SATELLITE DATA TIME SERIES FOR FORECASTING, HABIAT MODELLING AND VISUALISATION OF THE MANAGED BOREAL FOREST LANDSCAPE

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ABSTRACT:

Satellite data of Landsat and SPOT type are operationally used in Sweden for nationwide forest mapping; for detection of clear felled areas and for checking the need for deciduous shrub cleaning in young forest plantations. The data are also used by the Sami people for mapping areas of interest for reindeer grazing. The Swedish forest agency has since 1999 acquired a yearly and nationwide set of images. These images will, together with some older Landsat data collected between 1972 and 1998 and similar future data sets, be made available freely over internet. A similar data policy for Landsat data has recently also been introduced by USGS in USA. In this paper, we give three early examples where we explore the utility of using time series of image data for applications that are related to those that are already operational. In the first example, it is shown that the accuracy for satellite data based forest estimates, trained with national forest inventory field plots, is marginally improved when data from a second time point is added. In the second example, it is shown that young forest plantations can be much better characterised by using data from a series of yearly images than by only using the latest image. In the third example, it is illustrated how a forest data base made from a time series of images, can be used as basis for an economic model that simulates future forest actions, given strictly economic priorities and how such simulations can be used to study the potential impacts on other interests, in this case food resources for reindeer.

1. INTRODUCTION

The general aim of this conference contribution is to outline the potential of using time series of Landsat / SPOT and similar satellite data, in combinations with models, for simulating the forest landscape development. The examples are from the managed boreal forest landscape in Sweden. As a background the role of satellite data as information sources in the Swedish forest sector is reviewed.

1.1 The clear felling practise creates the future landscape but the consequences are not much studied

Sweden has 22 million ha of forest land, which is managed for the production of timber and pulp wood. This is 80 % of the total forest area (according to FAO definitions) and 54 % of the total land area in the country. More than 90 % of the stem volume of forest wood comes from only three species: Norway Spruce *(picea abies)*, Scots Pine *(pinus sylvestris)*, and Birch *(Betula spp.)*. The forest practice in the managed forests is almost exclusively clear felling of stands after about 100 years, preceded by a few thinning cuttings. The stand size is most often in the order of 1-10 ha. Since the same species that are native in the country are re-planted, and since there is a considerable natural re-generation of trees as well, the Swedish forest landscape can be considered as semi-natural. In most of the country, the clear felling practice has not yet lasted for a full 100 years rotation period. Even if the well maintained forest statistics shows an increasing stem volume on national level, the consequences of the total landscape pattern when a full rotation of forestry practice with clear fellings, implemented by a large number of independent forest owners, is very little studied. Furthermore, it is little studied how alternative management actions taking by the land owners today might influence the future landscape qualities for humans, as well as plant and animal species.

1.2 The use of remote sensing for obtaining information about the forest

1.2.1 Information supply for the forest owners: All production forest in Sweden is managed as private enterprises, including the state owned forests. Forest stand maps in the scale of 1:10 000 are traditionally used as part of the forest management plan for each estate. The maps are made by a combination of aerial photo interpretation and field work. The forest maps are the private property of the forest owners, and thus, they cannot be used to obtain a landscape overview that covers several estates.
Half of the Swedish forest land is owned by a few large industrial companies. These companies acquire some remote sensing information on their own, mostly air photos, but laser scanning is also being introduced as a commercial method for forest inventory in the Scandinavian countries (Næsset et al., 2004). Also SPOT satellite data are used to some degree, for example for updating forest maps and checking young forests that might be in need of pre-commercial thinning of deciduous shrubs.

1.2.2 The national forest inventory and satellite data estimates based on it: The information about the nations forest resources that is needed for an adequate forest policy has since 1923 been obtained by the national forest inventory (NFI) which is carried out by the Swedish University of Agricultural Sciences (SLU). The NFI is a purely field sample plot inventory with a strict statistical design. At present, about 10 000, 10m or 8m radius, sample plots are field measured yearly. About 200 variables are measured for each plot and the locations are record by GPS.

