Computer Visualization of forest development scenarios in Bäcksjön estate

-an evaluation of the Visual Nature Studio 2 software

Iker Manterola Matxain

Arbetsrapport 114 2003
Working Paper 114 2003

Table of contents

1.-INTRODUCTION

1.1. 3D visualization of forest

Concern about environmental problems has grown rapidly over the last decades and related to that emergent interest a lot of research has been done and regulations applied. Today public scrutiny is more intense and participation in decision-making has increased especially in forested environments. This situation requires good and easily understandable information, but usually there is not enough communication between authorities, managers and the general public. Those three components have to interchange information about the landscape development and its natural resources in order to maintain or improve environmental conditions. Therefore there is a need for newer techniques of exposing and explaining the future consequences of different management decision alternatives as well as showing forecasts according to different scenarios.

It is well established that graphics, specifically data visualizations, are usually the simplest and most powerful way for communicating results (Tukey, 1977; Tufte 1983). This concept has been expanded to include the use of visualizations for representing natural landscapes. Until recently, forest visualization efforts have focused mainly upon illustrating static concepts or the possible outcomes of management actions (Bishop and Karadaglis, 1997; McCaughey, 1997; Buckley, 1998). The development of computer and visualization technologies is making more popular the use of computer visualization as a delivery tool for the results of environmental change studies and management plans, especially concerning forested environments (Tang and Bishop, 2002). Furthermore, there are large needs for visualization in illustrating scenarios and forecast of forest growth, with different management alternatives, and give an idea about the consequences of sylvicultural actions (i.e. cuttings, thinnings, etc.). When delivering spatial and environmental information to a non-scientific audience, or even to managers, it is important to put it in a convincing way, in order that the more important data and their meaning are quickly understood. Particularly when referred to the presentation of spatial data concerning to management or land use change, realism provides the great advantage of familiarity to aid interpretation (Bishop, 1994). Owing to this, the visualization is a powerful tool for communicating with the public on participatory processes.

In this context, most commercial 3D visualization software packages have so far not been able to satisfy the forestry related needs. Since currently, these software packages have limitations, mainly because most packages have been aimed at Virtual Reality (VR) capability. Those problems are related to the circumstance that in VR applications, the computer tries to handle each tree as an object in the RAM memory, running into memory problems quickly, and also less developed integration with georeferenced GIS datasets, etc. For the basic forestry need, Virtual Reality capability is however not necessary and the rendering of an image taken from one view point might be sufficient. As an example of photorealistic visualization software, the new *Visual Nature Studio 2* promises to be useful in different scales, with other interesting characteristics like vector guided rendering, etc.

4

1.2. Goals and objectives

The main goal of this work is to demonstrate the potential of computer visualization as a tool for communicating the results of forest cover change studies with commercially available low cost software. Especially the utility of the new *Visual Nature Studio 2* software for forest related uses combined with the *Onyx tree* software for tree object creation is evaluated. To achieve this goal, the following specific objectives were outlined:

- Develop visualization examples from different time points to illustrate predicted forest cover change according to the foreseen sylvicultural actions in Bäcksjön estate.
- Generate a rendered animation with actual forest data.
- Create a step by step methodology to visualize forest cover using vector format data to drive the rendering.
- Complement the existing tree image object data base.
- Evaluate the performance and limitations with the used softwares.

2.-MATERIALS

2.1. Study area

The study area is Bäcksjön estate, located in Västerbotten County, Sweden, 10 km north from the county capital, Umeå. The 82 % of the landscape is covered by productive boreal forest in this 824 ha property, with three main species: *Pinus sylvestris, Picea abies* and *Betula spp.* The most common specie is *Pinus sylvestris* occupying the 64% of the stem volume, then *Picea abies* with the 28% and last *Betula spp.* with the 8 %.

In addition to this, there are impediments such as wetland and rock outcrop scattered all over the estate, occupying 148 hectare of the total area.
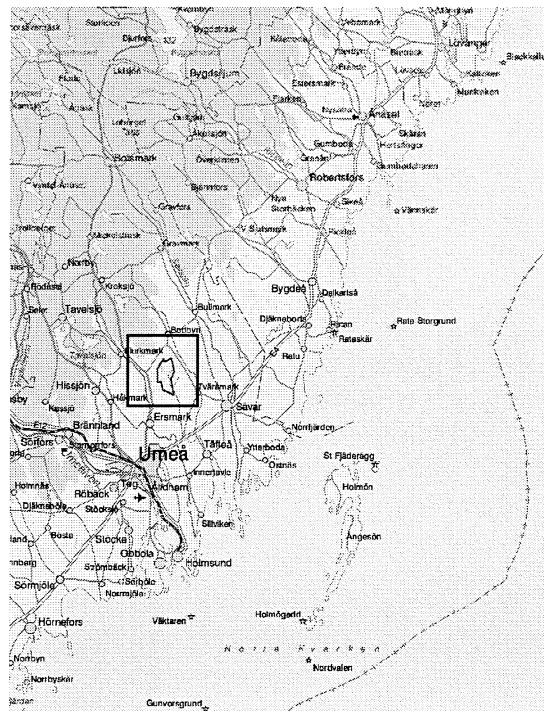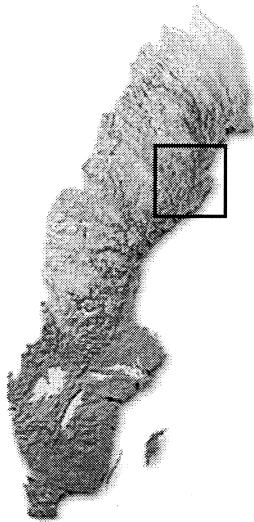
2.2. Data

The data used as a basis for developing the visualization consisted primarily of a 50m grid size Digital Elevation Model (Grid and ASCII array formats) and rivers and lakes Shapefile's. Bäcksjön estate 2:1 paper maps (from Forest Management Plan) at a scale of 1:25.000 were acquired from the Skogsvårdsstyrelsen (Regional Board of Forestry). Other tabular data related with stand's forest parameters in Excel format are used.

Real world tree images and forest area photographies were taken by a digital camera, on the study area and around Umeå.

2.3. Hardware

The computer used on this study was equipped with an Intel Pentium 4 processor, at 1.7 GHz, and 261616 KB of RAM memory.

2.4. Software

The software packages used on this project mainly have been *Visual Nature Studio 2* and *Onyx tree*. Adobe Photoshop was used to edit the real world trees images.

All the data has been processed, analyzed and integrated in a computer with a Geographic Information System (ArcGIS by ESRI).

Visual Nature Studio 2

The main software used and tested in this study is 3D Nature's (www.3dnature.com) *Visual Nature Studio 2* (VNS2). After earlier evaluations of other, Virtual Reality, based software packages, and check of the important limitations they had for forest related purposes, it was found interesting to evaluate the utility of this software for rendering photorealistic pictures. This package has some interesting characteristics in order to use it to visualize forested areas:
- Integration with georeferenced GIS datasets
- Flexibility of land cover type development
- Use of raster or vector formats to drive rendered vegetation components

The *VNS2* basic data inputs are Terrain data, Vector data and Image Objects.

The terrain data is presented as Digital Elevation Model (DEM), which can be imported or created using the Terrain Generator or Terrain Gridder functions of the software. The allowed importing formats (Arc Grid, ASCII array, images, etc.) are converted into the high-resolution WCS DEM format by *VNS2*. On the other hand, to create the DEM control point data is required and different formats are allowed (Arc ASCII DEM, ASCII array, Binary array, images, DXF, etc.). The imported point files data are regrided to *VNS2* DEM format.

The vector data can be imported into *VNS2* using DXF, Arc Shapefile, USGS ASCII or SDTS DLG formats. The most useful format is Arc Shapefile due to embedded attribute data can be imported, having the opportunity to assign components (i.e. Ecosystems) to these vectors after the importation; otherwise the parameters might be assigned individually to components.

Image Objects are images or image sequences, and they are used in *VNS2* for Foliage (pictures of trees, plants, etc.), colour maps (pictures to drape onto the terrain), textures (pictures of the ground), celestial objects (sun, stars, etc.) and backgrounds. The allowed image object files are: IFF, Targa, BMP, PICT, JPGE, TIFF, etc. Three-dimensional objects are also importable (Light Wave 3D, 3D Studio, DXF and Wavefront OBJ formats).

VNS2 organizes the input data, loading and saving all the scene details and a part of the input data in its own project files, which have an extension of ".proj". The project file includes Components (effects) and their settings, the Database (where *VNS2* stores the vector data and DEM's and Image Object addresses paths), the interface arrangement and preferences data. Some data (i.e. DEMs) is stored outside of the project file to make data sharing possible with other projects and keep project size at reasonable level. Some other preferences are stored as ".prefs" extension.

Created outputs are photorealistic pictures and animations, with a variable realism depending on their inputs and mainly on the quantity of information they have to handle.

VNS2, apart from the usual visualization functions like sky features (clouds, sun, etc.), foliage groups (trees, rocks, etc.), and etc. offers interesting functionalities for landscape rendering:
- DEM related functions: editing, painting, change point height, tile for faster rendering, different resolution DEMs merging, etc. Also DEM interpolation tool is available to set the resolution.
- Georeferenced: different coordinate system options, interactive ruler, etc.
- Texture editor: The texture editor of *VNS2* allows multiple options. Even though the texture editor complexity, VNS2 predesigned textures can be used and edited changing parameters and keeping the primary structural design, obtaining good results. Some of these possible texture utilities:
  - Georeferenced images importation: Taking high resolution photos over the visualized areas, might be possible to edit these images and drop them into their exact location on the terrain, increasing in that way the visual realism of the ground.
  - Planar images: Having aerial photos of the terrain, use them as a basis for make a realistic texture of different land uses.
- Vector editor: create new vector data to locate image objects.
- Terrafector: creates terrain elevation changes to hold lakes, roads, etc.
- Detail improvement tools: fractal depth (subdivision of the terrain polygons), level-of-detail control (more detailed near the camera, less when is far), etc.

8

Tree location options: densities per polygon or per unit area (i.e. hectare) located randomly according to the texture remapping functions. Also possible, having tree location information to place tree-by-tree accurately.

- Visual elements editor: Sky elements, Water, etc.
- Vector guided rendering using thematic maps.
- Dynamic linking between vectors and ecosystems using search queries.
- Real world image objects importation: it is possible to edit a photography of a real object (i.e. trees, snags, etc.) into standard photo editor software, and setting a black background, imported into *VNS2* as image object. In that way it is possible to create a realistic image objects library with images of the study area easily and without any especial software requirement.
- Movies: different kinds of movies like stereo movies, panoramic, etc can be created. It is also possible to make still videos with growing trees to show forecasts at stand level, or other objects in movement.
- Material locations into ecosystems: the materials and the containing foliage objects (i.e. trees) involved in an ecosystem can be placed according to different parameters (i.e. different kind of boulders can be located in a lake shore according to the water depth).
- Foliage object placement: objects can be located using *rules of nature*, which places the objects according to the parameter settings (i.e. slope, height, etc.).
- Instant data update: the data that guides the rendering (i.e. trees height per stand, density, etc.) can be updated putting the new information into the original vector table and restarting *VNS2*.
- Create new ecosystems according to how the real countryside looks like, and the possibility to store them into the *VNS2 Galleries*. In that way, new projects can be made just importing new data and loading pre-made ecosystems.
- Variable final render quality.

Onyx tree

The tree objects have been created using Onyx Computing's (www.onyxtree.com) *Onyx tree* software. This program is a procedural tree generator for modelling and rendering photorealistic trees. It has interesting qualities for working together with VNS2:

- Wide saving options: as parameter file (*.CON), image files (BMP, TGA) or 3D model (3DS, C4D, DXF, FAC, LWO, OBJ, or W3O file)
- Uses Parametric modelling technique

Due to the ample tree library of the software, tree creation initiation can be started using a prebuilt tree and changing the settings to fit into our requirements.

The inputs for *Onyx tree* are tree related parameters, and the parameter control interface is divided into four categories:
- Trunk and bough
- Branch and twig
- Volume
- Foliage

In all the categories there are similar parameters like height, length, angle, curving, density and twist, but there are also differences between those categories: On the *trunk and bough* category the crown centre and the bottom height (first branch), on *branch and twig* category length change, and on *volume* category trunk and branch width, colour and mould. On the *foliage* category the needles colour is controlled as the other parameters.

All the parameters are controlled by sliders, and after any parameter is changed an image of the tree is rendered.

The functionality offered by *Onyx tree* can be resumed in that way:
- Sun lightning and shadow parameters: intensity, colour, angle, etc.
- Chain saw tool: allows cutting off any part of the tree.
- Background colour setting: good for *VNS2* importing.
- Preview rendering options for faster render.

3.-METHODS:

3.1. Data acquisition and processing

The used GIS data has mainly been acquired from the SLU university database. The Digital Elevation Model (DEM) for Sweden had been made by Lantmäteriverket, with 50m resolution. Four DEM files have been used to cover the Bäcksjön estate and surroundings.

The forest parameters data were obtained from the Bäcksjön estate forest management plan. The management plan did not include all the data needed; consequently needed data was estimated from the available data, using management tables. The initial available parameters were:
- Stand age
- Site index
- Percentages of total stem volume estimation by species.

The species stem density in the stands was set to be the same as the percentage of total volume, and the stand height and density were estimated with stand age and the site index. Site index tables were used for estimating the tree height in the forecast.

