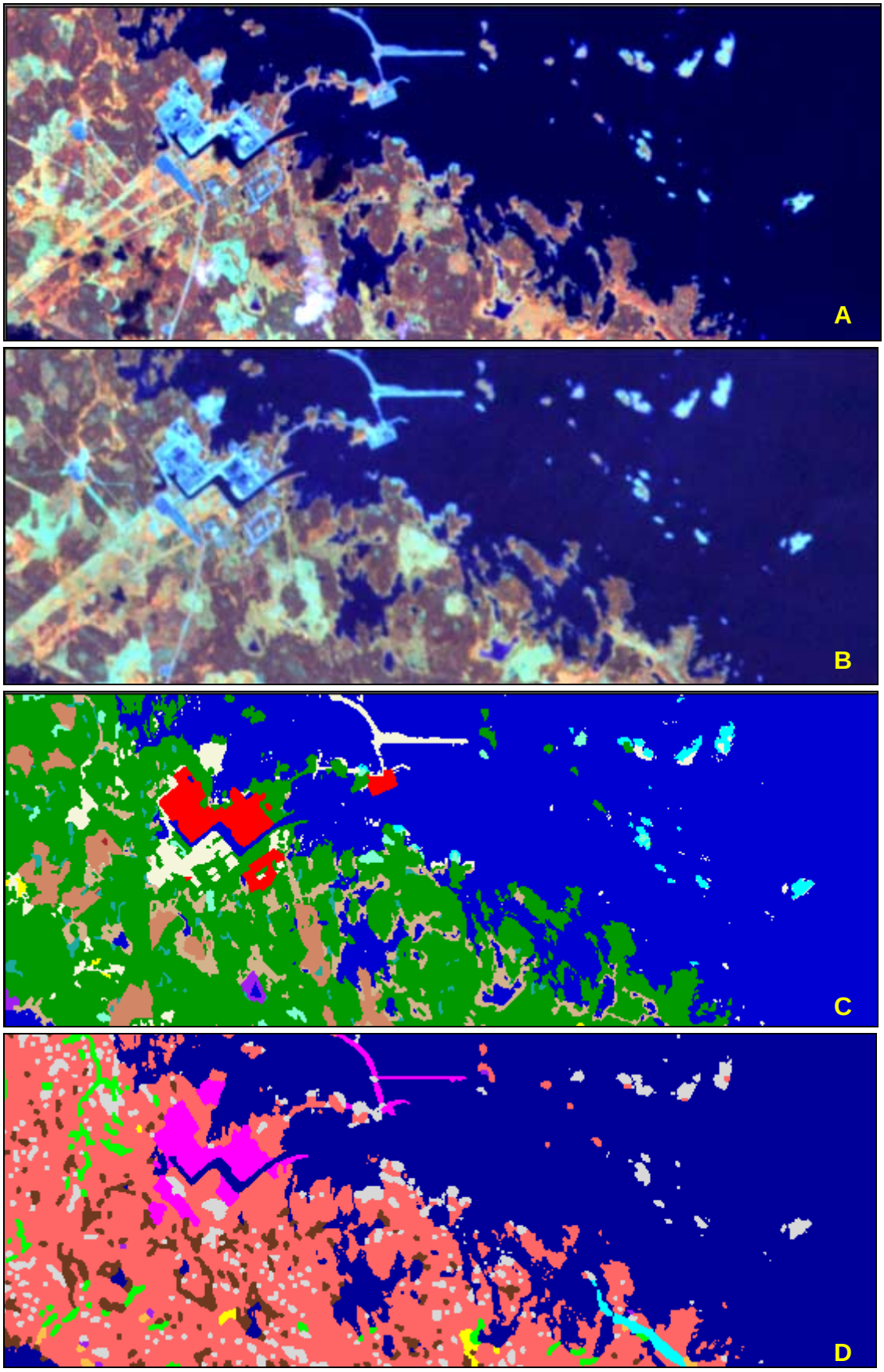


Figure 6. *Examples of data used in the Forsmark area. A) Spot4 X1 image from 1999-08-01, B) Landsat TM image from 1989-07-07, C) Masks from the topographic map, D) Soil type data.*

3 Methods

3.1 Accomplishment

The production of vegetation layers was carried out in two steps. In the first step the vegetation/land cover was classified by using satellite data and information from the topographic maps in a stratified approach. The aim was to produce as detailed base classification as possible in each study area. In the second step the vegetation/land cover classification was used together with other information in a ruled GIS procedure to produce the final results, the vegetation layers. The work carried out includes:

- Control and preparation of data
- Selection of training areas/ analysis of spectral signatures
- Field check/calibration
- Stratified classification and analysis of results
- Field check of classification result
- Modification of training areas/reclassification if necessary
- Merging of results to create vegetation/land cover map
- Editing and post-classification
- Generalisation
- Production of vegetation layers
- Control and editing, production of final result

An overview of the method is given in Figure 7. The work was carried out using the image processing program ERDAS Imagine 8.4 for NT.

3.2 Preparation of data

3.2.1 Topographic map data

The topographic map data was delivered as TIFF-layers with 5 meters resolution. The preparation of the topographic map data included the following step:

- Importing the separate information layers (TIFF-files) for each map into Erdas Imagine (~ 20 files/map sheet).
- Merging the separate information files into one layer with a unique code for each class.
- Mosaicing the involved map sheets for each study area.

3.2.2 Satellite data

In order to preserve the spatial resolution of the topographic map data the satellite data (SPOT and Landsat TM) images were resampled to 5 meters resolution before classification.

Since the SPOT images of Forsmark and Tierp contained some clouds, cloud masks were created for these areas. For the Forsmark image, which contained much more clouds than the Tierp image, the clouds and cloud shadows were classified by grey level slicing (tresholding) using band 1 (green band) in combination with manual editing. For the few clouds of the Tierp area manual editing was used. Figures 8 and 9 show the cloud masks created.

3.2.3 Soil type data

The soil type data was delivered as ArcView shape-files. The preparation of this data included the following step:

- Conversion of data to GRID-format (5 meters resolution).
- Importing of GRID-files to Erdas Imagine img-format.

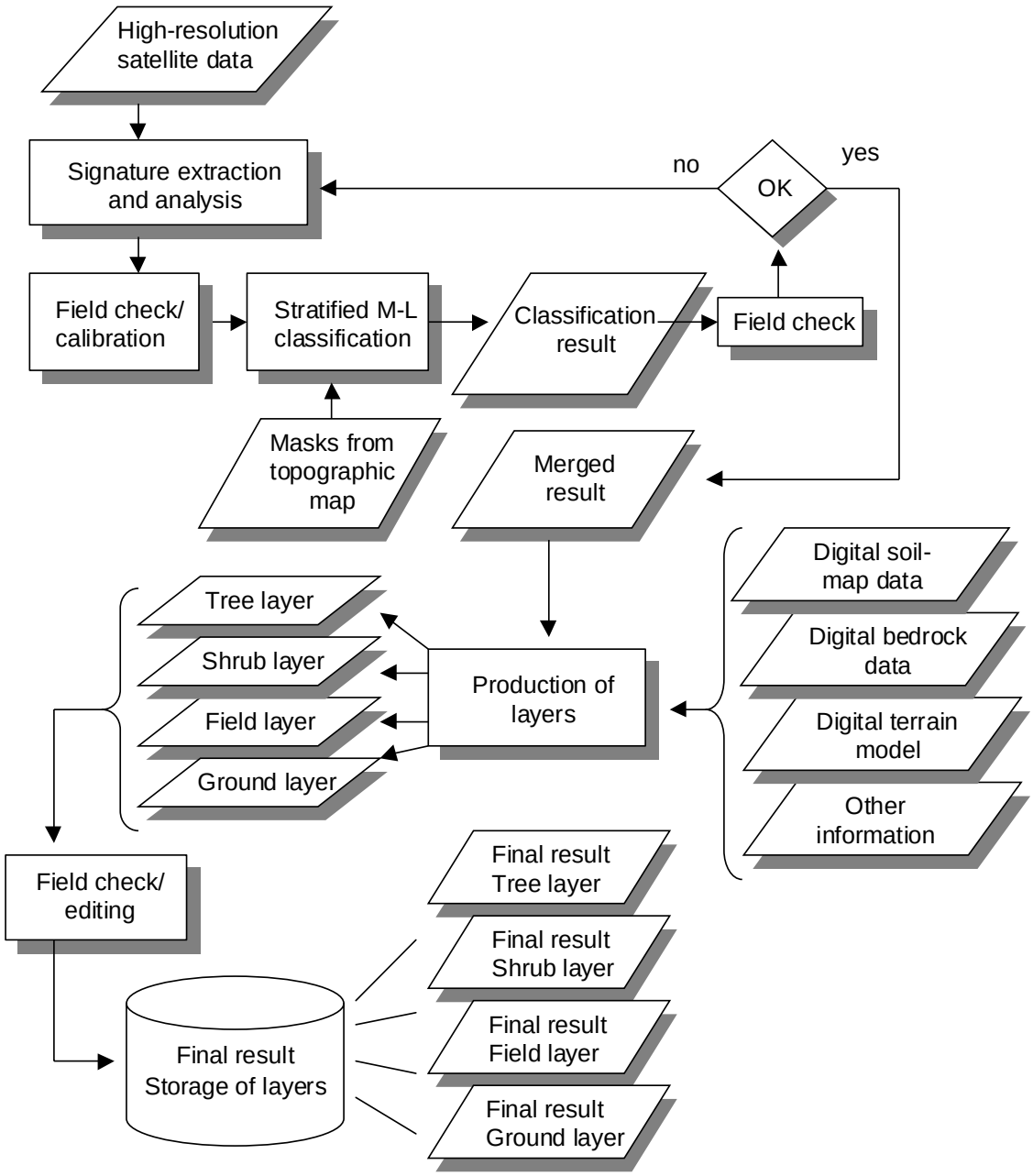


Figure 7. *Overview of the method used.*

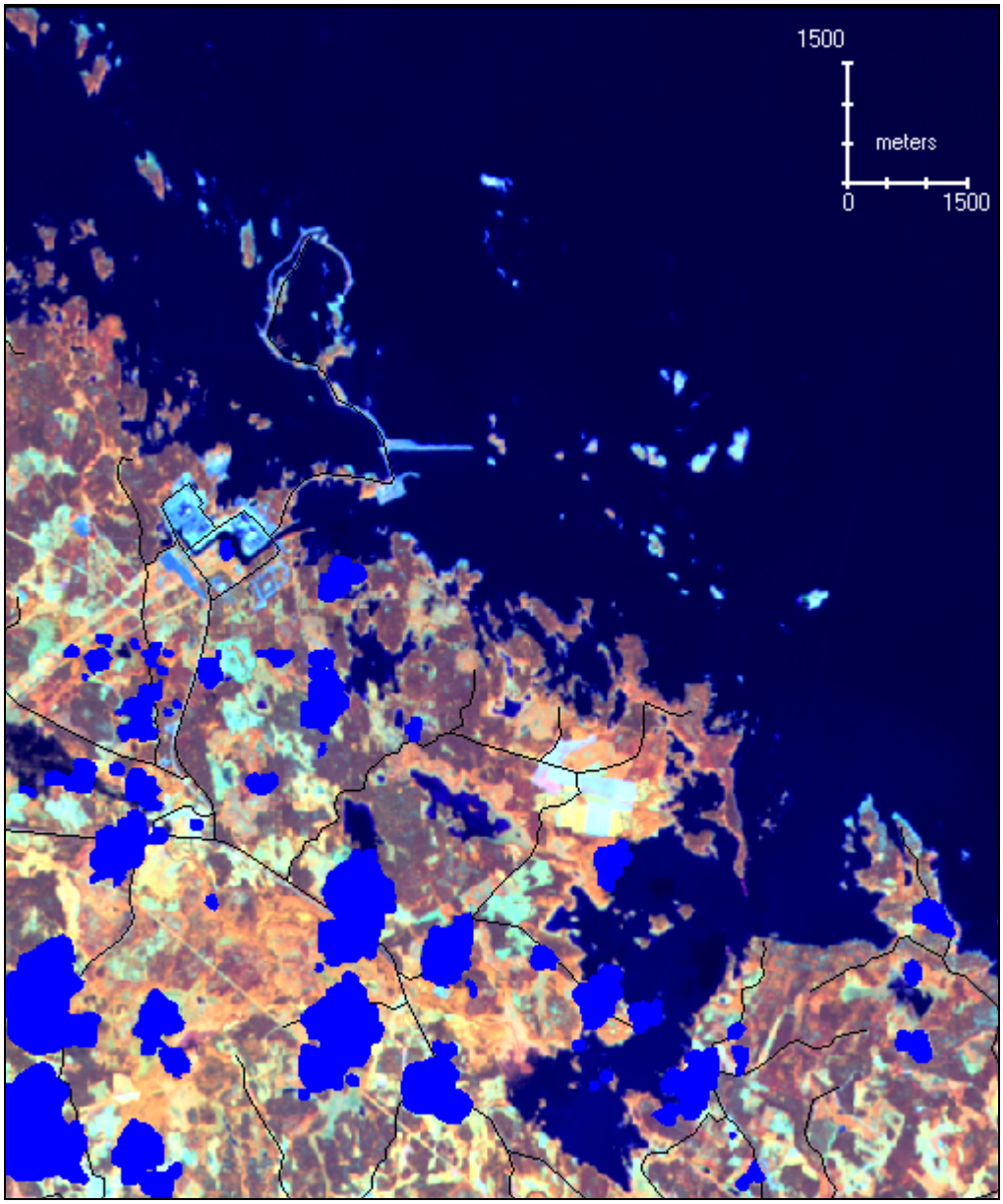


Figure 8. *The cloud mask for the Forsmark area. Clouds and cloud shadows areshown in blue colour.*

3.3 Classification of vegetation/land cover

The method used is based on a stratified approach where information from maps, or previous classifications, is used to create masks for classification in steps (Boresjö, 1989; Boresjö Bronge, 1999; 2000; Boresjö Bronge and Näslund-Landenmark, 2002; Boresjö Bronge and Wester, 1999). Stratified classification provides a possibility to reduce the number of potential misclassifications between spectrally similar classes if they occur under different masks, or if more than one image is used, to use an optimal band combination for the actual classes. The classification work includes selection of training areas, analysis of spectral signatures and statistics, field check/calibration, classification, merging of result and generalisation.

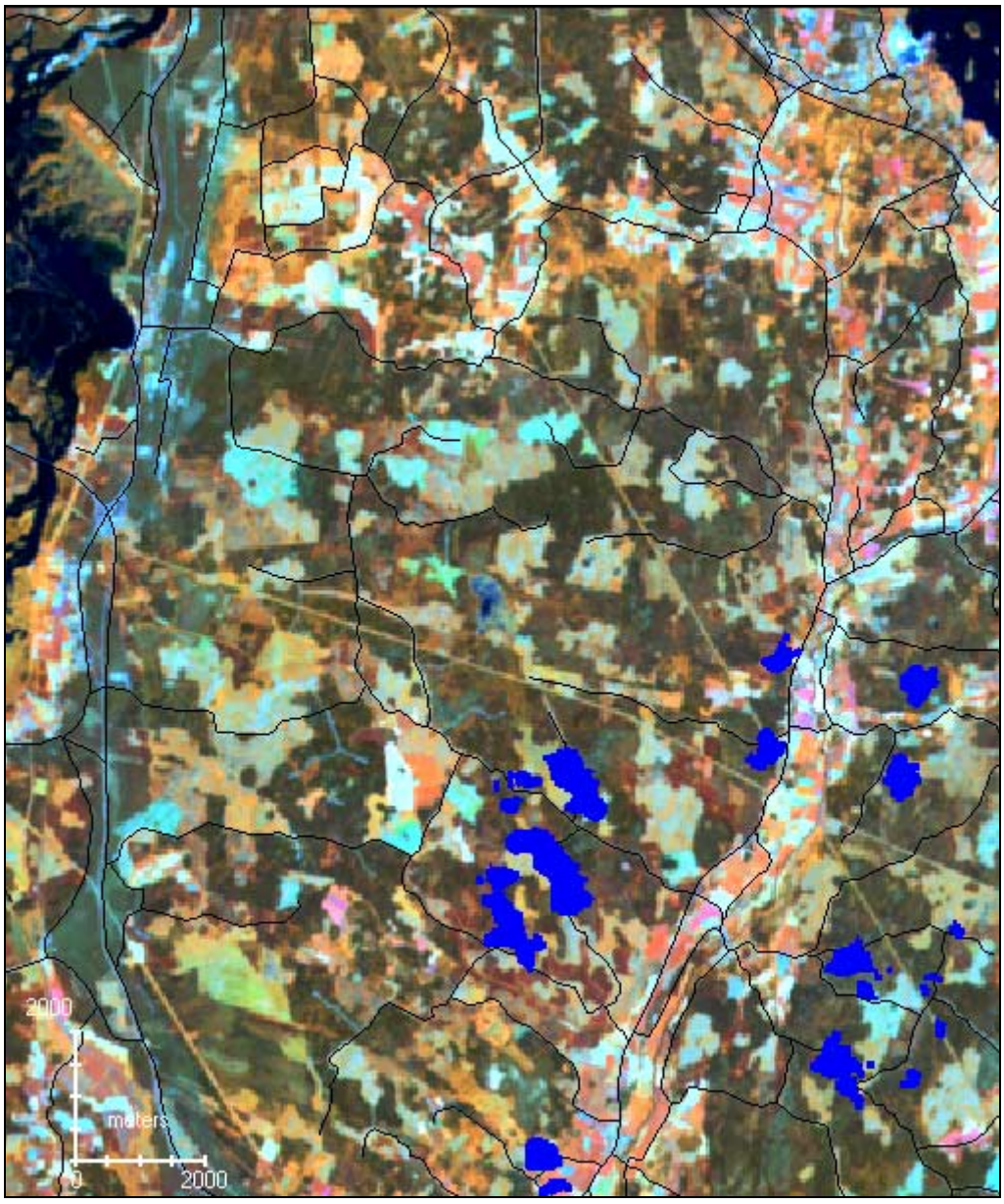


Figure 9. *The cloud mask for the Tierp area. Clouds and cloud shadows are shown in blue colour.*

3.3.1 Selection of training areas

Training areas were selected for a number of different vegetation units for analysis of their spectral characteristics and for deciding how detailed classification system could be used for the actual study areas. Previous studies of forest, wetlands and mountain vegetation have shown that classification systems suitable for satellite data follow relatively closely to systems used for interpretation of colour infrared aerial photographs (Boresjö Bronge 1998; 1999, Boresjö Bronge and Jönsson, 2000; Boresjö Bronge and Näslund-Landenmark, 1999; Boresjö Bronge and Wester, 1999). The signature analysis was focused on natural vegetation (forests and wetlands).

The training areas were selected in the most recent images (the SPOT images) by using the SEED function in Erdas Imagine. From a given "seed" (one pixel) in the image this function selects a spectrally homogeneous area according to the specified Spectral Euclidean Distance (ERDAS, 1999). Several areas were selected for each preliminar class to cover the spectral variation within the class. Colour infrared (CIR) aerial photographs

were used as a support in the selection of areas. Spectral signatures and statistics were generated for the selected areas. In total 101 areas were analysed for the Forsmark study area and 92 areas for the Tierp area. Figures 10a and b show their location in the satellite images.

Signatures and statistics for the same areas were also generated for the Landsat TM images.

3.3.2 Analysis of spectral signatures and statistics

Analysis of spectral signatures and statistics was performed to see how well different vegetation units could be separated and to decide the final classification system. Figure 11 gives an example of SPOT and Landsat TM signatures from the Forsmark area together with the SPOT image showing the selected areas. Since the clear-cut area was forest in the Landsat TM image only the SPOT signature is shown. The differences in signatures between comparable bands in SPOT and TM data are mainly explained by the difference in recording date (phenology) and by the ten years time span between the two recordings. The latter is for example obvious for the young spruce forest which compared to the other forest sites shows a decrease in the near-infrared reflectance between 1989 and 1999 (XI3 in SPOT data compared to TM4 for Landsat, compare with Table 2), due to increasing age of the stand.

3.3.3 Field check

Field work was performed for calibration and for checking selected training areas. Each site was documented with regard to tree layer, shrub layer, field layer and ground layer (Appendix 1). Field check was also performed after classification.

3.3.4 Classification scheme

Based on the analysis of spectral signatures, the field check and what information could be added from the topographic map, the final general classification scheme for the vegetation/land cover map was decided (Table 3). Occurring classes and database codes for each area are given in Appendices 2 and 3.

3.3.5 Stratified classification

Classification (maximum-likelihood) was carried out in steps using information from the topographic maps to create masks where only a selected number of classes were allowed. The most recent images (the SPOT-images) were the main data sources for the classifications.

The following classifications and operations were performed for each area:

1. Clear-cuts and regeneration areas were classified in the oldest image (Landsat TM from 1989) under the forest mask from the topographic map. The result was edited (misclassifications due to border effects were removed) and merged with the clear-cut layer from the topographic map creating a clear-cut mask.
2. A forest mask was created (forest mask from the topographic map minus the created clear-cut mask).
3. The clear-cut types were classified under the clear-cut mask using SPOT data from 1999.

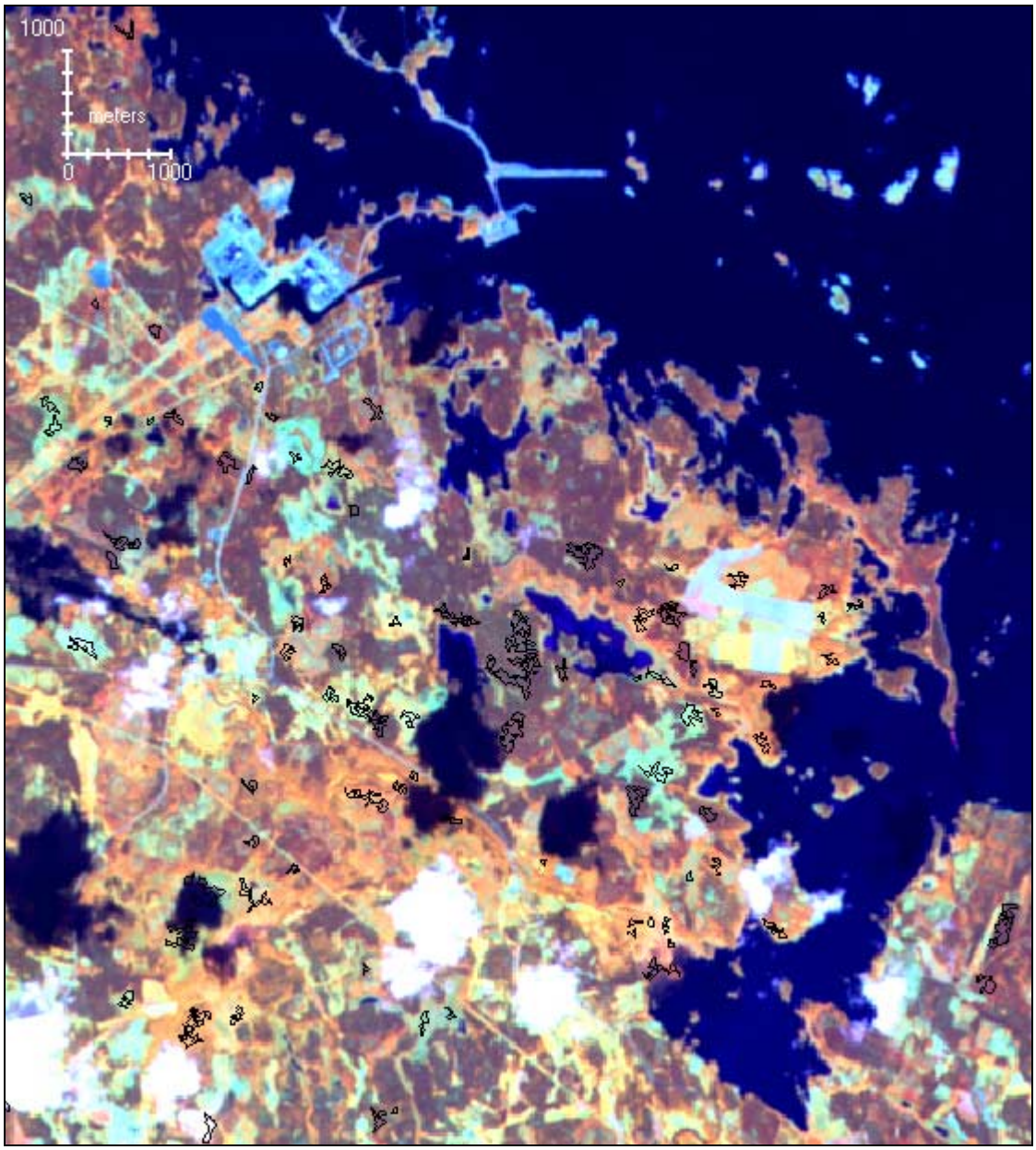


Figure 10a. *Analysed training areas in the Forsmark study area.*

4. The forest types were classified under the forest mask using SPOT from 1999.
5. New clear-cut areas were visually interpreted in the SPOT image and added (with priority) to the forest classification result.
6. Forested wetlands from the topographic map were classified using SPOT data.
7. Open wetlands from the topographic map were classified using SPOT data. Separate classifications were performed for open wet mires (blue mires on the map) and open other mires (brown mires on the map).

Since there were clouds in the SPOT images over the Forsmark and Tierp areas additional classifications using Landsat TM data were undertaken for the clouded and shadowed areas (Figures 8-9).

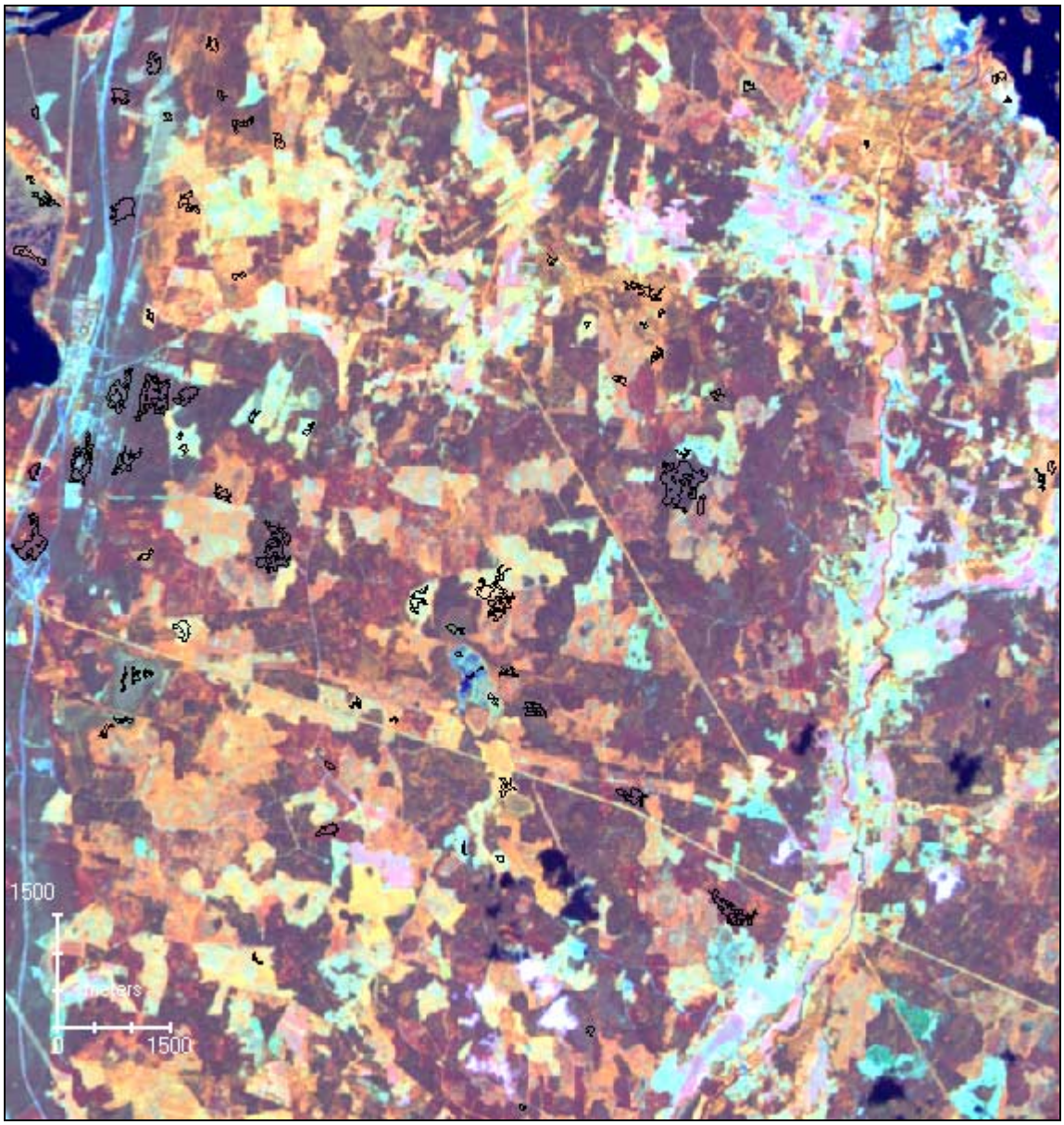
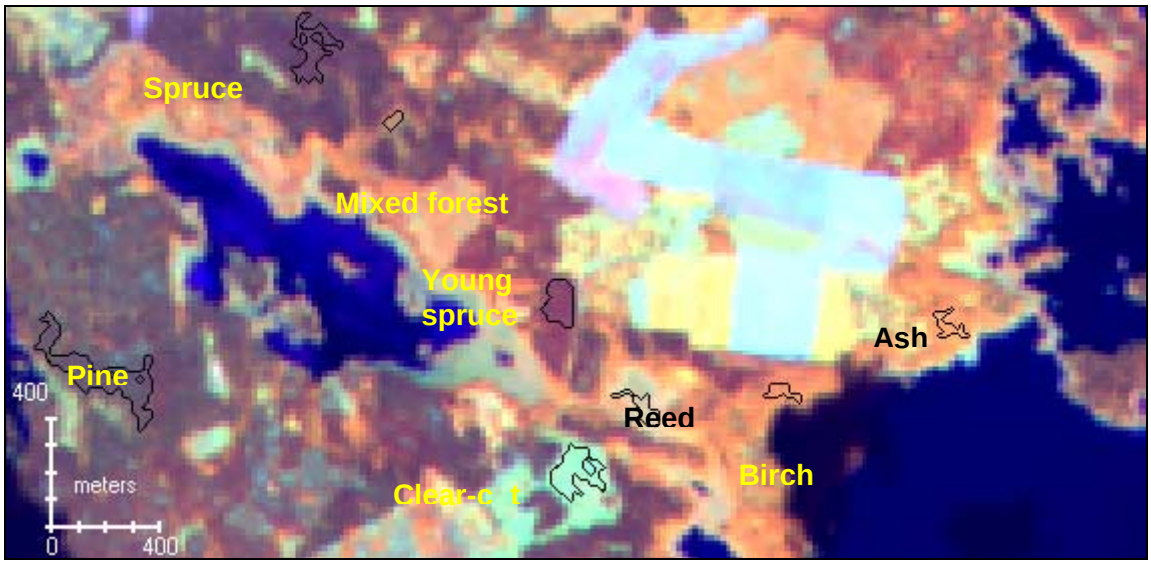


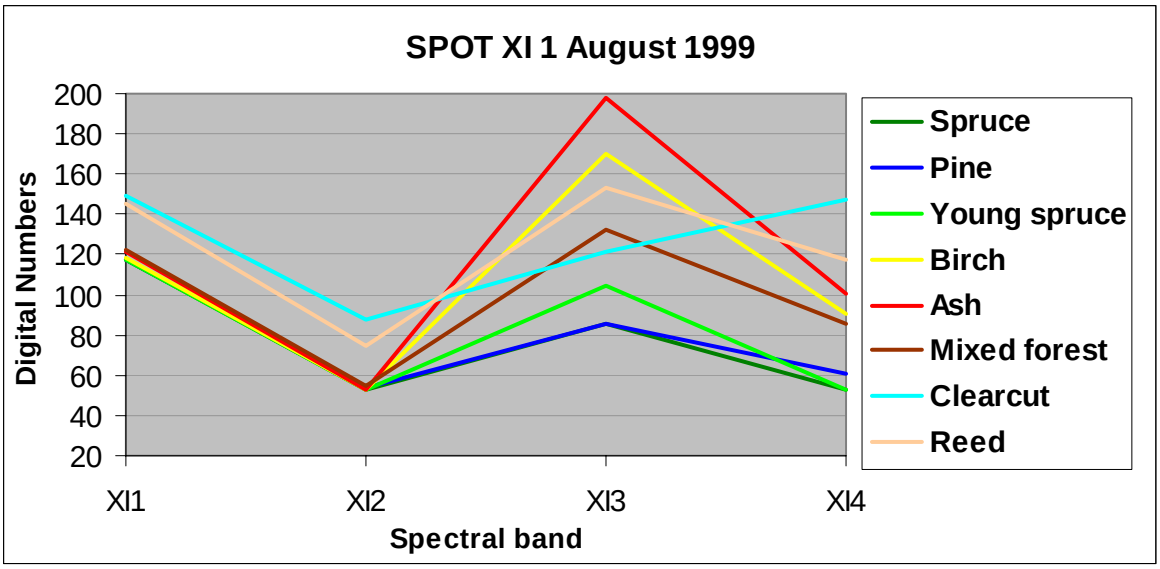
Figure 10b. *Analysed training areas in the Tierp study area.*

The following information was visually interpreted using the SPOT image from 1999:

- stone and sand pits,
- new clear-cuts,
- coastal bare rocks (visual interpretation combined with GIS operations) (only Forsmark).

Table 4 summarises the different classification steps that were performed.