The NFI plots have also been used as ground truth for various nationwide remote sensing products produced by SLU. The forest pixels in the Swedish part of the European CORINE land cover data base, including a more detailed national version called “GSD Marktäcke” where obtained by maximum likelihood classification trained by NFI plots. Since the NFI plots are representative for the landscape composition, the prior probabilities for the classes could be iterated until the class frequency within each satellite scene where equal to the corresponding frequency for the NFI plots in the scene (Hagner and Reese, 2007).

The same NFI plots and satellite data with base year 2000, where used for an additional product called kNN Sweden 2000. In this product, the forest recourses for each pixels in terms of stem volume per tree species is described with continues numbers for each variable instead of a few discrete classes. The name kNN reefers to the *k* Nearest Neighbour method, which Finnish researchers (Killki and Päivinen, 1987) have introduced for combining forest plot data with satellite data.

Following the success of the kNN Sweden 2000 product, a new product with base year 2005 for the image data is presently being finalised. Instead of Landsat TM scenes, SPOT scenes are used this time. This product is further described in section 2.5 below.

Since there are no recent, publically available, traditional forest maps, and since the vegetation maps are old and only cover 40 % of the country, the satellite data products trained by NFI plots are actually the best spatially explicit descriptions of the nations forest resources that exist. The satellite data estimates are however not considered accurate enough for operational forest management, and are therefore mainly used by authorities for obtaining an overview of the landscape composition.

1.2.3 Yearly verification of cuttings and follow on products at the Swedish Forest Agency: The Swedish Forest Agency has the role to supervise the forest owners and to ensure that they follow the forest law. Before they clearfell an area, forest owners have to send in requests for cutting permits. In order to later verify that the correct areas are cut, and to determine the year of cutting for later follow up of regeneration success, the Forest Agency has since 1999 acquired a yearly set of satellite images of Landsat / SPOT –type. The images are being interpreted in combination with the cutting permits in a tailor made PC application. In total, about 50 000 clearfelled areas yearly are being checked, edited, and labelled with the year of cutting. The existence of this “bred and butter” application at the Forest Agency has also resulted in ad-on applications. One of them is the use of for detection of young forest plantations where deciduous shrubs might hinder the development of the coniferous plants.

1.2.4 Mapping of areas of interest for reindeer herding: Parts of the Sami population in northern Sweden are active in commercial reindeer herding and the Swedish Reindeer Husbandry Act gives the Sami rights to graze their reindeer on almost 50% of the total Swedish land area. Since the reindeers during winter graze on private forest land, conflicts of interest with forest owners might occur. An instrument for common discussion between the Sami´s and the forest owners is maps where grazing land of interest have been marked (Sandström *et al.*, 2003). This mapping is being done by the Sami´s themselves, using screen digitizing with SPOT satellite data as a background for delineation of areas of interest.

1.3 The future supply of satellite data time series

The operational use of Landsat TM/ETM+, SPOT, IRS LISS and similar satellite data at the Swedish Forest Agency provides the foundation for a yearly procurement of a nationwide data set. Acknowledging that a large number of potential users in the society would have use for satellite data in case it would only be easily accessible and affordable, the Swedish Ministry of Environment, a number of national agencies, and a few forest companies have now joined forces and decided to store and distribute the yearly set of satellite images over Sweden. This will be done through a national satellite image archive named SACCESS which will be opened in May 2008. The archive will contain data over Sweden from 1972 and onwards, with an almost yearly coverage since year 1999. At least during the first 2 year evaluation period, the images will be freely available over internet for everybody. A similar data policy has also been decided in the USA, where USGS and NASA in January 2008 decided to open up the National Satellite Land Remote Sensing Data Archive for internet access free of charge (http://landsat.usgs.gov/images/squares/Landsat_Data_Policy. pdf). Since there now also is a new Landsat 8 being planned, this decision will most likely also influence other government sponsored satellite data programs that produce data in the Landsat scale range. In conclusion, we can expect that time series of image data in the Landsat scale will be more available and more affordable for more users.