The first step was to make a digital map of the study area, using the stand-ID black and white paper map as a basis. It was scanned and digitalized in ArcGIS (GIS software package by ESRI). Afterwards the forest stand's data, in Excel format, was linked to the stands. Other linear features like roads, rivers and electric lines were digitalized using the

Bäcksjön estate general map. As the digital map over Bäcksjön was stored in a Geodatabase (a new ArcGis storage format) as feature classes, it was necessary to convert all the features into Shapefile (vector file in the ESRI shape configuration) format in order to import it to the visualization software. All the stands data was imported into Shapefile's DBF format tables as well.

3.2. Tree database creation

All the generic tree objects have been created using the *Onyx tree* software. The pre-modelled trees from the software's library have been used as a basis for the new trees creation. Different digital photographs were used as models to get the right look of the generic trees. The tree object creation was divided in two different classes:
- Young forest: up to two meters high.
- Mature forest: over two meters high.

The generic tree objects have been saved as images with a black background (setting in *Onyx tree*) before being imported into *VNS2*.

Digital photographs of trees were acquired by digital camera and edited in Adobe Photoshop to set a black background in order to import into VNS2. These tree image objects were used in some image examples for the closest viewpoints.

3.3. Visualization

The first step was to import the Digital Elevation Model (DEM) files covering all the area of the Bäcksjön estate. The Bäcksjön estate is located between two DEMs, but in order to create a visual area wide enough to look realistic, two adjacent DEMs were taken. The imported DEMs are files in the Swedish National Grid, map sheets: 20 *KNO*, 20 *KNV*, 21 *KSV* and 20 *KSO*. There is two format options to import DEM´s: Grid or ASCII tables. Both ways were used, and both allow the option for tiling DEMs into little pieces and setting the output resolution on the importing process. The fifty meters resolution that this is the Swedish National Grid resolution, was judged enough considering the realism and the render time. Owing to each DEM file was formed by four layers, just the layers closest situated from the study area were enabled in the VNS database.

When the DEM´s were imported and checked rendering a preview, the vector data was imported: first the Bäcksjön estate stands polygon shapefile and then layers with the lakes, roads and other linear features.

Once all the data need for the visualization was acquired, the configuration for rendering was initialized. VNS can represent different vegetation types using real world image objects or photorealistic models. Objects can be placed either individually on the landscape or grouped together in associations called "ecotypes." Each ecotype consists of groups of image objects, each with their own height range and density specifications. VNS allows vector's attributes driven rendering for this object

parameters, using what they called "thematic maps". The tree objects made on *Onyx tree* were imported to the ecotypes together with the software's image objects.

Once the visualization project was created, the software's performance was analyzed. Preview rendering was mainly used, instead of the final rendering mode, in order to have faster results. The performance of *VNS2* has been evaluated, taking in mind the relation among the different parameters that affect rendering realism and their time requirement. The satisfactory performance level according to the time requirements has been fixed as maximum in 5 minutes, in order to been able to create instant forecasts for forest related purposes. For most of the parameter analysis preview rendered has been used. Time required for those renders are shown in tables and in comments below the figures, and are for guidance only. Those are the analyzed parameters:

- Fractal depth:
- Digital Elevation Model
- 3D Objects
- Image objects
- Render mode (Size of the image)
- Render quality (antialiasing quality)

The final image results are presented in photorealistic images and movies. The photorealistic images were rendered in two different resolutions 720*480 and 2160*1450 pixels. The movies were made with a 500*332 pixels resolution, 25 seconds of length with 20 frames per second and using fractal maps with maximum fractal depth of 3.

4.-RESULTS AND DISCUSSION

4.1. Tree database creation

At the beginning the trees were made using the default mode (without sun light). Even though their visual appearance was quite good the trees seem to be flat, being difficult to distinguish each tree, decreasing in that way the realism of the images.
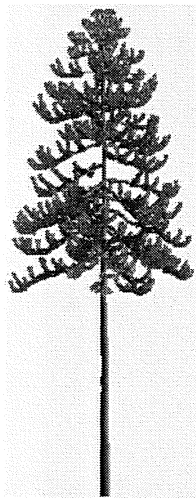

Fig.3: Tree image object made by Onyx tree package   *Fig.4:* Real world tree image taken as a model
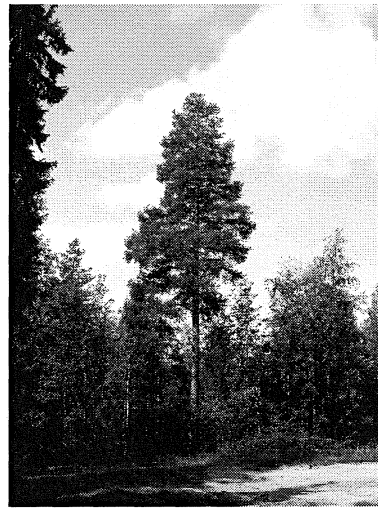
In a second step, the same trees were lighted using sun light tool in *Onyx tree*. Once those trees were imported, a large improvement of the realism on the rendered images was noticed.
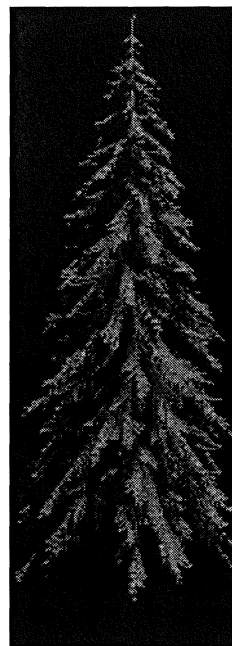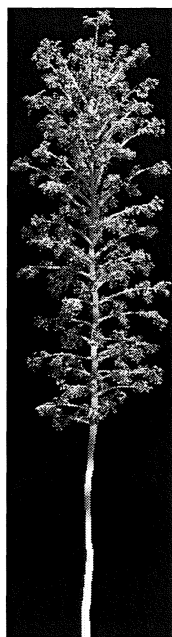

Fig.5 and 6: Lighted Onyx tree made trees ready to import into VNS2

13

Real digital photographs of mainly *Pinus sylvestris* were taken and after processing, were used to render some close view images, in order to check the potential use of this technique in following visualization projects.

Fig. 7,8 and 9: *Different steps of the processing From Real World Tree images to final importable image.*

The Real photograph technique's perform was considered successful and important in order to develop an image database from the areas to analyze.

Even though the final renders with lighted Onyx tree objects was successful, it was considered interesting for following visualization projects to create a more specific tree image database, with several images per each age class.

4.2. Performance

Fractal depth: *VNS2* allows increasing the terrain detail, subdividing each polygon into sub polygons by changing the fractal depth level, which increases by the power of four each time. Higher fractal depth takes longer render time and sometimes is possible to be close to this realism standard and get faster rendering, by decreasing the fractal depth and using another capability of *VNS2, bump intensity*. The *bump intensity* increases the visual roughness of the ground making it more natural looking.

The area used for the fractal depth study was a rock outcrop area with the understory disabled in order to notice more clearly the visual differences in the DEM. Used viewpoints were perspective and planimetric.

The rendering was made using different *Fractal Depth (FD)* intensities: 7 (maximum), 3 and 0 (minimum). In the low intensity levels two different renders were made, with and

without *Bump Intensity* using the default texture with 100 % of intensity at 3 *FD* and 100%-500% of intensity at 0 *FD*.

Table 1: Time required for rendering on two viewpoints (Perspective: topographic, and Planimetric: Nadir) and using different levels of Fractal Depth (0, 3 and 7) and Bump Intensity (BI at 0 and 100%) in minutes and seconds. For guidance use only.

| | *Fractal Depth 0* | | *Fractal Depth 3* | | *Fractal Depth 7* |
	0 % BI	100 % BI	0 % BI	100 % BI	0 % BI
Perspective	0,20	0,20	1,00	1,00	2,00
Planimetric	0,10	0,10	0,10	0,10	0,20

The increasing of *Fractal Depth* level has raised time requirements in this project. Decreasing from 7 to 3 the *Fractal Depth* level, the same image has been rendered in half time, being more noticeable the reduction using the minimum fractal depth level (0). At the same time the *FD* decrease involves less real renders. Even at the higher realism case, the time requirements are less than the maximum fixed and the realism differences are noticeable. When textures have been added the realism difference has shown more clearly. The less detailed terrain has produced green areas in the figures below (*fig.10*) due to the texture details are located overlapped on the same polygon. On the other hand, higher ground detail renders (*Figure 11*) has not shown these unrealistic patches, owing to the textures were placed at different location levels.

Figure 10   **Figure 11**

Fig.10: *Planimetric viewpoint image with a middle level of Fractal Depth (3) and rock with lichen texture ecosystem.*
Fig.11: *Planimetric viewpoint image with the maximum Fractal Depth (7) and the same texture ecosystem.*

The decrease of *FD* levels and using *Bump Intensity* default levels faster rendering and quite good realism levels were achieved. Despite of this realism improve, and looking to the time requirements, always below the 5 minutes, is easier and more real visually set *Fractal Depth* instead of create *Bump Intensity* textures in the analyzed case. The using of *Bump Intensity* might be helpful in case of low detail terrain data without active *Ecosystems* was required.
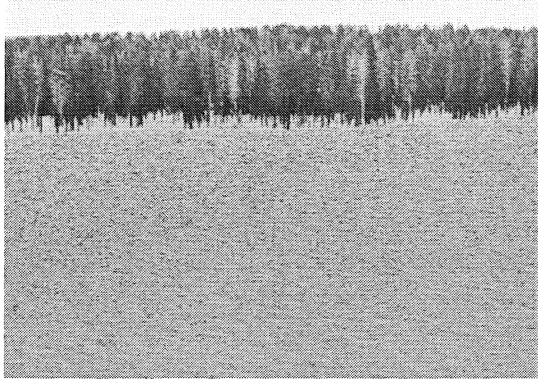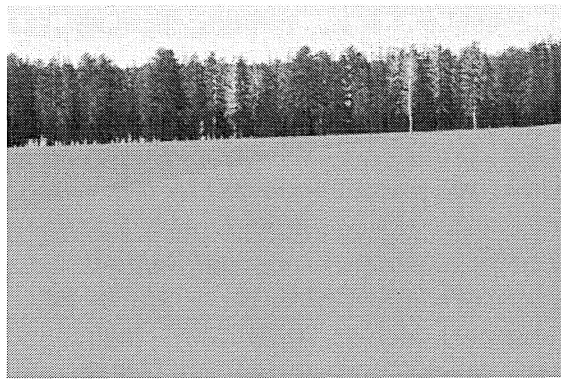
Figure 12   *Figure 13*

Fig.12: *Rendered image with 0 level of Fractal Depth and 100% of Bump Intensity*
Fig.13: *Render image with 0 level of Fractal Depth, without Bump Intensity*

The *Fractal Depth* level affects to the realism as well influencing how the stands borders are shown guided by vectors and how the ecosystems are visualized (especially textures as has been shown in previous figures). Higher terrain detail (higher *Fractal Depth*) involves more accurate fitting to the *Ecosystems* boundaries, which does not mean higher visual realism owing to it depends to the *Ecosystem* resolution as well. The *Ecosystems*, by default, have the same resolution as imported DEM's (50 meters in case study). Using the lowest terrain detail (*Fractal Depth* 0, 50*50 meters cells divided into two polygons) and default *Ecosystem* resolution a rough boundary definition was obtained (see figure 14), which was improved increasing the *Ecosystem* resolution to 5 meters getting closer result to the real stands borders (see figure 15) and more natural images.
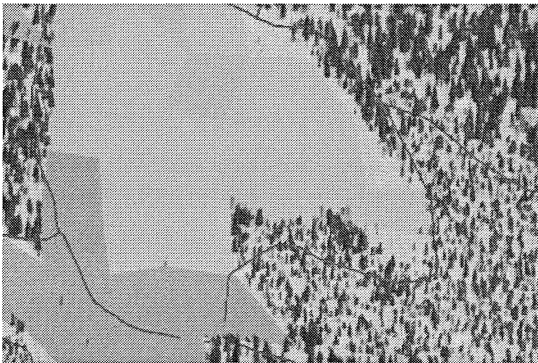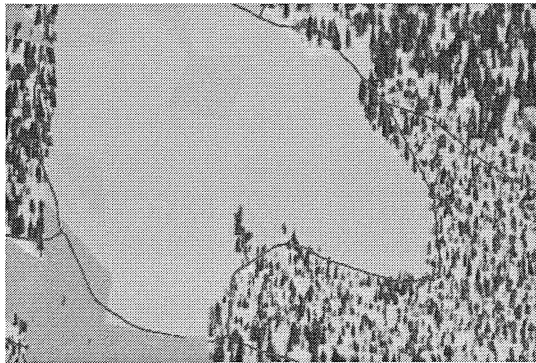

Figure 14   *Figure 15*

Fig.14: *Image rendered from Nadir viewpoint with minimum Fractal Depth (0) and default resolution of 50 meters on forest ecosystem.*
Fig.15: *Image rendered from Nadir viewpoint with minimum Fractal Depth (0) and 5 meters of forest ecosystem resolution.*

Even increasing the terrain detail increasing the *Fractal Depth* to the maximum (7) the *Ecosystem* resolution keeps on the default mode of 50 meters. This produces rectangular unreal stand borders (see figure 16) because the higher terrain detail makes possible to fit accurately to the rough borders of the *Ecosystem*. Increasing the *Ecosystems* resolution to 5 meters (see figure 17) the best and more natural result was achieved.
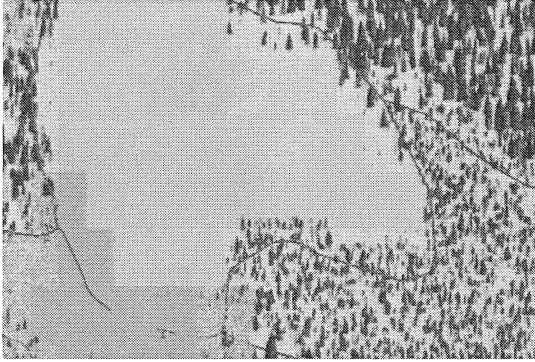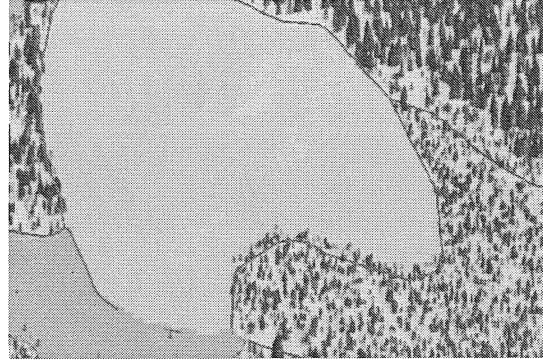
16

Figure 16   **Figure 17**

Fig 16: Image rendered from Nadir viewpoint with maximum Fractal Depth (7) and default resolution of 50 meters on forest ecosystem.
Fig 17: Image rendered from Nadir viewpoint with maximum Fractal Depth (7) and 5 meters of forest ecosystem resolution

Digital Elevation Model: The different levels of DEM resolution and the quantity of DEMs to render influence the time required for the visualization. In this study 50 meters resolution DEMs has been mainly used.