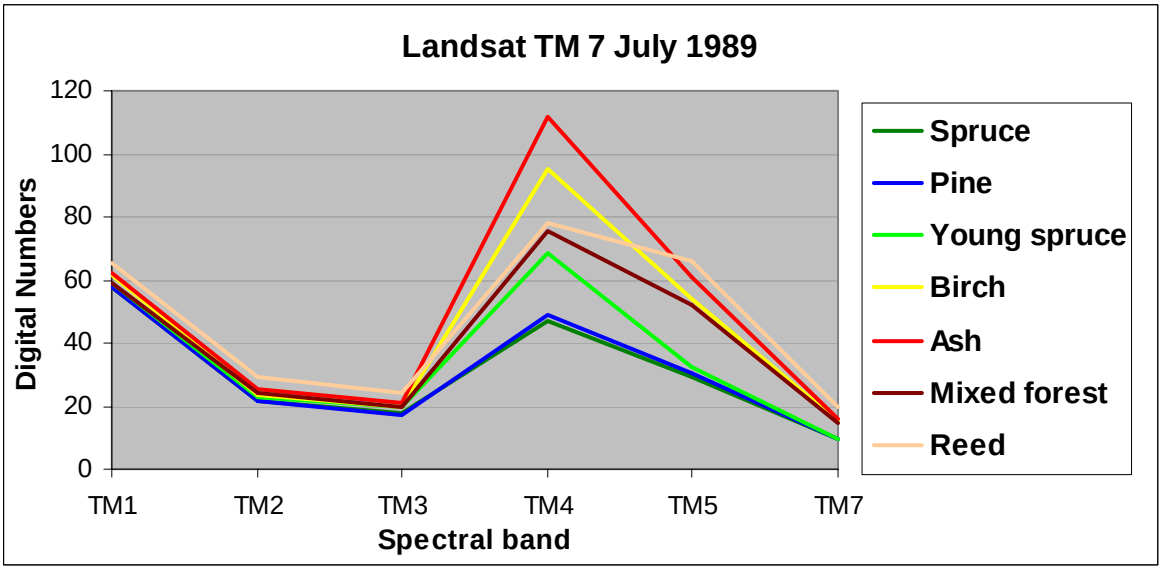


Figure 11. *SPOT image over a part of the Forsmark area from 1999-08-01 with some selected training areas (black outline, above), the corresponding SPOT XI signatures (middle) and the corresponding Landsat TM signatures (below).*

Table 3. *General classification scheme for the vegetation/land cover mapping.*

– **Coniferous forest (not clear-cut or regeneration forest 1989)** – Dry pine forest on acid rocks – Pine forest rich in lichens – Old pine forest, dry heath type – Young pine forest, dry heath type – Old spruce forest, mesic-wet types – Young spruce forest, mesic-wet types – Old pine forest, mesic-wet types – Young pine forest, mesic-wet types – **Deciduous forest** – Birch-dominated – Alder-dominated – Aspen-dominated – Oak-dominated – Ash-dominated – **Mixed forest (conifers/deciduous)** – **Older clear-cut, regeneration forest** – Spruce-dominated – Pine-dominated – Unspecified conifers – Birch thicket – Birch thicket/meadow type – Poor regrowth, meagre ground, boulders – **New clear-cut**	– **Forest-covered wetland (according to the topographic map)** – Spruce-dominated – Pine-dominated – Birch-dominated – Mixed forest (conifers/deciduous) – Clear-cut wetland – **Open wetland** – Hummock mire – Poor lawn mire – Lush lawn mire – Lush lawn mire, with willow – Lush lawn mire, with willow, birch – Poor carpet mire/mud-bottom mire – Lush carpet mire/mud-bottom mire – Reed-dominated mire – **Open land (according to the topographic map)** – Arable land (according to the map) – Other open land (pastures meadows) – Coastal bare rocks – Stone pit/sand pit – **Built-up areas** – Different types according to the topographic map – Other hard surfaces **100. Water**

3.3.6 Area specific operations

3.3.6.1 Forsmark

- Rock outcrop within clear-cut from the topographic map was recoded to “young pine forest”.
- Rock outcrop within forest land from the topographic map was recoded to “dry pine forest on acid rocks”.
- Rock outcrop within other open land from the topographic map was recoded to “coastal bare rocks”.
- Most coastal areas with bare rock were obtained by visual interpretation in combination with GIS-operations. Other open-land areas from the topographic map located near the sea with water contact were recoded to “coastal bare rocks”.

3.3.6.2 Tierp

- Small forest patches in the arable land (“åkerholmar”) wrongly classified to clear-cut due to border effects were recoded to “unspecified forest on small forest patches in arable land” (area specific class code, see Appendix 3).

Table 4. *Classifications and visual interpretation performed.*

Layers used in the topographic map	Maximum-likelihood classification	Visual interpretation
•Forest land (deciduous, coniferous forest, clear-cuts)	• Clear-cuts and forest 1989 • Forest classes 1999 • Clear-cut classes 1999	• New clear-cuts 1999
•Forested mires	• Forested mire classes	
•Open brown mires	• Open mire classes	
•Open blue mires	• Open wet mire classes	
•Other open land		• Pits, coastal bare rocks, other classes besides pastures/meadow
•Additional information (arable land, clear-cut on mire, built-up areas, water) – added directly to the final result		

3.3.7 Merging of results and editing

To produce the final map the different classification results were merged together and specified information from the topographic map was added. Before generalisation editing was performed to remove some remaining misclassifications due to border effects and to remove errors caused by misfit between the different layers of the topographic map.

3.3.8 Generalisation

Generalisation of the classification result was performed to produce a minimum-mapping unit of 800 m^2 (two SPOT pixels). The generalisation was made within the following layers: forest, forest-covered mires, and open mires, so that the original configuration (borders) of these layers should not be changed.

3.4 Production of vegetation layers

The final result – the vegetation layers was produced in a GIS process according to specified rules. The vegetation/land cover classification formed the basis for the derivation of information together with bedrock/soil type data, field data and area specific assumptions. The rules used for production of the vegetation layers are given in Appendix 4 and 5.

3.4.1 Tree layer

Dominating tree species for areas with > 30 % tree cover (forested areas according to the topographic map) were extracted from the classification result. Table 5 shows the classes produced for this layer.

The classification of the coniferous forest into young and old forest is based on the spectral characteristics of the stands. Above a certain age (related to the site quality class) the spectral characteristics of the forest does not change with increasing age. This occur approximately when the forest stand is in the cutting class “thinning forest” or older (Boresjö, 1989). The young forest is defined to include more or less dense regeneration

forest on old clear-cuts (the coniferous trees are perceptible in the spectral signature) up to forests in the thinning stage.

Table 5. *Produced classes in the tree layer.*

No tree layer (< 30% crown coverage)
– Within forest land
– Outside forest land

Coniferous trees
– Old Norway spruce (*Picea abies* (L.) H. Karst)
– Young Norway spruce
– Old Scotch pine (*Pinus sylvestris* L.)
– Young Scotch pine
– European larch (*Larix decidua* Mill)
– Unspecified young coniferous trees

Deciduous trees
– Birch (*Betula pendula* Roth., *B. Pubescens* Ehrh)
– Young birch (thicket on clear-cuts)
– European aspen (*Populus tremula* L.)
– European alder (*Alnus glutinosa* (L.) Gaertn.)
– English oak (*Quercus robur* L.)
– European ash (*Fraxinus excelsior* L.)

– **Mixed forest** (~ 40-60 % deciduous)

Old spruce (*Picea abies*)

3.4.2 Shrub layer

The shrub layer was defined to include only species that not grow to tall trees. Accordingly birch thicket on clear-cuts was classified to the tree layer as young birch. Four classes were produced for this layer (Table 6). For tree-covered areas were no information about the shrub layer could be derived the code “no information” was used.

Table 6. *Produced classes in the shrub layer.*

– No shrub layer (> 30 % crown coverage) is present
– No information

– Common juniper (*Juniperus communis* L.)
– Hazel (*Corylus avellana* L.)
– Willow (*Salix sp* L.)

Hazel (*Corylus avellana*)

3.4.3 Field and ground layers

3.4.3.1 Forest land

The classification scheme for the field and ground layers of forest land is based on the forest classification units developed for site quality classifying by the Forest Faculty of Swedish University of Agricultural Sciences (Hägglund and Lundmark, 1982). The classes are produced according to given rules using the vegetation/landcover classification, field data and soil type data (Table 7).

3.4.3.2 Wetlands

The classification scheme for the field layer of wetlands is designed to indicate the amount of green biomass (Table 8). The sedge-heath type includes field layer types of forested coniferous-dominated wetlands. The sedge type includes poor mire types with sparse field layer dominated by species of the *Cyperacea* family. The sedge-herb type includes more lush mire types with denser field layer than the poor types and higher amount of green biomass. The sedge-reed type is dominated by common reed (*Phragmites australis* (Cav.) Steud.) and may include other species in the field layer or be the only species (reed growing in water). The wet herb type includes field layer types of deciduous-covered wetlands on non-organic soils.

The ground layer classes of the wetlands mirror the soil type, organic or non-organic, in combination with vegetation type (Table 9).

Table 7. *Produced field and ground-layer classes in forest land, their correspondence in the forest classification units and the main conditions to be fulfilled for production of each class.*

Produced field-layer classes	Produced ground-layer classes	Corresponding forest classification units* for the produced field and ground layer classes	Vegetation/land cover classification	Soil type/ bedrock
No field layer-forest land	Moss type	Ground without field layer within forest land	Young spruce (only dense stands)	
Lichen-rich type	Lichen type	Lichen type, lichen-rich type	Pine on lichen ground	Glacifluvial
Dry heath type	Moss type	Cowberry type (*Vaccinium vitis-idaea*), Crowberry (*Empetrum sp*)/ Heather type (*Calluna vulgaris*)	Pine, dry heath type, dry pine on acid rocks, clear-cut classes	Glacifluvial; bedrock outcrop
Mesic bilberry heath type	Moss type	Bilberry type (*Vaccinium myrtillus*)	Mesic-moist spruce, pine, birch, aspen, clear-cut classes	
Herb-heath type	Moss type	Tall herb/low herb types with dwarf shrubs, grass types	Spruce, pine, clear-cut classes	Limestone/ limestone-influenced soils
Herb type	Moss type	Tall herb/low herb types	Deciduous forest, spruce	Limestone/ limestone-influenced soils, richer soils
Wet herb type	Moss type	_	Wetlands with deciduous forest	Non- organic soils

*****According to Hägglund and Lundmark (1982)

Table 8. *Produced field-layer classes for the wetland areas and the main conditions to be fulfilled for production of each class.*

Produced field-layer classes	Vegetation/land cover classification	Soil type
Sedge-heath type	Coniferous forest/mixed forest on wetland	
Sedge type	Hummock mire, poor lawn mire/carpet mire	
Sedge-herb type	Lush lawn mire/carpet mire, lush carpet mire with willow	
	Deciduous-forest covered wetland	Organic
Sedge-reed type	Reed	
Wet herb type	Deciduous-forest covered wetland	Non-organic

Table 9. *Produced ground-layer classes for the wetland areas and the main conditions to be fulfilled for production of each class.*

Produced ground-layer classes	Vegetation/land cover classification	Soil type
Peatland - Sphagnum type	Coniferous forest/mixed forest on wetland, Hummock mire, poor lawn mire/carpet mire, Lush lawn mire/carpet mire, lush carpet mire with willow, Reed	Organic
Peatland - other	Deciduous-forest covered wetland	Organic
Not peatland – moss type	Coniferous forest/mixed forest on wetland, Deciduous-covered wetland	Non-organic
Not peatland - other	Hummock mire, poor lawn mire/carpet mire, Lush lawn mire/carpet mire, lush carpet mire with willow	Non-organic

3.4.3.3 Other land

The field and ground layer classes for other land than forest and wetlands are created from the vegetation/land cover classification according to the following:

Field-layer class	Vegetation/land cover classification
• No field layer –other land	coastal rocks, stone/sand pit, buitl-up areas and other hard surfaces
• Arable land	arable land (according to the topographic map)
• Herb type	other open land (pastures and meadows)

Ground-layer class	Vegetation/land cover classification
• Arable land	arable land (according to the topographic map)
• Moss type	other open land (pastures and meadows)
• Built-up areas, pits etc	built-up areas, stone/sand pit
• Coastal bare rocks	coastal bare rocks

Besides the classes specified above, water is shown as a separate class in all layers.

3.4.3.4 Summary

Table 10 and 11 summarise the field and ground layer classes produced.

Table 10. *Produced field layer classes.*

– No field layer - forest land
– No field layer - other land
– Arable land
Forests and pastures
– Lichen-rich type
– Dry heath type
– Mesic bilberry heath type
– Herb-heath type
– Herb type
– Wet herb type
Wetlands
– Sedge-heath type
– Sedge type
– Sedge-herb type
– Sedge-reed type

Herb-heath type

Table 11. *Produced ground layer classes.*

Forest land
– Lichen type
– Moss type
Wetlands
– Peatland - Sphagnum type
– Peatland - other
– Not peatland - moss type
– Not peatland - other
Agricultural land
– Arable land
– Moss type (pastures and meadows)
Other
– Built-up areas, pits etc
– Coastal bare rocks

Peatland – Sphagnum type

3.4.4 Final generalisation

A final generalisation of the produced layers was performed to remove small areas. A final minimum-mapping unit of 0.25 ha was thus created. Areas less than 0.25 ha were removed and substituted with the classes of the surroundings. The generalisation was not allowed to change the borders between open land, forest and wetlands that were taken from the topographic map.

4 Results

The final result is four vegetation layers for each study area (Figure 12) showing the dominating species in each layer (tree and shrub layer) or a collective description of the layer (field and ground layer). The produced vegetation /land cover classification used as a base for generation of the layers is presented in section 4.1. Section 4.2 shows the layers for each area.

4.1 Vegetation/land cover classification

Figures 13-16 show the results for the Forsmark and the Tierp areas. Depending on the individual character of the two areas, the classification schemes differ slightly between the areas. The classification work of the Oskarshamn area was not finished since field check/calibration of the classifications could not be carried out.

4.2 Vegetation layer

The final result is four vegetation layers derived for each study area. Figures 17-20 show the layers of the Forsmark area, Figures 21-24 the layers of the Tierp area.

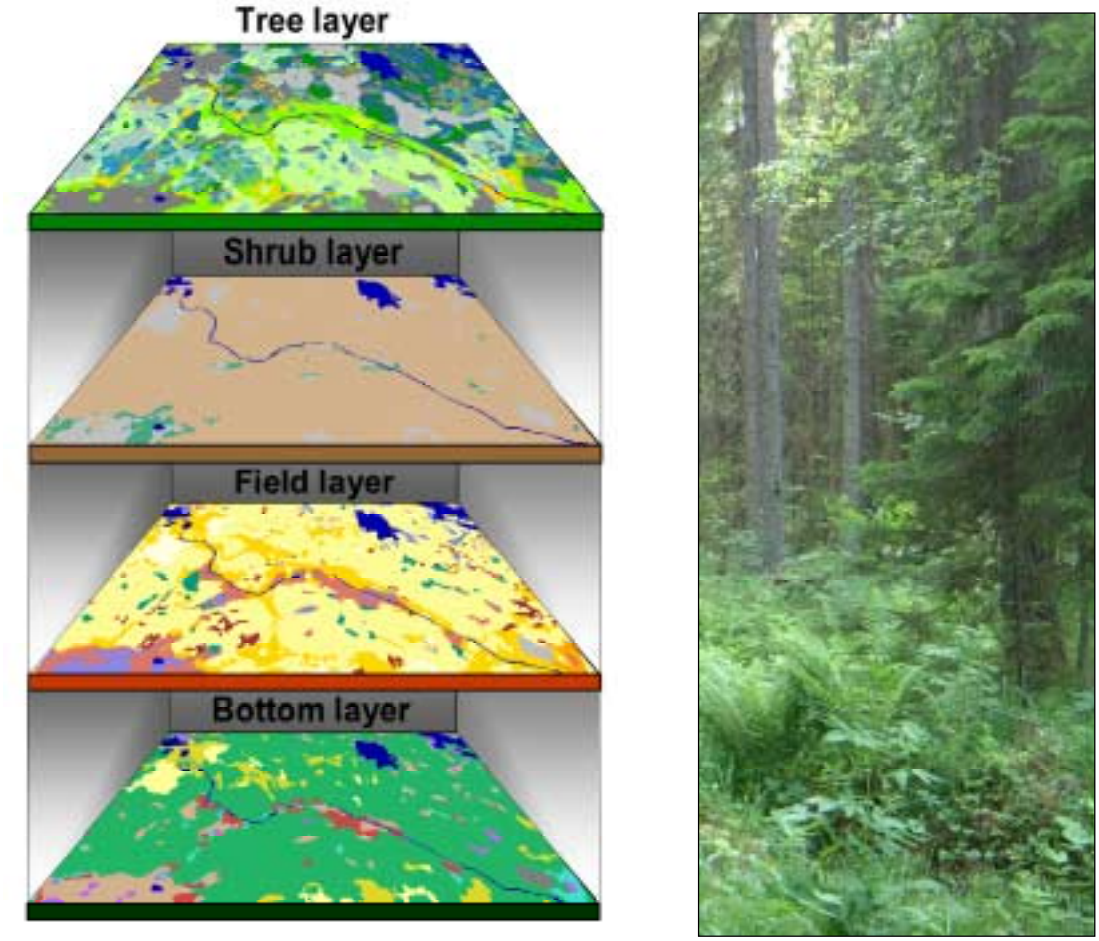


Figure 12. *The final vegetation layers of the Forsmark area.*

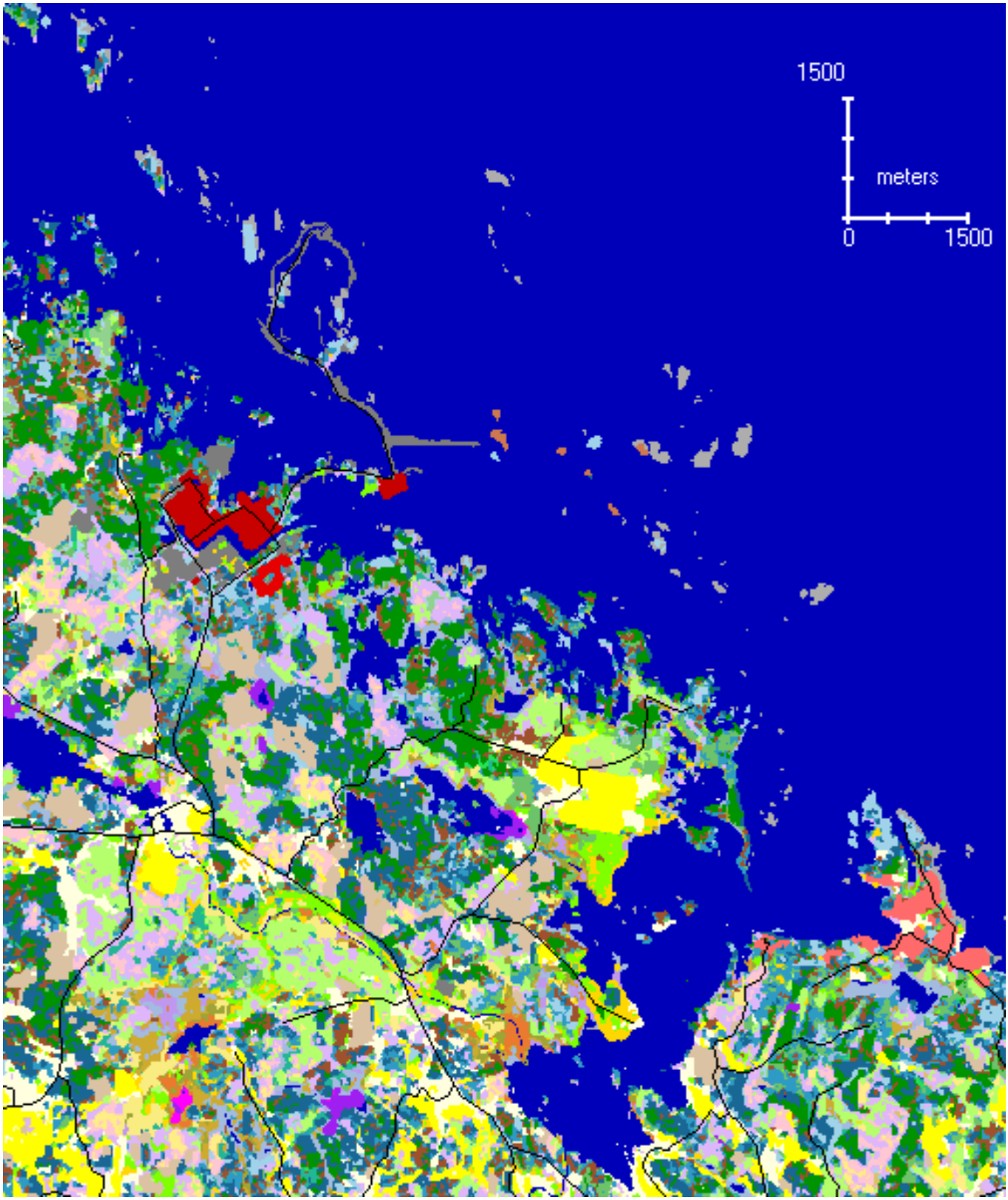


Figure 13. *The vegetation/land cover map of the Forsmark area. For a larger map see Appendix 7.*

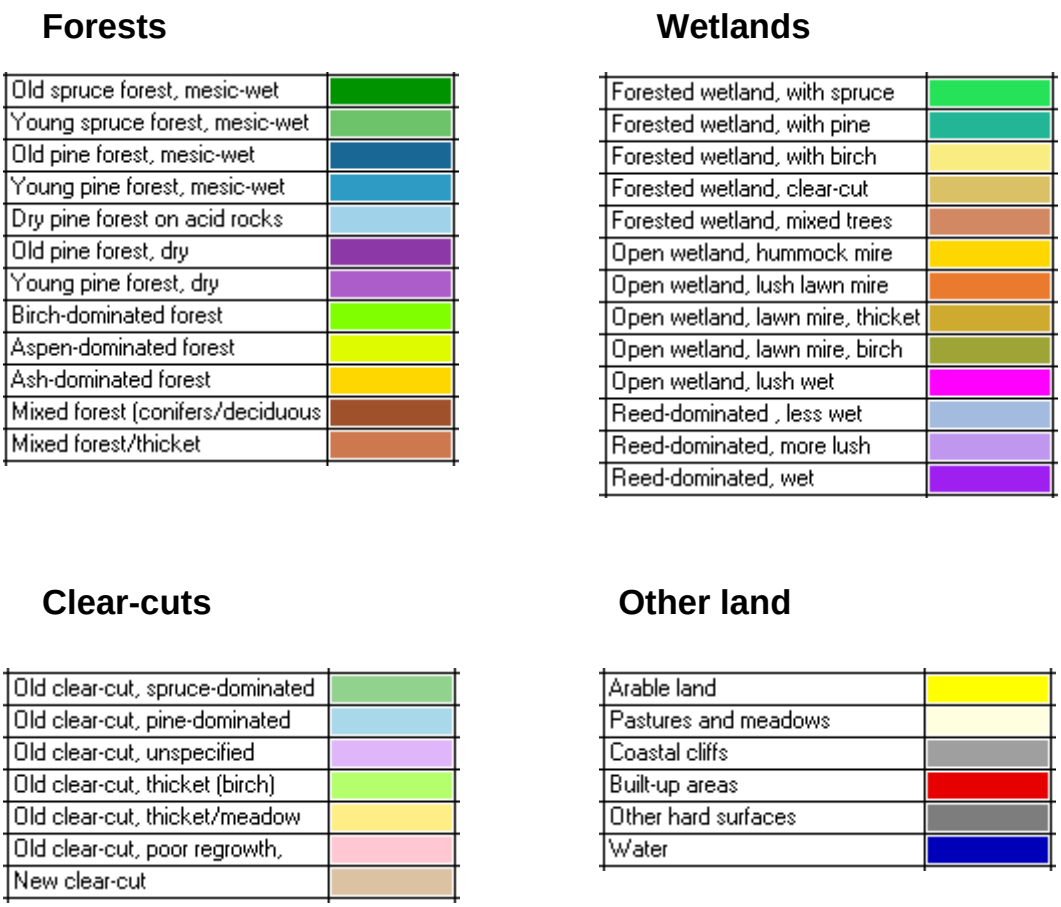


Figure 13. *Legend.*

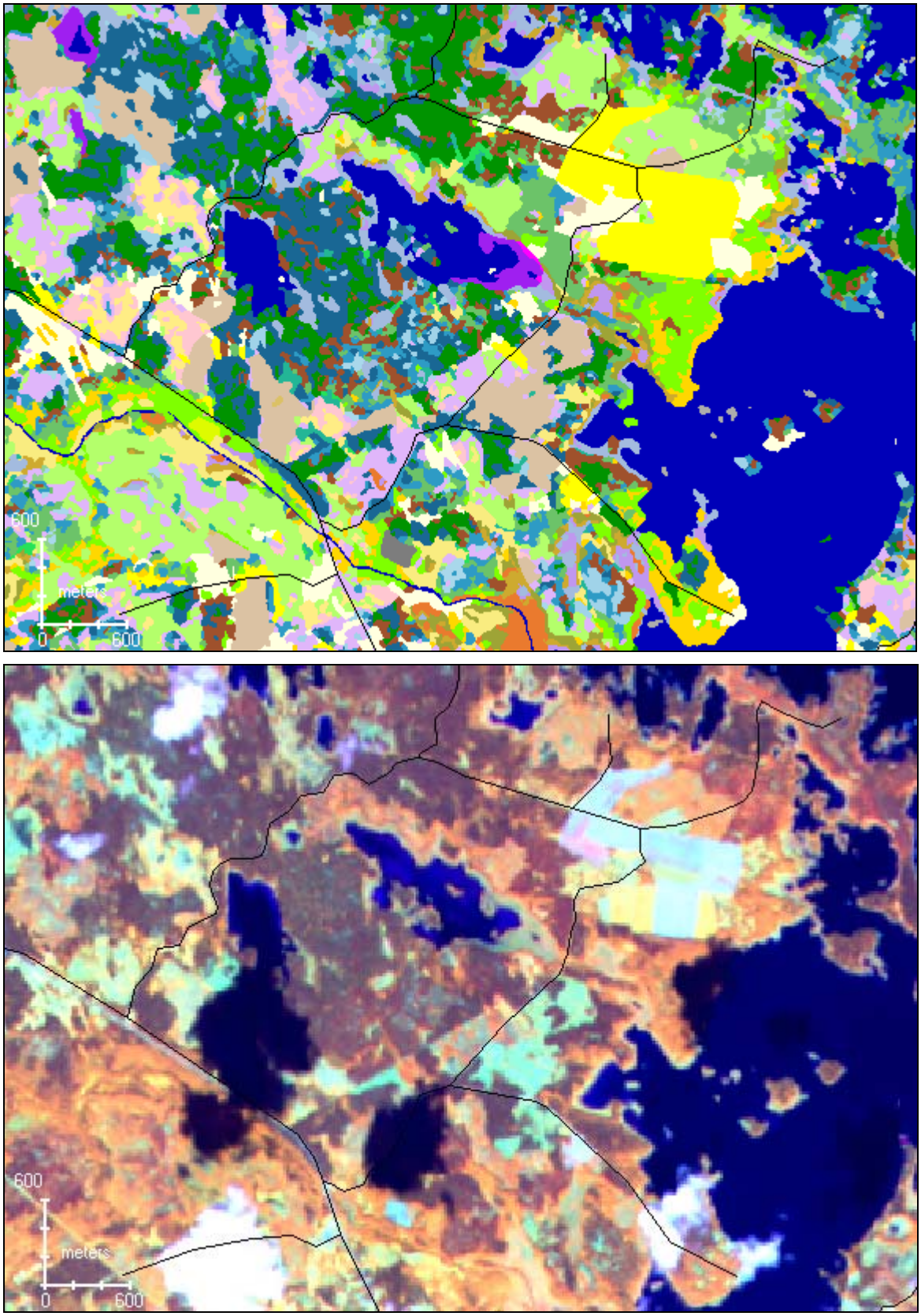


Figure 14. *Detail from the vegetation/land cover map of the Forsmark area (above) compared with the SPOT image for the same area (below). For a legend see Figure 13.*

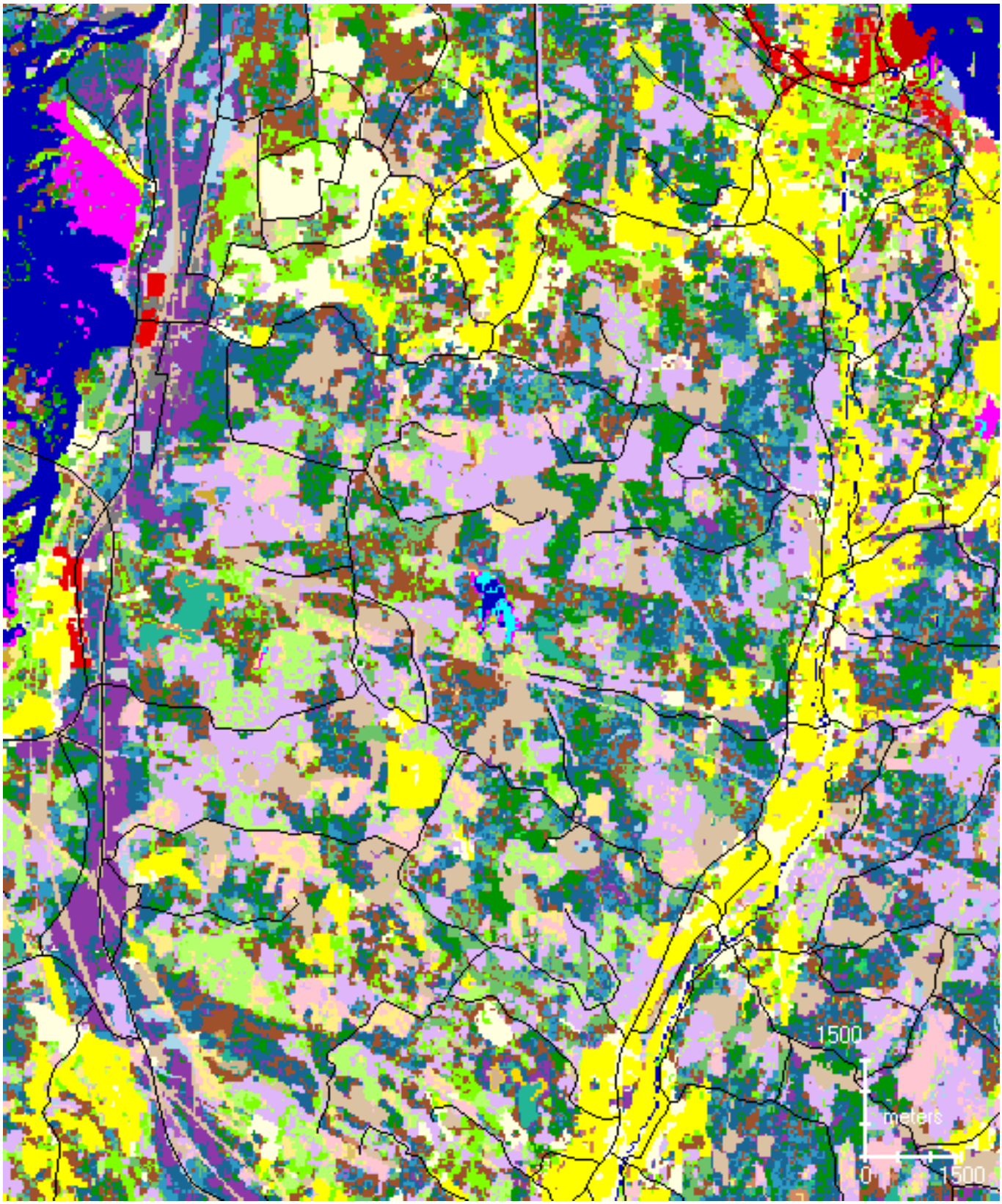


Figure 15. *The vegetation/land cover map of the Tierp area. For a larger map see Appendix 8.*

Forests

Old spruce forest, mesic-wet
Young spruce forest, mesic-wet
Old pine forest, mesic-wet
Young pine forest, mesic-wet
Dry pine forest on acid rocks
Old pine forest, dry
Young pine forest, dry
Birch-dominated forest
Mixed forest (conifers/deciduous

Clear-cuts

Old clear-cut, pine-dominated
Old clear-cut, unspecified
Old clear-cut, thicket (birch)
Old clear-cut, thicket/meadow
Old clear-cut, poor regrowth,
New clear-cut

Agricultural land

Arable land
Pastures and meadows

Wetlands

Forested wetland, with spruce
Forested wetland, with pine
Forested wetland, with birch
Forested wetland, clear-cut
Forested wetland, mixed trees
Open wetland, hummock mire
Open wetland, poor lawn mire
Open wetland, lush lawn mire
Open wetland, lawn mire, thicket
Open wetland, poor wet
Open wetland, lush wet
Reed-dominated , less wet
Reed-dominated, wet