1.4 The need for satellite data time series and landscape forecasting methods

Two-date change detection is well established in land remote sensing as well as time series analysis of coarse resolution data like MODIS or AVHRR. However, relatively few applications have so far used long time series of Landsat like data. There are however some ongoing studies in the USA where long spectral trends are analysed for studying disturbance patterns in forests (Kennedy *et al.*, 2007).

Given the earlier review of the nature of the Swedish forest landscape, and the present use of satellite data, a few potential applications might be outlined. General forest data bases, like the kNN Sweden products, might be slightly improved by including data from more than one timepoint. Especially in the quickly growing young forests, images from different years might contribute to distinguish different forest types. Of the present applications in Sweden, the detection of deciduous shrubs in coniferous plantations would probably gain most from this. In addition, it is also of interest for long time forecasting of the landscape development to know which species that is growing in the young forest.

The greatest potential is however provided by the improved possibilities to forecast the forest landscape development by knowing the age class for different patches that has been clear felled in the past. By simulating the future forest properties, including management actions taken by economic or other criteria's, a model of the total future forest can be achieved. Such predicted landscapes can be evaluated in different ways. Habitat models can be used to evaluate the suitability for different species and 3D visualisation can be used for illustrating the aesthetic landscape qualities.

1.5 Specific aims of the paper

In this paper, we present three studies that exemplifies of how the increased availability of multi time-point Landsat or similar satellite data might provide additional possibilities for remote sensing of managed boreal forests:

- Study 1 shows the improvement in the quality of the kNN estimates when data from one more time point is added.
- Study 2 shows the improved characterisation of young forests plantations that could be achieved by using a series of images.
- Study 3 shows a simulation of the future forest conditions, using kNN data and a time series of image data, including an evaluation of the simulated future forest landscape for one of the interests, reindeer grazing.

2. MATERIAL

2.1 Study area

The study is near the city of Vilhelmina in northern Sweden (Lat 65° N, Long 16° E). The area is dominated by managed boreal forests. It is also part of the Vilhelmina North and South reindeer herding communities' spring range.

2.2 National Forest Inventory plots and GIS data

The kNN estimates was trained with National Forest Inventory field sample plots that were forecasted, or back casted, to the year of the image data. Forest areas were delineated by use of the 1:00000 digital line map. Slope corrections were done by C-correction using a 50 m grid digital terrain model provided by the National land survey. In study 3, the Swedish version of CORINE land cover (called GSD Marktäcke), was used as general background outside forest areas.

2.3 Landsat TM time series

In study 2 and 3, a time series of Landsat MSS, TM and ETM+ summer satellite image data from the following years were available: 1973, 1981, 1986, 1988, 1990, 1992, 1994, 1995, 1999, 2000, 2002, 2003 and 2004. The images were geometrically precision-corrected to the Swedish National Grid (RT90), and geometrically matched to each other.

2.4 Field surveyed young stands

A field survey of 42 young stands that were clearfelled and re-planted between 1986 and 1992 were carried out during the autumn of 2006 and used in study 2 (Table 1).