The original terrain information was processed in three different ways:
- Original format: Each file was formed by 4 DEM layers (25*25 km) with a 50 meters resolution (called 4 Low Resolution successively).
- Tiled format: Each file was formed by 16 DEM layers (12, 5*12,5 km) with a 50 meters resolution (called 16 Low Resolution successively).
- Higher resolution format: Each file was formed by 16 DEM layers too, but with a 25 meters resolution (called 16 High resolution successively).

Diverse viewpoints were used in order to show images with different quantity of rendered DEMs and in that way, test the relation between time requirements and rendered DEM's surface. Due to the existence of two different DEM sizes (original and tiled) the information about the rendered surface is shown according to the smallest DEM layer, which has 3900 hectares of extension (called areas successively).

The differences were noticed among the 50 and 25 meters resolution layers, but not between the two DEM's extension (original size: 25*25 km and tiled format: 12,5*12,5 km). Theoretically the tiling should result in faster rendering, due to the extension to render is smaller, but it was not noticed. Even though the rendered area on the tiled version was sometimes the half or even a third part, render times were equal for original sized DEM and tiled ones.
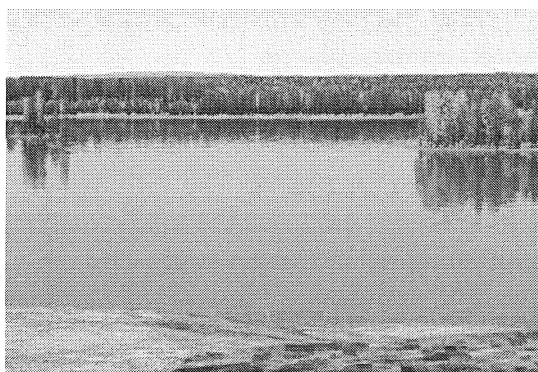
Figure 18

Figure 19

Figure 20

Figure 21

Fig.18: Image from viewpoint 1 with 12.5-meter cell resolution DEM (16 High Resolution), 16 areas.
Fig.19: Image from viewpoint 1 with 25-meter cell resolution DEM (4 Low Resolution), 16 areas.
Fig.20: Image from viewpoint 2 with 12.5-meter cell resolution DEM (16 High Resolution), 16 areas.
Fig.21: Image from viewpoint 2 with 25-meter cell resolution DEM (4 Low Resolution), 16 areas.

On most of the cases higher resolution terrain data has increased render time requirements by a 25%. The exception has been the planimetric view (Nadir), where the tree formats render time was similar (see table below).

Table 2: *Time requirements in minutes and seconds for render images from different perspective viewpoints and DEMs resolutions, with variable extension of the rendered area. Number of rendered areas (3900 hectares per area) on italics. For guidance use only.*

	4 Low Resolution	16 Low Resolution	16 High Resolution
Viewpoint 1	*4 areas/* 1,15	*2 areas/*1,20	*2 areas/* 1,50
Viewpoint 2	*16 areas/* 2,00	*5 areas/*2,00	*5 areas/* 2,30
Viewpoint 3	*4 areas/* 0,30	*1 area/*0,30	*1 area/* 0,30

In the study case data conditions, the DEMs resolution increasing it has been considered not worthy, being more useful in terms of time requirements and easier management, to increase the *Fractal Depth* level.

3D Objects: The number of 3D elements is one of most important parameters to determine how long the render takes; an increment of 3D elements raises time requirements.

18

In general views it is recommendable to disable the 3D objects render in order to improve the rendering speed without a noticeable realism or detail loses. On closer visualizations those objects should be used carefully and located just in the view area. In images with render times under 2 minutes, using 3D elements usually, the time requirements exceeds by much the proposed limit of 5 minutes. Between the figures using 2D and 3D elements, shown below, the increasing has been approximately half an hour.

Figure 22: Image created on preview mode from perspective viewpoint using exclusively 2D elements with render time requirements below two minutes.

Figure 23: Image created on preview mode from perspective viewpoint using mainly 2D elements and as 3D elements only the boulders on the lakeshore, with render time requirements above half an hour.

Figure 24: Image created on preview mode from perspective viewpoint using exclusively 2D elements with render time requirements below two minutes.

Figure 25: *Image created on preview mode from perspective viewpoint using mainly 2D elements and as 3D elements only the boulders on the lakeshore, with render time requirements above half an hour.*

For forestry-guided purposes, taking in mind the render time increasing that involves their presence and that any element of the nature can be rendered like 2D object with good visual appearance, 3D elements has been considered dispensable.

Image Objects:

For testing the influence of the number of image objects (number of trees in this case) on rendering, a 39 square kilometres DEM layer (3900 ha) out of Bäcksjön was chosen. For this purpose three different densities (50, 1000 and 2500 stems/ha) were taken and rendered in diverse ways:

- Default rendering.
- Image Objects Distance Dissolve ability enabled.
- Image Objects fast load ability enabled.

Three different viewpoints were used, from an overhead view (viewpoint 1) to a perspective view (viewpoint), going closer to the terrain each time.

Table 3: *Time for rendering in three viewpoints, going closer to the terrain each time, using Default render and Image Object Distance Dissolve tool enabled modes and three densities: 50 stems/hectare (195000 trees), 1000 stems/hectare (3900000 trees) and 2500 stems/hectare (9750000 trees) in minutes and seconds. For guidance use only.*

| | 50 stems/ha | | 1000 stems/ha | | 2500 stems/ha | |
	Default	Dissolve	Default	Dissolve	Default	Dissolve
Viewpoint 1	0,22	0,22	4,17	4,17	9,45	9,45
Viewpoint 2	0,20	0,20	2,18	1,00	4,30	2,00
Viewpoint 3	0,13	0,13	1,00	1,00	2,00	2,00

Higher Image Object densities involve extra render time, as is shown in the table above. The quantity of visible trees affects in the same way too.

The Image Objects Fast Load ability did not produce any noticeable improvement in render speed, having the same time requirements as default mode. Just in higher densities this mode was faster than the default one (15 seconds less, over 9,45 minutes).

Image Object Distance Dissolve ability saved time in most of the cases with a quite good visual results. The default dissolve mode was used, settled in two pixels the dissolving boundary. Overhead viewpoints are not recommendable for using the dissolving capacity owing to all the trees are seen with the same size, that is why it dissolves no tree or all of them (see figures 26 and 27). This tool was found more useful in perspective views from certain altitude, because in that case there are noticeable differences between closer and further tree images.
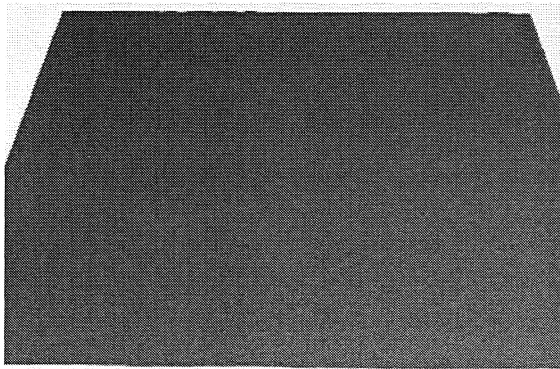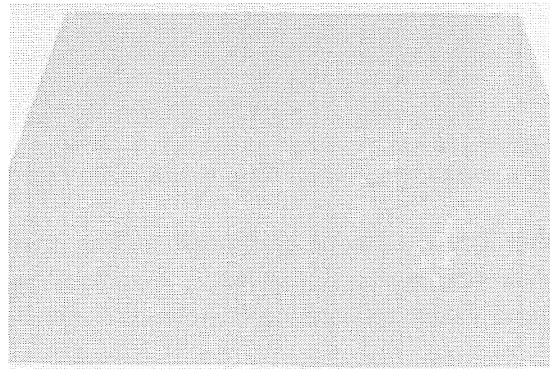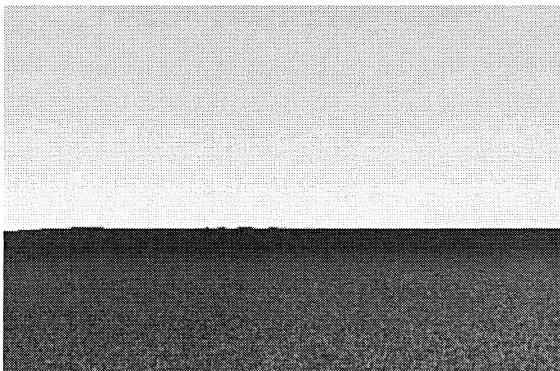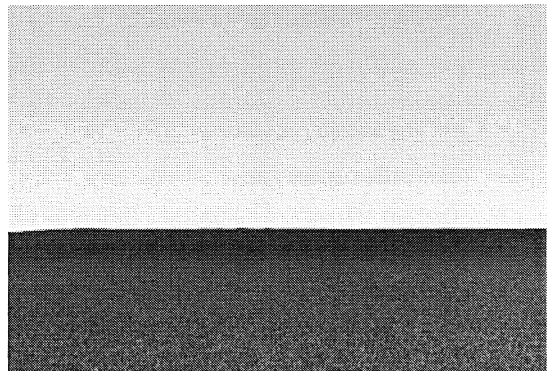

Figure 26

Figure 27

Figure 28

Figure 29

Figure 26: Image taken from perspective viewpoint using Default render mode (Image Object Distance Dissolve disabled) with 2500 stems/hectare density.

Figure 27: Image taken from perspective viewpoint using Image Object Distance Dissolve capability with 2500-stems/hectare density. Due to the viewpoint height the trees were seen smaller than 2 pixels, that is why all the trees were dissolved into the set colour.

Figure 28: Image taken from a viewpoint close to Overhead using Default render mode (Image Object Distance Dissolve disabled) with 2500-stems/hectare density.

Figure 29: Image taken from a viewpoint close to Overhead using Image Object Distance Dissolve capability with 2500-stems/hectare density. At the bottom of the image the trees were dissolved according to the set colour or texture in that case.

Render mode: There are two main render modes: preview render and final render. The final mode has multiple render options of output size, quality, which objects will render, etc. Using the default preview and final renders, the visual quality of the final render is better, and the time requirement is also higher. Usually the final render mode takes at least two times longer for render the same image.

There is an option to make bigger previews (full screen images), but it takes two times longer than the final default one.

Figure 30: Image created using Preview default render mode. Render time: 1 minute.

Figure 31: Image created using Final default render mode (40 of antialiasing, default mode) with 720*480 pixels *resolution. Render time: 2,45 minutes.*

Figure 32: *Image created using Preview default render mode. Render time: 2,08 minutes.*