Other land

Sand pit
Built-up areas
Other hard surfaces
Water

Figure 15. *Legend.*

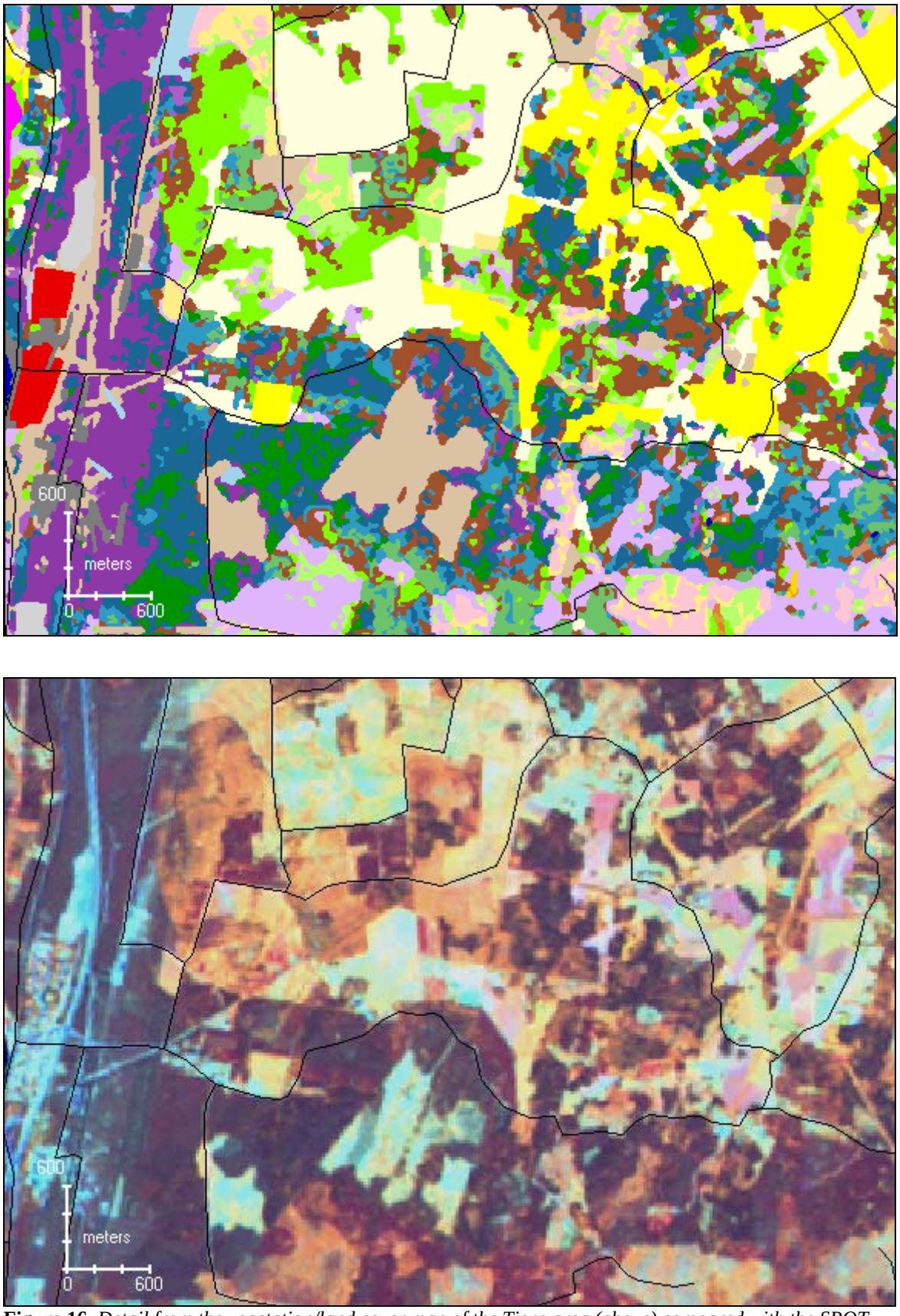


Figure 16. *Detail from the vegetation/land cover map of the Tierp area (above) compared with the SPOT image for the same area (below). For a legend see Figure 15.*

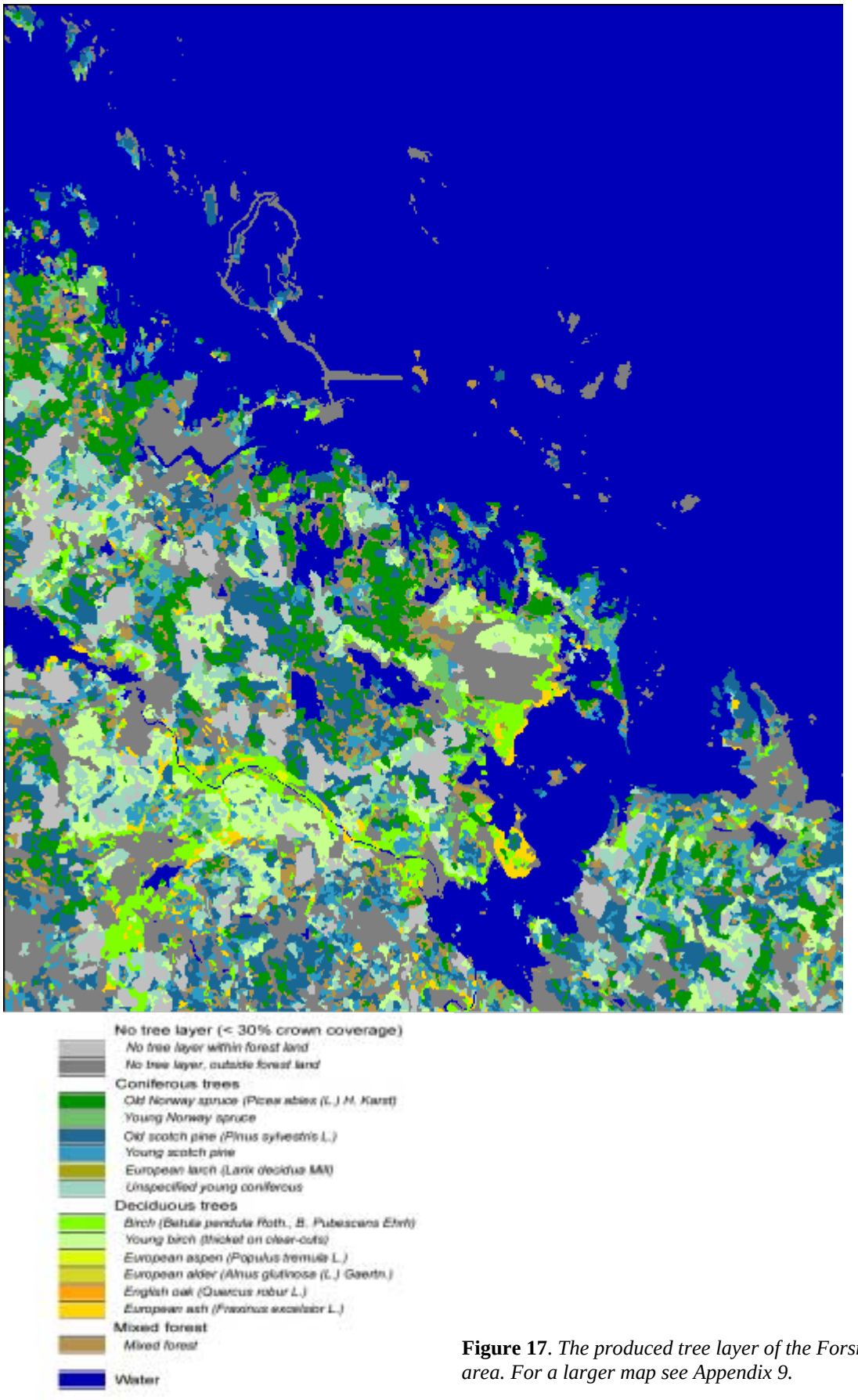


Figure 17. *The produced tree layer of the Forsmark area. For a larger map see Appendix 9.*

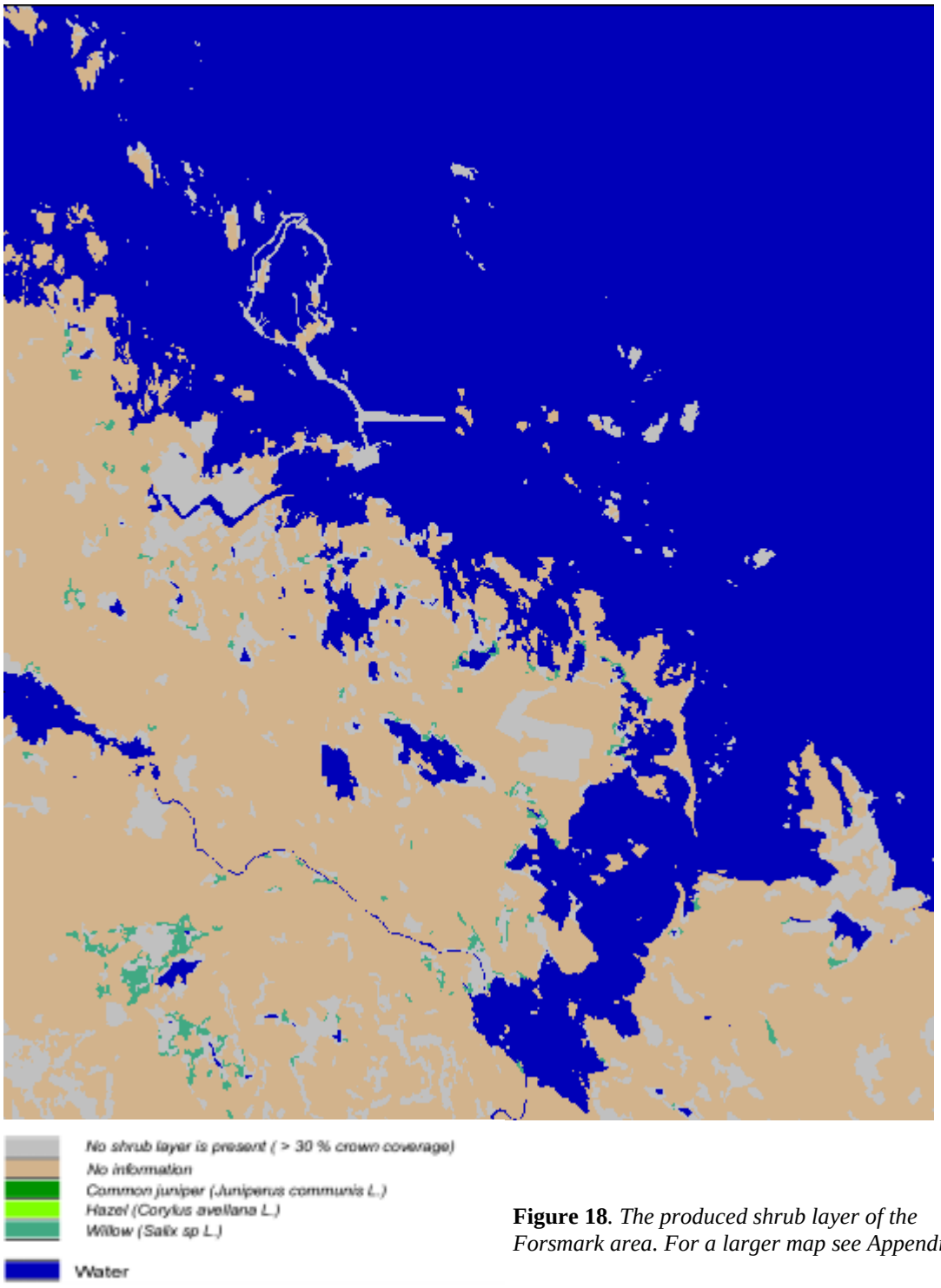


Figure 18. *The produced shrub layer of the Forsmark area. For a larger map see Appendix 10.*

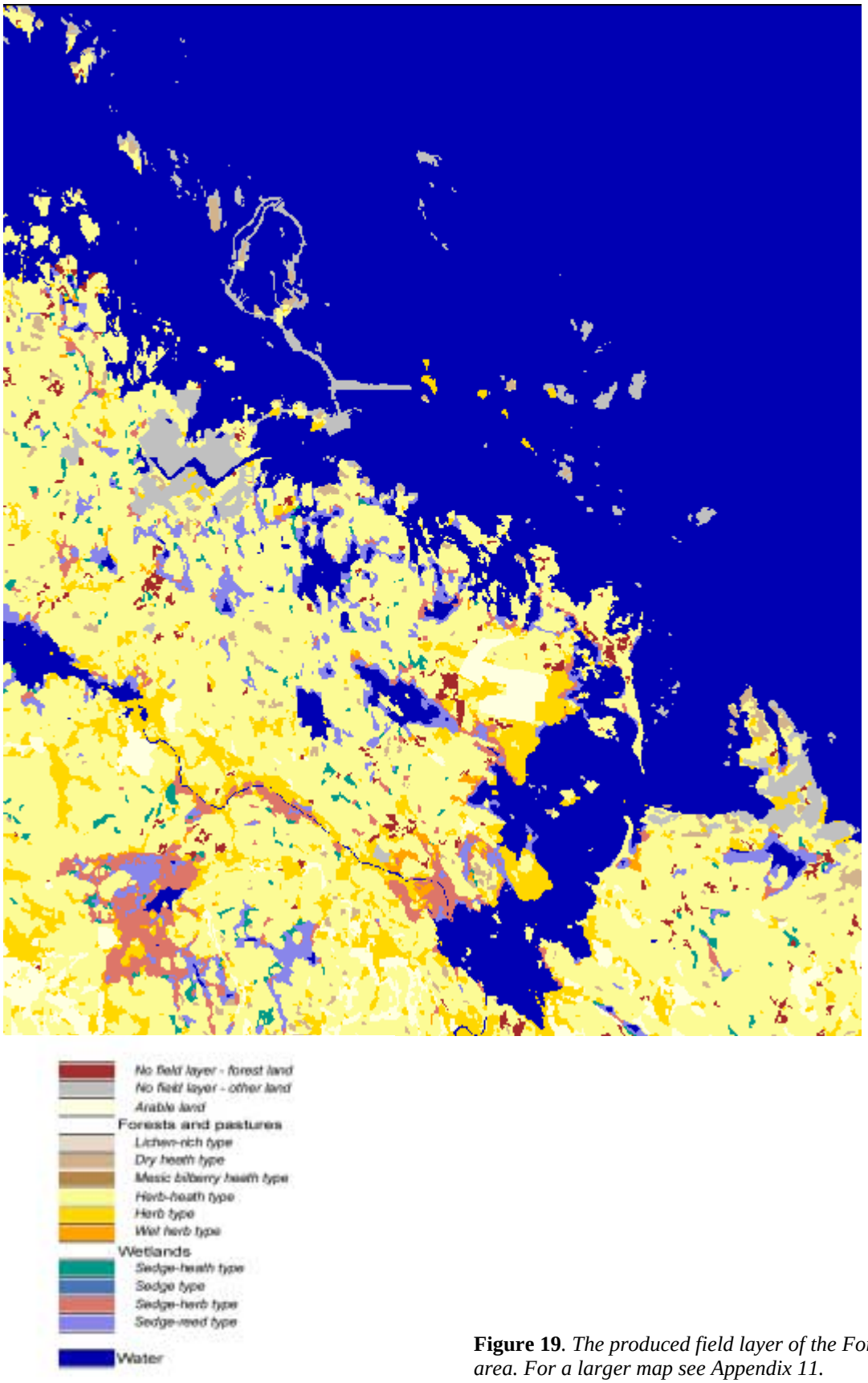


Figure 19. *The produced field layer of the Forsmark area. For a larger map see Appendix 11.*

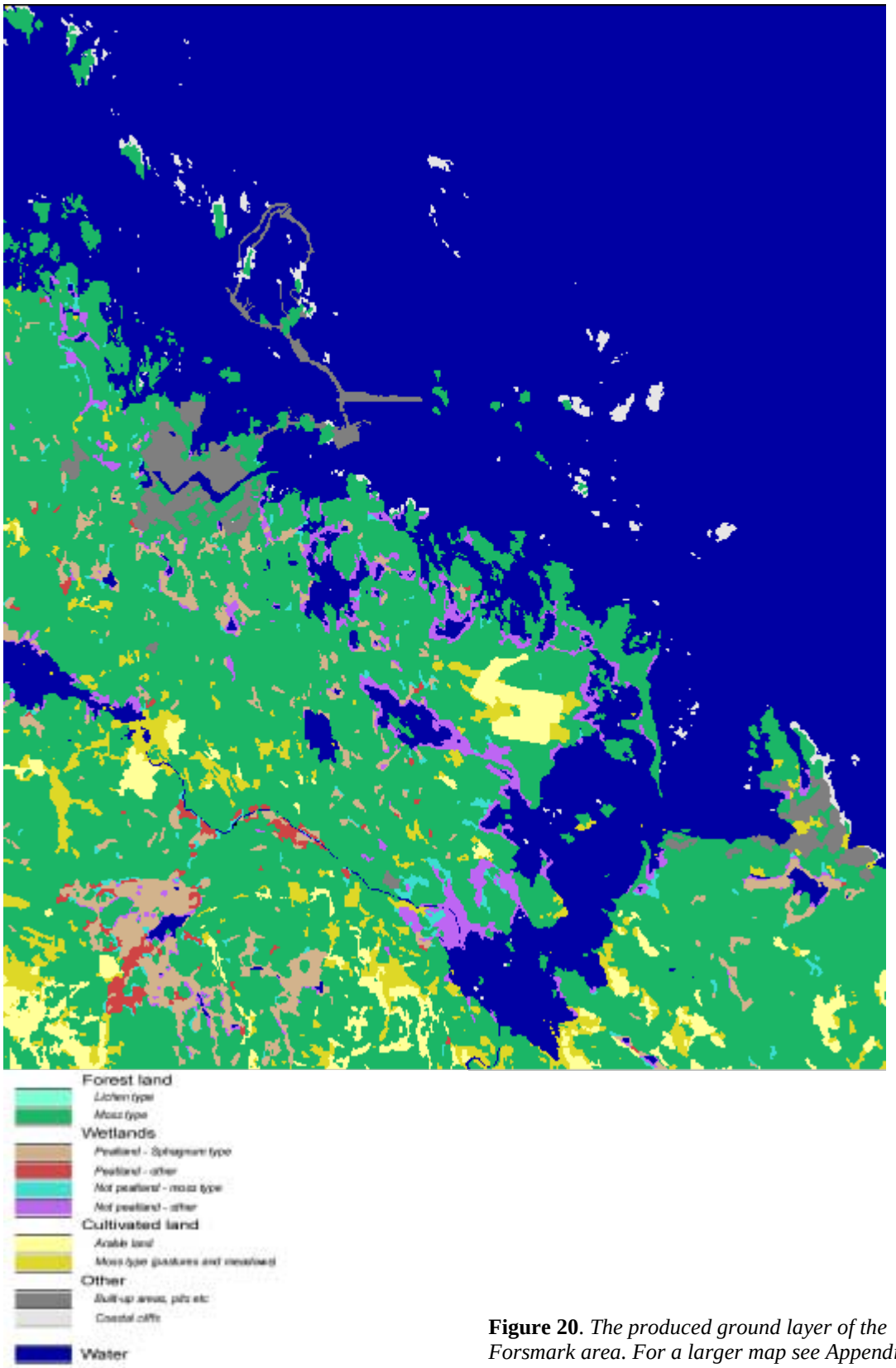


Figure 20. *The produced ground layer of the Forsmark area. For a larger map see Appendix 12.*

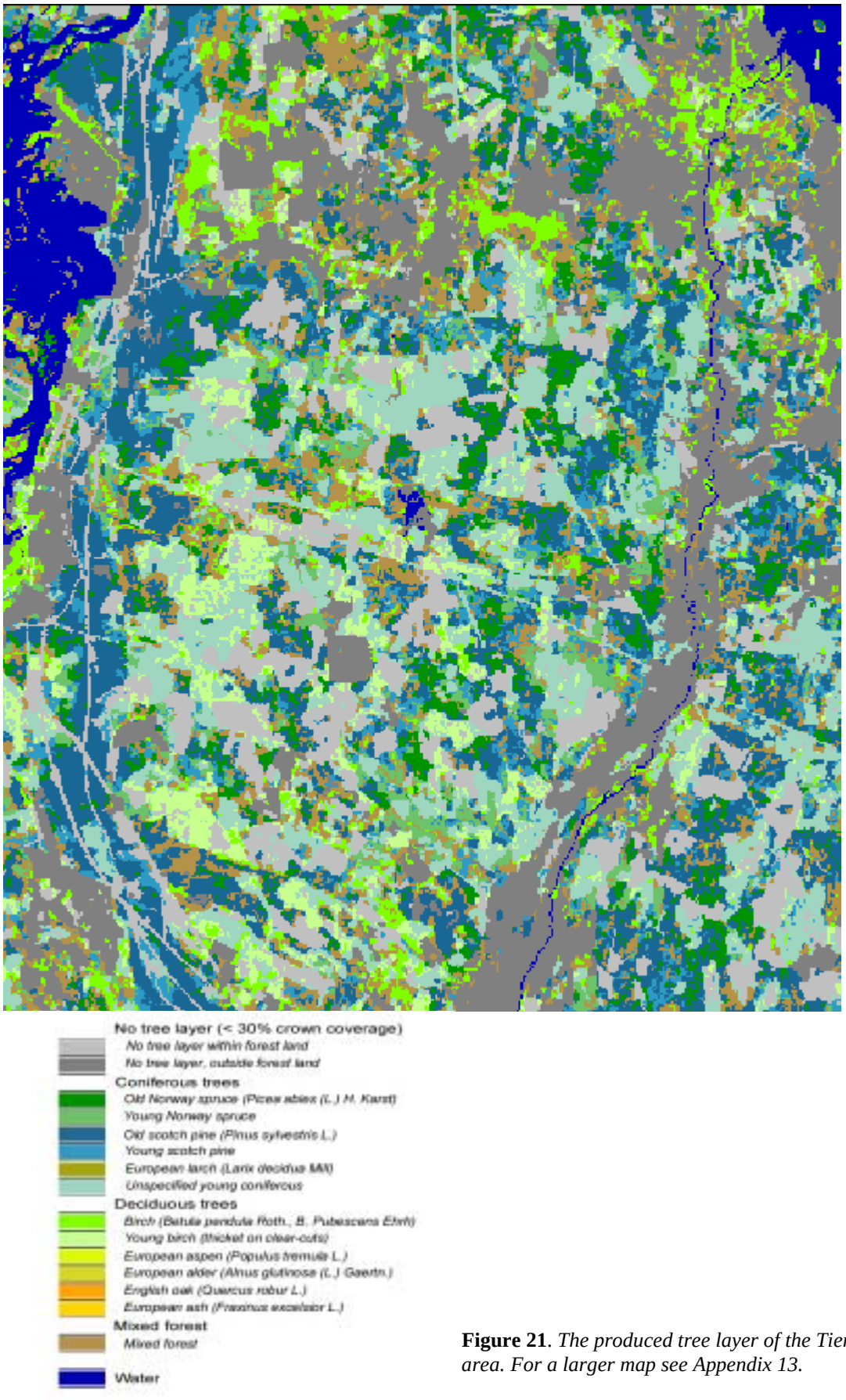


Figure 21. *The produced tree layer of the Tierp area. For a larger map see Appendix 13.*

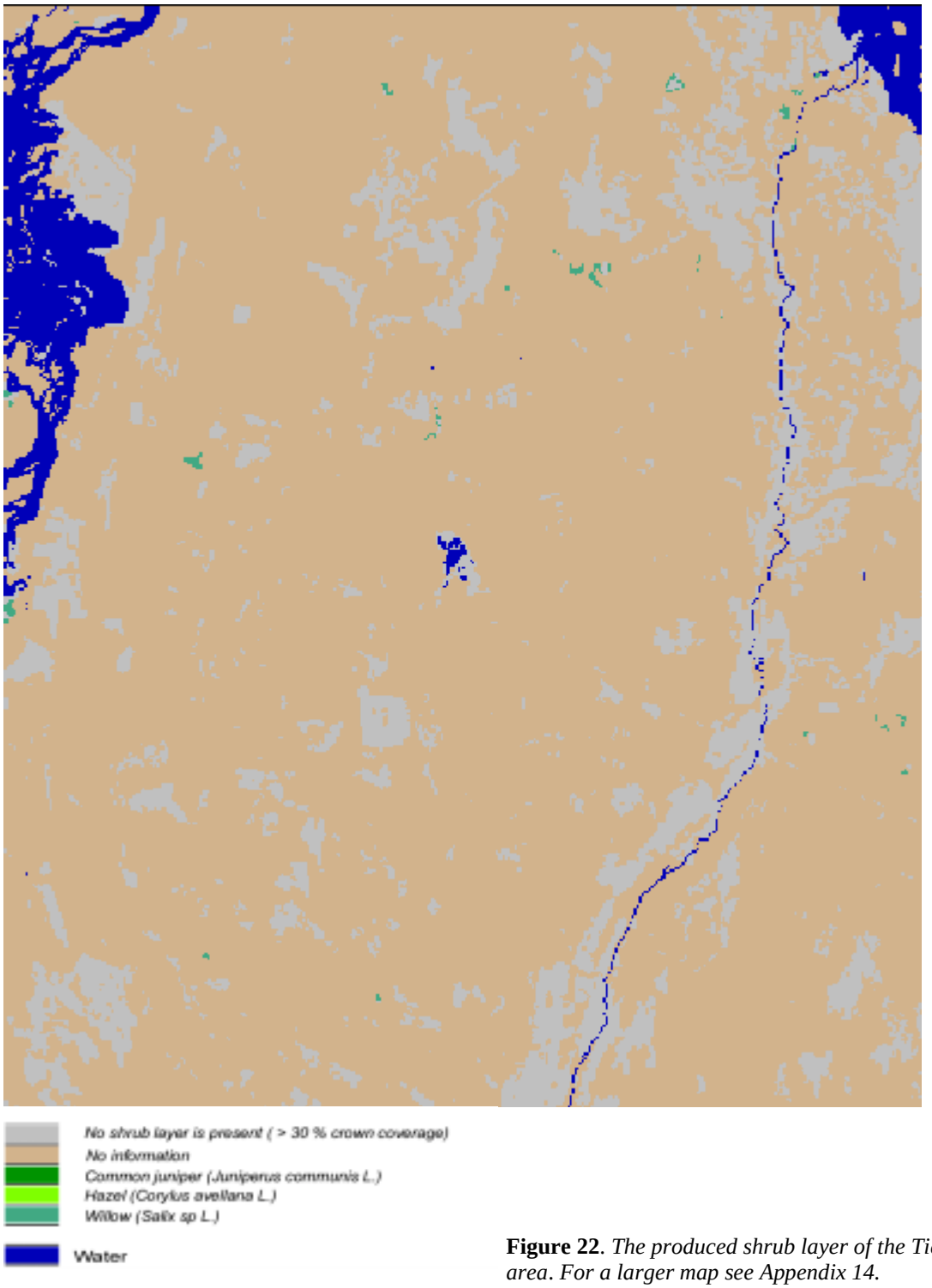


Figure 22. *The produced shrub layer of the Tierp area. For a larger map see Appendix 14.*

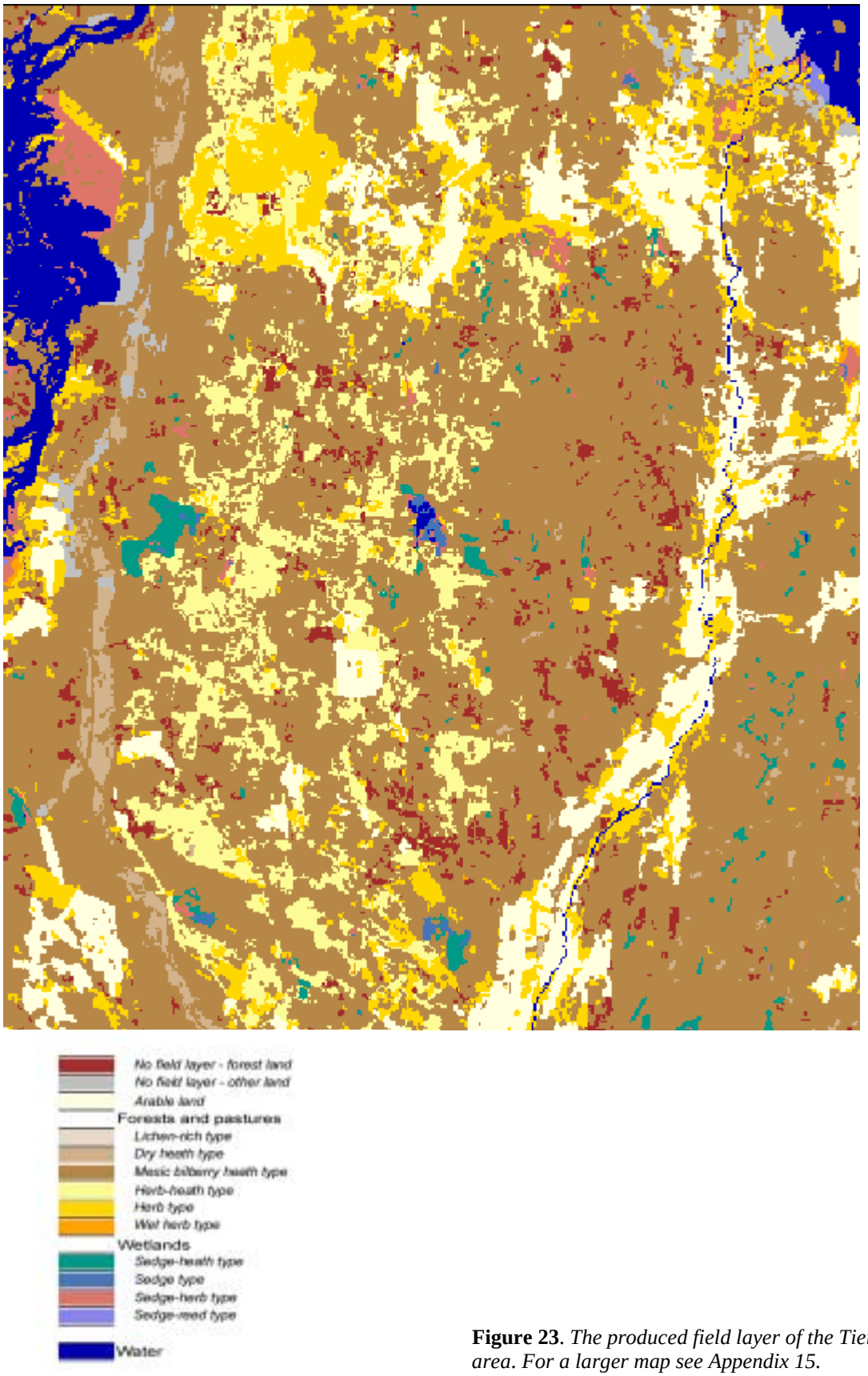


Figure 23. *The produced field layer of the Tierp area. For a larger map see Appendix 15.*

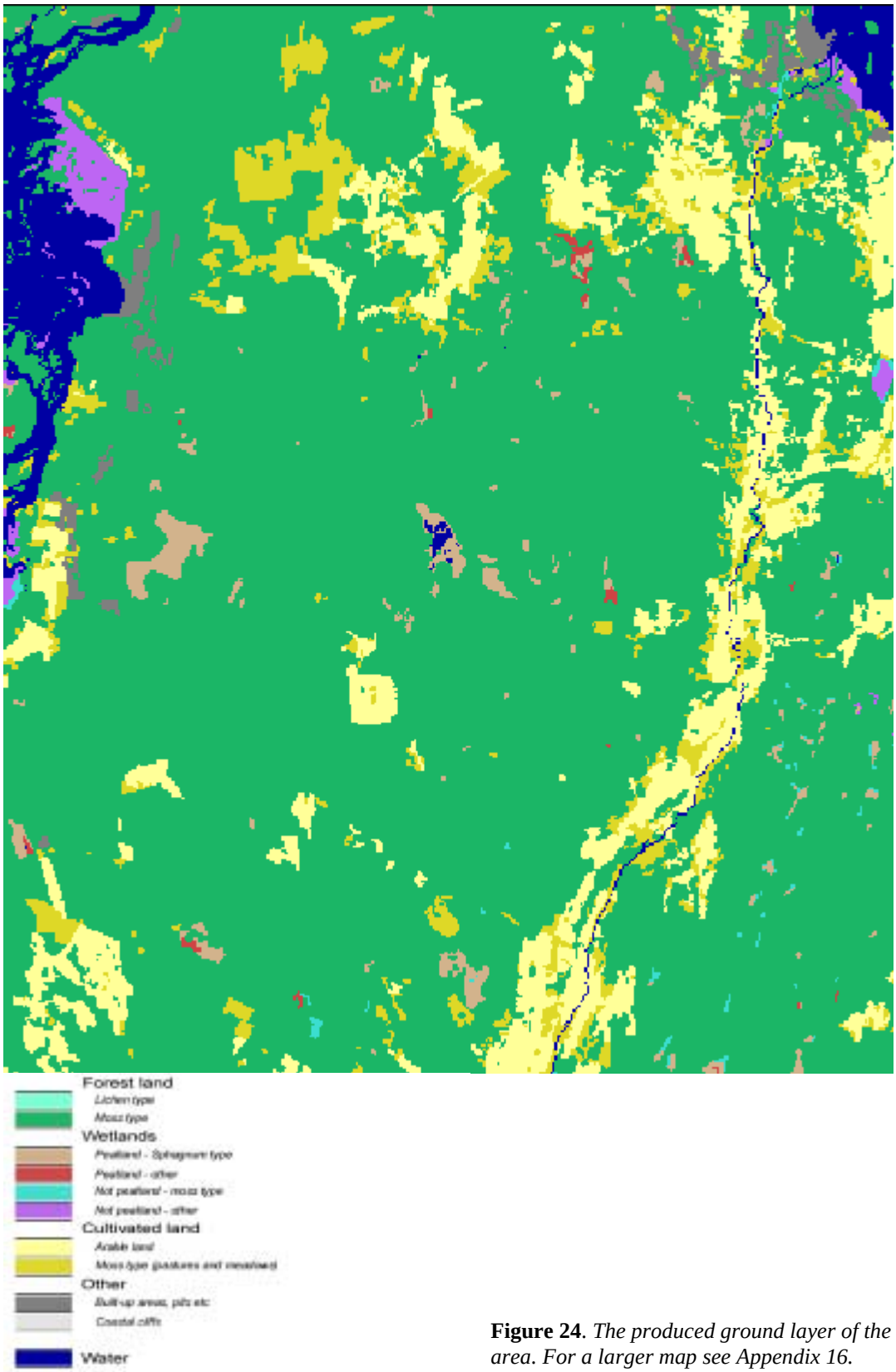


Figure 24. *The produced ground layer of the Tierp area. For a larger map see Appendix 16.*

5 Discussion

5.1 General aspects of the produced database

To use the digital maps correctly it is important to understand how they have been produced. The final product is the four vegetation layers. *The vegetation/land cover classification is a result produced to obtain the final result*.

In a first step the vegetation/land cover was classified using satellite data and information from the topographic map with the aim to produce as detailed base classification as possible in each study area. Thus, the classification of each area has been governed by what preliminary has been possible to distinguish in the area depending on its character and which vegetation units that occur together. Since, a general classification scheme was used a certain class do not necessarily occur in both areas in the vegetation/land cover classification. Also, since this classification is a result produced to obtain the final result effort has not been made to verify it in detail.

The final result, the vegetation layers, were produced from the vegetation/land cover classification with support of other data such as bedrock/soil data and field data. Thus, in this step any uncertainties in the vegetation/land cover classification could be reduced with support of other data.

One example of dissimilarities of classes between the vegetation maps of the Tierp and Forsmark areas is the occurrence of pine forest of dry heath type versus pine forest on acid rocks. These two classes show spectral similarities in satellite data and are sometimes difficult to separate from each other. The former class was classified in step 1 in the Tierp area but not in Forsmark. In the Tierp area pine forest of dry heath type is much more common than pine forest on acid rocks (very limited occurrence) and therefore only this type was classified with the satellite data. Pine forest on acid rocks in the vegetation/land cover classification for this area is taken from the topographic map (recoded bedrock outcrop).