2.5 kNN 2005 national forest data base

A new version of the nation-wide forest cover map, called kNN 2005 is under production and has been used as source data in study 3. The image data being used in the kNN production are about 350 SPOT, HRG, HRVIR and HRV multispectral scenes from the summer months of 2005 and 2006, in addition a few IRS P6 LISS-III, Landsat 5 TM scenes where used as well. All images where resampled to 25 x 25 m pixel size before the actual estimation. Forest estimates were only made for forest pixels as defined by the digital line map. The training data used were about 30000 national forest inventory field plots (10 m or 8 m radius). Each pixel was assigned forest variables using the kNN algorithm (Tomppo *et al.*, 2008). A mean value of the 10 spectrally nearest field plots was used. Each SPOT scene was covered with about 500 NFI plots. Since this is close to the lower limit for a successful kNN estimation, strips of several adjacent scenes from the same date were used wherever possible. The spectral distance was calculated with a canonical distance measure (Gittins 1985), where the weight of the spectral bands were optimized against a combination of all estimated variables. The estimates were done in a second version of a fully automated production line called MUNIN 2005. Among the estimated variables are: total stem volume, tree biomass, stem volume by tree species, tree height and age. The work is ongoing and the plan is to be finished in late 2008.

Year for cutting according to satellite data	No of stands	No of coniferous stems/ha mean min- max	Height of coniferous stems (m) mean min- max	Proportion of deciduous stems (%) mean min- max
1986-1988	10	1493 800 - 2295	3.9 1.9 - 5.7	51 10 – 82
1988-1990	14	1448 233 - 3967	3.2 1.7 - 5.0	48 12 – 94
1990-1992	18	1430 420 - 2453	2.6 1.6 - 3.7	51 3 – 88

Table 1. Field surveyed stands used in study 2.

3. METHODS AND RESULTS

3.1 Study 1, kNN estimation using data from two time points

Previous studies have shown that the accuracy for the forest parameters in the kNN Sweden 2000 product is low on a pixel level but that it increases as the pixels are aggregated into larger areas (e.g., Reese *et al.*, 2003). Thus, an investigation was made regarding the possibility to increase the quality of the kNN pixel estimations by using satellite image data from two time points instead of just using a single date image.

A Landsat image pair from the available time series (track 195, frame 15) consisting of one TM image from 11 June 1986 and one ETM+ image from 27 July 2000 was used together with field data from the Swedish NFI. In total, 1753 NFI plots (7 m or 10 m radius) that had been field measured between 1996 and 2001 was used in the study.

In the kNN method, forest parameters are estimated as weighted averages of observed variable values for the k most similar plots in a feature space consisting of spectral and other ancillary variables (e.g., Tomppo 1996, McRoberts *et al.* 2007). Similarity is defined by the feature space distance (d).

$$v_p = \sum_{j=1}^{k} w_{j,p} \cdot v_{j,p}, \tag{1}$$

where

$$w_{j,p} = \frac{1}{d_{j,p}^2} \Bigg/ \sum_{i=1}^{k} \frac{1}{d_{i,p}^2}, \tag{2}$$

$$d_{1,p} \le d_{2,p} \le \ldots \le d_{k,p},$$

v_p = estimated forest values for pixel p
$d_{j,p}$= feature space distance from pixel p to plot j, and
$v_{j,p}$= forest parameter value for the plot with distance $d_{i,p}$.

In this test, the feature space was defined by the Landsat digital numbers for bands 1-5 and 7, and feature space distances were measured using the Euclidean distance. All forest parameters (total stem volume, stem volume by tree species, stand age and tree height) were estimated using the 10 most similar plots (k=10). The Landsat ETM+ image from 2000 was used for the estimations based on a single image. For the estimations based on image data from two time points, the digital numbers from this Landsat image was used together with a difference image, made from the year 2000 and 1986 images.

The estimation accuracy for all tested forest parameters was evaluated using leave-one-out cross-validation where forest parameters are estimated for a plot by applying the kNN method using all plots except itself. Both bias and root mean squared error (RMSE) between estimated and field measured parameter values was calculated.

As shown in Table 2, the RMSE (relative to the mean field estimate) decreased for all tested forest parameters, except stem volume for Norway Spruce, as compared to only using image data from one date. This raises the question if the estimation accuracy can be further improved by using images from more than two time points. The high RMSE values obtained on plot/pixel level is not a major problem since the estimates were almost unbiased and therefore will improve when larger areas are aggregated.