Figure 33: *Image created using Final default render mode (40 of antialiasing, default mode) with 720*480 pixels resolution. Render time: 4,11 minutes.*
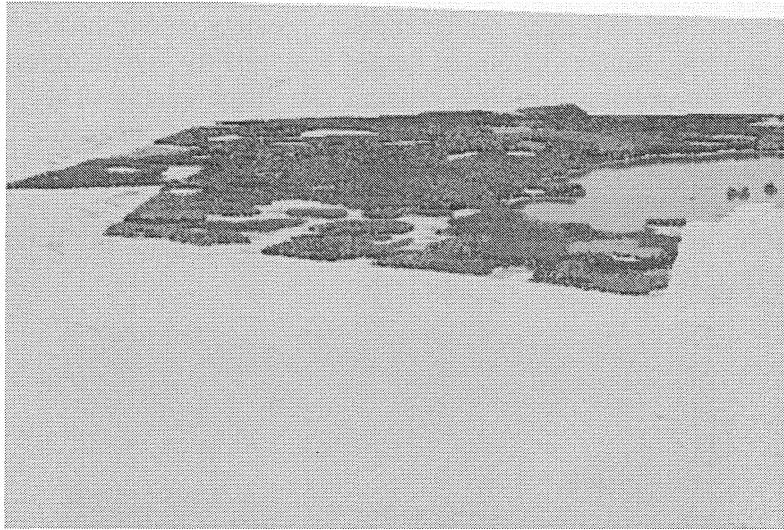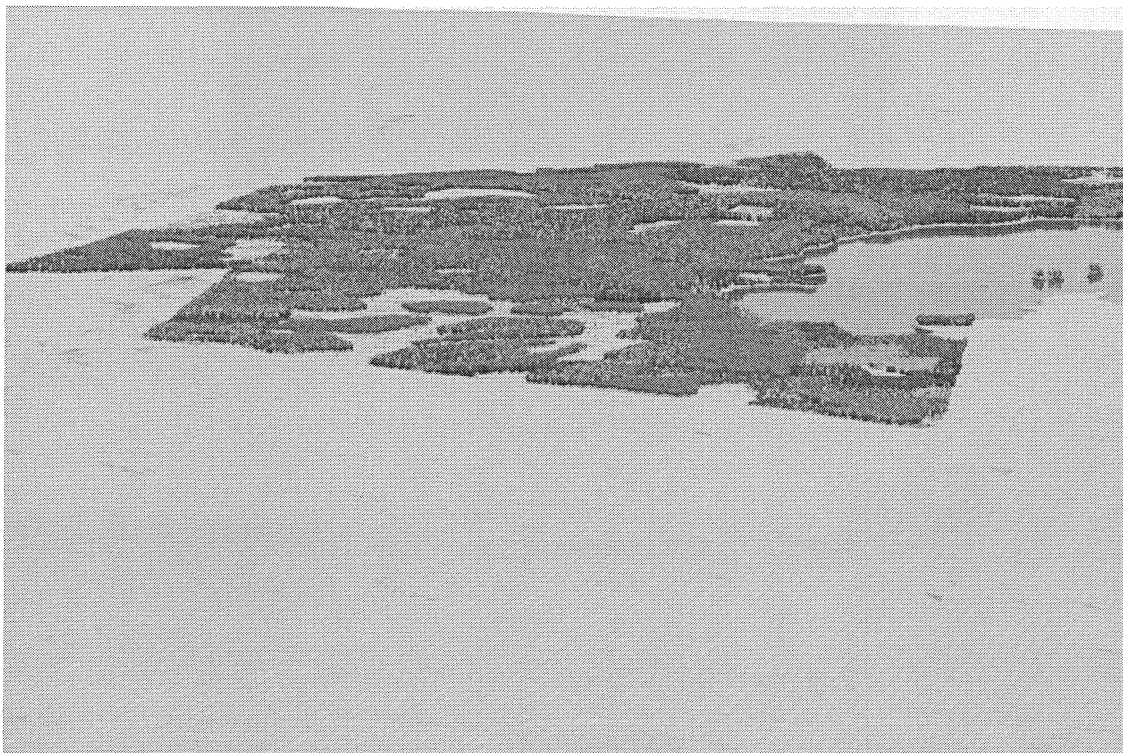
For immediate visualization of forecasts in forestry, normally the preview mode might be enough. In spite of this, the final render can be made in most of the cases with time requirements below 5 minutes.

The default final render size is 720*480 pixels, and increasing this size the time requirements increase also. Using the default final render mode the time requirements were around 5 minutes. Bigger sizes, like 2160*1458 pixels required around 3-4 hours.

24

Bigger rendering was probed but due to the Memory Allocation Failure it was impossible.

Render quality: The final render quality would be improved increasing the antialiasing quality, which also increases the time requirement. The default render quality was 40 of antialiasing (see figure 31) and another rendered image was created using 100 of antialiasing (see figure 34) to compare. In the case study the visual quality was equal, and the required time too

Figure 34: *Image created using Final render mode with 100 of antialiasing.*

Other aspects: Apart of these parameters a faster rendering was noticed, usually about 30 seconds, when the image was rendered keeping the visualization window minimized. It was noticed also, that the viewpoint has an effect on the render time requirements. General views (generally taken from overhead, planimetric of high altitude planimetric views) are the higher time demanding views. On the other hand, closer views takes less time for rendering.

4.3. Image examples

On this section different rendered images are shown, actual situation visualization and forecasted images. Different viewpoints and scales can be seen. ***Onyx tree*** made tree objects have mainly been used, but images with real world tree objects are shown at the end.

Ten stands with a common extension of 89 hectares were analyzed and a forecast for 30 years was made according to the management plan proposals. Although during these 30

years new management plans should be made, with other proposals that will affect to the state of the stands, any other sylvicultural action was not supposed. For the clearcut area plantation the previous species percentage was kept, and 2500 stems per hectare density was supposed.
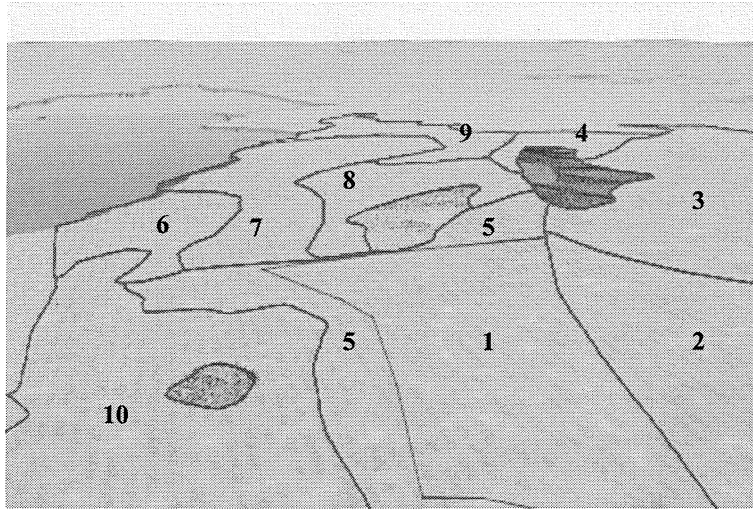

Figure 35: Analyzed stands

The analyzed stands current and forecasted data is shown below.

Table 4: Current and forecasted stand's information with the sylvicultural taken actions; Height in meters and Density in trees per hectare.

| Stand	2003		2033		Action
	Height	Density	Height	Density	
1	0	0	11	2500	Plantation
2	23	561	25	561	No action
3	24	542	26	542	No action
4	19	832	22	560	Thinning (30%)
5	24	596	9	2500	Final cut and Plantation
6	13	1000	19	1000	No action
7	19	800	22	560	Thinning (30%)
8	12	1835	15	1193	Thinning (35%)
9	18	985	21	690	Thinning (30%)
10	14	1356	17	1356	No action

Figure 36: Visualization of stand's current state.

Figure 37: Visualization of forecasted state. Year 2033.

Images shown below where taken in order to show the utility of visualization for illustrating different future scenarios and make decisions consequently. Different thinning

percentages were applied to the foreseen state (plantation of 2500 trees per hectare keeping the same species percentage) of the actual clearcut stand of 5,3 hectare. The used thinning intensities were: 15, 30 and 45%. The images were taken with 720*480 pixels resolution using overhead and perspective (north-south direction) viewpoints. In order to show more clearly the stand situation and for getting faster renderings all the other vectors were disabled. The information about stand density (general and per species) and the tree outputs are shown below the figures.
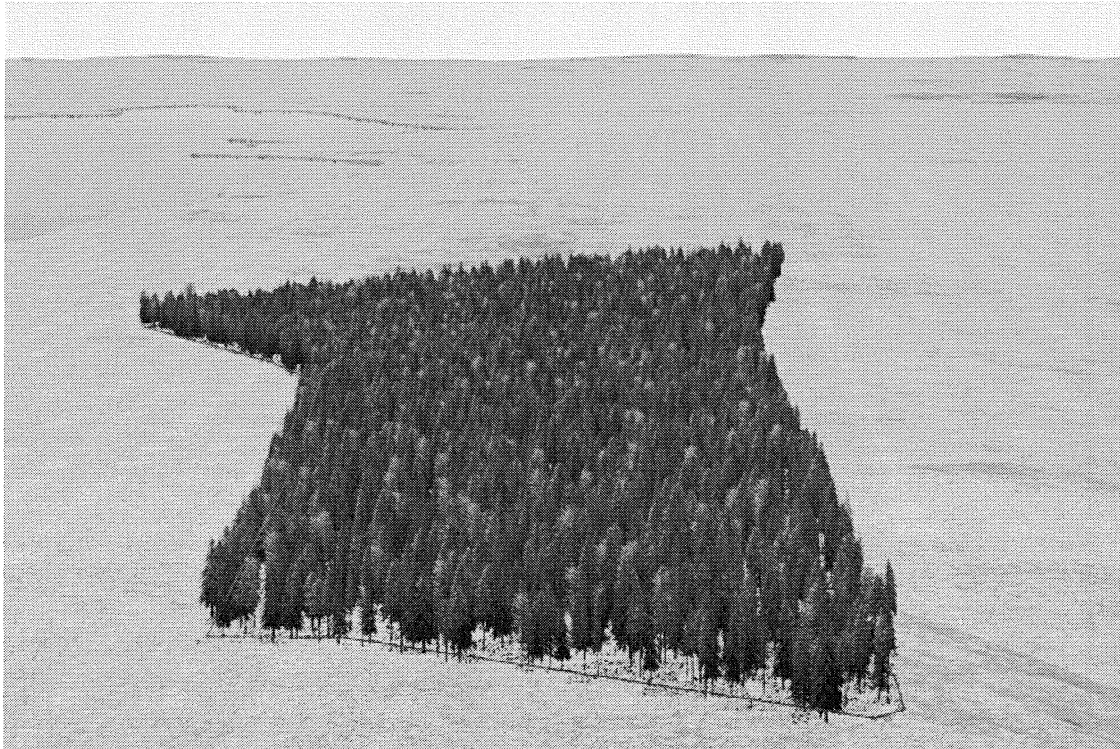
Initial situation:

Density: 2500 tree per hectare.
Picea abies: 70%
Pinus sylvestris: 20%
Betula spp.: 10%
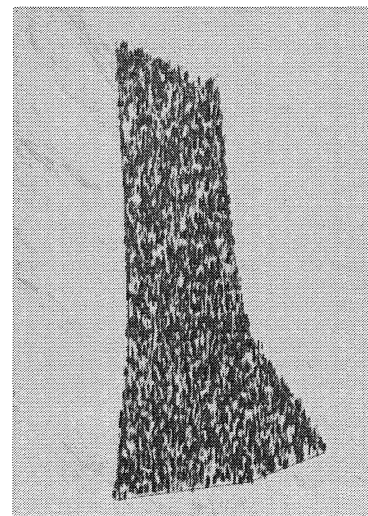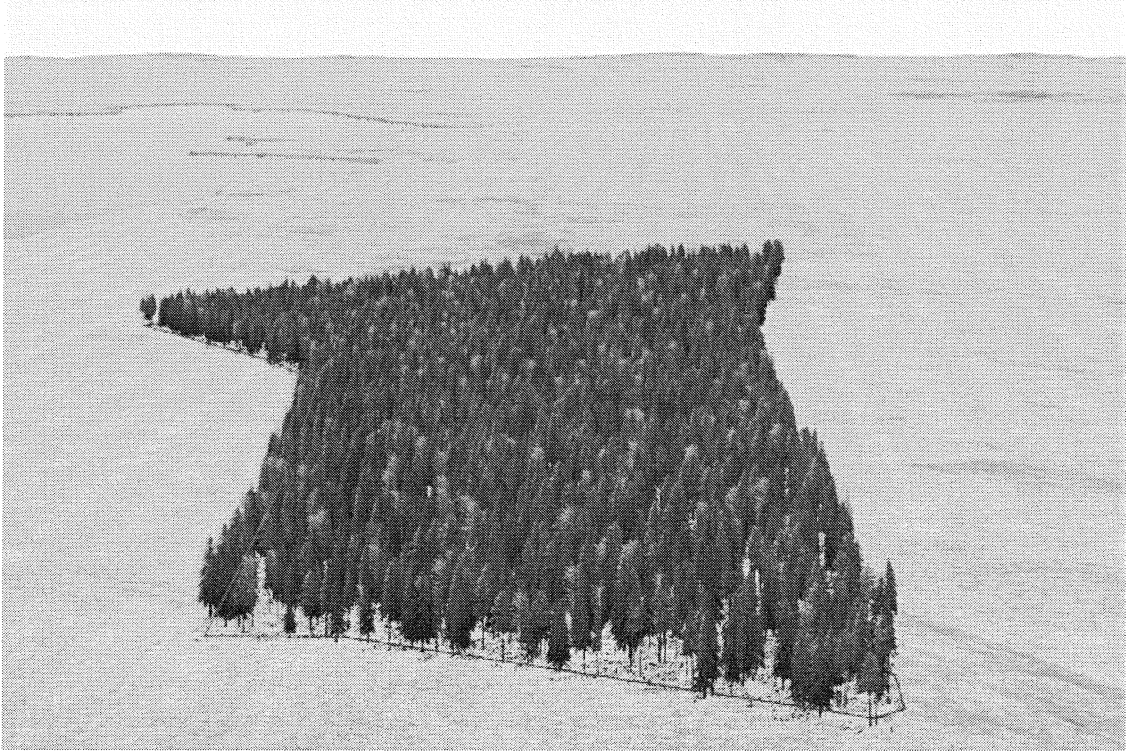
After the thinning of 15%:

     Density: 2125 trees per hectare.
     Outputs: 1988 trees
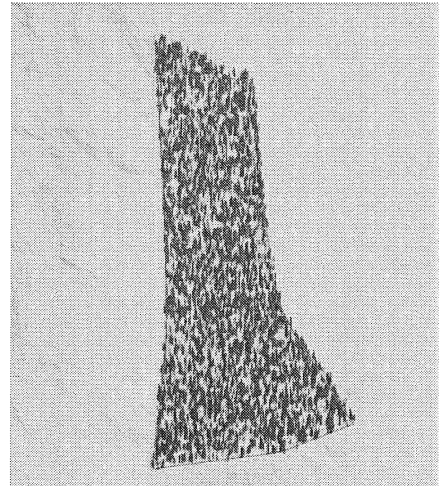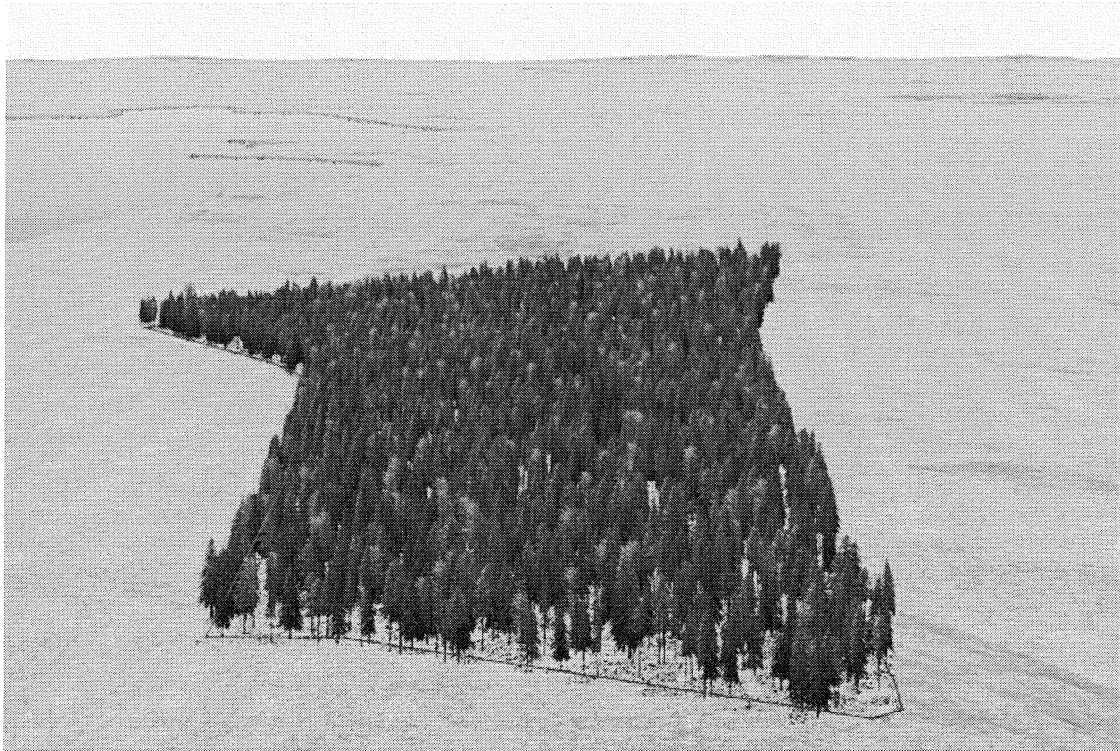
After the thinning of 30%:

Density: 1750 trees per hectare.
Outputs: 3975 trees.
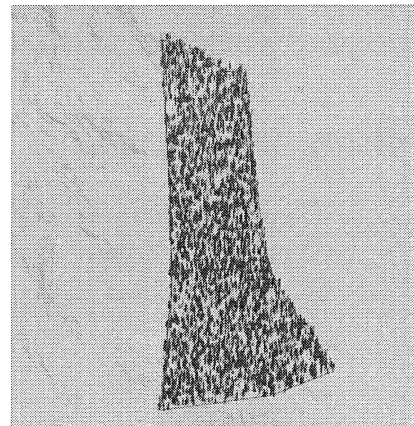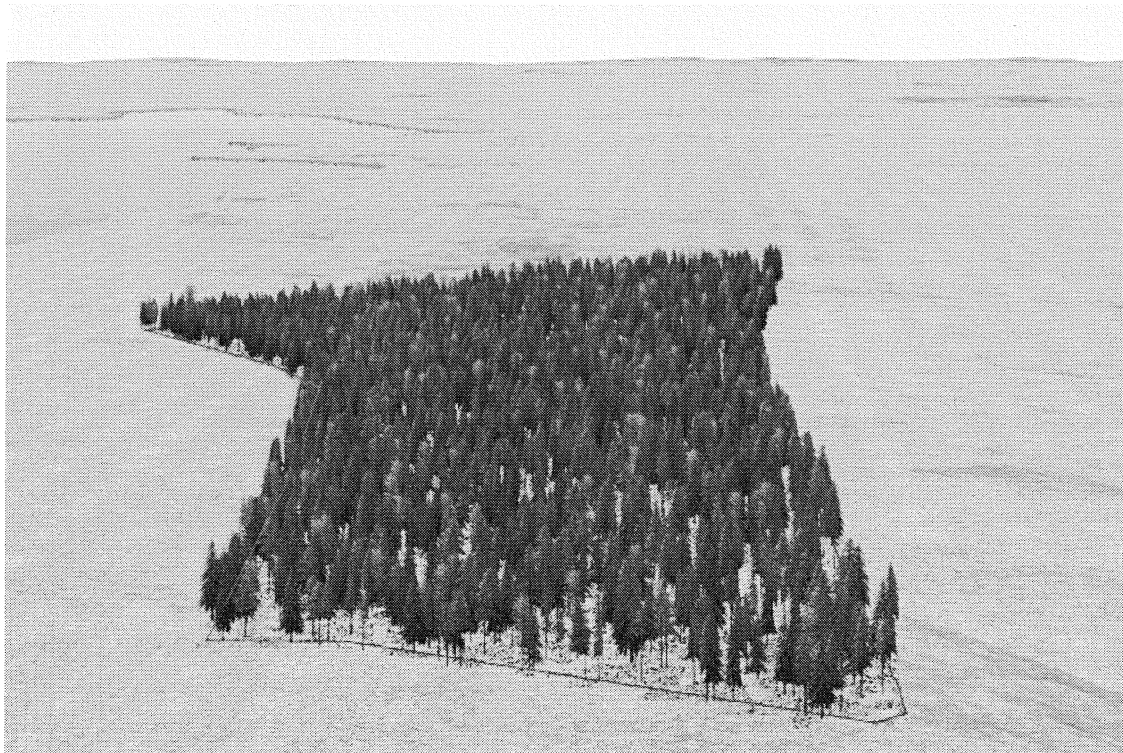
After a thinning of 45%:

        Density: 1375 trees per hectare.
        Outputs: 5962 trees.
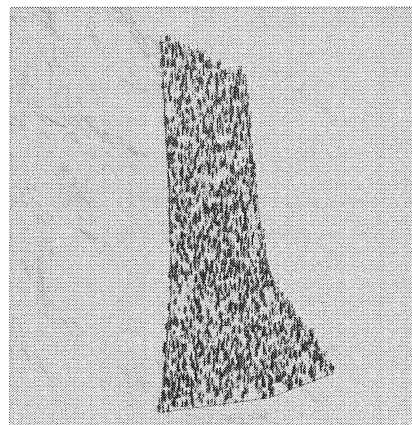
A selective thinning has been forecasted on the same stand as well. In 30 years, 2 selective thinnings with 30% of intensity were supposed. Just *Picea Abies* trees were removed in order to increase the percentage of the other species. The images were taken with 720*480 pixels resolution using overhead and perspective (south-north direction) viewpoints. In order to show more clearly the stand situation and for getting faster renderings all the other vectors were disabled. The information about stand density (general and per species) and the tree outputs are shown below the figures.
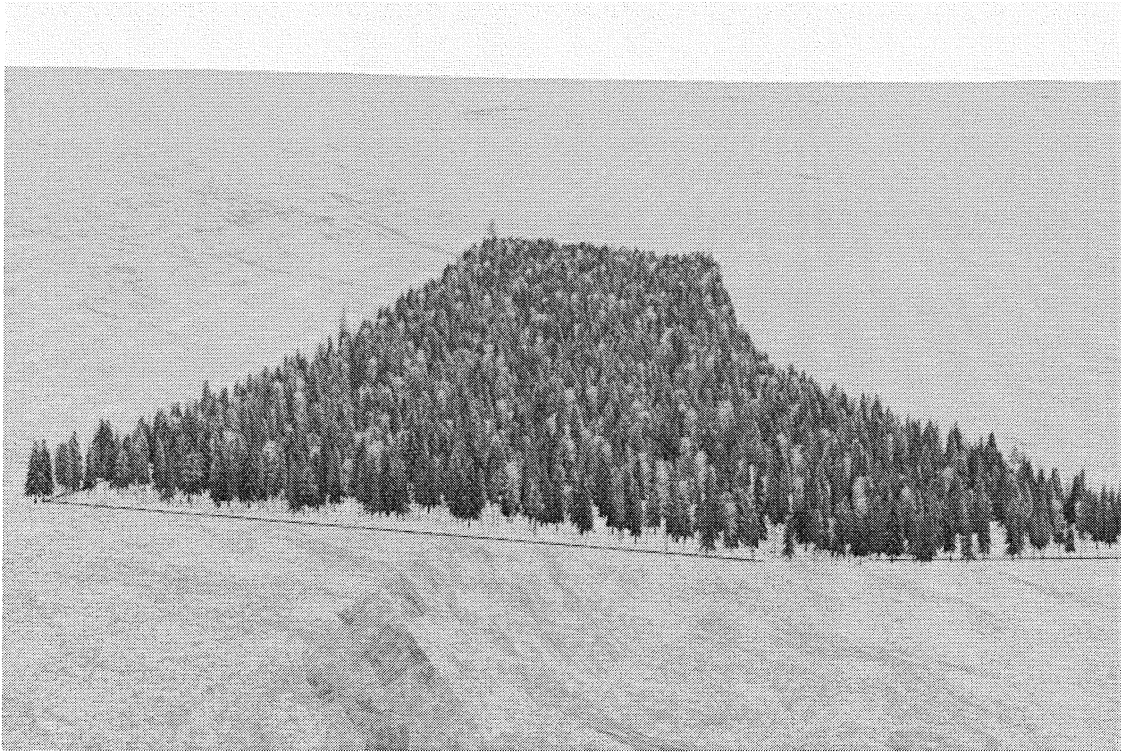
Initial state:

Density: 2500 trees per hectare.

*Picea abies*: 70%
Pinus sylvestris: 20%
Betula spp: 10%
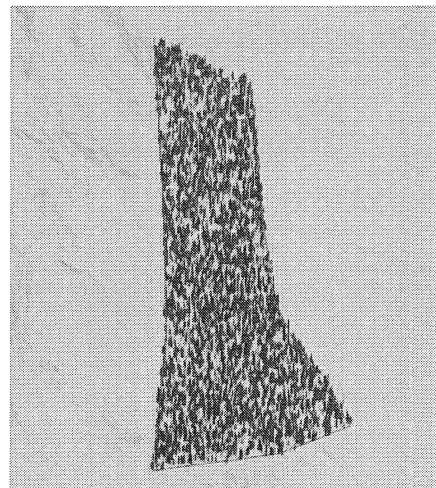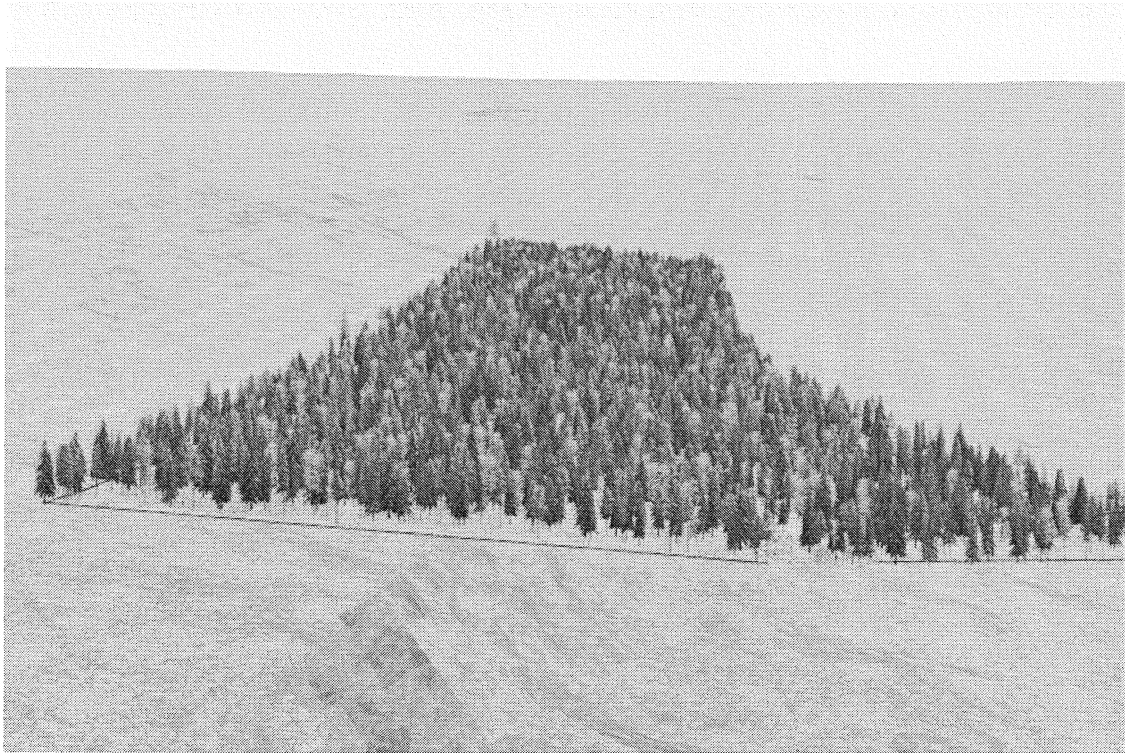
First thinning:

Density: 1750 tree per hectare.