In production of the field layer for the Tierp area (step 2) dry heath type was produced only if it occurred on bedrock outcrop (soil depth < 50 cm) or on glacifluvial deposits according to the soil data, or was mapped as bedrock outcrop in the topographic map.

In the Forsmark area where pine forest on acid rocks is common and dry heath type outside these areas are rare, the opposite is valid. Only pine forest on acid rocks was classified in step 1. Pine forest of this type in the base classification is made up of classified pine forest on acid rocks and areas with bedrock outcrops from the topographic map. Thus, pine forest of dry heath type is not to be found in the vegetation/land cover classification of the Forsmark area.

In production of the field layer in Forsmark dry heath type was produced if the area was mapped as pine forest on acid rock in the base classification or “clearcut, poor regrowth” and occurred on bedrock outcrops according to the soil data.

In conclusion, when using the vegetation/land cover classification it is important to remember that it is a result in the production line to the final results and ought to be used with caution.

5.2 General aspects on the classification accuracy

There are several parameters of importance for the classification accuracy. The most important are how well the different classes are separated spectrally and the heterogeneity of the landscape.

The spectral separability between classes varies during the vegetation period depending on the phenological stage of the vegetation and the weather situation. The separability is also dependent on which vegetation units that are present in an area and their character. Normally, best separation between forest classes is obtained in images recorded in the beginning of the summer. For mire vegetation images from July and August is preferable.

The structure and heterogeneity of the landscape are important parameters since the size of the vegetation units in relation to the ground resolution of the satellite data determine if the units can be detected and correctly classified. The smaller vegetation units the more borders between classes are found which results in mixed signatures. Especially borders between spectrally light objects such as arable land and dark objects such as coniferous forests may cause misclassifications due to mixed signatures.

The classifications undertaken in this work have been made under masks from the topographic map. This means that allowing only certain classes depending on main group in the topographic map (forest, forested mires, open mires etc.) the classification result can be optimised and the accuracy improved since confusion between the classes can be reduced. However, due to misfit between satellite data and the topographic map border effects may occur which reduce the classification accuracy in affected pixels (the border pixels). This may be the case between arable land and dark forest and between new clear-cuts (highly reflective) and the dark forest.

In producing the field-layer classes some general assumptions about the richness of the flora have been made for the study areas based on general knowledge of bedrock influence etc in combination with the collected field data. Critical classes in this case are the distinction between the mesic bilberry heath types and the herb-heath type. Since, the field data are not evenly distributed in the areas there may be parts, especially in Tierp, for which the assumptions are more uncertain. Also, in the main part of the Tierp area, the digital soil data used have a coarser resolution than in Forsmark.

6 References

Boresjö, L., 1989: *Multitemporal analysis of satellite data for vegetation mapping in Sweden.* Department of Physical Geography, Stockholm University, No A 233, 191 p. (Doctoral Thesis).

Boresjö Bronge, L., 1998: Vegetation mapping using satellite and topographic map data in a stratified approach - method development and application. In "Future Trends in Remote Sensing" (Ed. P. Gudmandsen*). Proceedings of the 17th EARSeL Symposium on Future Trends in Remote Sensing", Lyngby, Denmark, 17-19 June, 1997*, pp 103-111.

Boresjö Bronge, L., 1999: Mapping boreal vegetation using Landsat TM and topographic map data in a stratified approach. *Canadian Journal of Remote Sensing*, Vol. 25, No 5, 460-474.

Boresjö Bronge, L. 2000*: Ädellövskogskartering baserad på satellitdata. Statusrapport maj 2000.* Satellus, G-PUBL-8, 56 p. (In Swedish).

Boresjö Bronge, L., and Jönsson, C., 2000*: Myrklassificering med satellitdata.* Satellus, G-PUBL-11, 53 p. (In Swedish)

Boresjö Bronge, L. and Näslund-Landenmark, B., 1999*: Satellite data for wetland classification.- Spectral characteristics of Swedish mire vegetation.* Swedish Space Corporation, X-PUBL-41, 79 p.

Boresjö Bronge, L., and Näslund-Landenmark, B., 2002: Wetland classification for Swedish CORINE Land Cover adopting a semi-automatic interactive approach. *Canadian Journal of Remote Sensing.* (In press)

Boresjö Bronge L., and Wester K., 1999*: Mapping of high mountain areas for Swedish Land Cover Data.* Satellus, X-PUBL-52, 95 p.

ERDAS, 1999: *ERDAS Field Guide*. Fifth Edition, ERDAS Inc., Atlanta Georgia, 672 p.

Hägglund, B., and Lundmark, J.-E., 1982: *Handledning i bonitering med Skogshögskolans boniteringssystem. Del 3. Markvegetationstyper – Skogsmarksflora*. Skogsstyrelsen, Jönköping, 124 p. (In Swedish)

Sveriges Nationalatlas, 1994: *Berg och jord*. Sveriges Nationalatlas Förlag, 208 p. (In Swedish)

Appendix 1

Field data – example of field protocols and photographs Forsmark

Figure A1:1 shows an overview of the area for general orientation. Figures A1:2-6 show areas visited in the field 27 and 28 June and 26 September 2001. The numbers refer to numbers in the field protocols.

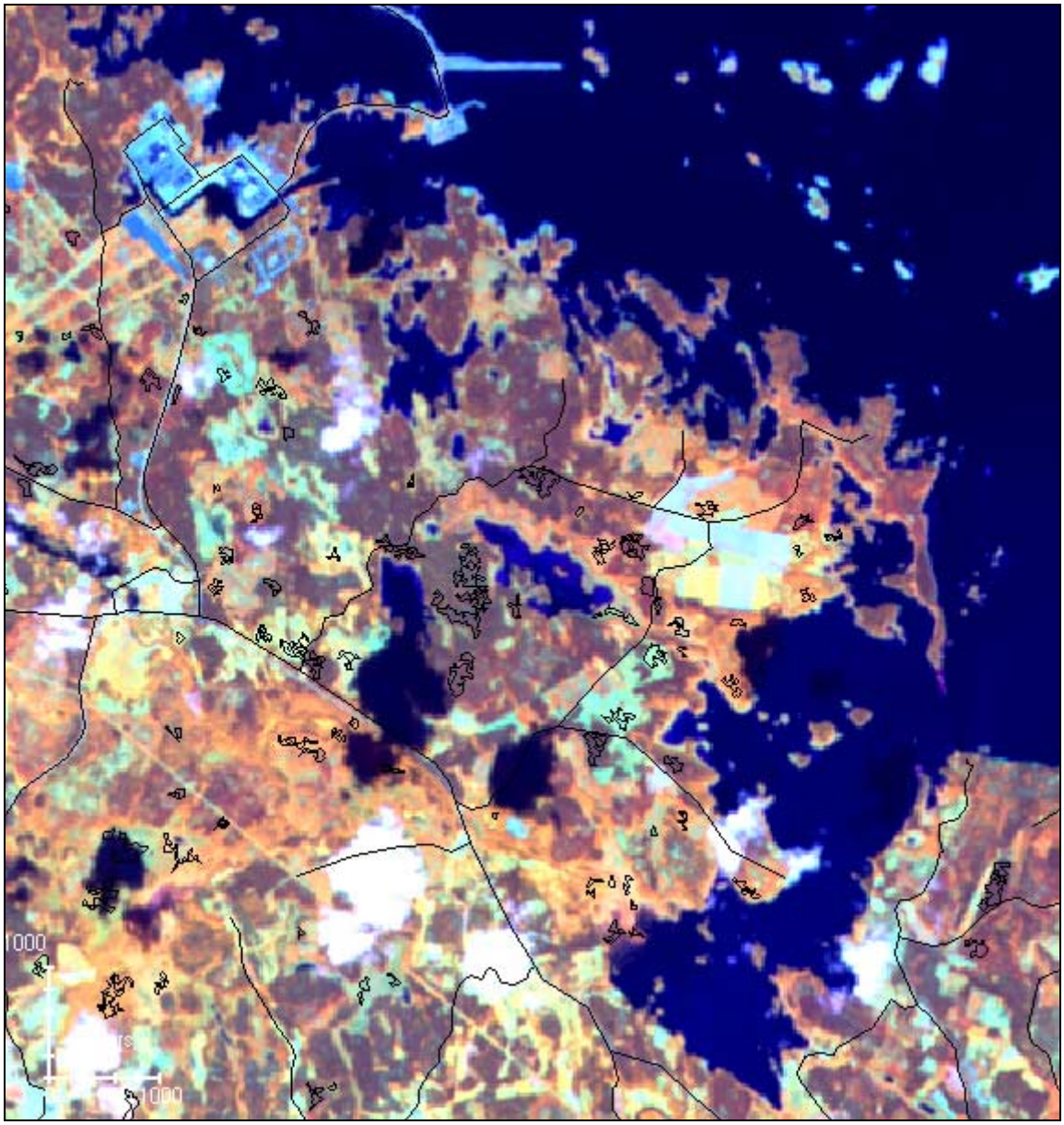


Figure A1:1. *Overview of the Forsmark area to facilitate orientation of visited areas shown in Figures A1:2-6. Black lines are roads from the 1:250 000 scale map. Areas with black outline are training areas for signature analysis.*

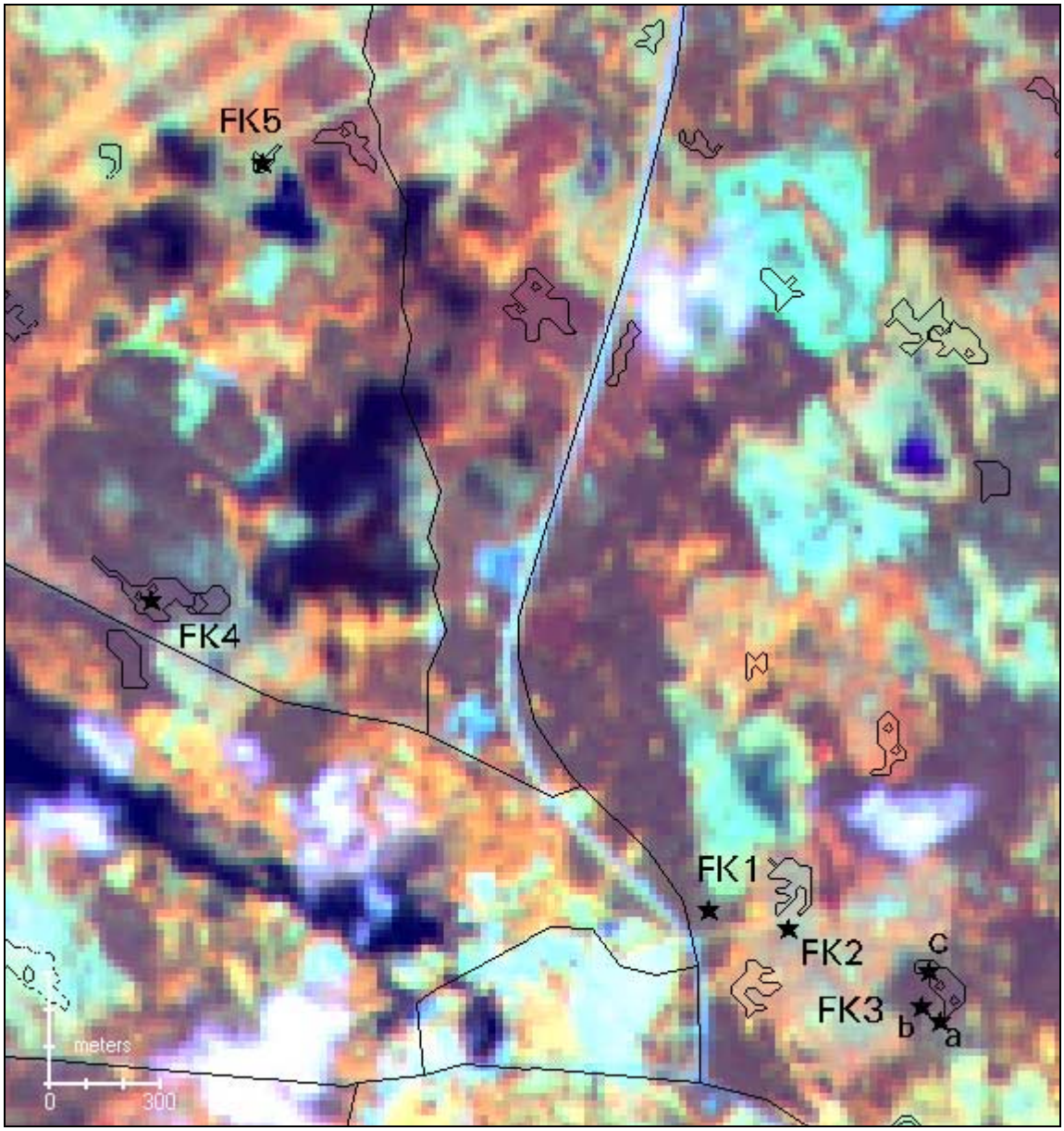


Figure A1:2. *Areas marked with a cross (+) and denoted F1, F2 etc were visited 27-28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted FK1, FK2 etc were visited 26 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

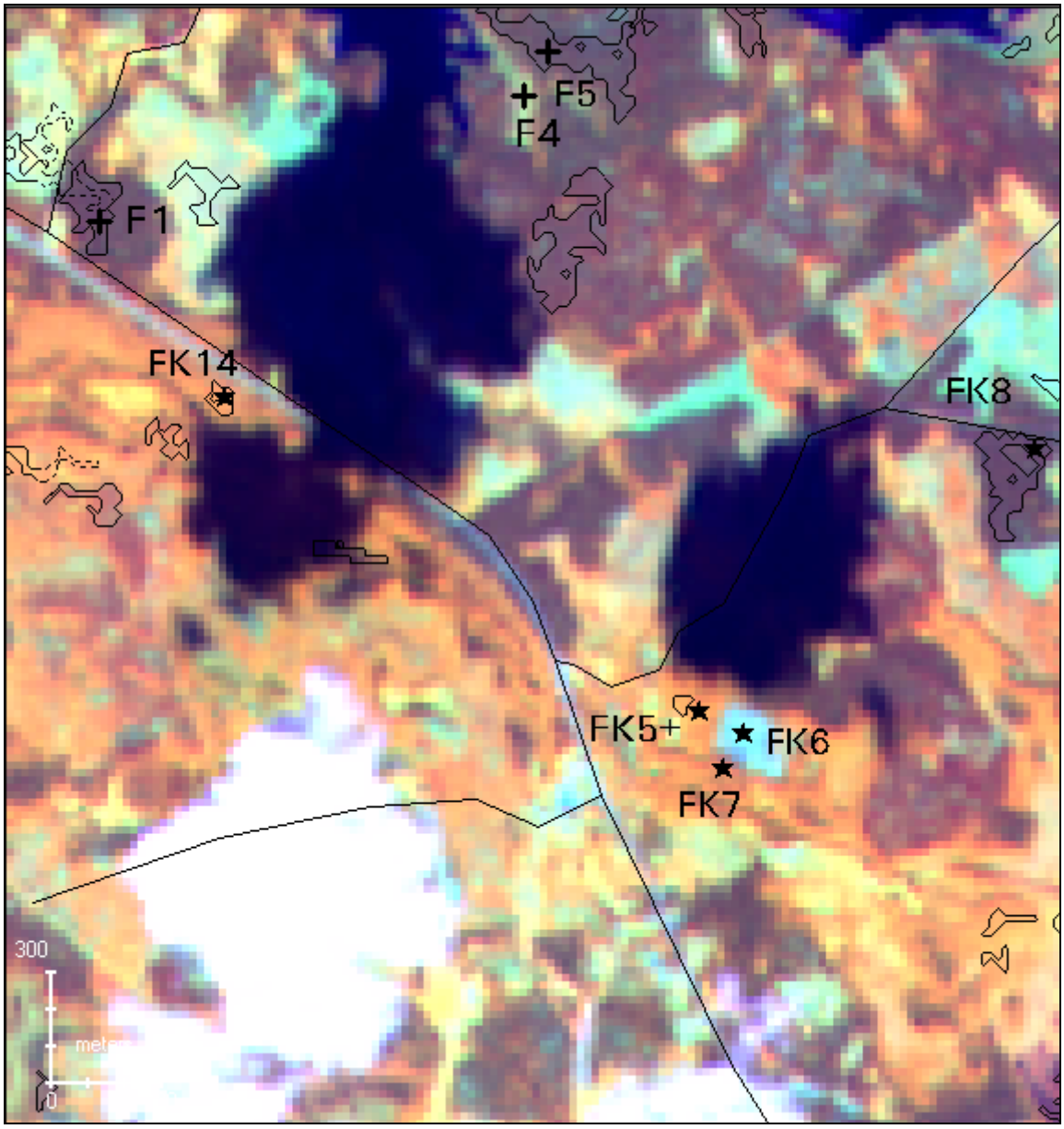


Figure A1:3. *Areas marked with a cross (+) and denoted F1, F2 etc were visited 27-28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (⋆) and denoted FK1, FK2 etc were visited 26 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

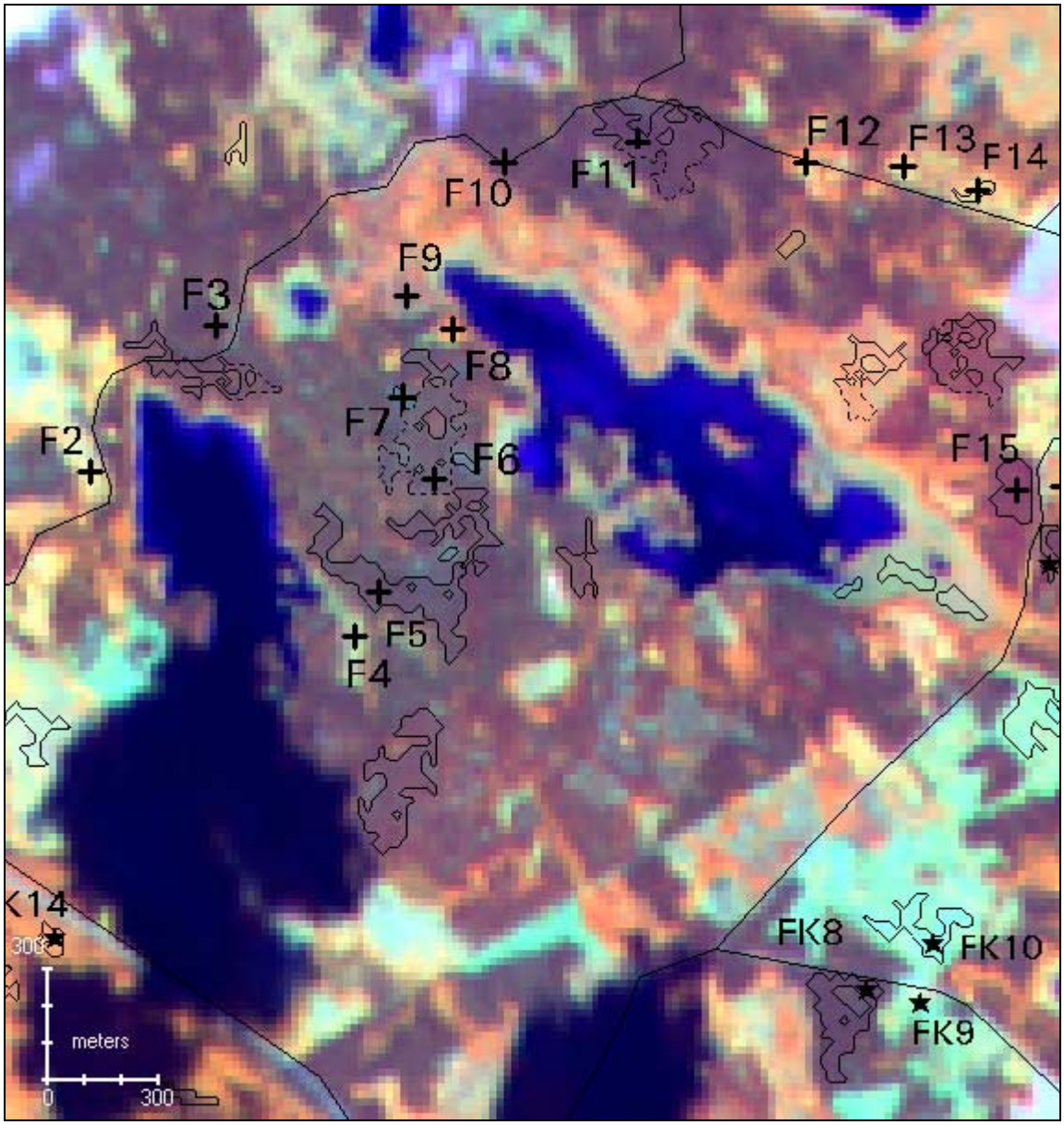


Figure A1:4. *Areas marked with a cross (+) and denoted F1, F2 etc were visited 27-28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted FK1, FK2 etc were visited 26 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

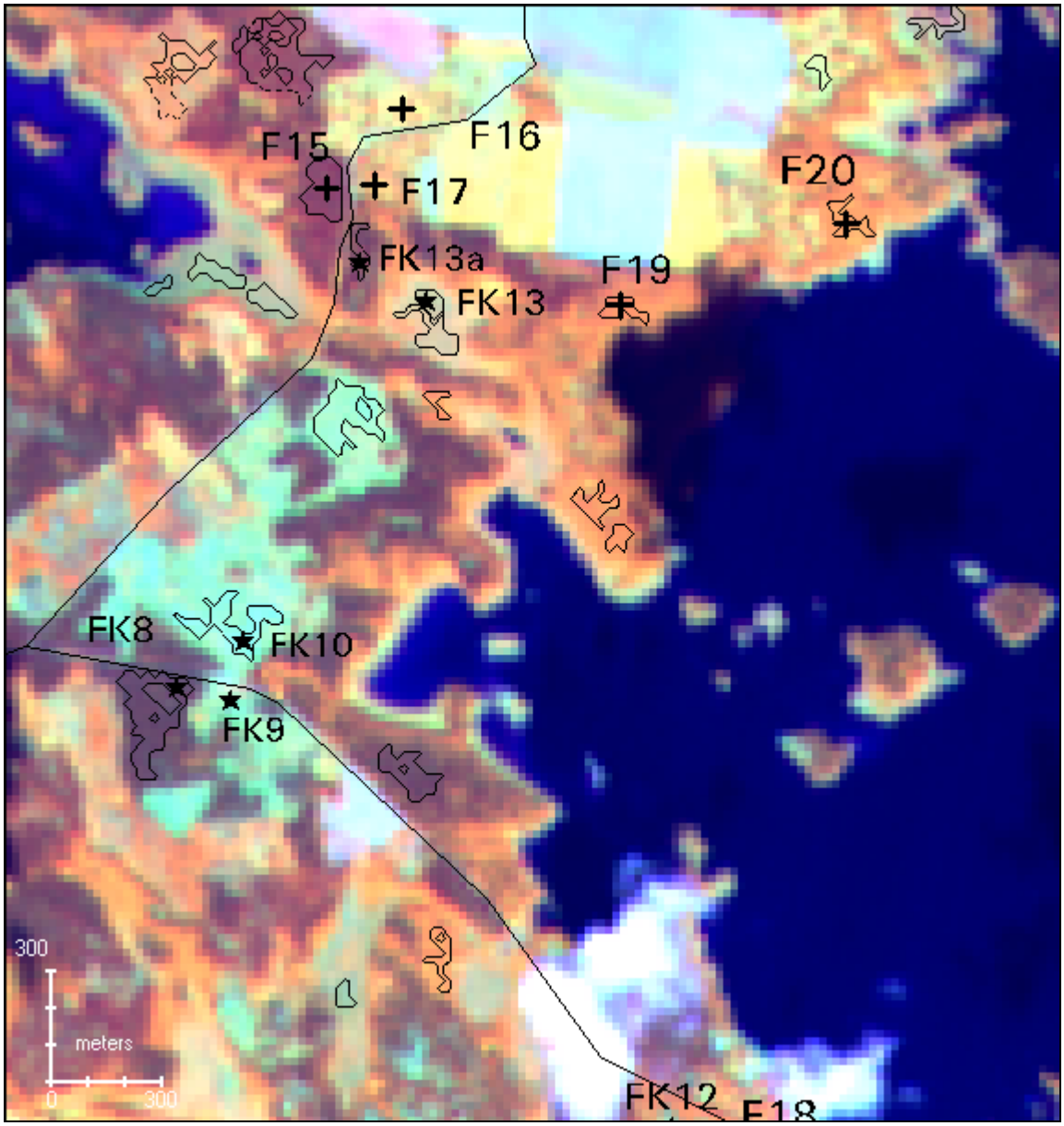


Figure A1:5. *Areas marked with a cross (+) and denoted F1, F2 etc were visited 27-28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted FK1, FK2 etc were visited 26 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

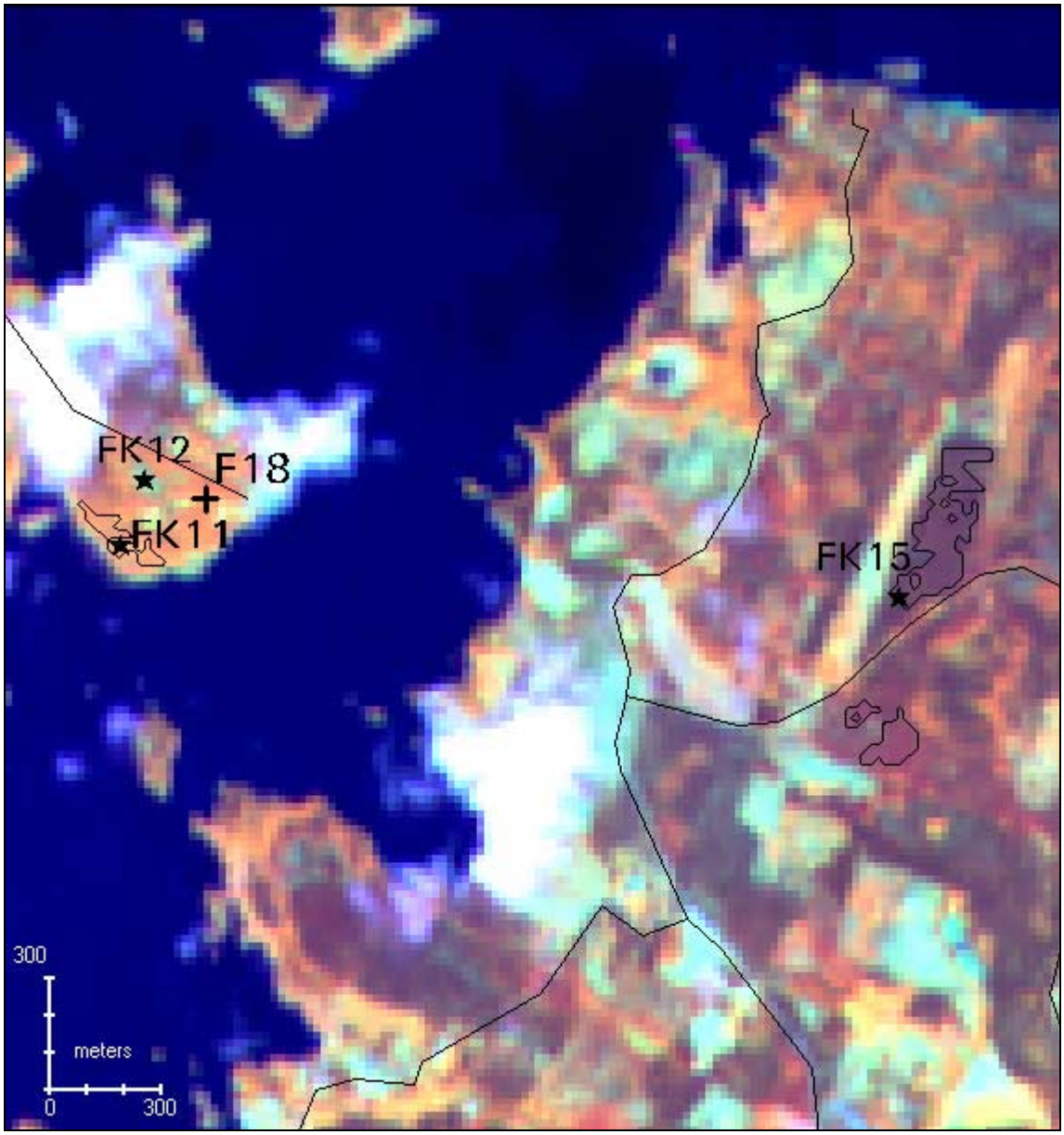


Figure A1:6. *Areas marked with a cross (+) and denoted F1, F2 etc were visited 27-28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted FK1, FK2 etc were visited 26 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

YTNÄRA EKOSYSTEM

Fältprotokoll (SKB - VEGETATIONSKARTERING MED SATELLIT-/FLYGBILDER)

Område	Datum
FORSMARK	27/6

Utförare	Protokoll nr	Övrigt
Laine Boresjö Bronge, SwedPower Kjell Wester, SwedPower		

Provnamn	Tidpunkt	Foto
F1	12^{55}	1, 2, 3

Signatur

Trädskikt	Gran, någon enstaka tall > 20 m
Buskskikt	—
Örtskikt	Örtrik med inslag av blåbär vitsippa, skogsnäva11, ekbräken, ekorrbär, ormbär, bergslok, örnbräken
Markskikt	Mossor
Övriga kommentarer	bilder träd, markskikt, markskikt örtrik granskog utan buskskikt

Provnamn	Tidpunkt	Foto	
F2	13^{25}	4	från vägen mot väster

Trädskikt	Enstaka björkar 3-4m, granplantor 0.5-1m, enstaka tallplantor, en
Buskskikt	
Örtskikt	tätt med örnbräken, örter, lite blåbär torrare partier med lingonris, blocke, blåbär, vitsippa
Markskikt	
Övriga kommentarer	

Provnamn	Tidpunkt	Foto	
F3	13^{35}	5, 6, 7, 8, 9	10 (andra sidan)

Trädskikt	Grandom. skog som brunnit (delvis huggen) (på andra sidan vägen gran med inslag av tall
Buskskikt	—
Örtskikt	Torrare partier – blåbär med inslag av örter, blodrot, ängsnäva11, fryle, senecio fuktigare partier gräsdom., mära (på andra sidan blåbär, skogsnäva11, ekorrbär
Markskikt	mossor (husmossa) på andra sidan vägen
Övriga kommentarer	Foton tagna ca 30 m från "mätesplats" (norr om) foto 5 mot SV, 6 längs vägen mot norr, 7 skogen på andra sidan vägen, 8-9 fält foto 10 fältskiktet på andra sidan vägen – örtrik blåbärsgranskog

FORSMARK (27 juni 2001)

Lokal F1

Foto 1 – kl 12.57

Foto 2 – kl 12:58

Foto 3 - kl 13.03

FORSMARK (27 juni 2001)

Lokal F2

Foto 4 – kl 13:23

Tierp

Figure A1:7 shows an overview of the area for general orientation. Figures A1:8-19 show areas visited in the field 28 June and 24-25 September 2001. The numbers refer to numbers in the field protocols.