Forest parameter	Mean field estimate	Single-date Landsat estimates RMSE, bias (%)	Two-date Landsat estimates RMSE, bias (%)
Volume			
- Total	104 m^3/ha	67.6 -0.5	65.3 -0.1
- Scots pine	43 m^3/ha	141.9 1.8	135.9 2.3
- Norway spruce	46 m^3/ha	130.9 -1.8	131.1 -1.3
- Deciduous	15 m^3/ha	166.7 -1.9	162.9 -0.2
Stand age	64 yrs	49.9 -0.1	46.8 1.2
Tree height	10,6 m	30.7 -0.3	28.4 0.2

Table 2. RMSE (%) and bias on plot level for forest parameters derived using Landsat data from one and two dates using the kNN method.

3.2 Estimating the status of young forests using time series

In study 2, Landsat TM/ETM+ spectral time series was studied for the three cohorts of young stands shown in Table 1. The study is presented in more detail in Olsson *et al.*, (2007)The stands were labelled as pine, spruce, lodgepole pine or mixed coniferous, if the stem numbers for one of these categories were larger than 1000 ha^{-1} and in majority among the coniferous. Thus even stands with more deciduous than coniferous stems was labelled as coniferous in case the number of coniferous stems was sufficient for later forming a coniferous forest. This is relevant for forecasting the future forest development, but lowers the accuracy figures in the estimations. Figure 1 shows the general spectral development in TM band 7 after data for the different stand categories had been spectrally relative calibrated, adjusted for year of cutting and averaged per category.

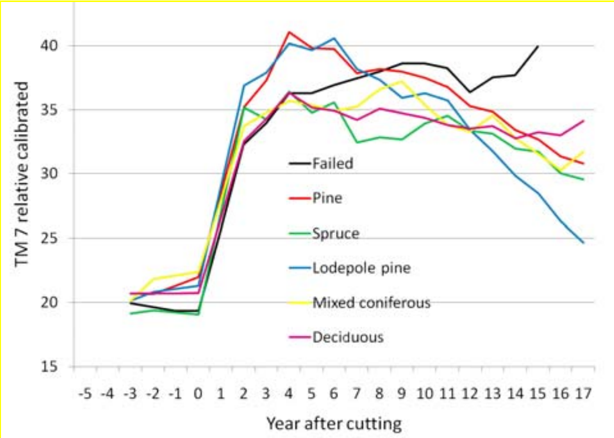

Figure 1. Standardized mean values in TM 7 for different classes of young stands, as a function of time after felling of the previous old stand. The shown values are smoothed over time.

It is obvious from Figure 1 that clear felling causes a steep spectral increase, often followed by an additional increase because of soil scarification and drying cutting waste. Then a few years of quite unchanged spectral development takes place, before the new plants starts growing and causes shadows. It is also seen that sites planted with pine, which are usually dryer sites, has a higher reflectance. The question is how this type of data could be analyzed. The approach taken in study 2 was to compute the slope and offset for a linear regression through the relatively calibrated spectral mean values, starting five years after the year of cutting.

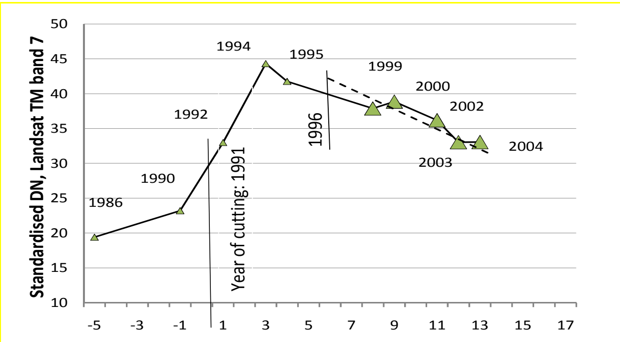

Figure 2. Spectral mean values in TM band 7 for a stand that was clearfelled between 1990 and 1992. The large triangles and the dashed line through them illustrates the regression line of the spectral darkening, which is computed with start five year after the year of cutting

As shown in Table 3, the inclusion of slope and offset of the spectral trends, starting 5 years after the year of cutting generally improves multiple regression estimates of the features of the young forest, compared to only using the latest image from year 2004.