Picea abies: 57%
Pinus sylvestris: 28%
Betula spp: 15%
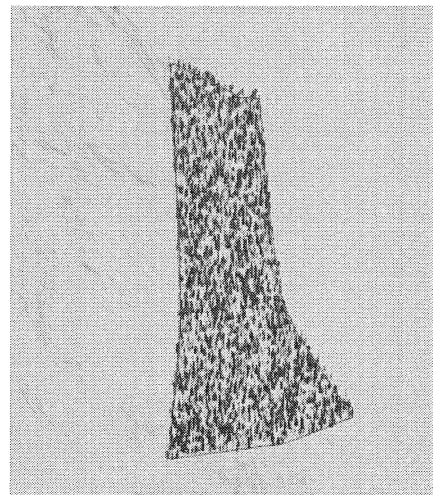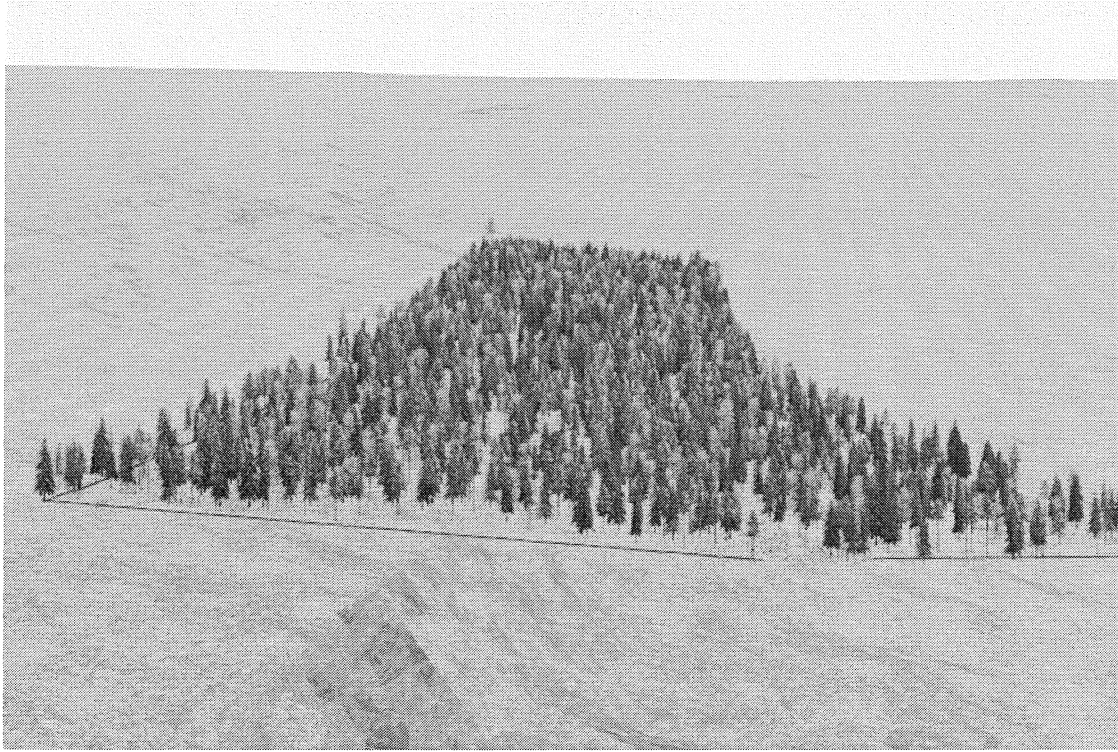
Second thinning:

    Density: 1225 tree per hectare.

    Picea abies: 39%
    Pinus sylvestris: 41%
    Betula spp: 20%
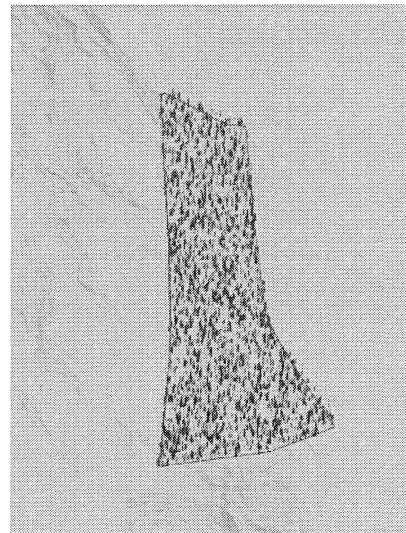
Real world trees images were used as an example to demonstrate the possibilities of this technique to create realistic image objects and show the level of realism obtained in close views compared with the *Onyx tree* made images. Even though the visual realism is good, the improvement margin has been considered large. Besides this, the huge possibilities to create all kind of image objects (trees, rocks, etc.) makes this technique very interesting for image objects database creation and to apply in next visualization projects.

Figure 38: *Image created using perspective viewpoint with real world trees after their edition and importation to VNS2.*

The movies were made using Fractal Maps as the software information recommends. Even though the instability shown by the software creating Fractal Maps and consecutive gaps on the rendered DEMs, the final result was successful as for show a general overview of the estate combining with the still images. The movies were created with 500*333 pixels resolution default camera mode in AVI format using MPEG 4 compression. A stereo movie was made as well.

For movies and more images, see annex 3.

4.4. Possibilities and limitations

The possibilities and limitations of the ***VNS2*** and ***Onyx tree*** software packages will be commented separately but having in mind their combined use.

The possibilities will be related with the utility of the commented softwares, for forest-related purposes and questions not analyzed on this study but considered possible to make or at least interesting to analyze. On the other hand, the limitations will be related mainly with the time and visual realism requirements.

Onyx tree

- **Possibilities:** Makes possible to create all the necessary arboreal vegetation (trees and bushes) for *VNS2* visualization projects. Even though 2D images were used

35

mainly on this project might be interesting to make renderings on *VNS2* using this 3D image objects.

- **Limitations:** A texture editor was missed. Owing to this lack, mainly the trunk of the trees shows very poor realism, which might be a problem on close views. Forestry-guided uses require more general views, or at least over stand views, and on these general views the performance of *Onyx tree* made image objects was successful, especially when the sunlight tool was used.

Other limitation, which is related with the possible use of 3D tree models into *VNS2*, is the large file size of these *Onyx tree* made elements and the huge time requirements it involves. *VNS2* contain 3D elements (i.e. boulders) that are composed of approximately 2112 polygons, when the *Onyx* 3D trees have 1193610 initially and 89008 after minimizing (40 times bigger).

VNS2

- **Possibilities:** The utility of the software depends mainly on the scale of the visualization, even though the utilities are not strictly limited to specific visualization scales. Visualisation could be discussed in relation to three main visual scales: Landscape level, Stand level and Plot level. Due to that landscape level visualization involves large areas (from an estate to a county) at low detail, the software's capability to drape remotely sensed data images over a digital terrain model is useful. The visualization at landscape level provides an overview of the study area; illustrating properties of remotely sensed data and giving a general idea of the land cover structure.

Visualizations at the landscape and stand levels are useful for communicating the general structure of land cover patterns or land cover change, and consequently the visual impact of different sylvicultural actions. This level of visualization is the more interesting for forestry related purposes, owing to the estate is the level of decision and the capability for visualizing the whole estate (i.e. 1000 hectare as in the case study) provides a great advantage in order to illustrate the forecasted results of the actions proposed on the management plan or to show different alternative actions. Spatial analysis is becoming widely used in many aspects of ecological assessment and resource management on forest environments. Tables can show differences representing change in forest landscapes, but for indicating levels of change produced by biotic (pests, etc.) or abiotic (human activities like thinning, clearcut, etc.) variables, using the visualization the information is offering a more accessible way for forest managers, authorities and the public. The improvement communicating this information influences the decision-making, making it easier

The plot level visualization shows the specific structural characteristics of a particular forest plot. More precise changes in forest composition and structure can be shown at this scale, due to the capability for describe relative position and size of individual trees and other landscape components.

Summarizing, the visualization is the easiest way for communicate information about forest visual aspects with all the potentiality that involves.

- **Limitations:** The main limitations of the software are related with the 3D objects render time requirements. Even at low densities takes too long, being not useful for quick visualizations. It would be interesting to provide *VNS2* with a 3D elements distance dissolve tool (like for Image Objects) in order to render just the visible 3D objects.

The software has shown some instability: loss of data, DEM importation problems especially with the coordinate system recognition, projects crushes, etc. Due to this, it would be useful to have the option to save the settings out of the project, in order to reimport if the project crushes saving time in that way.

It is also a bit problematic to make changes in the shapefile tabular data, owing to that it is in DBF format and has to be edited into an Excel format with the consequent format conflict. To update the data it is necessary to restart *VNS2*. The update sometimes has created problems due to the stand data (tree height, density and species percentage) was reimported twice: the old data and the update one. This duplicity of information affects to the consequent render, and the created final image was rendered according to the old data. This problem was resolved disabling or removing the old data vectors.

When forest parameters data is updated the trees are relocated, producing images with different tree locations. Due to this to make realistic forest cover changes tree location data is required.

Even though the texture editor is fine, a capability to create transparent textures to use in electric lines, or fire lanes was missed.

A limitation was encountered attempting to save different viewpoints using the same camera. Using key frames was possible to save viewpoints and render chosen previews, but it was impossible to render the chosen final viewpoint images, just the first one was rendered.

Even though is possible to make growing trees video forecasts, this is limited at a stand level, owing to is just possible to apply animation operations to maximum height, but not to the thematic maps. It would be interesting for forest guided uses to equip the VNS next versions with the capability to link somehow the animation operations and the thematic operations. In that way will be possible to create still forecast videos. It might be possible making large number of forecasted render images (i.e. every year) and after that use a video player with frame sequence capability.

Another limitation was found in the *diagnostic data* window. This tool allows seeing, clicking on the rendered image, some information about the chosen image area: slope, longitude, latitude, component (which ecosystem is), etc. It might be

interesting to be able to see more information, especially information about the forest parameters on the stands: height, density, etc.

Fractal Maps creation has been conflictive, due to its instability. It was difficult the creation of complete fractal maps, causing gaps in the DEMs during the movies.

4. -CONCLUSIONS

This study verifies the validity of 3D computer visualizations for illustrating forest cover forecasts and future scenarios due to alternative actions. The objective of render large forest areas with reasonable time requirements, high visual realism and using actual GIS datasets was fulfilled, validating the usefulness of *VNS2* for forestry related purposes, especially at the estate level. Even though at the beginning the use of 3D elements was supposed, finally has been demonstrated that 2D elements exclusive use provides better time/realism balance.

The ability of better communication that provides the visualization could benefit any kind of forest related data presentation: forest management plans, forest modelling, remote sensing based research resulting in forest compositional or structural classification, ecological studies about diverse impacts, or landscape management.

5. -ACKNOWLEDGEMENTS

6. –REFERENCES

Blaschke,T. and Tiede, D.. 2003. Bridging GIS-base landscape analysis/modelling and 3-D simulation. Is this already 4D? SCHRENK, M. (ed.): CORP 2003 Geo Multimedia 03, CD ROM.

Berry, J.K. 2003. Using 3D landscape Visualization to Simulate Forest Management Impacts. URL:http://www.innovativegis.com/basis/Berry/VF_reading.htm

McGaughey, R.J.Techniques for Visualizing the Appearance of Forest Operations. Journal of Forestry, June 1998.

Berry, J.K., Buckley, D.J., and Ulbritcht, C. 1998. Visualize Realistic Landscapes: 3D Modelling Helps GIS Users Natural Resources, GEOWorld.
URL: http://www.geoplace.com/gw/1998/0898/898vis.asp

Döllner, J., Hinrichs, K. 2000. Computers &Geociences, 26 (2000), 67-76, Elsevier Science Verlag.

Angel, E. Interactive Computer Graphics, a top down approach with OpenGL. 2000. 2nd edition. Addison-Wesley Longman, Inc.

Ervin, S. and Hasbrouck, H. Landscape Modeling, Digital techniques for landscape visualization. 2003. McGraw-Hill.

McDonald, T; Stokes, B. A Forest Landscape Visualization System. 1998. Seventh Annual Conference: Computers in Agriculture Proceedings.

ANNEX 1: Step by step tutorial.

This tutorial is directed to show how to make a vector guided rendering with *VNS2*, and especially how to make it to visualize forest stands. That is why all the tutorial examples are related with the forest *Ecosystem's overstory* (trees). If some difficulties have been founded with the terminology, have a look in *Annex 2: Glossary*.

When you will open *VNS2* program, it will show a window that is possible to follow in order to start a new project. Using this option the project parameters (ground, sky, etc.) will be chosen. Another option is to close this first window and **file→new**. When the new project will be **created&saved** the program will make you an offer to import data.

Required data and importation to VNS: The essential data is the Digital Elevation Model (DEM), and for normal uses it is usually enough with 50m DEM's (the Swedish National Grid resolution). There are different file formats accepted by *VNS*, among those the ESRI ones: Arc ASCII Array, Arc Grid or Arc Export Grid. The first two formats were used and their performance was similar. In the National Swedish Grid there are eight different files into every area file; any of those ".adf" format might be used. Arc ASCII Array files' importing was found simpler considering that there is just one file per area.

The next data requirement will be vector data. It can be imported using different file formats as well, but the most common is the Arc Shapefile. The essential tabular data related with the Shapefile must be:
- Tree height
- Tree density

In case there is more than one specie, percentage or absolute density values per specie will be needed. It has been necessary in our project to introduce a column in the table, specifying the ecosystem (i.e. forest, marsh, water, etc.)

Last, the tree object images are wanted. Although the software package is provided with an extensive image object library, tree image creation software has been used. *VNS* allows different image file formats: IFF, Targa, BMP, PICT, JPEG, TIFF, etc.

More data might be imported later using the "import wizard". The DEM import process is easily done following wizard instructions. On the other hand, vector data imports require better understanding of the data and the how we are going to use it. On the third window we will see is important to check the **Reimport when project loads** box, in order to update automatically the changes we will make on vector data (i.e. a new clearcut area, change the height and density values to zero). On the fifth window the **Conform to the terrain** box will be checked.