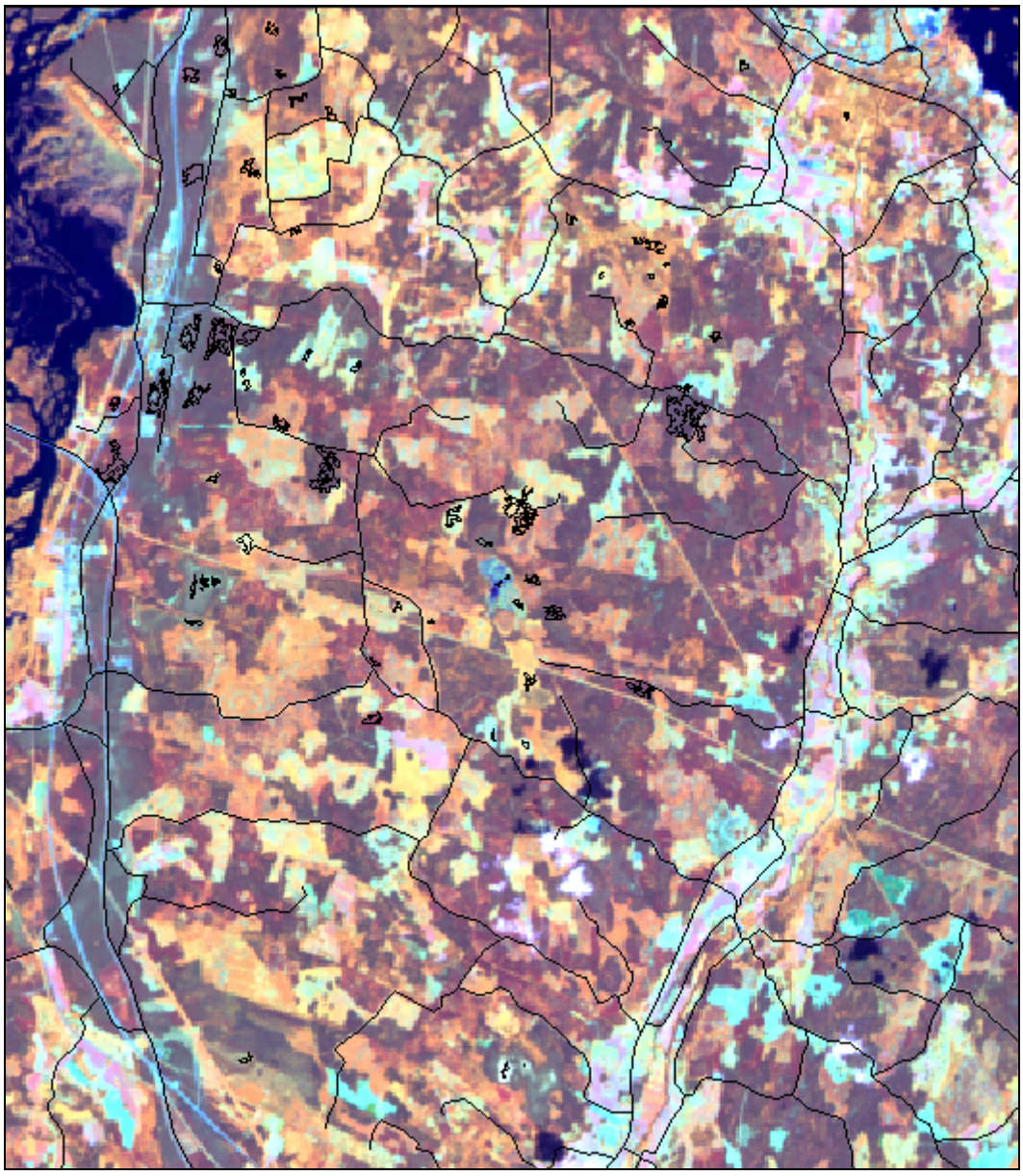


Figure A1:7. *Overview of the Tiep area to facilitate orientation of visited areas shown in Figures A1:8-19. Black lines are roads from the 1:250 000 scale map. Areas with black outline are training areas for signature analysis.*