Forest variable	Only 2004 image	Only time series slope and offset	Combined 2004 image and time series	Improve ment with time series
Coniferous stem no	51.5	31.2	52.9	1.4
Coniferous Height	70.7	78.7	80.9	10.2
Coniferous growth rate	74.8	71.6	78.6	3.8
Age	22.8	46.4	56.8	34.0
Proportion Deciduous	44.8	40.6	55.7	10.9

Table 3. R^2(adj) for best subset multiple regressions of young forest features, based on: *i)* all relevant bands in the latest TM image; *ii)* only slope and offset time series measures; and *iii)* a combination of *i)* and *ii)*

3.3 Simulating the development of forest stands and landscapes exemplified with the case of reindeer grazing

Study 3 is an early example of how the satellite data products, including the time series, could be used for simulating the forest landscape development. The general landscape was described by GSD Martäcke land cover data base, and further details for the forest pixels were provided by the new kNN 2005 data base. In addition, the age information for forest stands cut after year 1973 were improved by adding information about year and locations for clear fellings made between 1973 and 2004. This was done by pair wise change detection between the satellite images in the available image time series described in section 2.3.

Pixels featuring similar forest attributes were clustered to form segments with similar size as forest stands. The development over time of the individual pixel was modelled using a Markov-chain type forest growth model called SMAC (Sallnäs, 1990). This model is based on the establishment of a large number (ca. 16000) of possible forest states. For every state, probabilities for transitions to other states during one 5-year growth period were estimated using data from the National Forest Survey. The probabilities were made dependent on management actions taken.

In the simulations decisions on management actions were based on the state of each segment, while the development (transition) of the individual pixel was based on the state of the pixel. Expected economic value of all possible management actions were calculated for each forest state. In the simulations the action yielding the highest expected value was chosen for the cluster.

We use the issue of reindeer movement and habitat use to exemplify the utility of simulating future forest conditions. Reindeer mainly use our study area during spring time before moving to their calving lands in the mountains. When the reindeer arrive to these forests from their winter grazing areas closer to the coast, the snowpack is usually dense due to