The first **Database Fields** window is for **Attributes**. The next "request windows" will depend on your choices in the last Attributes window. The wanted Attributes are in our case the Ecosystem type, **ECOS** (forest, marsh, rocks, etc.), the tree **DENSITY**, tree **HEIGHT** and the different species percentage of total density: **GRAN, TALL,** and **LOV**.

The second **Database Fields** window is for layers. As the Ecosystem type, **ECOS** is a group identifier we will choose it as a layer.

The last **Database Fields** window is for **ID-Name**, so we should choose one value identifier. In our case we have chosen **ID** (stand ID).

Ecosystems creation: Once we have all the necessary data imported, we will start creating *Ecosystems*, which is defined as concrete type of land cover (forest, marsh, rocks, etc.). First of all, the *land cover task mode* will be activated. Then **right-click** and **add component of this type**. After that, go to **material&foliage** tab and create ecotypes making a click: **Overstory** ecotype for trees and **Understory** for the rest of objects (i.e. bushes, rocks, etc.).This will be made for all the different vector data ecosystems.

Ecotypes creation: On the ecotypes editor all the tabs will be checked and some corrections made:

- <u>General tab</u>: Absolute height and density there will continuous being in Ecotype. The density will be changed to **per unit area** (Hectare).
- <u>Ecotype tab</u>: Ecotype height and density will be guided stand-by-stand using *thematic maps* (see **Thematic maps**).
- <u>Groups tab</u>: Foliage groups will be added , if is an overstory→different tree species, one foliage group per specie. *Thematic maps* will be made for group density, in that way every stand will have a concrete percentage of the total density per specie, specified on the vector tabular data (i.e. 20% *Pinus sylvestris* and 80% *Picea abies* of total density: 1500 stems/ha).
- <u>Objects tab</u>: Foliage objects will be added . Then, using *Search new object* located in the dropdown list, the wanted image will be imported from the disk. Every foliage group should have more than at least two foliage objects.

Ecosystems linkage: Once the different ecosystems and ecotypes are made, ecosystems will be linked to the vector data polygons (i.e. stands) in order to visualize their attributes. As an example, on the forest ecosystem editor (double click on the wanted ecosystem icon), general tab, on the *Dynamic link* dropdown list chose *New search query*. Then, the search query window will appear and *selected filter* tab will be selected. After that, on *Attribute field* dropdown list the proper attribute will be chosen, in our project **ECOS**, and after checking the equal (=) box, write the elected value (forest) on *to the value* box.

Thematic maps: Once the ecosystems are linked, turn back to the ecotype edition window (ecosystem→material&foliage tab→edit ecotype: overstory or understory), and ecosystem's height and density will be rendered according to these parameters data using the *thematic maps*. For both parameters, click *create thematic maps* icon. On the *general tab* of the editor, choose the dynamic link on the dropdown list (**ECOS** in our case). Then, on the *data tab*, on the *data channel* dropdown list select the appropriate channel: height or density. To rendered the partial densities of the different species, the same procedure will be made but creating a thematic map on *groups tab, Group density (% of ecotype)*.

ANNEX 2: Glossary

Some of the VNS 2terms used profusely during the report are explained below:

Ecosystem: On VNS 2 ecosystem is used to describe one type of land cover: forest, tundra, marsh, roads, etc. Each ecosystem is divided into 2 Ecotypes: Overstory and Understory.

Ecotype: Image objects group collection into Ecosystems.

Foliage objects: Image objects of whatever individual object rendered into VNS 2, i.e. trees, bushes, sun, etc.

Foliage groups: Group formed by foliage objects of the same characteristics (i.e. tree species, bushes group, rocks, etc).

Overstory: Up level Ecotype (i.e. trees) organized in foliage groups.

Terraffector: Linear or areal displacement effects of VNS 2 applied linked to a vector. Allows to create roads, stream beds, lake beds, mountains, etc.

Thematic maps: Tool that allows to control VNS 2 parameters (i.e. tree height, density, etc.) automatically using attribute values from Shapefila File data.

Understory: Down level Ecotype (i.e. bushes, small plants, etc.) organized in foliage groups

ANNEX 3: Images.

ANNEX 4: CD-Rom.

This CD-Rom contains Tree Image Objects (*Onyx tree* made and photo edited), final render images of some areas of Bäcksjön, and movies.

Serien Arbetsrapporter utges i första hand för institutionens eget behov av viss dokumentation. Rapporterna är indelade i följande grupper: Riksskogstaxeringen, Planering och inventering, Biometri, Fjärranalys, Kompendier och undervisningsmaterial, Examensarbeten samt internationellt. Författarna svarar själva för rapporternas vetenskapliga innehåll.

This series of Working Papers reflects the activity of this Department of Forest Resource Management and Geomatics. The sole responsibility for the scientific content of each Working Paper relies on the respective author.

Riksskogstaxeringen: *(The Swedish National Forest Inventory)*

1995   1   Kempe, G. Hjälpmedel för bestämning av slutenhet i plant- och ungskog.
ISRN SLU-SRG-AR--1--SE

        2   Riksskogstaxeringen och Ståndortskarteringen vid regional miljöövervakning.
- metoder för att förbättra upplösningen vid inventering i skogliga avrinningsområden.
ISRN SLU-SRG-AR--2--SE.

1997 23   Lundström, A., Nilsson, P. & Ståhl, G. Certifieringens konsekvenser för möjliga uttag av industri- och energived. - En pilotstudie. ISRN SLU-SRG-AR--23--SE.

     24   Fridman, J. & Walheim, M. Död ved i Sverige. - Statistik från Riksskogstaxeringen.
ISRN SLU-SRG-AR--24--SE.

1998 30   Fridman, J. & Kihlblom, D. & Söderberg, U. Förslag till miljöindexsystem för naturtypen skog. ISRN SLU-SRG-AR--30--SE.

     34   Löfgren, P. Skogsmark, samt träd- och buskmark inom fjällområdet. En skattning av arealer enligt internationella ägoslagsdefinitioner. ISRN SLU-SRG-AR--34--SE.

     37   Odell, G. & Ståhl, G. Vegetationsförändringar i svensk skogsmark mellan 1980- och 90-talet. -En studie grundad på Ståndortskarteringen. ISRN SLU-SRG-AR--37--SE.

     38   Lind, T. Quantifying the area of edge zones in Swedish forest to assess the impact of nature conservation on timber yields. ISRN SLU-SRG-AR--38--SE.

1999 50   Ståhl, G., Walheim, M. & Löfgren, P. Fjällinventering. - En utredning av innehåll och design. ISRN SLU-SRG--AR--50--SE.

     52   Riksskogstaxeringen inför 2000-talet. - Utredningar avseende innehåll och omfattning i en framtida Riksskogstaxering. Redaktörer: Jonas Fridman & Göran Ståhl.
ISRN SLU-SRG-AR--52--SE.

     54   Fridman, J. m.fl. Sveriges skogsmarksarealer enligt internationella ägoslagsdefinitioner. ISRN SLU-SRG-AR--54--SE.

     56   Nilsson, P. & Gustafsson, K. Skogsskötseln vid 90-talets mitt - läge och trender.
ISRN SLU-SRG-AR--56--SE.

57   Nilsson, P. & Söderberg, U. Trender i svensk skogsskötsel - en intervjuundersökning. ISRN SLU-SRG-AR--57--SE.

1999 61   Broman, N & Christoffersson, J. Mätfel i provträdsvariabler och dess inverkan på precision och noggrannhet i volymskattningar. ISRN SLU-SRG-AR--61--SE.

65   Hallsby, G m.fl. Metodik för skattning av lokala skogsbränsleresurser. ISRN SLU-SRG-AR--65--SE.

75   von Segebaden, G. Komplement till "RIKSTAXEN 75 ÅR". ISRN SLU-SRG-AR--75--SE.

2001 86   Lind, T. Kolinnehåll i skog och mark i Sverige - Baserat på Riksskogstaxeringens data. ISRN SLU-SRG-AR--86--SE

2003 110   Berg Lejon, S. Studie av mätmetoder vid Riksskogstaxeringens årsringsmätning. ISRN SLU-SRG-AR--110--SE.

Inventering och planering: *(Forest inventory and planning)*

1995   3   Holmgren, P. & Thuresson, T. Skoglig planering på amerikanska västkusten - intryck från en studieresa till Oregon, Washington och British Columbia 1-14 augusti 1995. ISRN SLU-SRG-AR--3--SE.

4   Ståhl, G. The Transect Relascope - An Instrument for the Quantification of Coarse Woody Debris. ISRN SLU-SRG-AR--4--SE

1996 15   van Kerkvoorde, M. A sequential approach in mathematical programming to include spatial aspects of biodiversity in long range forest management planning. ISRN SLU-SRG-AR--15--SE.

1997 18   Christoffersson, P. & Jonsson, P. Avdelningsfri inventering - tillvägagångssätt och tidsåtgång. ISRN SLU-SRG-AR--18--SE.

19   Ståhl, G., Ringvall, A. & Lämås, T. Guided transect sampling - An outline of the principle. ISRN SLU-SRGL-AR--19--SE.

25   Lämås, T. & Ståhl, G. Skattning av tillstånd och förändringar genom inventerings-simulering - En handledning till programpaketet "NVSIM". ISRN SLU-SRG-AR--25--SE.

26   Lämås, T. & Ståhl, G. Om dektering av förändringar av populationer i begränsade områden. ISRN SLU-SRG-AR--26--SE.

1999 59   Petersson, H. Biomassafunktioner för trädfraktioner av tall, gran och björk i Sverige. ISRN SLU-SRG-AR--59--SE.

63   Fridman, J., Löfstrand, R & Roos, S. Stickprovsvis landskapsövervakning - En förstudie. ISRN SLU-SRG-AR--63--SE.

2000 68 Nyström, K. Funktioner för att skatta höjdtillväxten i ungskog.
ISRN SLU-SRG-AR--68--SE.

70 Walheim, M. & Löfgren, P. Metodutveckling för vegetationsövervakning i fjällen.
ISRN SLU-SRG-AR--70--SE.

73 Holm, S. & Lundström, A. Åtgärdsprioriteter. ISRN SLU-SRG-AR--73--SE.

76 Fridman, J. & Ståhl, G. Funktioner för naturlig avgång i svensk skog.
ISRN SLU-SRG-AR--76--SE.

2001 82 Holmström, H. Averaging Absolute GPS Positionings Made Underneath Different
Forest Canopies - A Splendid Example of Bad Timing in Research.
ISRN SLU-SRG-AR--79--SE.

2002 91 Wilhelmsson, E. Forest use and its economic value for inhabitants of Skröven and
Hakkas in Norrbotten. ISRN SLU-SRG-AR--91--SE.

94 Eriksson, O. m fl. Wood Supply From Swedish Forests Managed According to the
FSC-standard. ISRN SLU-SRG-AR--94--SE.

Biometri: *(Biometrics)*

1997 22 Ali, Abdul Aziz. Describing Tree Size Diversity. ISRN SLU-SRG-AR--22--SE.

1999 64 Berhe, L. Spatial continuity in tree diameter distribution.
ISRN SLU-SRG-AR--64--SE

2001 88 Ekström, M. Nonparametric Estimation of the Variance of Sample Means Based on
Nonstationary Spatial Data. ISRN SLU-SRG-AR--88--SE.

89 Ekström, M. & Belyaev, Y. On the Estimation of the Distribution of Sample Means
Based on Non-Stationary Spatial Data. ISRN SLU-SRG-AR--89--SE.

90 Ekström, M. & Sjöstedt-de Luna, S. Estimation of the Variance of Sample Means
Based on Nonstationary Spatial Data with Varying Expected Values.
ISRN SLU-SRG-AR--90--SE.

2002 96 Norström,F. Forest inventory estimation using remotely sensed data as a stratification
tool - a simulation study. ISRN SLU-SRG-AR--96--SE.

Fjärranalys: *(Remote Sensing)*

1997 28 Hagner, O. Satellitfjärranalys för skogsföretag. ISRN SLU-SRG-AR--28--SE.

29 Hagner, O. Textur till flygbilder för skattning av beståndsegenskaper.
ISRN SLU-SRG-AR--29--SE.

1998 32 Dahlberg, U., Bergstedt, J. & Pettersson, A. Fältinstruktion för och erfarenheter från vegetationsinventering i Abisko, sommaren 1997. ISRN SLU-SRG-AR--32--SE.

43 Wallerman, J. Brattåkerinventeringen. ISRN SLU-SRG-AR--28--SE.

1999 51 Holmgren, J., Wallerman, J. & Olsson, H. Plot - Level Stem Volume Estimation and Tree Species Discrimination with Casi Remote Sensing.
ISRN SLU-SRG-AR--51--SE.

53 Reese, H. & Nilsson, M. Using Landsat TM and NFI data to estimate wood volume, tree biomass and stand age in Dalarna. ISRN SLU-SRG-AR--53--SE.

2000 66 Löfstrand, R., Reese, H. & Olsson, H. Remote Sensing aided Monitoring of Non-Timber Forest Resources - A literature survey. ISRN SLU-SRG-AR--66--SE.

69 Tingelöf, U & Nilsson, M.Kartering av hyggeskanter i pankromaötiska SPOT-bilder.
ISRN SLU-SRG-AR--69--SE.

79 Reese, H & Nilsson, M. Wood volume estimations for Älvsbyn Kommun using SPOT satellite data and NFI plots. ISRN SLU-SRG-AR--79--SE.

2003 106 Olofsson, K. TreeD version o.8. An Image Processing Application for Single Tree Detection. ISRN SLU-SRG-AR--106--SE.