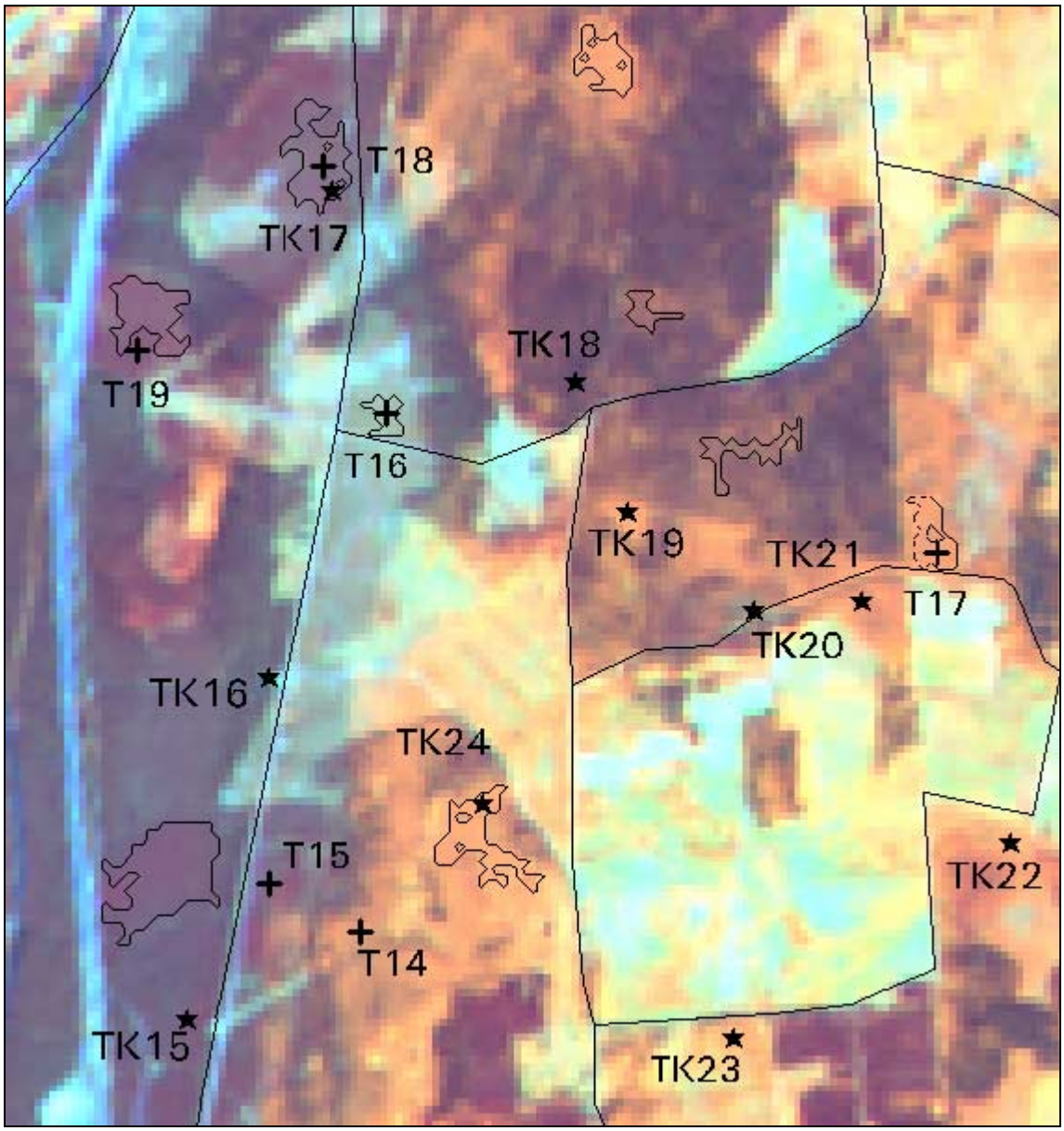


Figure A1:8. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

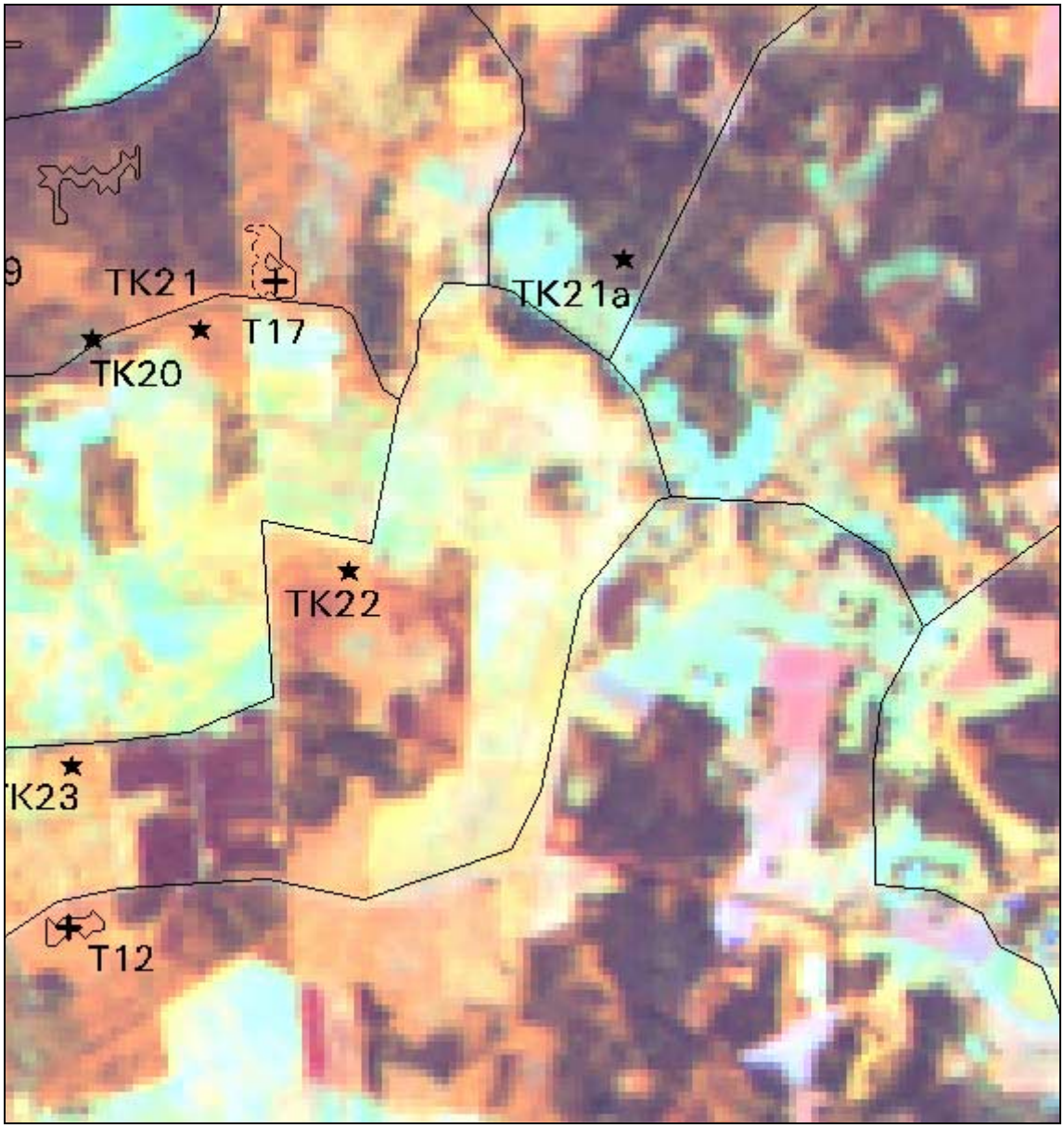


Figure A1:9. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

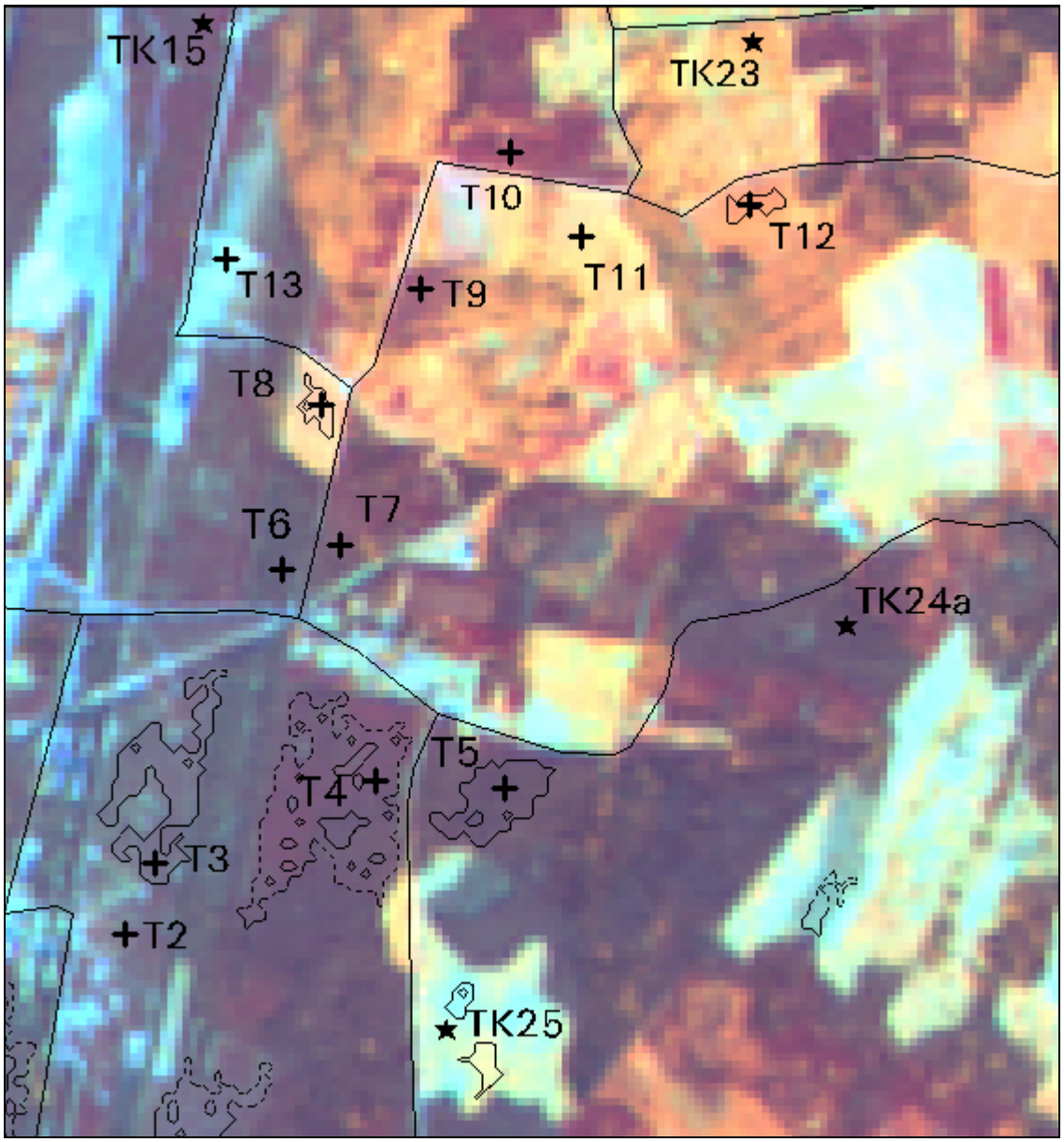


Figure A1:10. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

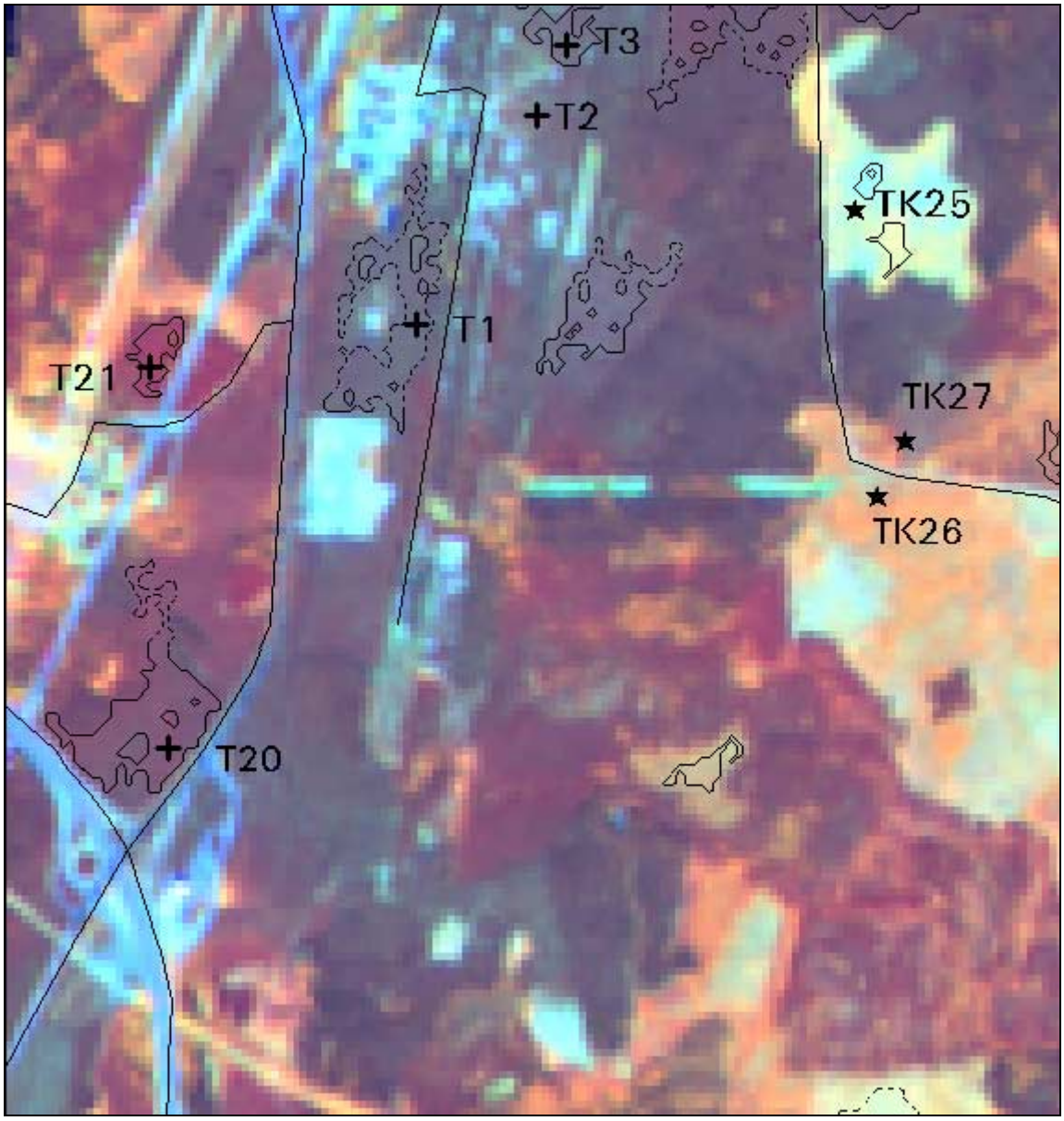


Figure A1:11. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

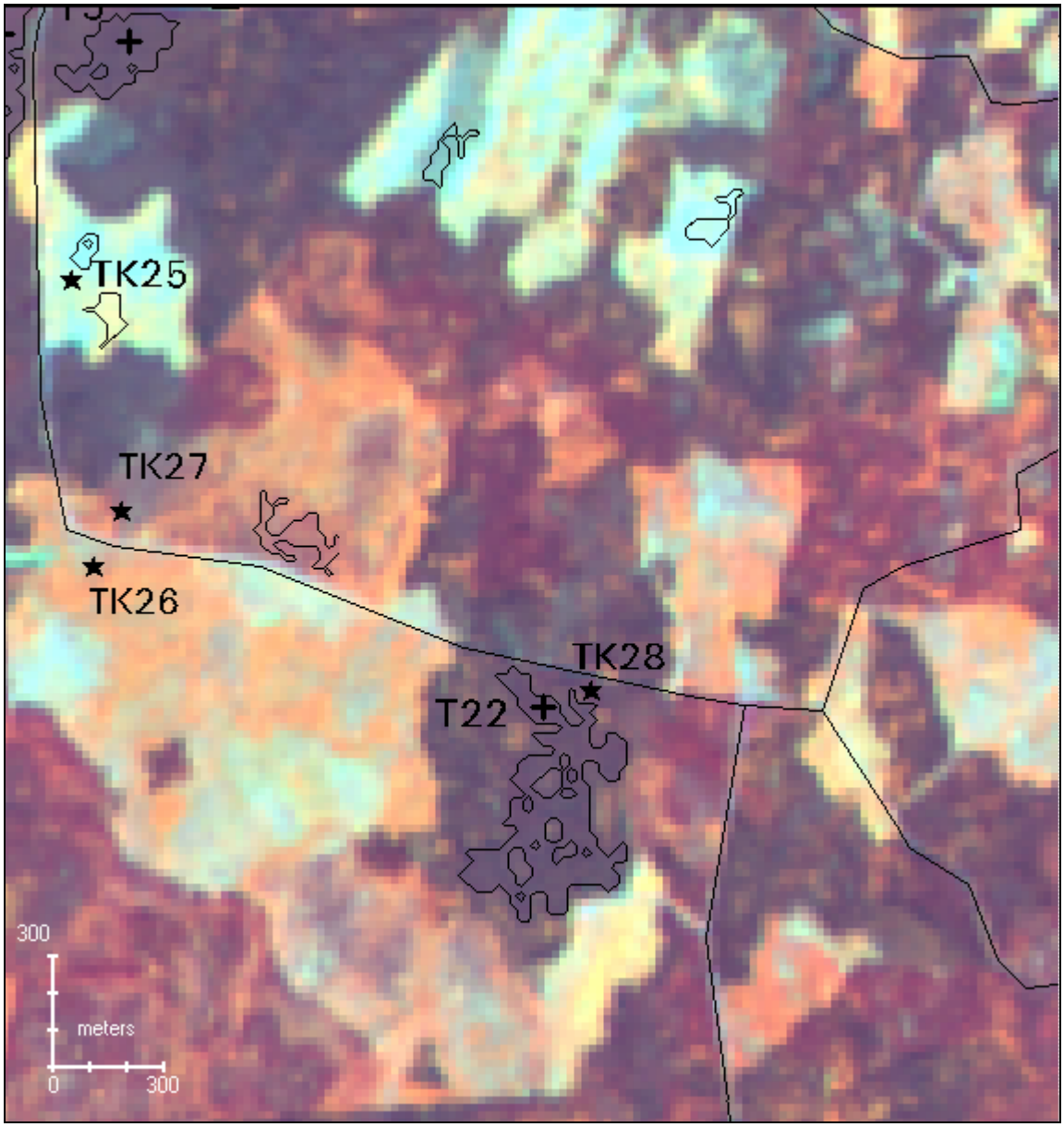


Figure A1:12. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

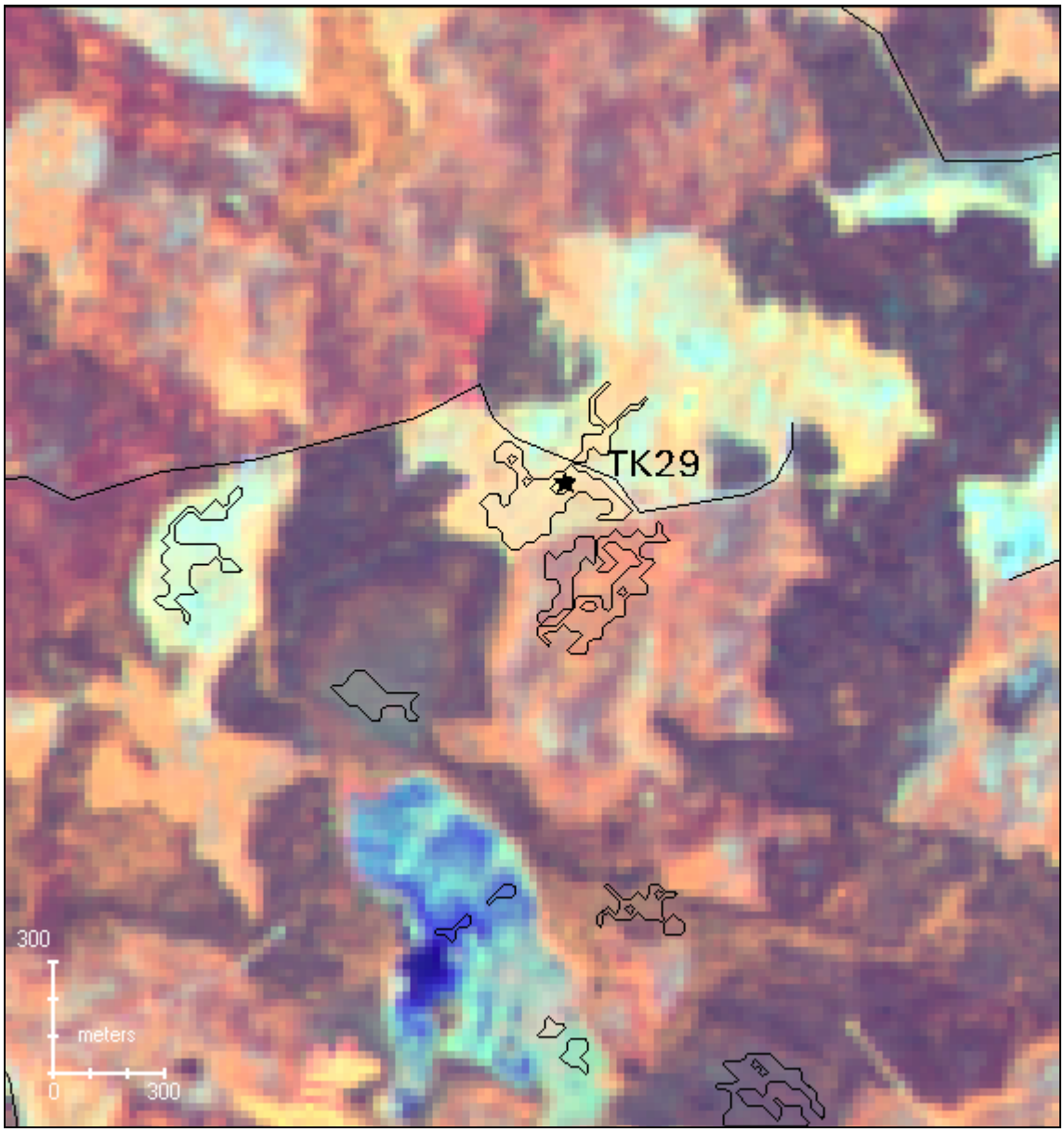


Figure A1:13. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

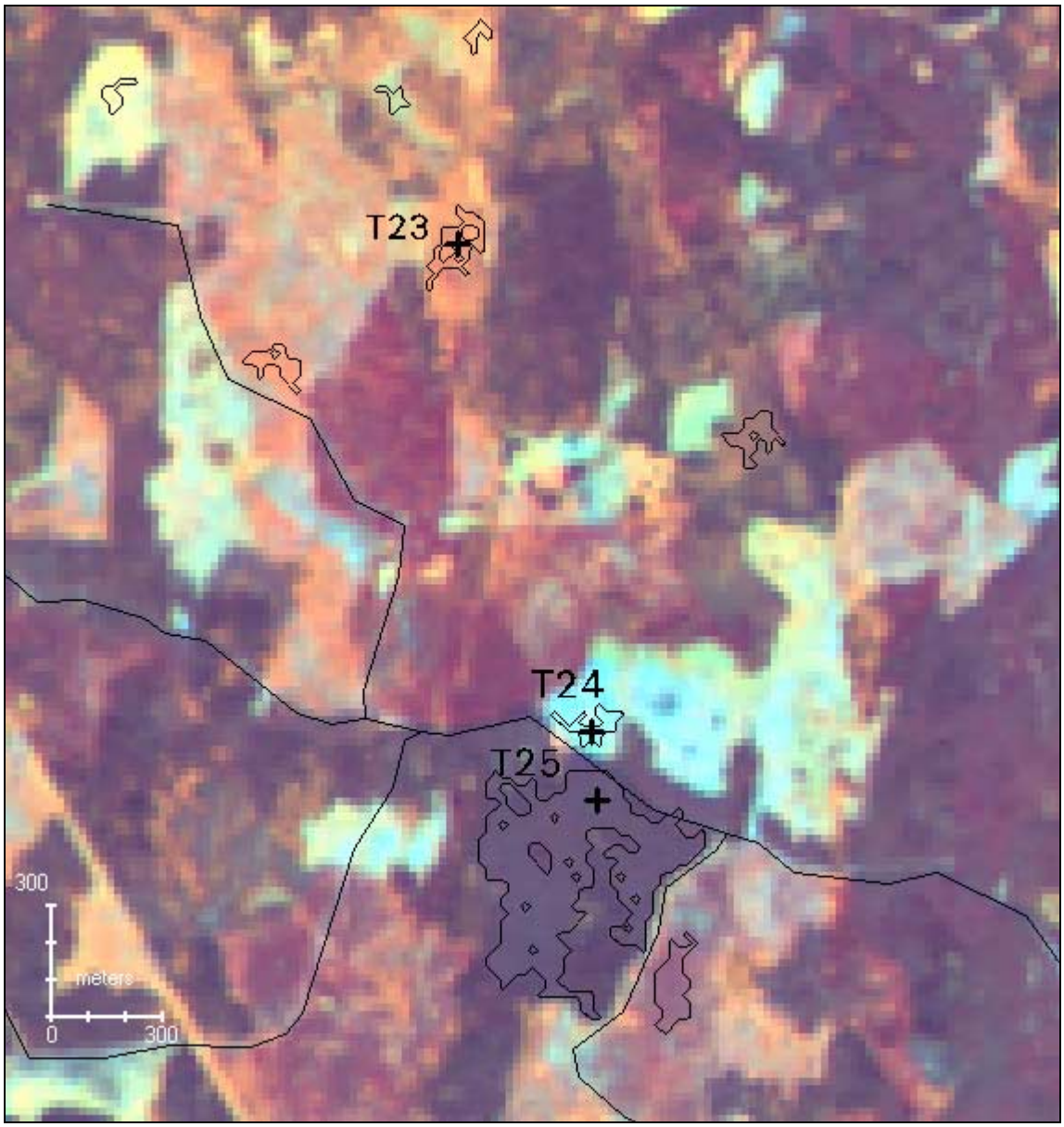


Figure A1:14. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

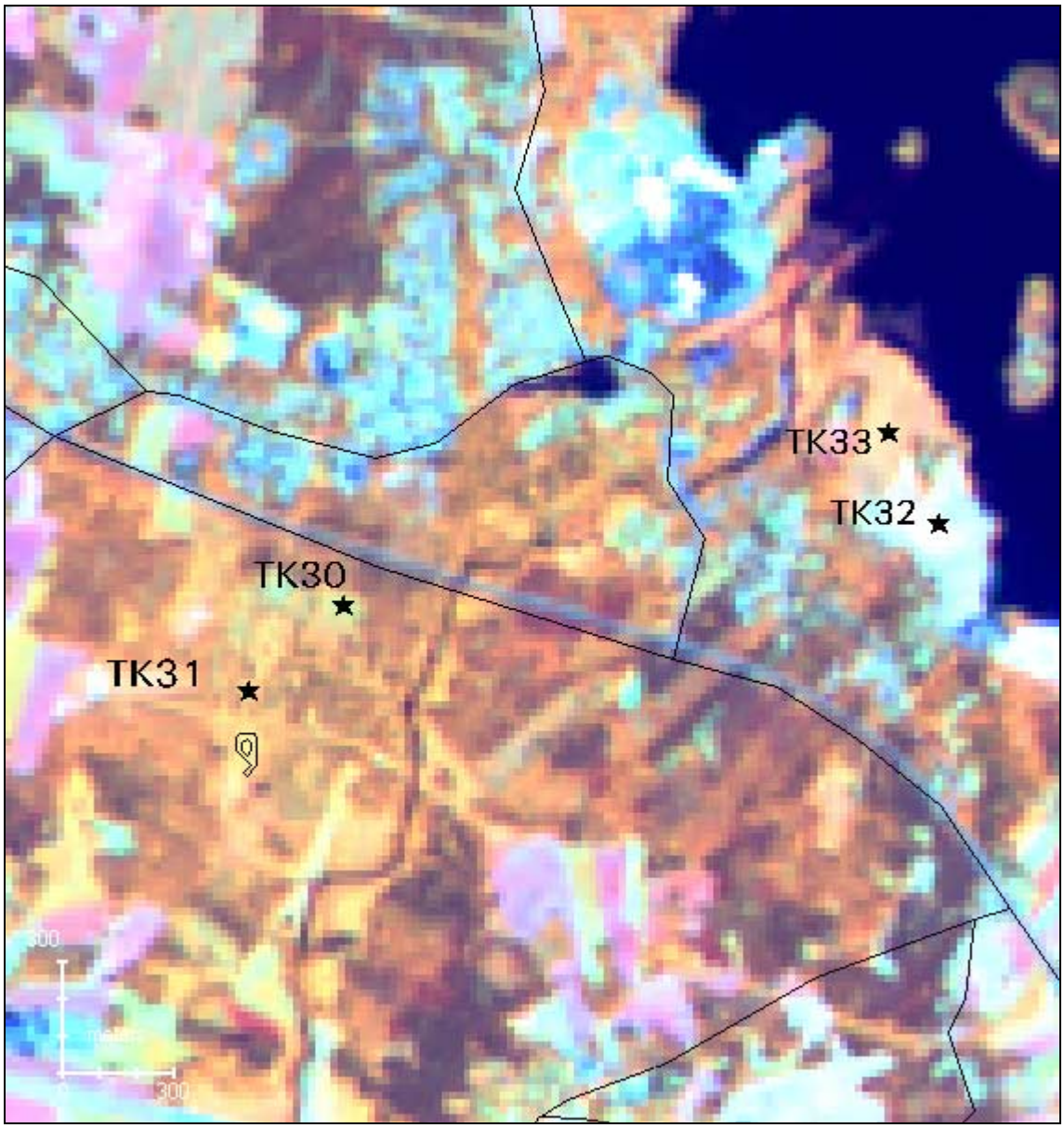


Figure A1:15. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

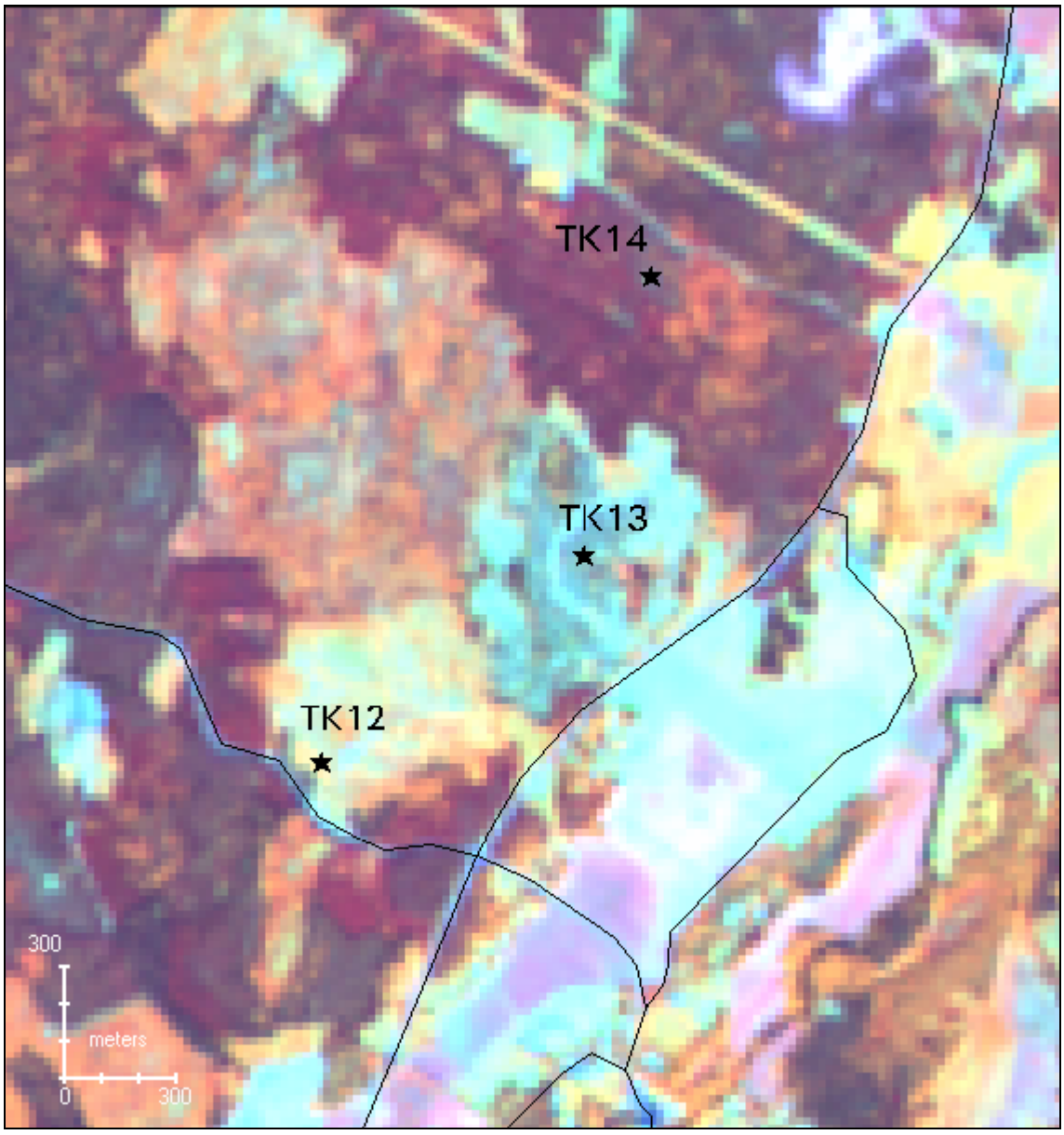


Figure A1:16. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

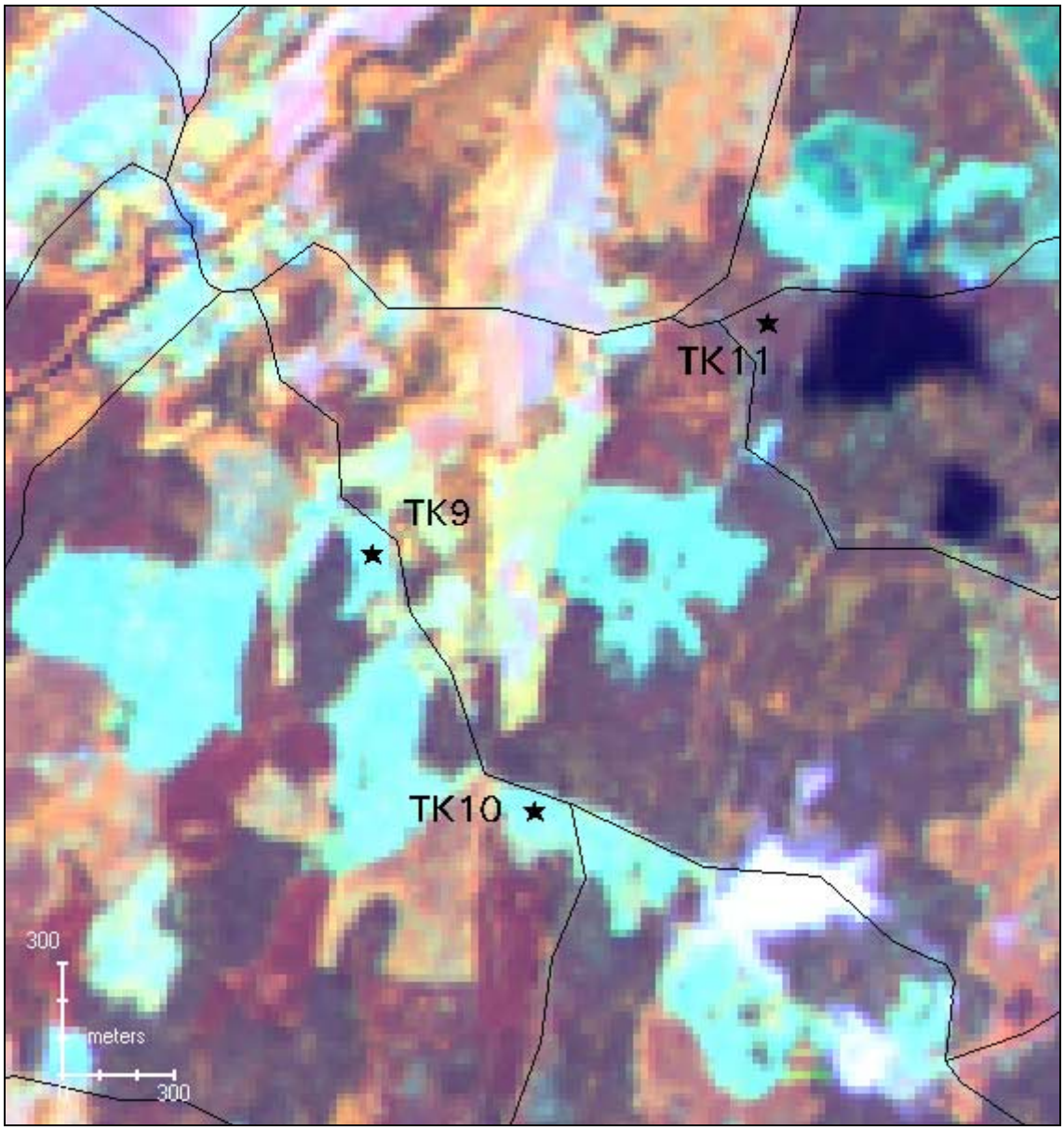


Figure A1:17. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

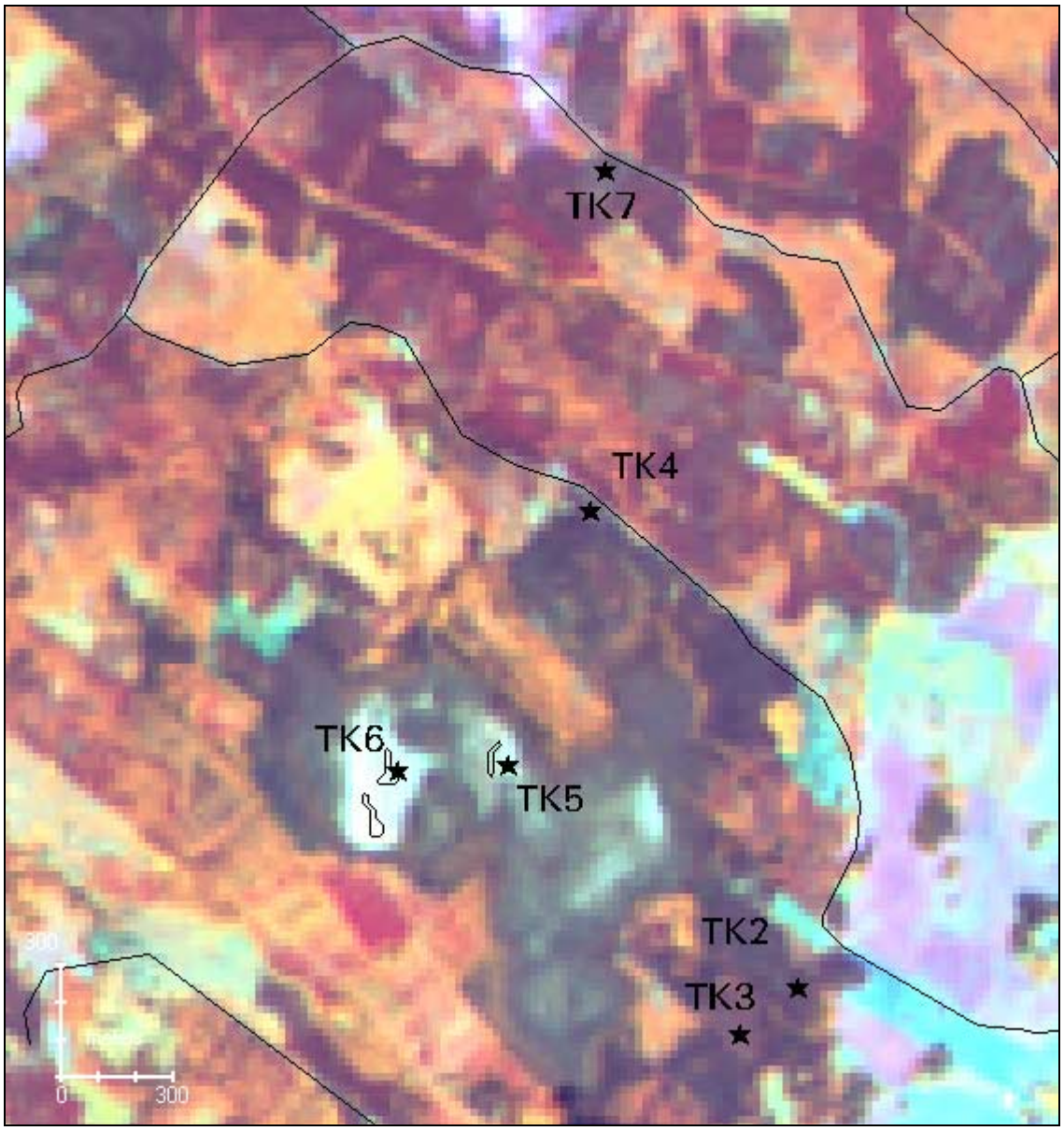


Figure A1:18. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (⋆) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

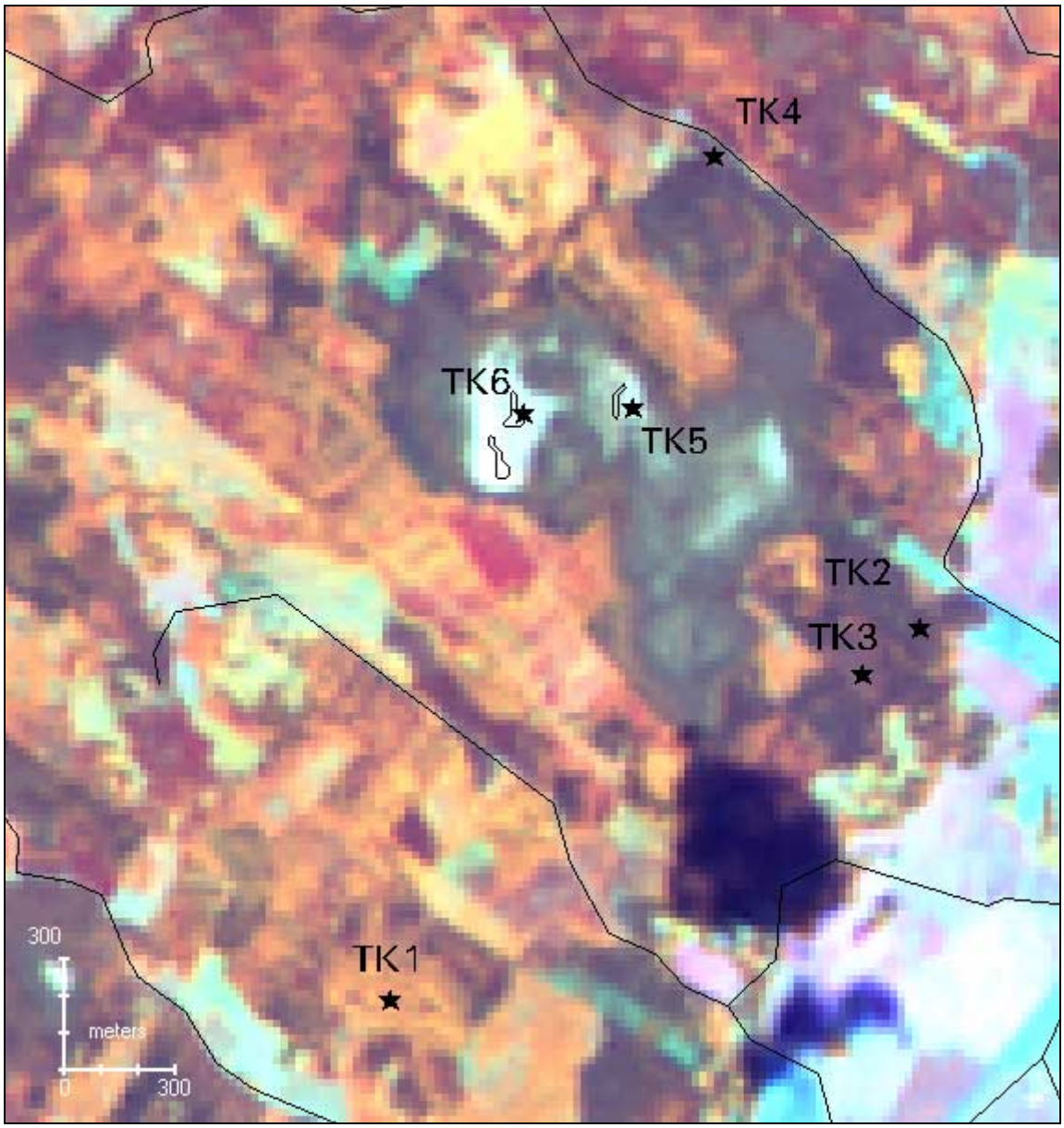


Figure A1:19. *Areas marked with a cross (+) and denoted T1, T2 etc were visited 28 June 2001 and are described in detail with reference to field photos. Areas marked with a star (*) and denoted TK1, TK2 etc were visited 24-25 September for a more brief control of the preliminary classification result. Areas with black outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:250 000 scale map (the mismatch with the satellite data is due to the generalisation level of the map).*

Oskarshamn

Figure A1:20 shows an overview of the area for general orientation. Figures A1:21-29. show areas visited in the field 8-9 August 2001. The numbers refer to numbers in the field protocols.

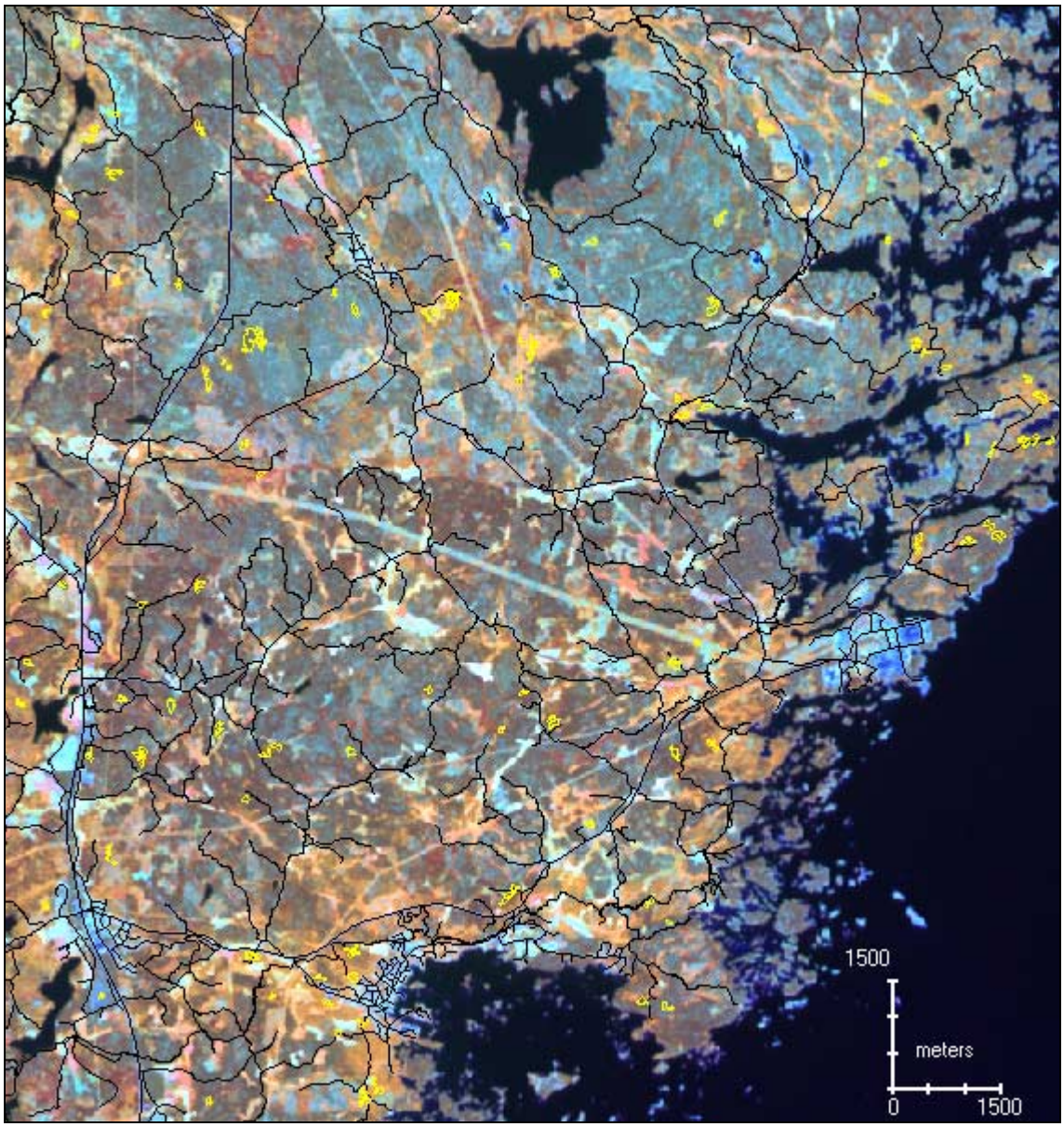


Figure A1:20. *Overview of the Oskarshamn area to facilitate orientation of visited areas shown in Figures A1:21-29. Black lines are roads from the 1:250 000 scale map. Areas with yellow outline are training areas for signature analysis.*