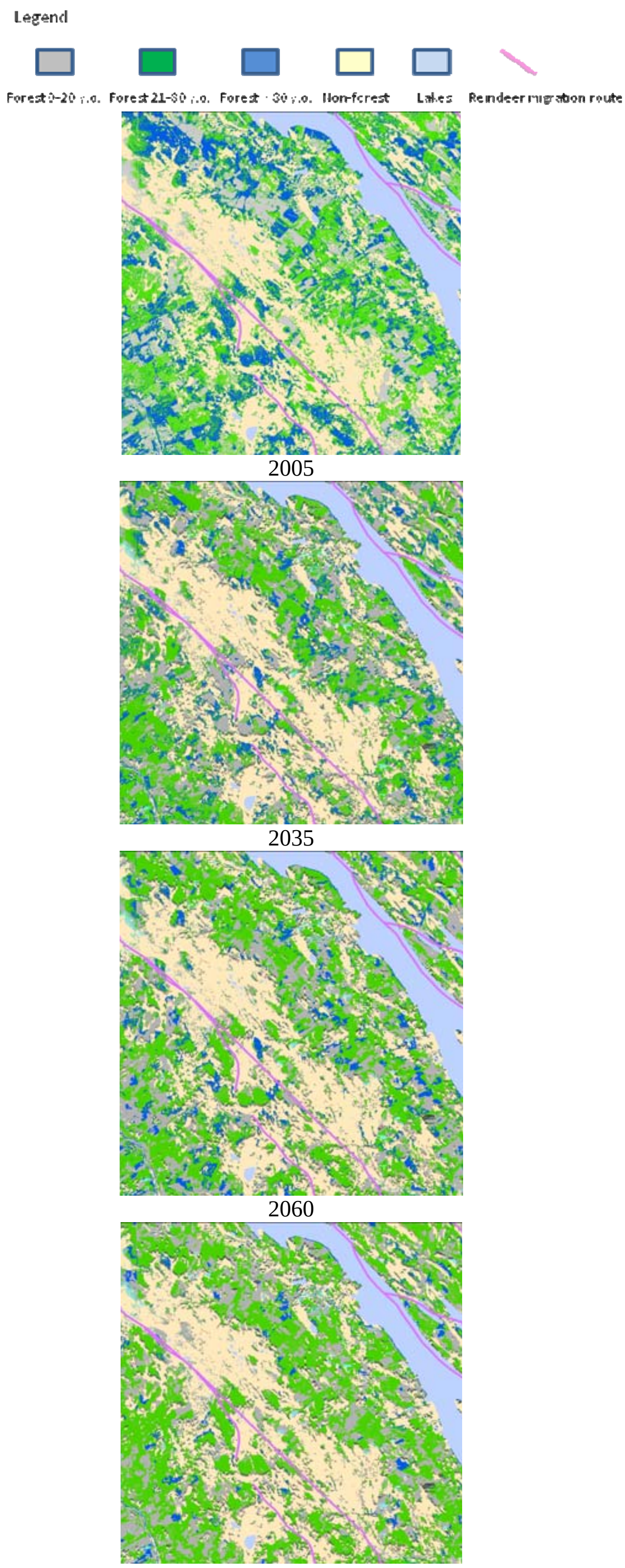

Figure 3. Example of a simulation of the development of forest older than 80 years (blue areas) from year 2005 – 2080. The old forest has a much higher potential to contain epiphytic lichens, which is an important food source for the reindeers moving along the marked routes in the spring (the lake still with ice). Repeated melting and freezing cycles makes it difficult for the reindeers to dig to the ground for food this time of the year. The

main natural food during this time is therefore epiphytic lichens which are associated with forests older than 80 years. Areas with epiphytic lichens are especially important along the migrations paths often stretching along large lakes and open areas.

The simulation model illustrates the future forest conditions under strictly economic conditions (Figure 3). In the illustrated case is a rather short rotation period used. In the figure are forest areas older than 80 years, which has a potential to carry epiphytic lichens, marked as blue (dark).

It is evident that during the economic conditions used in this simulation, the proportion of forests older than 80 years would decline drastically over time. In case this would happen, it would most likely have negative consequences for the reindeer. During the yearly migration to calving areas along the open areas and lakes, pockets of old forest with arboreal lichen play an important role. Especially for pregnant females stressed from a long winter can be highly dependent on these forests.

4. DISCUSSION

The three studies presented in this paper illustrates the utility of the increasingly available satellite data time series for providing improved information about forest landscapes that are managed with a clear felling practice followed by equally aged plantations. The mosaics of scenes with different spatial extent and from different time points will however quickly be complicated to handle and a more operational use would probably require specially developed software.

Models for landscape simulation of the type illustrated in study 3 would gain especially much from the time series information, since a correct stand age can be obtained. Most likely, such models will be more used in the future in order to complement the statistical estimates of forest stocks obtained from summations of inventory plots only. The spatially explicit models enables the further analysis of simulated future landscapes with habitat models, as well as illustration of aesthetic effects with 3D computer visualisations. We have good experiences with using commercial software's like Visual Nature Studio II and Onyx tree for the final visualisation step. It must however be stressed that this early example was made for illustrative purposes only and that the current model implies a management that is rational according to the economic man concept. That concept is most likely far from the reality and agent based models that consider the priorities of different land owner categories is one of the further directions that should be developed also for the boreal forest landscape in Scandinavia.

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