112 Proceedings of the ScandLaser Scientific Workshop on Airborne Laser Scanning of Forests. September 3 & 4, 2003. Umeå, Sweden. Edited and organised by J. Hyyppä, E.Naesset, H. Olsson, T. Granqvist Pahlén and H. Reese.
ISRN SLU-SRG-AR--112--SE.

114 Manterola Matxain, I. Computer Visualization of forest development scenarios in Bäcksjön estate. ISRN SLU-SRG-AR--114--SE.

Kompendier och undervisningsmaterial: *(Compendia and educational papers)*

1996 14 Holm, S. & Thuresson, T. samt jägm.studenter kurs 92/96. En analys av skogstill-ståndet samt några alternativa avverkningsberäkningar för en del av Östads säteri.
ISRN SLU-SRG-AR--14--SE.

21 Holm, S. & Thuresson, T. samt jägm.studenter kurs 93/97. En analys av skogsstill-ståndet samt några alternativa avverkningsberäkningar för en stor del av Östads säteri. ISRN SLU-SRG-AR--21--SE.

1998 42 Holm, S. & Lämås, T. samt jägm.studenter kurs 93/97. An analysis of the state of the forest and of some management alternatives for the Östad estate.
ISRN SLU-SRG-AR--42--SE

1999 58 Holm, S. samt studenter vid Sveriges lantbruksuniversitet i samband med kurs i strate-gisk och taktisk skoglig planering år 1998. En analys av skogsstillståndet samt några alternativa avverknings beräkningar för Östads säteri. ISRN SLU-SRG-AR--58--SE.

2001 87 Eriksson, O. (Ed.) Strategier för Östads säteri: Redovisning av planer framtagna under kursen Skoglig planering ur ett företagsperspektiv HT2000, SLU Umeå. ISRN SLU-SRG-AR--87--SE..

2002 93 Lind, T. (Ed.) Strategier för Östads säteri: Redovisning av planer framtagna under kursen Skoglig planering ur ett företagsperspektiv HT2001, SLU Umeå. ISRN SLU-SRG-AR--93--SE..

Examensarbeten: *(Theses by Swedish forestry students)*

1995 5 Törnquist, K. Ekologisk landskapsplanering i svenskt skogsbruk - hur började det?. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--5--SE.

1996 6 Persson, S. & Segner, U. Aspekter kring datakvaliténs betydelse för den kortsiktiga planeringen. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--6--SE.

7 Henriksson, L. The thinning quotient - a relevant description of a thinning? Gallringskvot - en tillförlitlig beskrivning av en gallring? Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--7--SE.

8 Ranvald, C. Sortimentsinriktad avverkning. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--8--SE.

9 Olofsson, C. Mångbruk i ett landskapsperspektiv - En fallstudie på MoDo Skog AB, Örnsköldsviks förvaltning. Examensarbete i ämnet skogsuppskattning och skogs- indelning. ISRN SLU-SRG-AR--9--SE.

10 Andersson, H. Taper curve functions and quality estimation for Common Oak (Quercus Robur L.) in Sweden. Examensarbete i ämnet skogsuppskattning och skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--10--SE.

11 Djurberg, H. Den skogliga informationens roll i ett kundanpassat virkesflöde. - En bakgrundsstudie samt simulering av inventeringsmetoders inverkan på noggrannhet i leveransprognoser till sågverk. Examensarbete i ämnet   skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--11--SE.

12 Bredberg, J. Skattning av ålder och andra beståndsvariabler - en fallstudie baserad på MoDo:s indelningsrutiner. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--12--SE.

13 Gunnarsson, F. On the potential of Kriging for forest management planning. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--13--SE.

16 Tormalm, K. Implementering av FSC-certififering av mindre enskilda markägares skogsbruk. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--16--SE.

1997 17   Engberg, M. Naturvärden i skog lämnad vid slutavverkning. - En inventering av upp
             till 35 år gamla föryngringsytor på Sundsvalls arbetsomsåde, SCA. Examensarbete i
             ämnet skogsuppskattning och skogsindelning. ISRN-SLU-SRG-AR--17--SE.

      20   Cedervind, J. GPS under krontak i skog. Examensarbete i ämnet skogsuppskattning
             och skogsindelning. ISRN SLU-SRG-AR--20--SE.

      27   Karlsson, A. En studie av tre inventeringsmetoder i slutavverkningsbestånd.
             Examensarbete. ISRN SLU-SRG-AR--27--SE.

1998 31   Bendz, J. SÖDRAs gröna skogsbruksplaner. En uppföljning relaterad till SÖDRAs
             miljömål, FSC's kriterier och svensk skogspolitik. Examensarbete.
             ISRN SLU-SRG-AR--31--SE.

      33   Jonsson, Ö. Trädskikt och ståndortsförhållanden i strandskog. - En studie av tre bäckar
             i Västerbotten. Examensarbete. ISRN SLU-SRG-AR--33--SE.

      35   Claesson, S. Thinning response functions for single trees of Common oak (Quercus
             Robur L.) Examensarbete. ISRN SLU-SEG-AR--35--SE.

      36   Lindskog, M. New legal minimum ages for final felling. Consequences and forest
             owner attitudes in the county of Västerbotten. Examensarbete.
             ISRN SLU-SRG-AR--36--SE.

      40   Persson, M. Skogsmarksindelningen i gröna och blå kartan - en utvärdering med
             hjälp av riksskogstaxeringens provytor. Examensarbete. ISRN SLU-SRG-AR--40--SE.

      41   Eriksson, F. Markbaserade sensorer för insamling av skogliga data - en förstudie.
             Examensarbete. ISRN SLU-SRG-AR--41--SE.

      45   Gessler, C. Impedimentens potientiella betydelse för biologisk mångfald. - En studie av
             myr- och bergimpediment i ett skogslandskap i Västerbotten. Examensarbete.
             ISRN SLU-SRG-AR--45--SE.

      46   Gustafsson, K. Långsiktsplanering med geografiska hänsyn - en studie på Bräcke
             arbetsområde, SCA Forest and Timber. Examensarbete. ISRN SLU-SRG-AR--46--SE.

      47   Holmgren, J. Estimating Wood Volume and Basal Area in Forest Compartments by
             Combining Satellite Image Data with Field Data. Examensarbete i ämnet Fjärranalys.
             ISRN SLU-SRG-AR--47--SE.

      49   Härdelin, S. Framtida förekomst och rumslig fördelning av gammal skog.
             - En fallstudie på ett landskap i Bräcke arbetsområde. Examensarbete SCA.
             ISRN SLU-SRG-AR--49--SE.

1999 55   Imamovic, D. Simuleringsstudie av produktionskonsekvenser med olika miljömål.
             Examensarbete för Skogsstyrelsen. ISRN SLU-SRG-AR--55--SE

      62   Fridh, L. Utbytesprognoser av rotstående skog. Examensarbete i skoglig planering.
             ISRN SLU-SRG-AR--62--SE.

2000 67 Jonsson, T. Differentiell GPS-mätning av punkter i skog. Point-accuracy for differential GPS under a forest canaopy. ISRN SLU-SRG-AR--67--SE.

71 Lundberg, N. Kalibrering av den multivariata variabeln trädslagsfördelning. Examensarbete i biometri. ISRN SLU-SRG-AR--71--SE.

72 Skoog, E. Leveransprecision och ledtid - två nyckeltal för styrning av virkesflödet. Examensarbete i skoglig planering. ISRN SLU-SRG-AR--72--SE.

74 Johansson, L. Rotröta i Sverige enligt Riksskogstaxeringen. Examens arbete i ämnet skogsindelning och skogsuppskattning. ISRN SLU-SRG-AR--74--SE.

77 Nordh, M. Modellstudie av potentialen för renbete anpassat till kommande slut-avverkningar. Examensarbete på jägmästarprogrammet i ämnet skoglig planering. ISRN SLU-SRG-AR--77--SE.

78 Eriksson, D. Spatial Modeling of Nature Conservation Variables useful in Forestry Planning. Examensarbete. ISRN SLU-SRG-AR--74--SE.

81 Fredberg, K. Landskapsanalys med GIS och ett skogligt planeringssystem. Examensarbete på skogsvetarprogrammet i ämnet skogshushållning. ISRN SLU-SRG-AR--81--SE.

2001 83 Lindroos, O.Underlag för skogligt länsprogram Gotland. Examensarbete i ämnet skoglig planering. ISRN SLU-SRG-AR--83-SE.

84 Dahl, M. Satellitbildsbaserade skattningar av skogsområden med röjningsbehov. Examensarbete på akogsvetarprogrammet i ämnet skoglig planering. ISRN SLU-SRG-AR--84--SE.

85 Staland, J. Styrning av kundanpassade timmerflöden - Inverkan av traktbankens stlorlek och utbytesprognosens tillförlitlighet. Examensarbete i ämnet skoglig plane ring.I SRN SLU-SRG-AR--85--SE.

2002 92 Bodenhem, J. Tillämpning av olika fjärranalysmetoder för urvalsförfarandet av ungskogsbestånd inom den enkla älgbetesinventeringen (ÄBIN). Examensarbete på skogsvetarprogrammet i ämnet fjärranalys. ISRN SLU-SRG-AR--92--SE.

95 Sundquist, S. Development of a measure of production density for the Swedish National Forest Inventory. ISRN SLU-SEG-AR--95--SE.

98 Söderholm, J. De svenska skogsbolagens system för skoglig planering. *The planning system of Swedish forest companies.* Examensarbete på skogsvetarprogrammet i ämnet skoglig planering. ISRN SLU-SRG-AR--98--SE.

99 Nordin, D. Fastighetsgränser. Del 1. Fallstudie av fastighetsgränsers lägesnoggrannhet på fastighetskartan. Examensarbete på skogliga magisterprogrammet i ämnet skogs-hushållning med inriktning skoglig planering. ISRN SLU-SRG-AR--99--SE.

100   Nordin, D. Fastighetsgränser. Del 2. Instruktion för gränsvård. Examensarbete på skogliga magisterprogrammet i ämnet skoghushållning med inriktning skoglig planering. ISRN SLU-SRG-AR--100--SE.

101   Nordbrant, A. Analyser med Indelningspaketet av prIvata skogsfastigheter inom Norra Skogsägarnas verksamhetsområde. Examensarbete på skogsvetarprogrammet i ämnet skoglig planering. ISRN SLU-SRB-AR--101--SE.

2003 102   Wallin, M. Satellitbildsanalys av gremmeniellaskador med skogsvårdsorganisationens system. Examensarbete på skogsvetarprogrammet i ämnet skogshushållning med inriktning fjärranalys. ISRN SLU-SRG-AR--102--SE.

103   Hamilton, A. Effektivare samråd mellan rennäring och skogsbruk - förbättrad dialog via ett utvecklat samrådsförfarande. More effective consultations between reindeer herding and forestry - improved dialog by a developed constultation process. Examens arbete på skogsvetarprogrammet i ämnet skoghushållning.
ISRN SLU-SRG-AR--103--SE.

104   Hajek, F. Mapping of Intact Forest Landscapes in Sweden according to Global Forest Watch methodology. MSc Thesis in forest Resource management, specialization in remote sensing. ISRN SLU-SRG-AR--104--SE.

105   Anerud, E. Kalibrering av ståndortsindex i beståndsregister - en studie åt Holmen Skog AB. Examensarbete på skogsvetarprogrammet i ämnet skoglig planering.
ISRN SLU-SRG-AR--105--SE.

107   Pettersson, L. Skördarnavigering kring skyddsvärda objekt med GPS-stöd. Examensar bete på skogsvetarprogrammet i ämnet skogshushållning.
ISRN SLU-SRG--AR--107--SE.

108   Paz von Friesen, C. Inverkan på provytans storlek på regionala skattningar av skogs typer. En studie av konsekvenser för uppföljning av miljömålen. Examensarbete i ämnet skogshushållning. ISRN SLU-SRG-AR--108--SE.

109   Östberg, P-A. Försök med subjektiva metoder för datainsamling och analys av hur fel i data påverkar åtgärdsförslagen. Examensarbete i ämnet skogshushållning.
ISRN SLU-SRG-AR--109--SE.

111   Hansson, J. Vad tycker bilister om vägnära skogar- två enkätstudier. Examensarbete i ämnet skogshushållning. ISRN SLU-SRG-AR--111--SE.

113   Eriksson, P. Renskötseln i Skandinavien. Förutsättningar för sambruk och konflikt-hantering. Examensarbete i ämnet skogshushållning med inriktning skoglig planering. ISRN SLU-SRG--AR--113--SE.

Internationellt: (*International issues*)

1998   39   Sandewall, Ohlsson, B & Sandewall, R.K. People´s options on forest land use - a research study of land use dynamics and socio-economic conditions in a historical perspective in the Upper Nam Nan Water Catchment Area, Lao PDR.
ISRN SLU-SRG-AR--39--SE.

       44   Sandewall, M., Ohlsson, B., Sandewall, R.K., Vo Chi Chung, Tran Thi Binh & Pham Quoc Hung. People´s options on forest land use. Government plans and farmers intentions - a strategic dilemma. ISRN SLU-SRG-AR--44--SE.

       48   Sengthong, B. Estimating Growing Stock and Allowable Cut in Lao PDR using Data from Land Use Maps and the National Forest Inventory (NFI). Masters thesis.
ISRN SLU-SRG-AR--48--SE.

1999   60   Inter-active and dynamic approaches on forest and land-use planning - proceedings from a training workshop in Vietnam and Lao PDR, April 12-30, 1999.
.   Edited by Mats Sandewall ISRN SLU-SRG-AR--60--SE.

2000   80   Sawathvong. S. Forest Land Use Planning in Nam Pui National Biodiversity Conservation Area, Lao P.D.R. ISRN SLU-SRG-AR--80--SE.