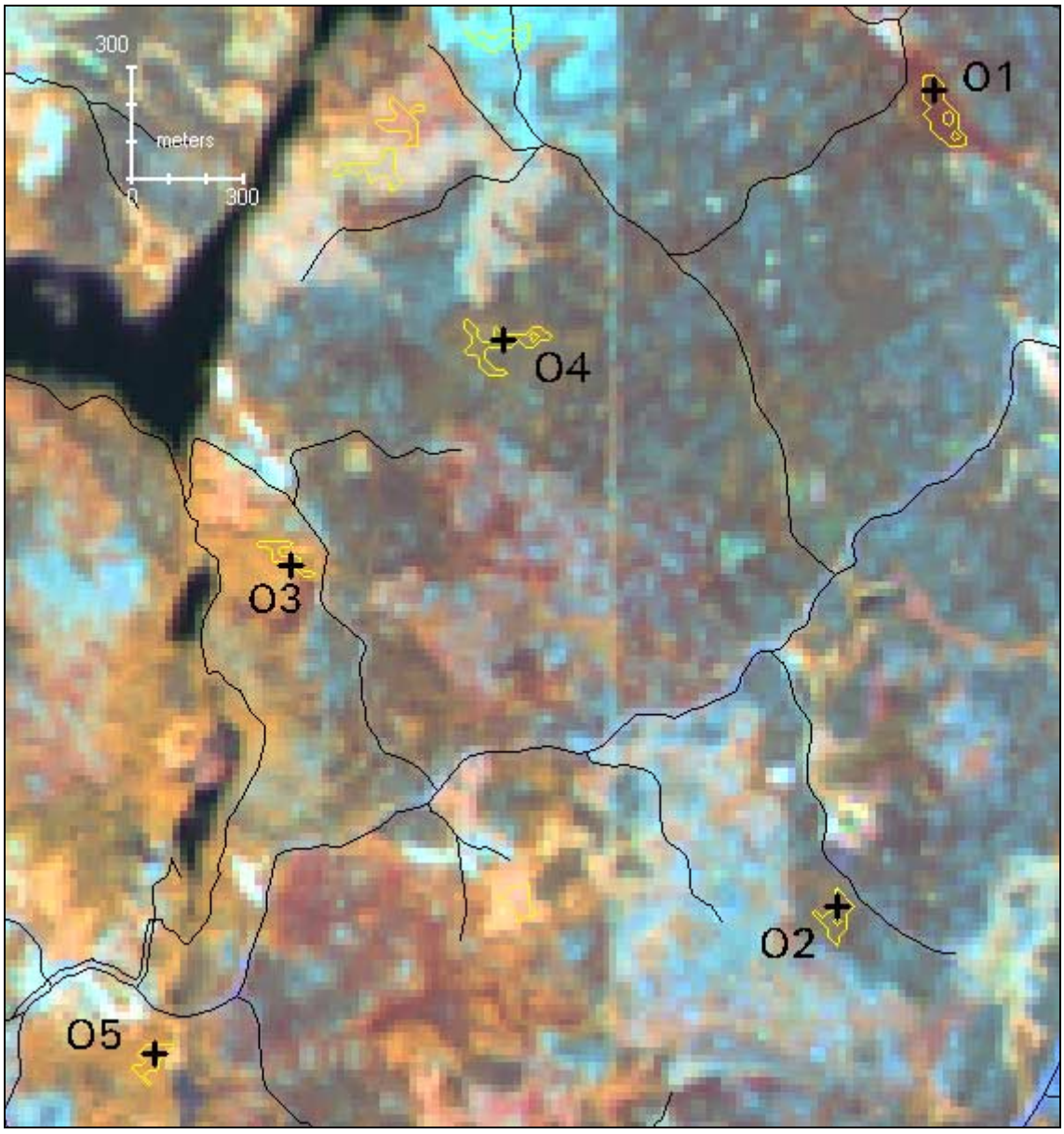


Figure A1:21. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

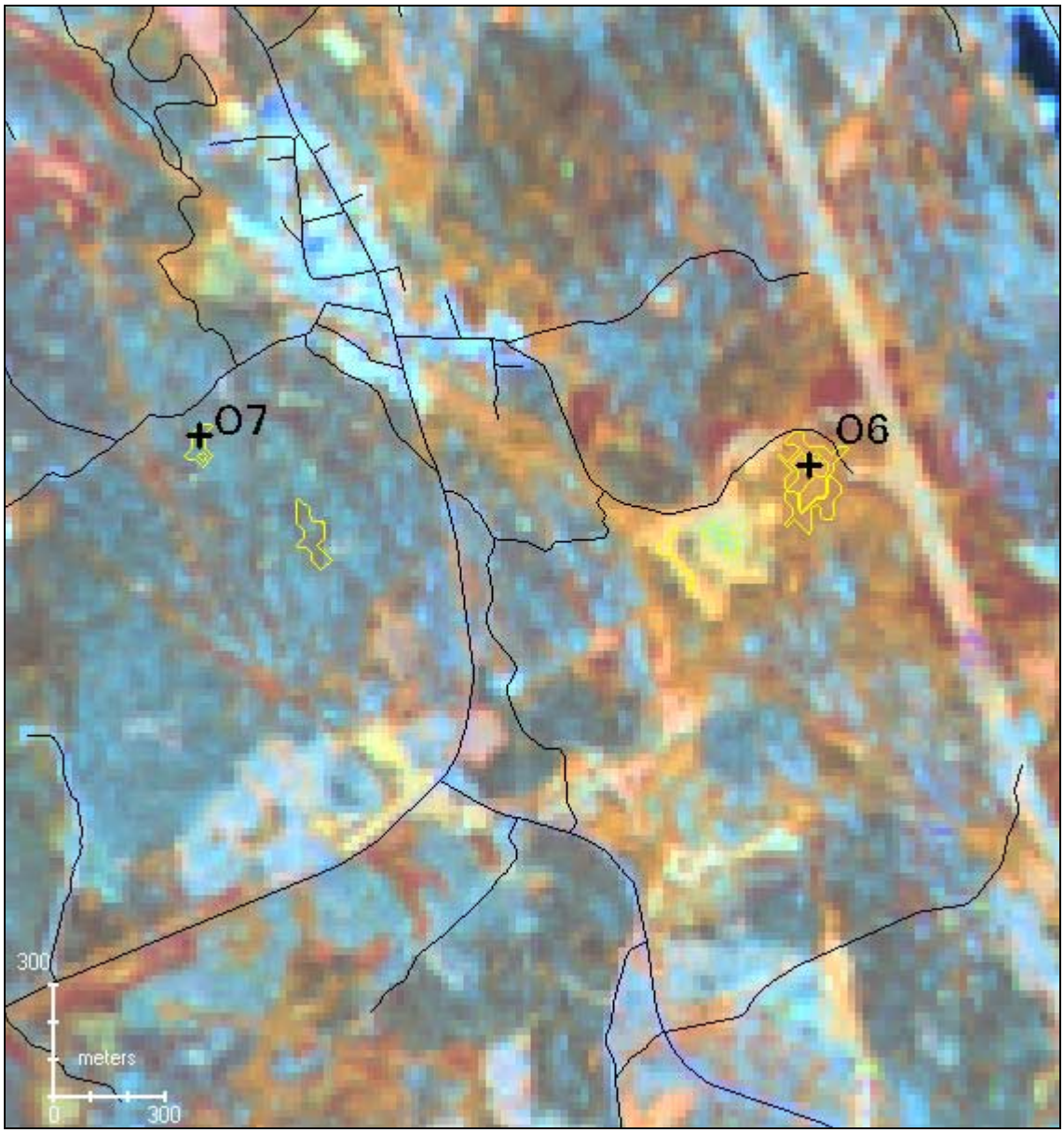


Figure A1:22. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

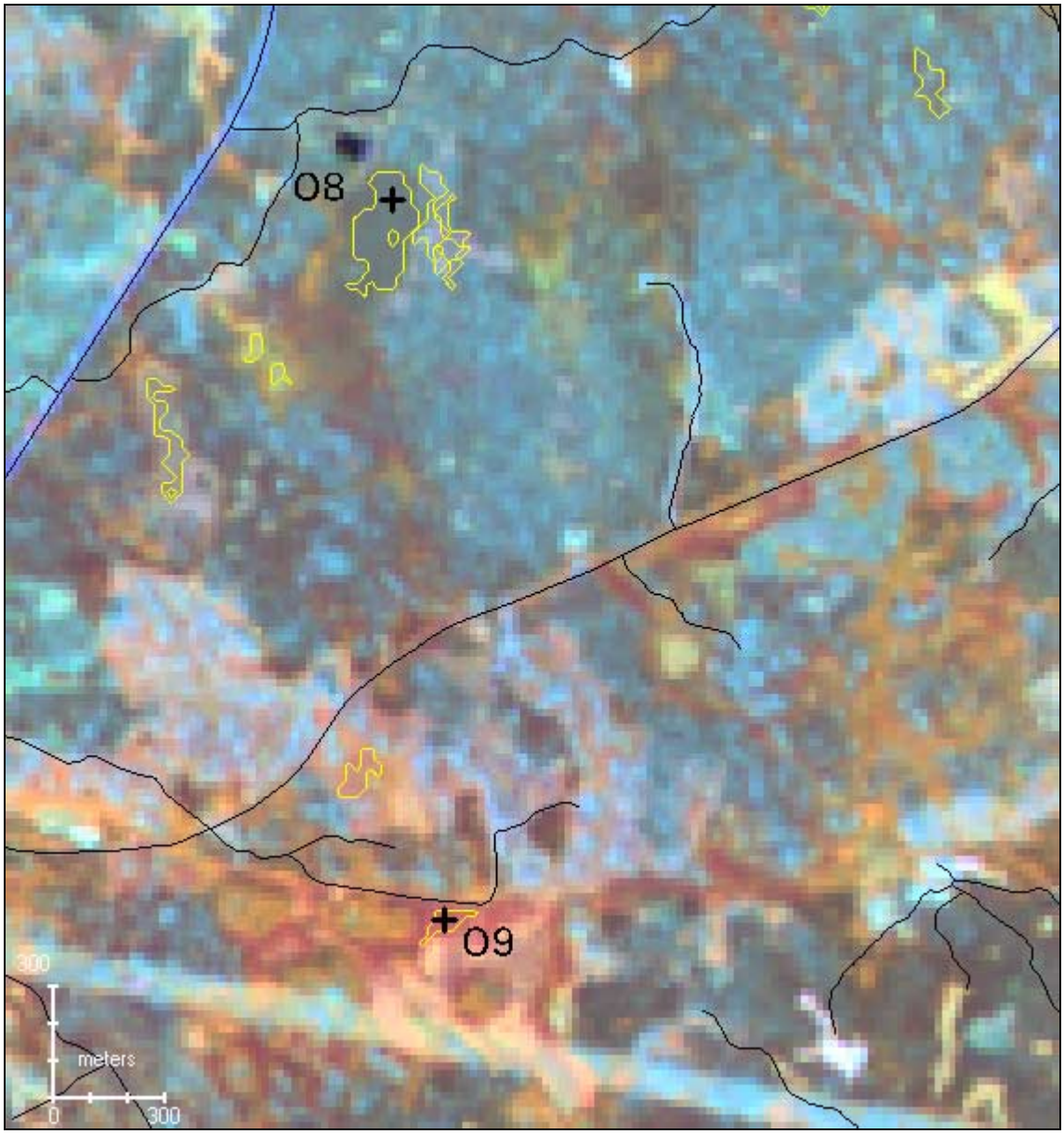


Figure A1:23. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

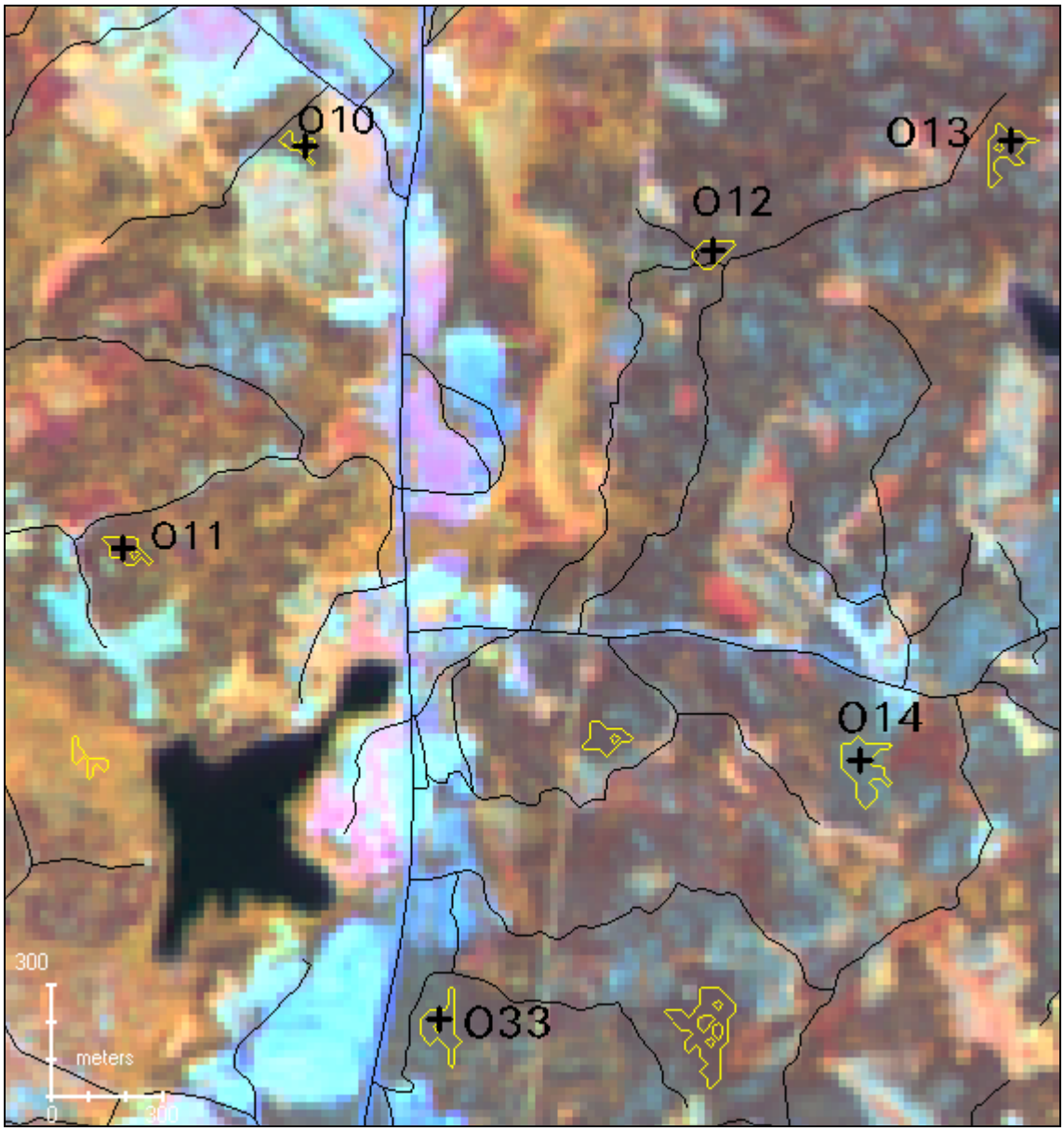


Figure A1:24. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

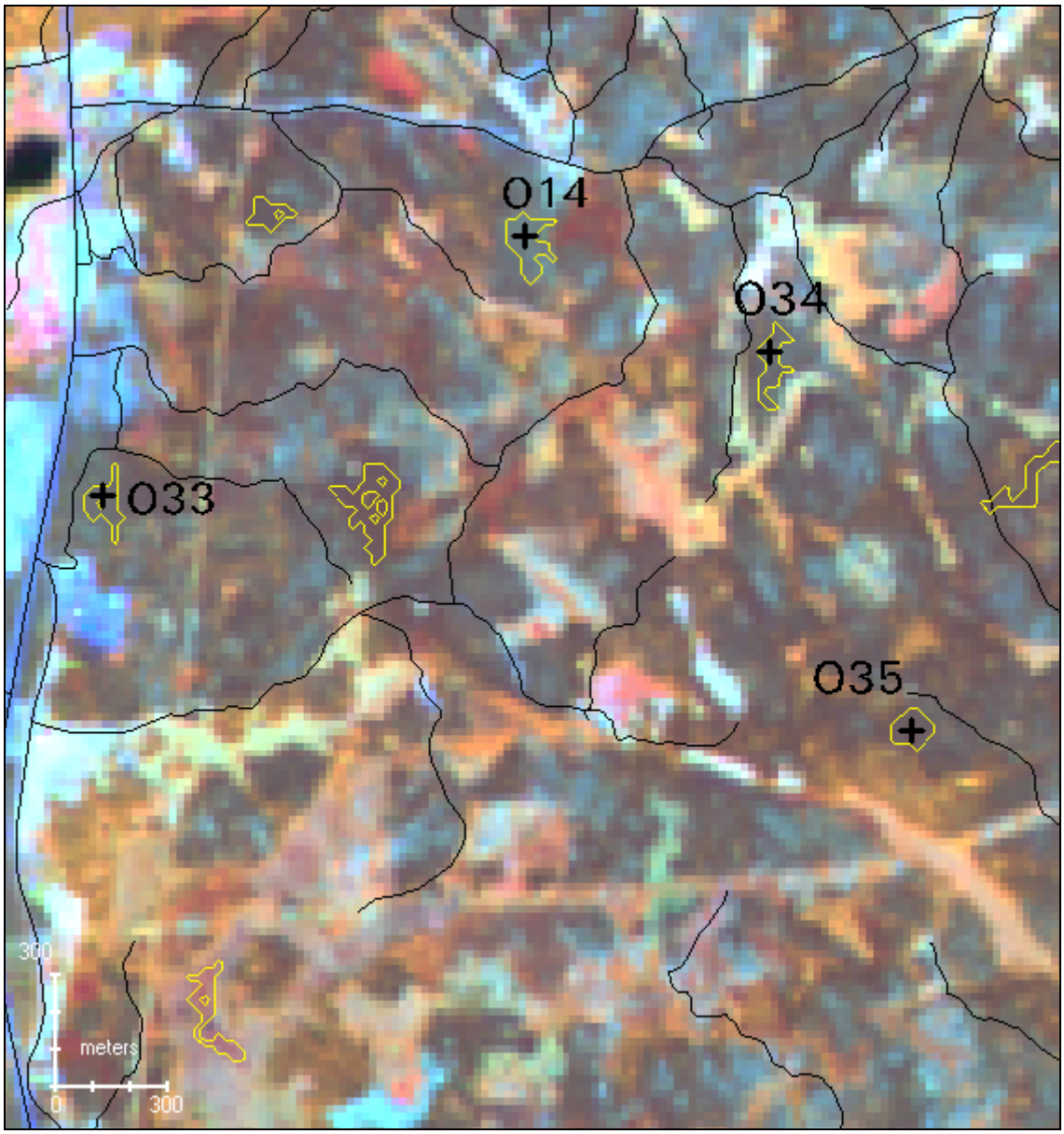


Figure A1:25. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

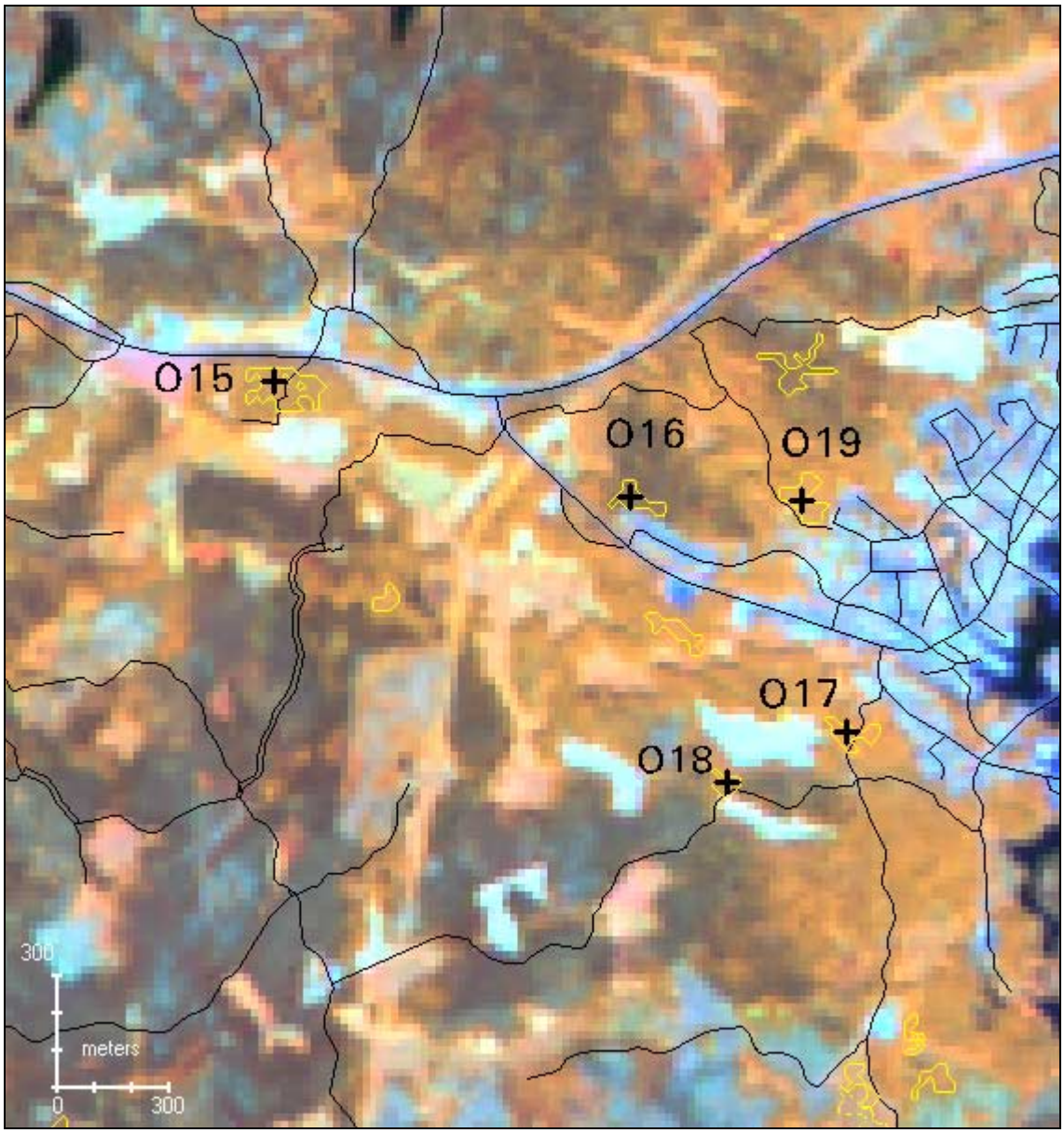


Figure A1:26. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

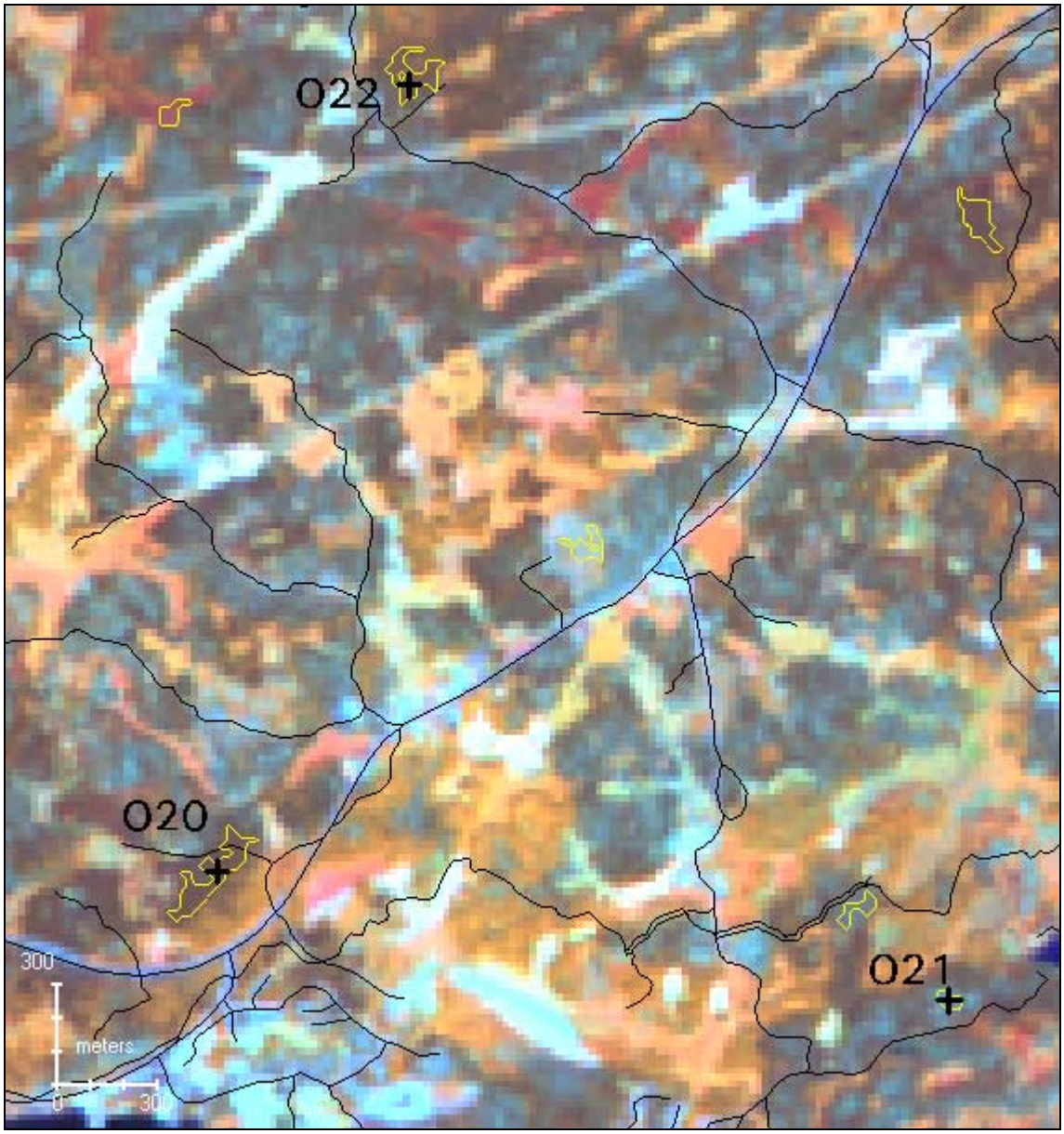


Figure A1:27. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

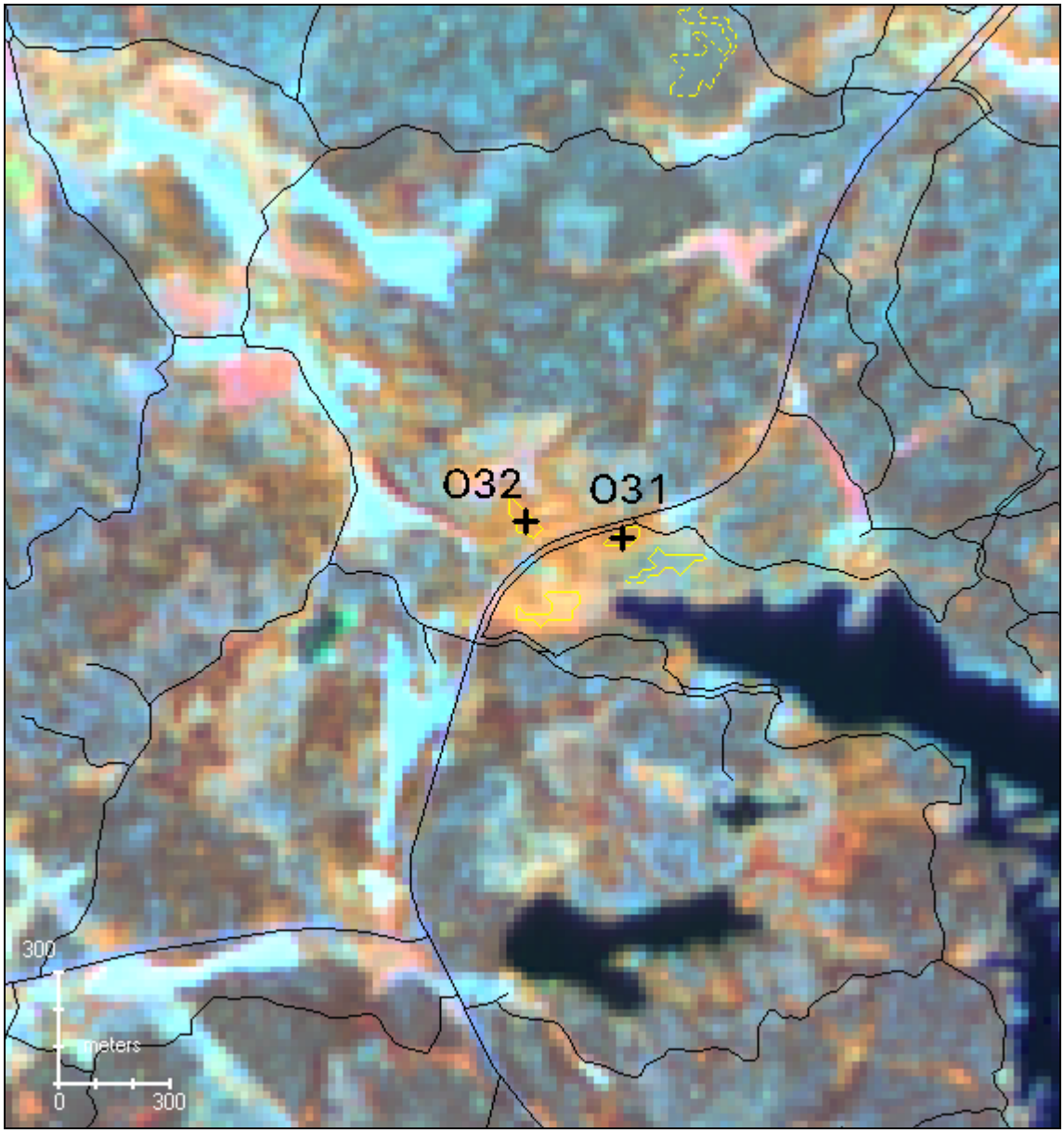


Figure A1:28. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

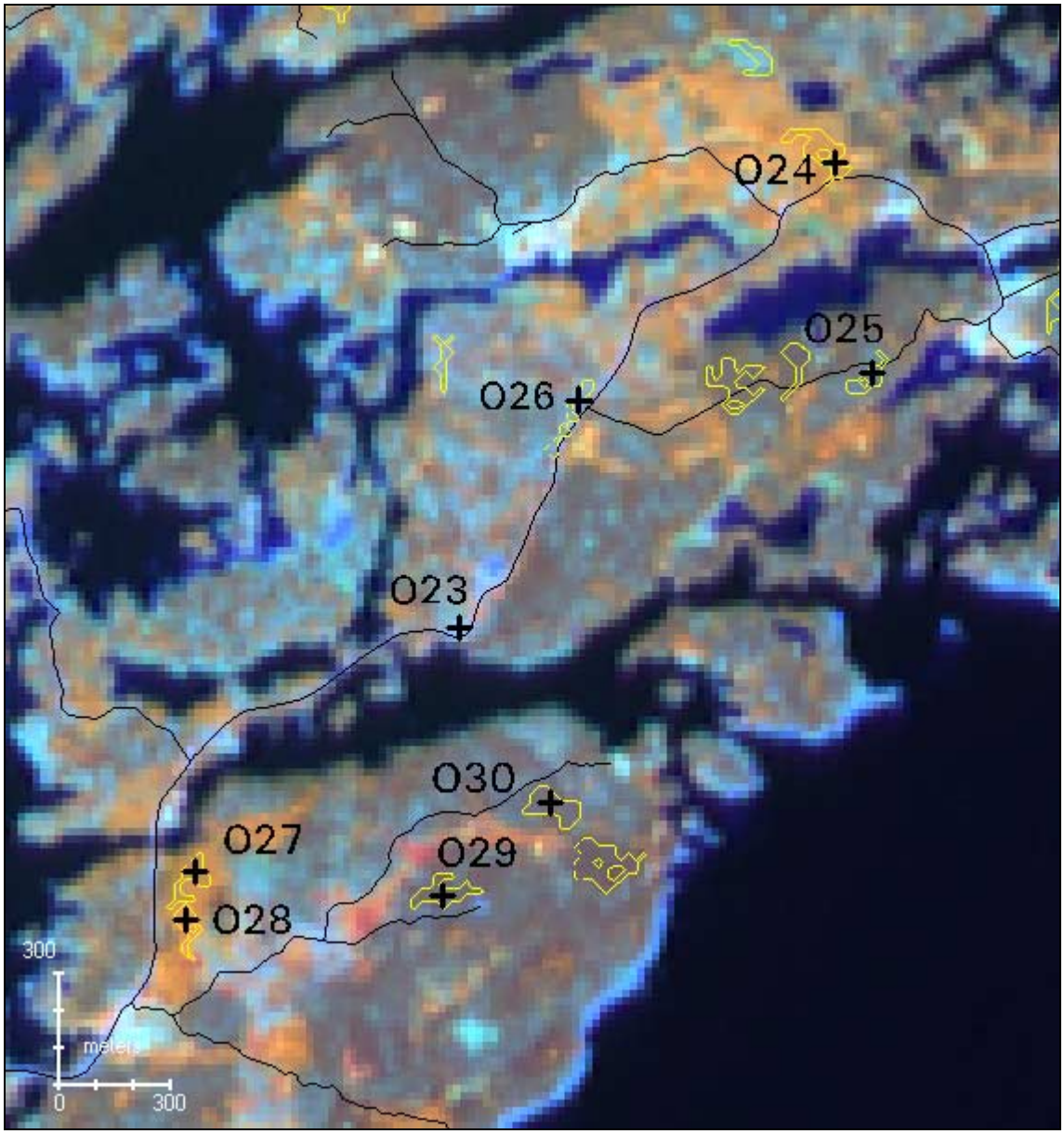


Figure A1:29. *Areas marked with a cross (+) and denoted O1, O2 etc were visited 8-9 August 2001 and are described in detail with reference to field photos. Areas with yellow outline are training areas used for analysis of spectral signatures. Solid black lines are roads from the 1:50 000 scale map.*

Appendix 2

Class codes for vegetation/land cover classification in Forsmark

Code 1 = outside area

Class code	Forest (not clear-cut or regeneration forest 1989)
11	Old spruce forest, mesic-wet types
12	Young spruce forest, mesic-wet types
13	Old pine forest, mesic-wet types
14	Young pine forest, mesic-wet types
15	Dry pine forest on acid rocks
21	Birch-dominated forest
23	Aspen-dominated forest
26	Ash-dominated forest
30	Mixed forest (conifers/deciduous)
31	Mixed forest/shrub on bedrock islands

Class code	Clear-cut, regeneration forest
41	Young spruce
42	Young pine
43	Unspecified young conifer
44	Birch thicket
45	Birch ticket/meadow type
46	Poor regrowth, meagre ground, boulders
50	New clear-cut

Class code	Wetlands
61	Forested wetland, spruce-dominated
62	Forested wetland, pine-dominated
63	Forested wetland, deciduous-dominated
64	Forested wetland, clear-cut
72	Open wetland, lush carpet mire/mud-bottom mire
74	Open wetland, lush lawn mire
75	Open wetland, lush lawn mire, with willow
76	Open wetland, lush lawn mire, with willow, birch
77	Open wetland, reed-dominated, less wet
78	Open wetland, reed-dominated/more lush
79	Open wetland, reed-dominated, wet

Class code	Other
81	Arable land
82	Other open land (pastures and meadows)
83	Coastal bare rocks
91	Holiday house
92	Industry
93	Lowrise house
96	Other hard surfaces
100	Water

Appendix 3

Class codes for vegetation/land cover classification in Tierp

Code 1 = outside area

Class code	Forest (not clear-cut or regeneration forest 1989)
11	Old spruce forest, mesic-wet types
12	Young spruce forest, mesic-wet types
13	Old pine forest, mesic-wet types
14	Young pine forest, mesic-wet types
15	Dry pine forest on acid rocks
17	Old pine forest, dry heath type
18	Young pine forest, dry heath type
21	Birch-dominated forest
30	Mixed forest (conifers/deciduous)
31	Unspecified forest on small forest patches (”åkerholmar”) in arable land

Class code	Clear-cut, regeneration forest
42	Young pine
43	Unspecified young conifer
44	Birch thicket
45	Birch ticket/meadow type
46	Poor regrowth, meagre ground, boulders
50	New clear-cut

Class code	Wetlands
61	Forested wetland, spruce-dominated
62	Forested wetland, pine-dominated
63	Forested wetland, deciduous-dominated
64	Forested wetland, clear-cut
65	Forested wetland, mixed conifer-deciduous
71	Open wetland, hummock mire
72	Open wetland, poor lawn mire
74	Open wetland, lush lawn mire
75	Open wetland, lush lawn mire, with willow
76	Open wetland, poor carpet mire/mud-bottom mire
77	Open wetland, lush carpet mire/mud-bottom mire
78	Open wetland, reed-dominated, less wet
79	Open wetland, reed-dominated, wet

Class code	Other
81	Arable land
82	Other open land (pastures and meadows)
86	Sand pit
91	Holiday house
92	Industry
93	Lowrise house
96	Other hard surfaces
100	Water

Appendix 4

Decision rules for production of vegetation layers in Forsmark

Tree layer

Code 0 = Outside mapping area

Code in tree layer	Produced tree-layer class (dominating species)	Code in vegetation/land cover classification
1	No tree-layer (< 30 % crown coverage) within forest land*	45, 46, 50, 64
2	No tree-layer (< 30 % crown coverage) outside forest land	72, 74, 75, 77, 78, 79, 81, 82, 83, 91, 92, 93, 96
11	Old spruce	11, 61
12	Young spruce	12, 41
13	Old pine	13, 15, 62
14	Young pine	14, 42
17	Unspecified young conifer	43
21	Birch	21, 63, 76
22	Young birch (thicket on clear-cut)	44
23	Aspen (one area, manually edited)	23
26	Ash	26
30	Mixed forest	30, 31
100	Water	100

* defined by the forest mask from the topographic map

Shrub layer

Code 0 = Outside mapping area

Code in shrub layer	Produced shrub-layer class (dominating species)	Code in vegetation/land cover classification
1	No shrub layer (> 30% crown coverage) is present	72, 74, 77, 78, 79, 81, 83, 91, 92, 93, 96
2	No information	11, 12, 13, 14, 15, 21, 23, 26, 30, 31, 41, 42, 43, 44, 45, 46, 50, 61, 62, 63, 64, 76, 82
12	Willow	75
100	Water	100

Field layer

General assumption: the whole area is influenced by the Cambrian-Ordovician bedrock of the Baltic Sea.

Code 0 = Outside mapping area

Code in field layer	Produced field-layer class	Code in vegetation/land cover classification and decision rule/logic operation
1	No field layer – forest land	Code = 12 *and* (SPOT b4 < 65 *or* SPOT b4 > 200)
2	No field layer – other land	83, 91, 92, 93, 96
4	Arable land (according to T5)	81
12	Dry heath type	Code = 15 *and* bedrock outcrop according to digital soil data
12	Dry heath type	Code = 46 *and* bedrock outcrop *and* not clearcut in T5
15	Herb-heath type	11, 13, 14, 30, 41, 42, 43, 44, 45, 50
15	Herb-heath type	Code = 12 *and* (SPOT b4 $\geq$ 65 *and* SPOT b4 $\leq$ 200)
15	Herb-heath type	Code = 15 *and* not on bedrock outcrop according to digital soil data
15	Herb-heath type	Code = 46 *and* on bedrock outcrop *and* clearcut in T5 *or* (code = 46 *and* not on bedrock outcrop)
16	Herb type	21, 23, 26, 31
16	Herb type	82
20	Sedge-heath type	61, 62 or 64
22	Sedge-herb type	Code = 63 *and* on organic soil according to diigtal soil data
22	Sedge-herb type	72, 74, 75, 76
23	Sedge-reed type	77, 78, 79
25	Wet herb type	Code = 63 *and* not on organic soil soil according to diigtal soil data
100	Water	100

Bedrock outcrop = bedrock outcrop according to digital soil data (SGU soil map)
Organic soil = organic soil according to digital soil data (SGU soil map)
T5 = topographic map
SPOT b4 = SPOT digital value in band 4 (mid-infrared). The value is set based on signature analysis.
NB! The value is applicable only for this scene and recording date.

Ground layer

Code 0 = Outside mapping area

Code in ground layer	Produced ground-layer class	Decision rule/logic operation, code in vegetation/land cover classification
Within forest land*		
12	Moss type	No field layer, dry heath type, herb-heath type, herb type or wet herb type**
Within wetland*		
21	Peatland – Sphagnum type	Forested and open wetland classes (61, 62 , 64, 72, 74, 75, 76, 77, 78, 79) on organic soil according to digital soil data
22	Peatland other	Deciduous-covered wetland (63) on organic soil according to digital soil data
24	Not peatland - moss type	Forested wetland (61, 62, 63, 64) not on organic soil according to digital soil data
25	Not peatland - other	Open wetland classes not on organic soil according to digital soil data
Within agricultural land*		
31	Arable land	81
32	Moss type (pastures and meadow)	82
Other		
41	Built-up areas, pits etc.	91, 92, 93, 96
42	Coastal bare rocks	83
100	Water	100

* According to the topographic map

** Produced field-layer classes

Organic soil = organic soil according to digital soil data (SGU soil map)

Appendix 5

Decision rules for production of vegetation layers in Tierp

Tree layer

Code 0 = Outside mapping area

Code in tree layer	Produced tree-layer class (dominating species)	Code in vegetation/land cover classification
1	No tree-layer (< 30 % crown coverage) within forest land*	45, 46, 50, 64
2	No tree-layer (< 30 % crown coverage) outside forest land	71, 72, 74, 75, 76, 77, 78, 79, 81, 82, 86, 91, 92, 93, 96
11	Old spruce	11, 61
12	Young spruce	12
13	Old pine	13, 15, 17, 62
14	Young pine	14, 18, 42
15	Larch (one area, manually edited)	-
17	Unspecified young conifer	43
21	Birch	21, 63, 76
22	Young birch (thicket on clear-cut)	44
30	Mixed forest	30, 31
100	Water	100

* defined by the forest mask from the topographic map

Shrub layer

Code 0 = Outside mapping area

Code in shrub layer	Produced shrub-layer class (dominating species)	Code in vegetation/land cover classification
1	No shrub layer (> 30% crown coverage) is present	46, 71, 72, 74, 76, 77, 78, 79, 81, 86, 91, 92, 93, 96
2	No information	11, 12, 13, 14, 15, 17, 18, 21, 30, 31, 42, 43, 44, 45, 61, 62, 63, 64, 65, 82
12	Willow	75
100	Water	100

Field layer

Code 0 = Outside mapping area

Code in field layer	Produced field-layer class	Code in vegetation/land cover classification and decision rule/logic operation
1	No field layer – forest land	Code = 12 *and* SPOT b4 < 65
2	No field layer – other land	86, 91, 92, 93, 96
4	Arable land (according to T5)	81
12	Dry heath type	15
12	Dry heath type	Code = 17 *or* 18 *and* (bedrock outcrop *or* glacifluvial deposits according to digital soil data)
12	Dry heath type	Code = 42 *and* (bedrock outcrop *or* glacifluvial deposit according to digital soil data)
12	Dry heath type	Code = 46 *and* bedrock outcrop *and* not clear-cut in T5
13	Mesic bilberry heath type	Code = 11 *or* 30 *or* 31 *and* outside herb-heath area 1
13	Mesic bilberry heath type	13, 14
13	Mesic bilberry heath type	Code = 17 *or* 18 *and* (not on bedrock outcrop *or* glacifluvial deposits according to digital soil data)
13	Mesic bilberry heath type	Code = 12 *and* SPOT b4 $\underline{\geq}$ 65 *and* outside herb-heat area 1
13	Mesic bilberry heath type	Code = 21 *and* deciduous forest area < 1 ha *and* outside herb-heath area 2
13	Mesic bilberry heath type	Code = 43 *or* 44 *or* 45 *and* outside herb-heath area 2
13	Mesic bilberry heath type	Code = 43 *or* 44 *or* 45 *and* inside herb-heath area 2 *and* SPOT b3 $\underline{\leq}$ 149
13	Mesic bilberry heath type	Code = 50 *and* inside herb-heath area 2 *and* SPOT b3 $\underline{\leq}$ 155
13	Mesic bilberry heath type	Code = 50 *and* ouitside herb-heath area 2
13	Mesic bilberry heath type	Code = 42 *and* not (bedrock outcrop *or* glacifluvial deposit according to digital soil data)
13	Mesic bilberry heath type	Code = 46 *and* bedrock outcrop *and* clear-cut in T5 *or* (code = 46 *and* not on bedrock outcrop)
15	Herb-heath type	Code = 11 *or* 30 *or* 31 *and* inside herb-heath area 1
15	Herb-heath type	Code = 12 *and* SPOT b4 $\underline{\geq}$ 65 *and* inside herb-heat area 1
15	Herb-heath type	Code = 21 *and* deciduous forest area < 1 ha *and* inside herb-heath area 2

15	Herb-heath type	Code = 43 *or* 44 *or* 45 *and* (inside herb-heath area 2 *and* SPOT b3 > 149)
15	Herb-heath type	Code = 50 *and* inside herb-heath area 2 *and* SPOT b3 > 155
16	Herb type	Code = 21 *and* deciduous forest area ≥ 1 ha
16	Herb type	82
20	Sedge-heath type	61, 62, 64 or 65
21	Sedge type	71, 72, 76
22	Sedge-herb type	Code = 63 *and* on organic soil
22	Sedge-herb type	74, 75, 77
23	Sedge-reed type	78, 79
25	Wet herb type	Code = 63 *and* not on organic soil
100	Water	100

Bedrock outcrop = bedrock outcrop according to digital soil data (SGU soil map)
Organic soil = organic soil according to digital soil data (SGU soil map)
T5 = topographic map

SPOT b4 = SPOT digital value in band 4 (mid-infrared). The value is set based on signature analysis.
NB! The value is applicable only for this scene and recording date.

SPOT b3 = SPOT digital value in band 3 (near-infrared). The value is set based on signature analysis.
NB! The value is applicable only for this scene and recording date.

Herb-heath area 1 (Figure A5:1a) = area approximately equivalent with northern part of class “other soils” in digital soil data of Tierp map sheet 13HSO (mainly clay, sand, and gravel) used for delimit herb-heath type for old spruce and mixed forest.
Herb-heath area 2 (Figure A5:1b) = extended area based on visual interpretation of lushness of clear-cuts for delimit herb-heath type from mesic bilberry type for clear-cuts and small deciduous forest patches.

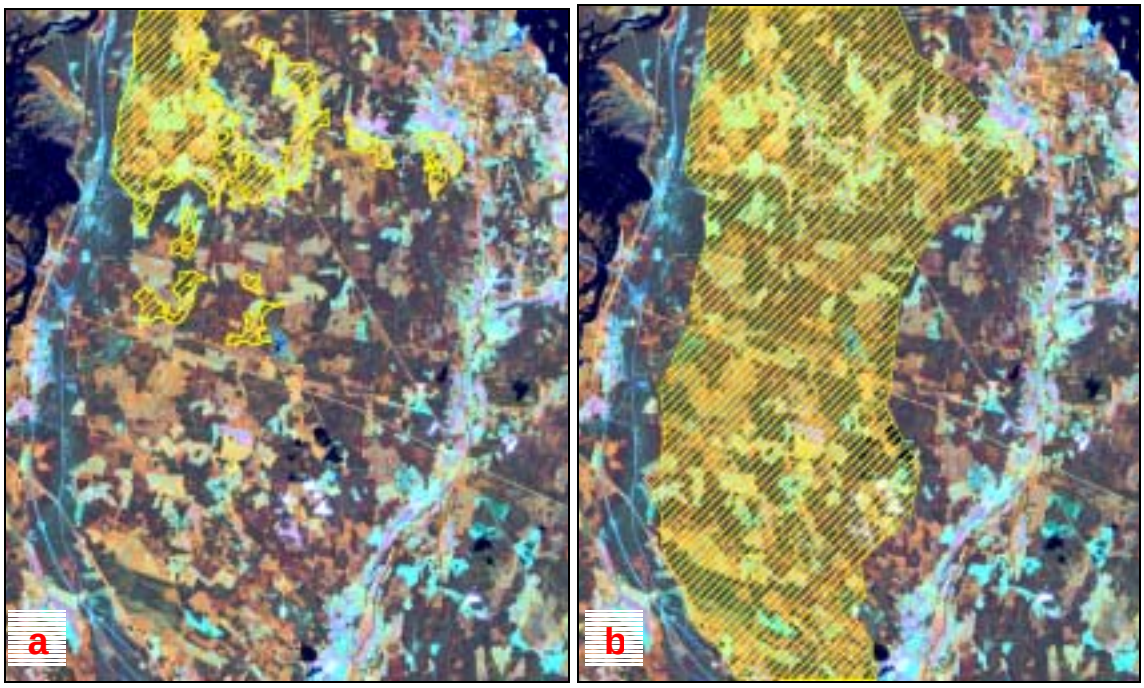


Figure A5:1. *a. Herb-heath area 1 b. Herb-heath area 2*

Ground layer

Code 0 = Outside mapping area

Code in ground layer	Produced ground-layer class	Decision rule/logic operation, code in vegetation/land cover classification
Within forest land*		
12	Moss type	No field layer, dry heath type, herb-heath type, herb type or wet herb type**
Within wetland*		
21	Peatland – Sphagnum type	Forested and open wetland classes (61, 62 , 64, 65, 71, 72, 74, 75, 76, 77) on organic soil
22	Peatland other	Deciduous-covered wetland (63) on organic soil
24	Not peatland - moss type	Forested wetland (61, 62, 63, 64, 65) not on organic soil
25	Not peatland - other	Open wetland classes not on organic soil (71, 72, 74, 75, 76, 77)
Within agricultural land*		
31	Arable land	81
32	Moss type (pastures and meadow)	82
Other		
41	Built-up areas, pits etc.	86, 91, 92, 93, 96
100	Water	100

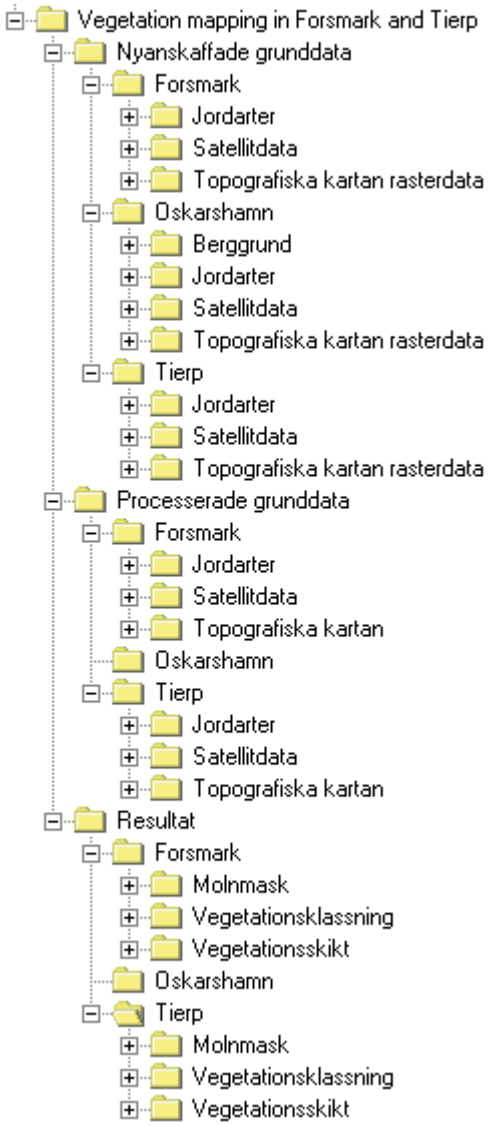
* According to the topographic map

** Produced field-layer classes

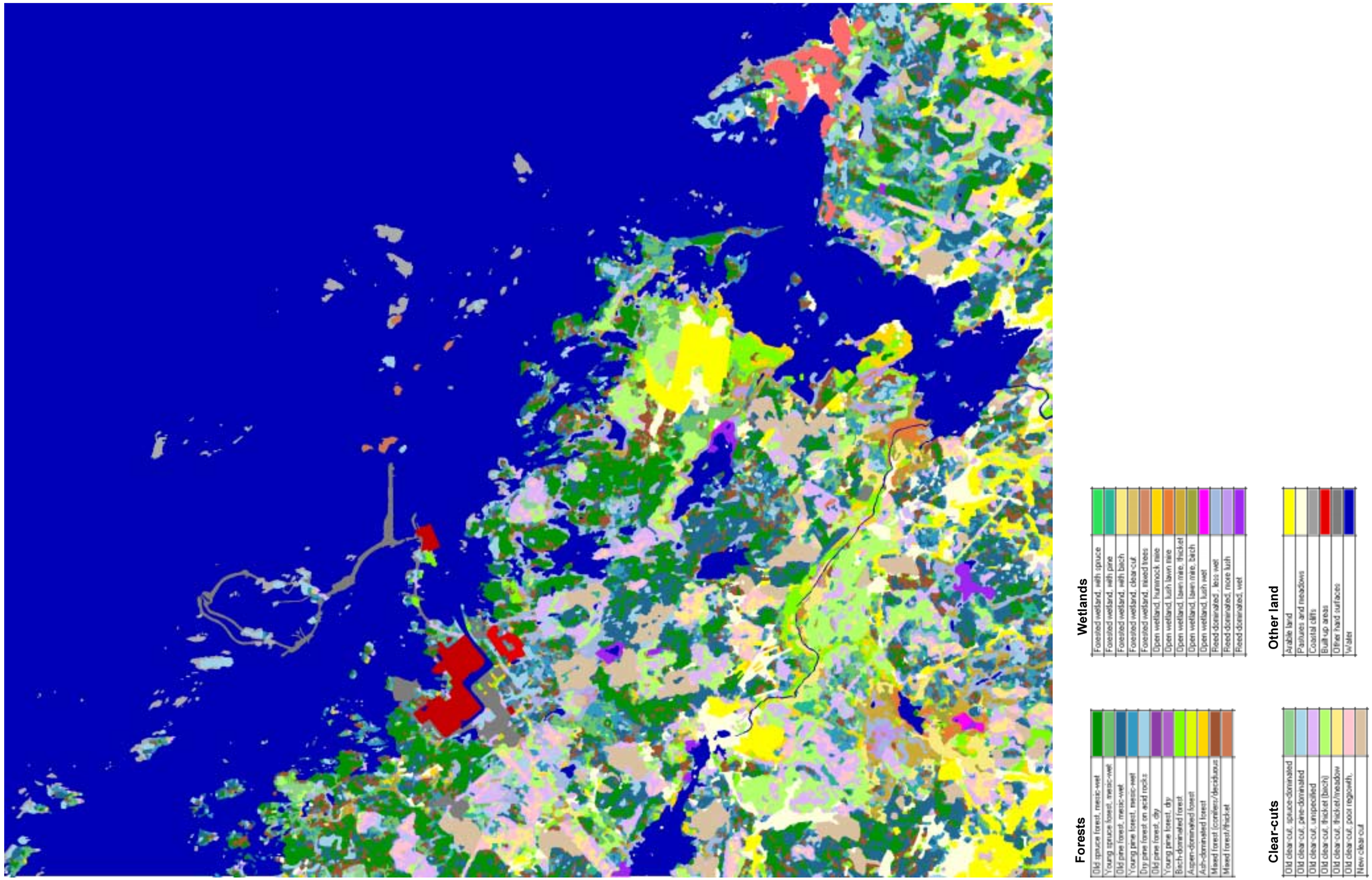
Appendix 6

Delivery description

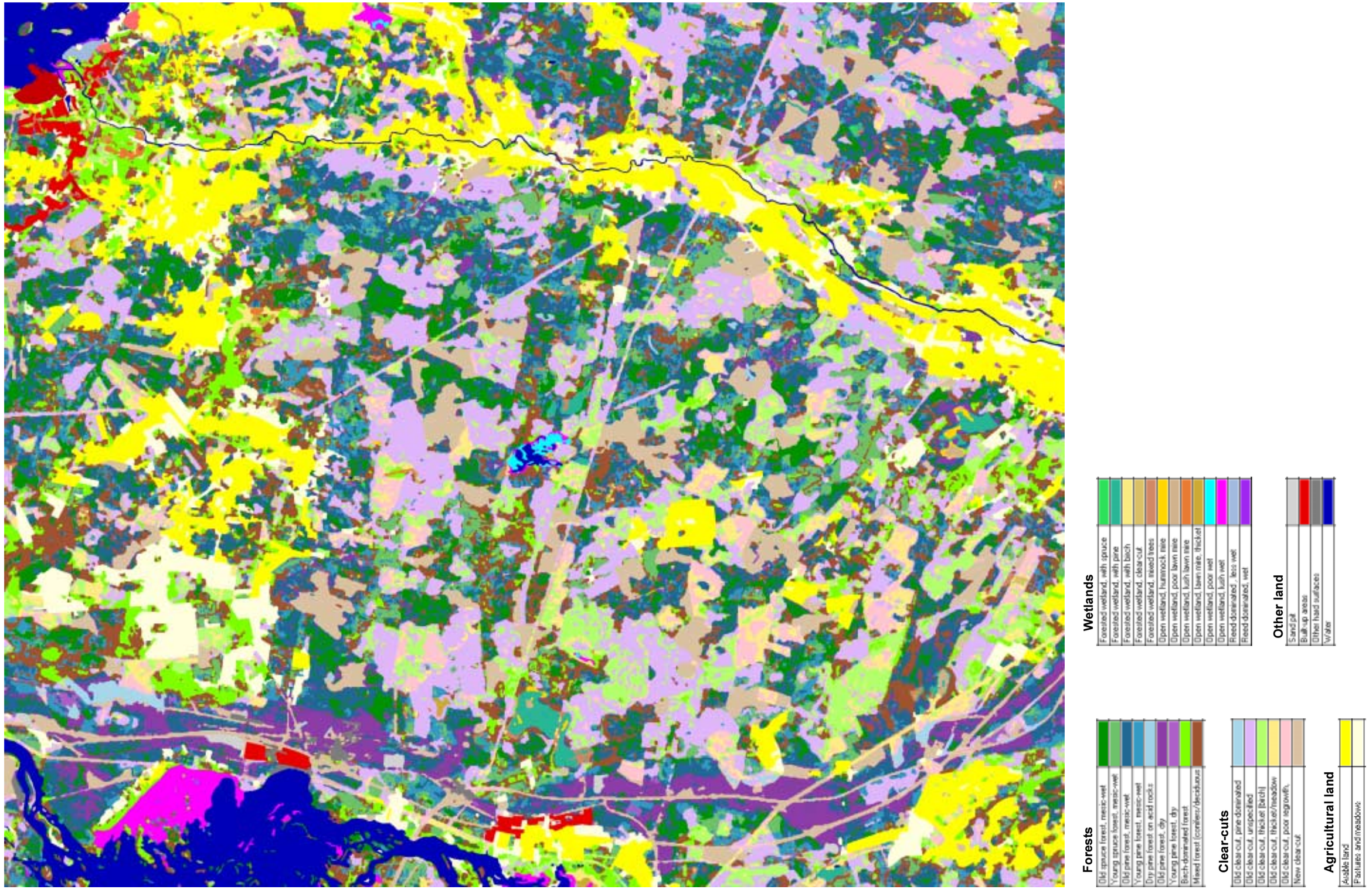
CD Vegetation mapping in Forsmark and Tierp



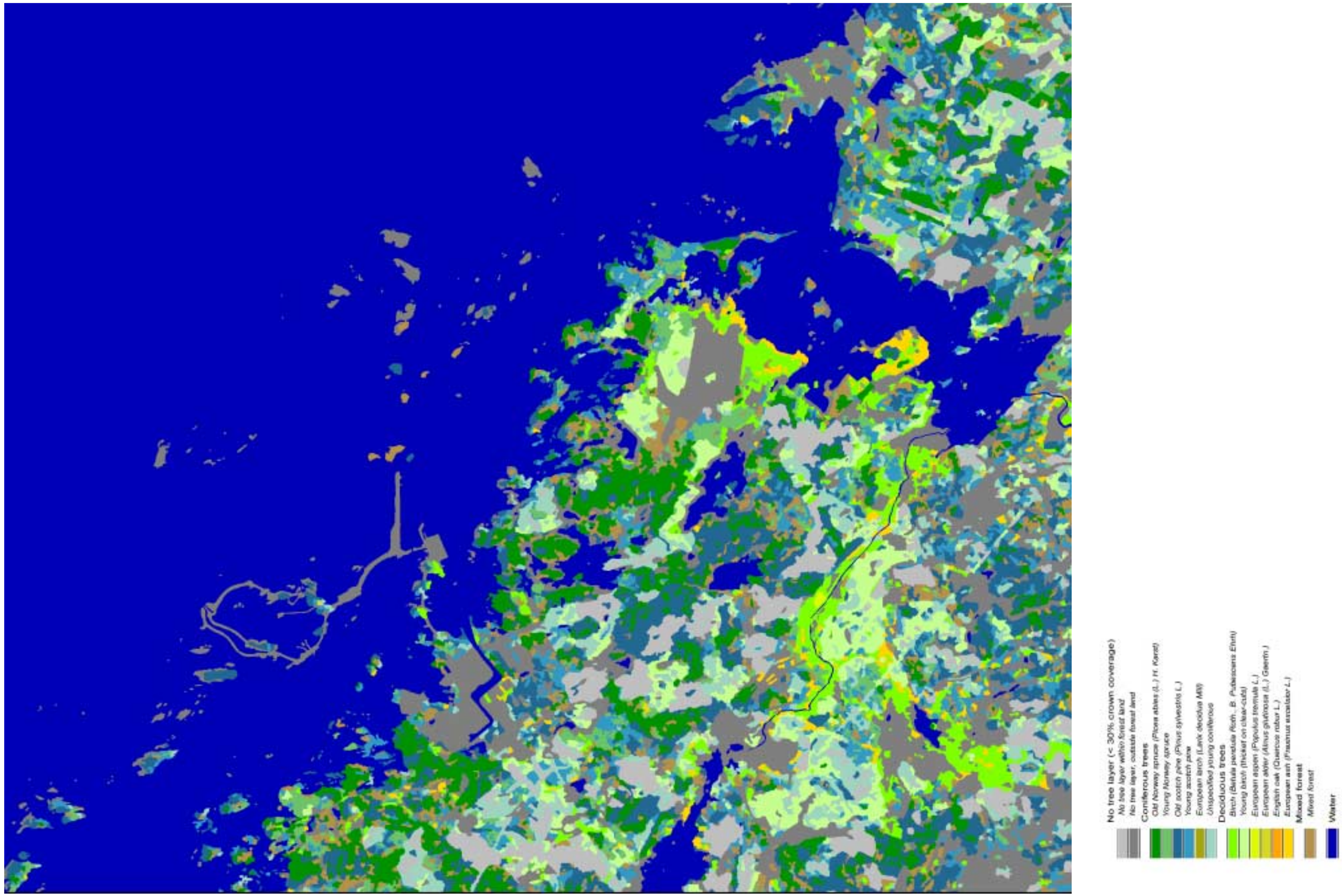
Appendix 7. Vegetation/land cover map of forsmark



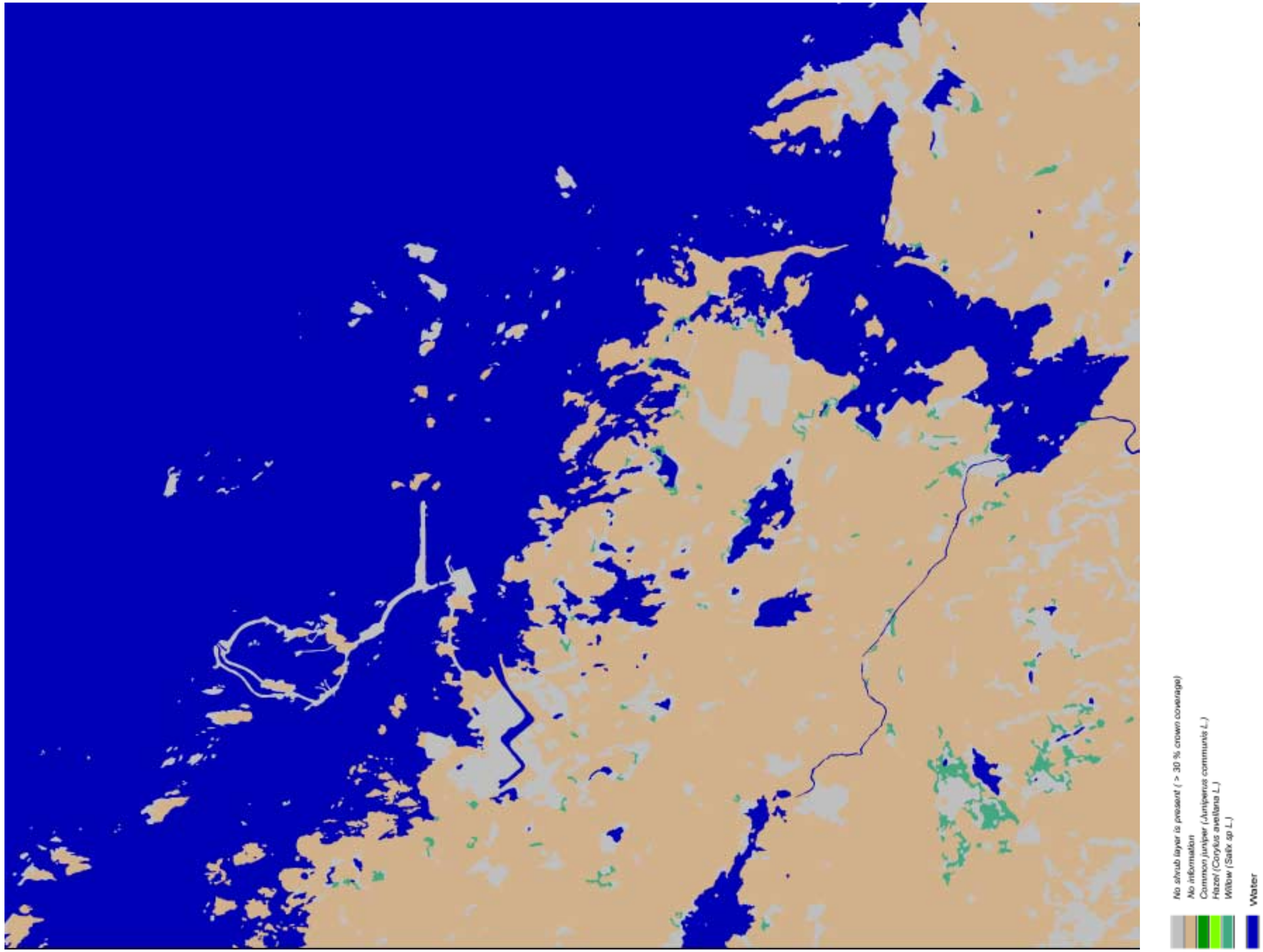
Appendix 8. Vegetation/land cover map of tierp



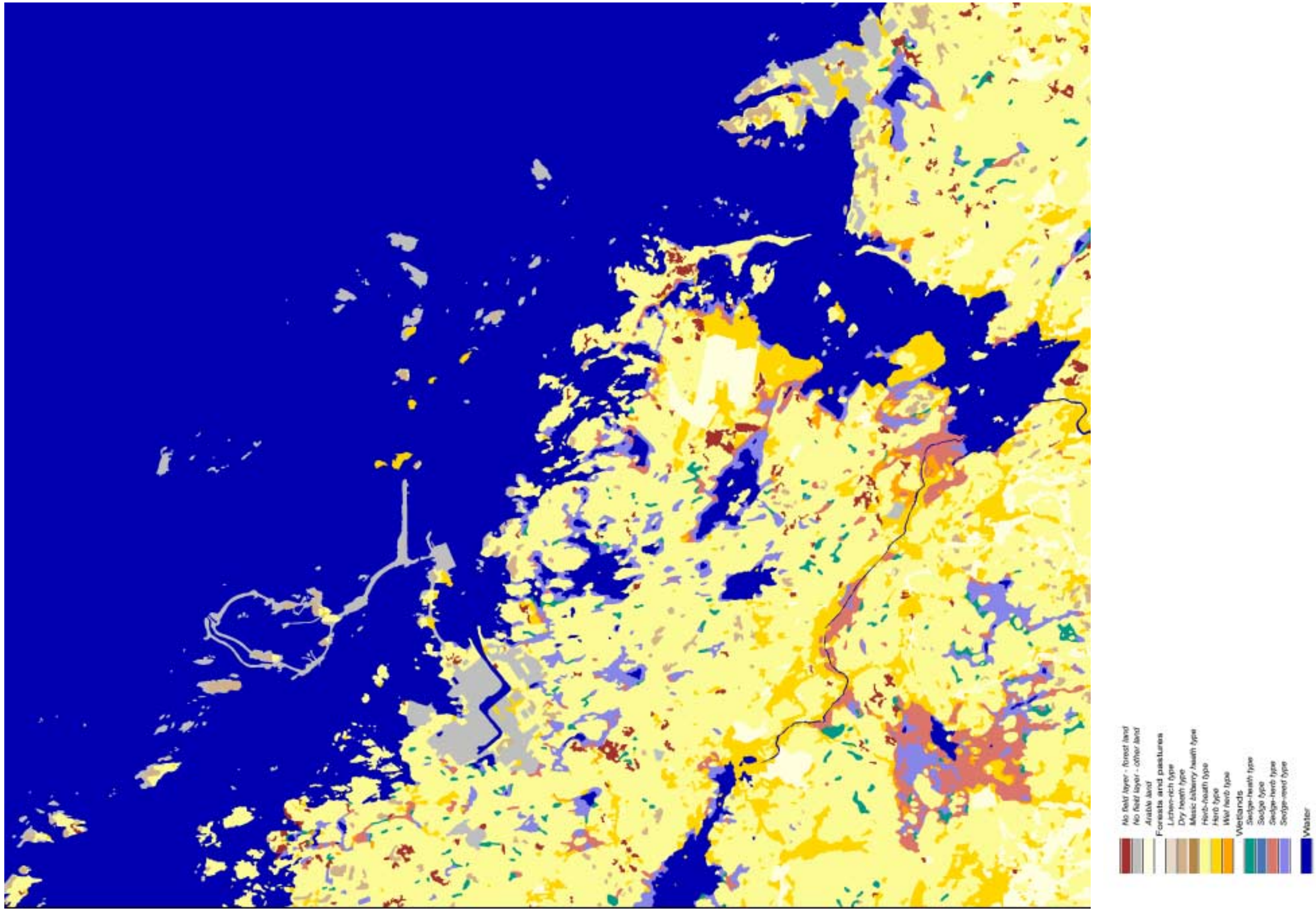
Appendix 9. Forsmark –tree layer



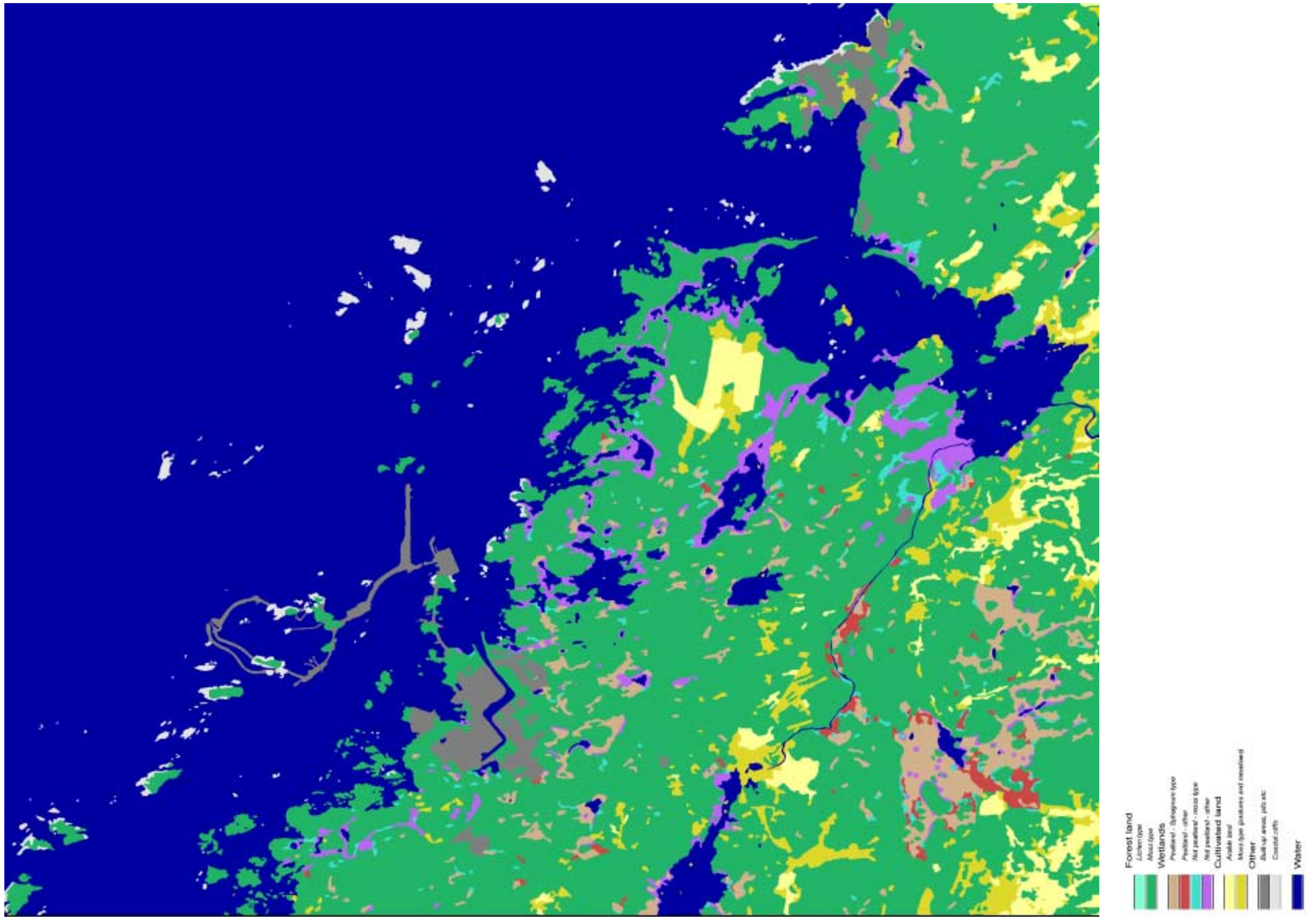
Appendix 10. Forsmark – shrub layer



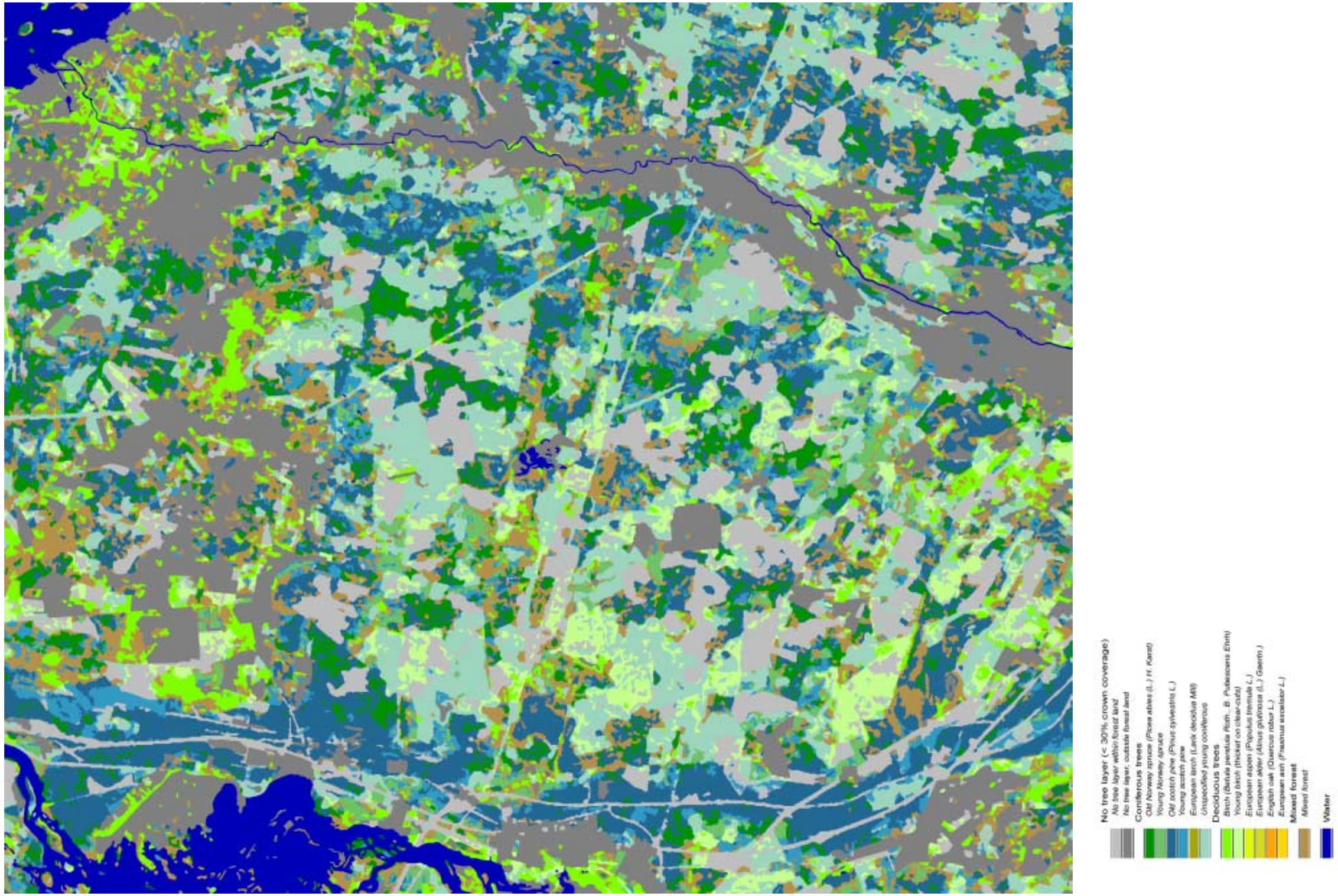
Appendix 11. Forsmark – field layer



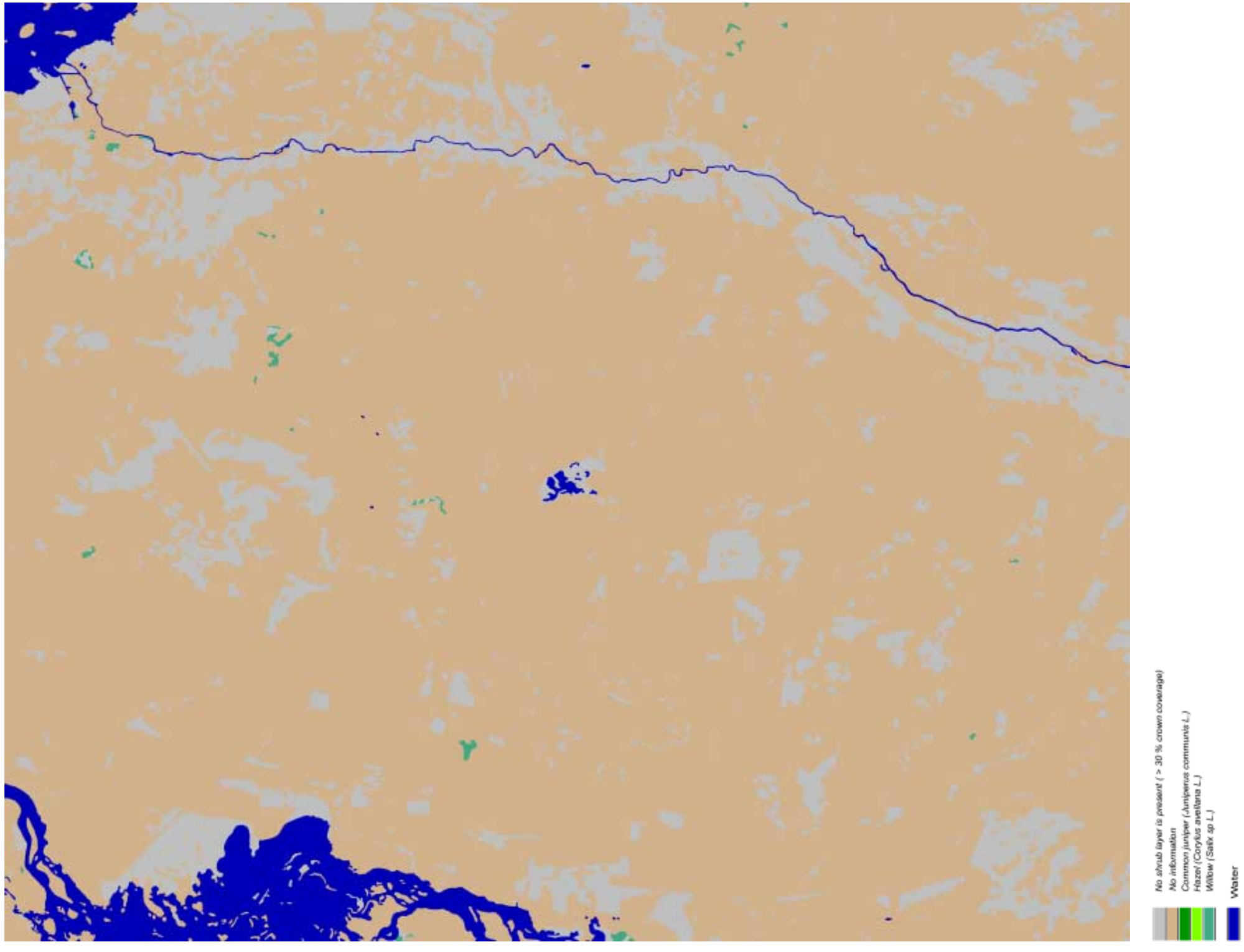
Appendix 12. Forsmark – ground layer



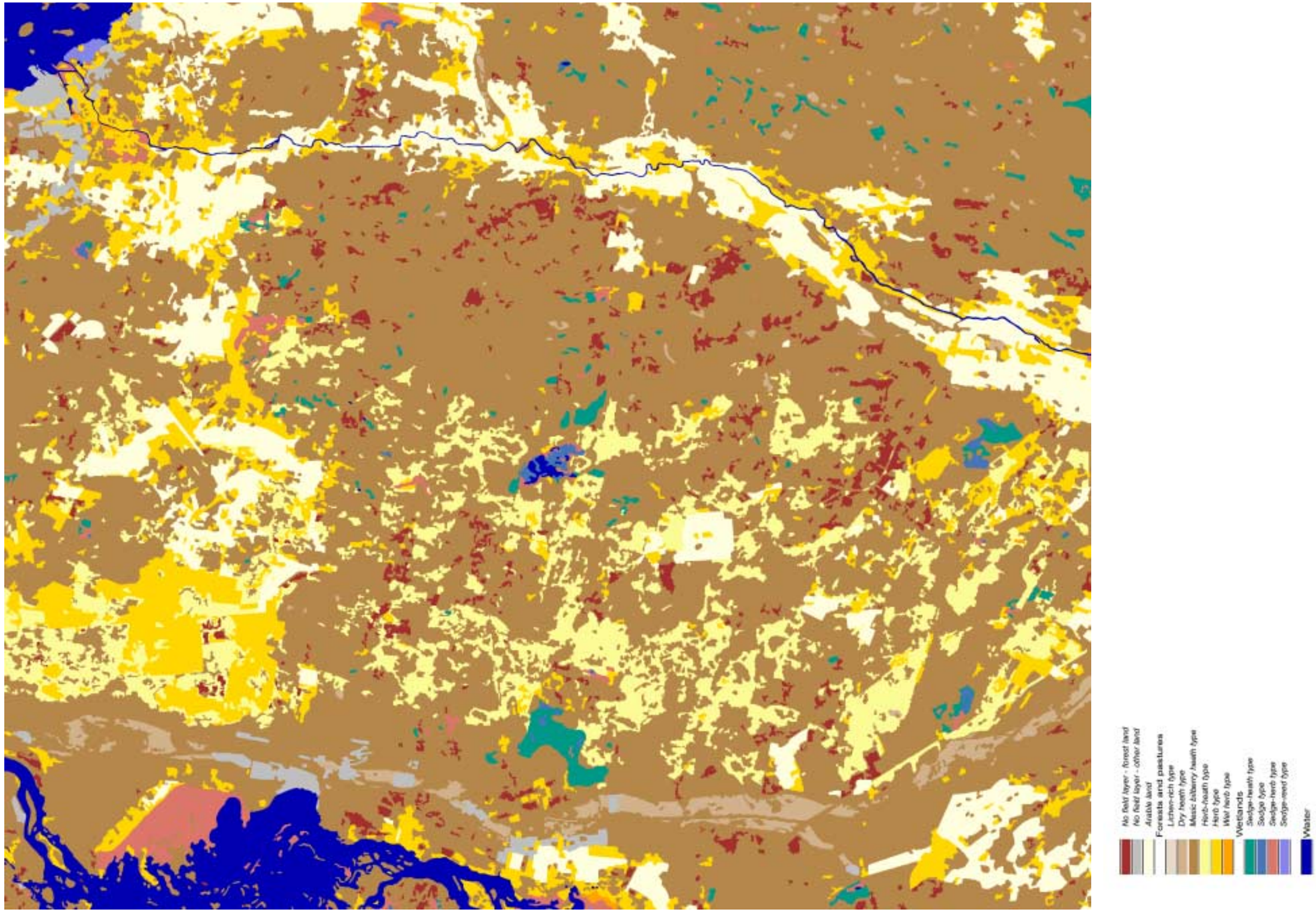
Appendix 13. Tierp – tree layer



Appendix 14. Tierp – shrub layer



Appendix 15. Tierp – field layer



Appendix 16. Tierp – ground layer